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Article

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Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Hosseini, Seyed Mohsen; Saifoddin, Amirali; Shirmohammadi, Reza; Aslani, Alireza (2019) : Forecasting of CO2 emissions in Iran based on time series and regression analysis, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 5, pp. 619-631, <https://doi.org/10.1016/j.egyr.2019.05.004>

This Version is available at:

<https://hdl.handle.net/10419/243616>

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Research paper

Forecasting of CO₂ emissions in Iran based on time series and regression analysisSeyed Mohsen Hosseini, Amirali Saifoddin^{*}, Reza Shirmohammadi, Alireza Aslani

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ARTICLE INFO

Article history:

Received 27 February 2019

Received in revised form 21 May 2019

Accepted 22 May 2019

Available online xxxx

Keywords:

Regression

Paris agreement

CO₂ emission

Energy

Scenario

ABSTRACT

Iran has become one of the most CO₂ emitting countries during the last decades. The country ranks after Japan and Germany in terms of CO₂ emissions. However, from an economic viewpoint, the gross domestic product (GDP) of Iran is lower than the summation of Berlin and Tokyo GDP. Moreover, a large proportion of Iran's revenue comes from the crude oil export; therefore, this level of CO₂ emission cannot be economically driven and is as a result of high energy intensity in this country. This is while the government also has not a clear program in this regard. The Sixth Five-year Development Plan of Iran, in addition, sets a number of ambitious targets mostly regarding the energy intensity, GDP growth, and renewable energies, but does not mention to CO₂ emission issue. Therefore, prospects for an early settlement of the dispute are seemingly dim. Our aim is to predict Iran's CO₂ emissions in 2030 under assumptions of two scenarios, i.e. business as usual (BAU) and the Sixth Development Plan (SDP), using multiple linear regression (MLR) and multiple polynomial regression (MPR) analysis. Findings suggest that Iran most likely will not meet its commitment to the Paris Agreement under the BAU's assumptions; however, full implementation of the ambitiously shaped SDP could have met the target by end 2018.

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1. Introduction

The continuous rise of carbon dioxide emissions is a major cause of global warming. Global warming is one of the biggest and probably most difficult environmental, social and economic threats that the world has faced so far in the recent century (Shirmohammadi et al., 2018). Increasing carbon dioxide emission into the atmosphere is one of the main reasons for global warming with adverse environmental effects such as sea level rise, floods, droughts, etc. During the 20th century, the average temperature of the earth has increased by 0.6 degrees, and it is estimated that it will increase 1–5 more degrees in the next century (Bistline and Rai, 2010). According to the studies conducted by the world meteorological organization, the average global temperature in 2015 has been the highest one ever recorded. Based on research, a combination of El Nino streams and global warming resulted by human activities has led to the highest recorded average global temperature in 2011 to 2015.

All nations nowadays have faced a thorny problem of finding a way to lessen the adverse effects of climate change. This is a worldwide issue and not limited to a particular area. All of the people living from the Arctic Ocean to the Antarctic Ocean

are in danger due to the unprecedented rise in the earth's average temperature. Melting permafrost in Alaska and Russia, as well as, polar ice cap indeed will influence all the living things. Unfortunately, excessive consumption of fossil fuels and deforestation in the last two decades also have exacerbated the situation (Razmjoo and Davarpanah, 2019). The atmosphere contains about 44% more CO₂ molecules from the 1750 level at the present time (Tarasova et al., 2018). The issue has led to a 0.8 °C global warming since 1880 with an increase rate of approximately 0.15–0.20 °C per decade. About two-thirds of the figure is related to the post-1975 years (Carlowicz, 2010). Continuation of the anthropogenic CO₂ emissions reportedly could have easily increased the figure to 2 °C in the coming years (Allen et al., 2009). Therefore, the CO₂ emission is an urgent problem and needs tackling straight away.

Environmentalists continuously have urged the international community to take decisive actions on this disastrous problem. COP21 conference in Paris could be regarded as a sign of solidarity and amenability for tackling the problem of climate change. The primary aim of COP21 is to prevent the increase of global temperature under 2 °C and also to limit this increase under 1.5 °C compared to the time before industrialization (Armin Razmjoo et al., 2019). Most of the developed countries, particularly the EU members, like the Nordic Countries have shaped and adopted coherent policies on renewable energies and low-carbon technologies over the last two decades to satisfy the strong desire

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of carbon-free societies (Ardakani et al., 2018; Hosseini et al., 2017). This is while most of the third world countries such as Iran still have not put forward a strong action plan in order to tackle the climate change problem (Armin Razmjoo et al., 2019). Table 1 defines Iran's policies on sustainable development and low-carbon technologies in summary. Because failed to put forth applicatory action plans to follow these policies, the country still has not achieved the desired results from the formulation of development policies.

After Venezuela, Saudi Arabia, and Canada, Iran has the largest proven oil resources in the world (Davarpanah and Mirshekari, 2018). The country also advantageously have the biggest natural gas reservoirs after Russia. The abundance of fossil resources in this country, and deficiency in the formulation of integrated energy policies, as well as, inconsistency in the implementation of the existing plans have vastly deteriorated the climate situation. This is why the energy use per capita in this country is 57% higher than the global average (Bank, 2019b). Moreover, Iran has the seventh position among the highest CO₂ emitting countries as shown in Fig. 1 (ATLAS, 2016). Iran's CO₂ emission has had a jump between 1960 and 2014. The figure has risen by more than 17 times in this period (Bank, 2019a).

After all, Iran is one of the signatories of the Paris Agreement and has a commitment to reduce 4% of the overall CO₂ emissions by 2030. However, Iran's deputy environment chief has stated that there is a potential for a 12% reduction in the case of receiving international support and no further sanction exposure. The agreement has its particular opponents and proponents in the government body. Opponents mainly point to the significant expenses of this fulfillment and remark that the developed countries must incur the relevant expenses. The other reason is fear of further sanctions and embargo due to environmental reasons. But Iran, either way, is going to the expenses of buying the CO₂ share of the other countries in the case of non-performance. As a result, controversy has been arising over the Iran retraction after the US withdrawal from the Paris Agreement and the Joint Comprehensive Plan of Action. Along with the serious administrative problems in decision-making, cultural and behavioral problems also have been considered as the other drivers of climate change in this country. Indeed, findings suggest that social and economic issues had been the first priorities of the Tehran residents in the 2000s and the environmental issues were of little importance (Calabrese et al., 2008); however, serious concerns have been arising over the air and water quality of Iran in the recent years. The evidence against environmental problems in this country is overwhelming and the relevant authorities need to formulate comprehensive policy action plans in order to tackle the abovementioned problems (Amirnekoeei et al., 2012; Lotfalipour et al., 2013).

This paper aims to make a prediction about the environmental state of Iran in 2030 and its commitment to the Paris agreement. For this, a literature review over the potential driving forces of CO₂ emissions will be conducted in order to determine the prominent determinants of CO₂ emissions in Iran. With the acquisition of historical data from valid databases and analysis of their trends over time, the identified determinants then are used in two statistical approaches, multiple linear regression (MLP) and multiple polynomial regression (MPR) models, in order to develop prediction models for estimation of CO₂ emissions between 1971 and 2014. From the regression analysis, a linear equation and a polynomial equation will be derived which relate the annual CO₂ emission to the identified determinants. Through a variety of forecasting methods, including expert neural net, hybrid forecasting method, quadratic growth, linear exponential smoothing, single exponential smoothing, damped exponential smoothing, triple exponential smoothing, linear growth, moving

average, polynomial growth, and double moving average, the predictors will be forecasted by 2030. Predictive models with the lowest mean absolute percentage error (MAPE) will be selected for forecasting of the determinants. Finally, with putting the forecasted predictors into the derived equations, annual CO₂ emission values will be projected by 2030. Two scenarios also have been designed in this study to scrutinize the possible influence of adaptation of different policies over the state of Iran in terms of CO₂ emission in 2030. The first scenario considers insignificant changes in the current policies of the government; while, the second one considers the targets of "Law on the Sixth Five-Year Economic, Cultural, and Social Development Plan for 1396–1400 (2016–2021)" – "The Sixth Development Plan".

2. Literature review

2.1. Driving forces of CO₂ emission in Iran

At the early 2000s, the International Energy Agency (IEA) strongly urged the country members, particularly, the developing countries to reconsider the policy over energy subsidy. In most cases, this action results in a small increase in economic growth and a great reduction in energy consumption and CO₂ emissions (1999). Despite the IEA's notifications in about the last two decades, Iran still has not changed its policy and allocates a large proportion of the GDP to the energy subsidies in all sectors. Actually, China is in the face of stiff competition from Iran on this matter. This is a legitimate reason why per capita CO₂ emission and per capita energy use are 66% and 57% higher than the global average (Bank, 2019a,b).

Population is considered as a major driving force of CO₂ emissions in the majority of regions (O'Mahony, 2013; O'Mahony et al., 2013; Xu et al., 2014). Although Begum et al. (2015) failed to find a meaningful relationship between CO₂ emissions and population in Malaysia, a number of studies (Ardakani et al., 2018; Hosseini et al., 2017; Jorgenson and Clark, 2010; Xu et al., 2014; Yang et al., 2015) feature a positive correlation between population and CO₂ emissions in both developed and developing societies. Iran gradually became an energy-intensive society after the revolution in 1979. In fact, steep population growth between 1977 and 1990, particularly, during the Iran–Iraq War triggered serious problems during the post-war years. There is a growing alarm at population growth and per capita energy consumption and CO₂ emission in this country. Ministry of Health and Medical Education predict that Iran's population will reach the top in 2050 and fall into a decline afterward. Therefore, Iran needs to adopt flexible policies toward sustainable energy systems to secure the energy supply and environmental health in the coming years. Fig. 2 shown Iran's population growth during the past years.

Globally and regionally, energy consumption is the main driving force of anthropogenic CO₂ emissions. Since CO₂ is a product of fossil fuel consumption, therefore, energy consumption bears a positive relationship with CO₂ emission. As a result, CO₂ emission is drastically high in the major fossil fuel consuming countries, particularly, China and the U.S. (Apergis and Payne, 2010; Heidari et al., 2015; Kais and Sami, 2016; Kaivo-oja et al., 2016; Soytaş et al., 2007). Fig. 3 shows the growth trend of per capita energy use in Iran between 1971 and 2014. As the population, energy use also has been on increase during this period. Fossil fuels are the main sources of energy in this country. Actually, a significant proportion of Iran's CO₂ emissions is related to the consumption of vehicle fuels in the transportation sector and natural gas in the building sector in this country. Fig. 4 shows the composition of Iran's carbon footprint in 2014. Despite the emissions from coal consumption, the per capita CO₂ emissions from the other sources are significantly higher than Europe's average. That is

Table 1

Iran's policies on sustainable development in the last decade.

Policy	Year	Policy sector	Agency	Targets
Liquid fuel exchange purchase	2013	Electricity, Framework policy	Ministry of Energy – Renewable Energy Organization of Iran (SUNA)	<ul style="list-style-type: none"> Improvement of energy efficiency in governmental and private power plants; Development of renewable energies; Optimization of energy consumption.
Supply of 20% of electricity consumed by governmental and public organizations from renewables	2016	Electricity, Framework policy	Renewable Energy and Energy Efficiency Organization (SATBA)	<ul style="list-style-type: none"> Supply of 20% of the electricity demand of governmental and public buildings from renewable energies for two years; Set of electricity consumption tariff based upon the renewable feed-in tariff.
Renewable portfolio standards – The Sixth Development Plan	2016	Electricity, Framework policy	Renewable Energy and Energy Efficiency Organization (SATBA)	<ul style="list-style-type: none"> Enhancement of share of carbon-free energies in the energy mix to 5% by the end of 2021.
Renewable electricity compliance	2015	Framework policy	Renewable Energy and Energy Efficiency Organization (SATBA)	<ul style="list-style-type: none"> Introduction of tariff as renewable electricity duty in electricity bills to develop and maintain rural electricity grids.
Payment of benefit of conserving fossil fuels	2015	–	Renewable Energy and Energy Efficiency Organization (SATBA)	<ul style="list-style-type: none"> Improvement of energy efficiency in all sectors; Development of renewable energies; Increase in natural gas consumption in large cities; Production of hybrid, fuel efficient, and electric cars; Reduction of cost of freight; Improvement of energy efficiency through construction of combined heat and power facilities and small scale generation power plants; Reduction of generation and transmission losses; Electrification of agricultural wells using renewable technologies. Involvement of electricity instead of fossil fuels in the wealth-producing activities; Production of electricity from waste plants.
Renewable energy development fund	2013	Electricity, Framework policy, Multi-sectoral policy	Ministry of Energy – Renewable Energy Organization of Iran	<ul style="list-style-type: none"> Introduction of tariff by an amount of 30 Rials per kilowatt-hour as electricity duties to develop and maintain rural electricity grids.
Promotion of awareness about renewable technologies	2011	Framework policy, Multi-sectoral policy	Science and technology deputy of presidency – Renewable energies technology development headquarters	<ul style="list-style-type: none"> Acquisition of technical know-how on production of renewable technologies and construction of renewable power plants; Allocation of research and development funds for renewable projects; Concentration on realization and localization of renewable technologies in the country; Introduction and implementation of pilot projects on renewable energies.
Financial support for the feed-in tariff	2005	Electricity	Ministry of Energy – Renewable Energy Organization of Iran (SUNA)	<ul style="list-style-type: none"> Undertaking a definite proportion of electricity generation cost via renewable technologies by Iran Department of Environment; Guaranteed purchase of electricity generated via renewable technologies by subsidiary companies of Ministry of Energy.
Financial supports	2011	–	Ministry of Energy – Renewable Energy Organization of Iran (SUNA)	<ul style="list-style-type: none"> Persuasion of investment in renewable energies.
Renewable portfolio standards	2012	Electricity, Framework policy, Multi-sectoral policy	Ministry of Energy – Renewable Energy Organization of Iran (SUNA)	<ul style="list-style-type: none"> Installation of 5000 MW solar and wind energy by 2020.

mainly because Iran has limited is agenda to crude oil, while it has 1.15 billion tons of proven coal reserves according to the remarks of deputy head of Middle East Mines Industries Development Holding Company (MIDHCO). Natural gas production projects also have not sufficiently financed by the government, despite the huge potential in this country.

Increase in the share of renewables and nuclear energy in energy mix also can exert a negative influence over CO₂ emissions in both short-term and long-term (Apergis et al., 2010; Baek,

2016; Cansino et al., 2015). For those trend-setters of climate change, China and the U.S., who failed to involve renewable energies in the wealth production activities, GDP still bears a close relationship with CO₂ emissions. This is while in some part of the world such as European Union (EU) Member States who efficiently raised the share of carbon-free energies in their energy mix, such relationships between CO₂ emissions and GDP are not observable (Kaivo-oja et al., 2016). Technological development in the field of nuclear energy may have a negative impact on CO₂

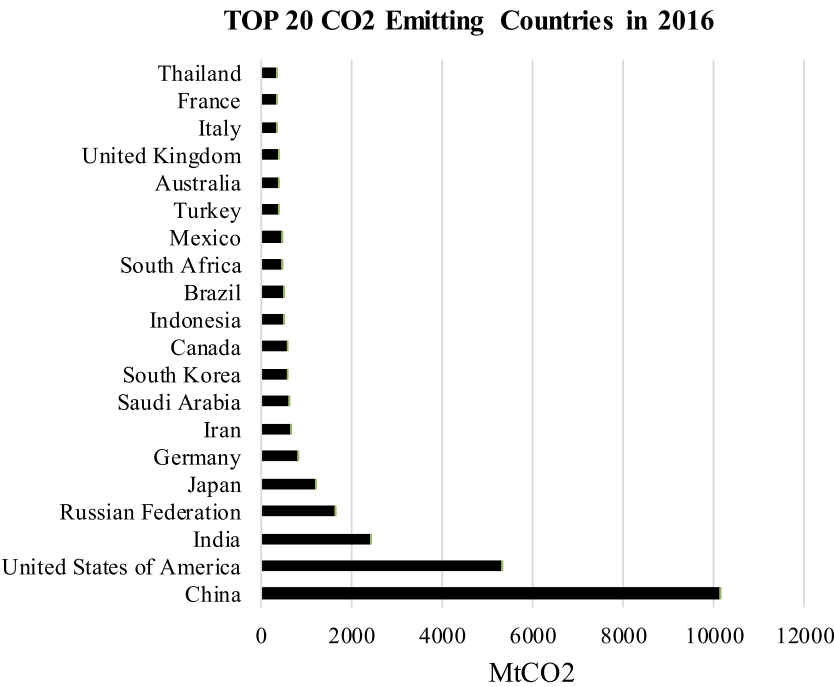


Fig. 1. Top CO₂ emitting countries in 2016 (ATLAS, 2016).

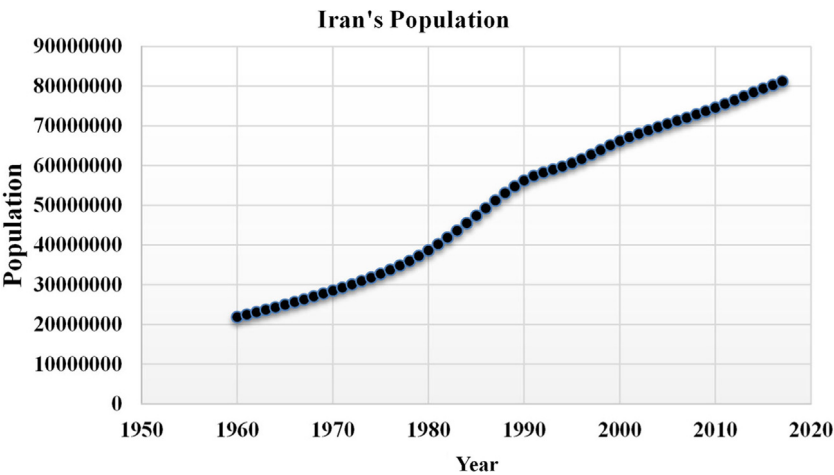


Fig. 2. Iran's population growth between 1960 and 2017.

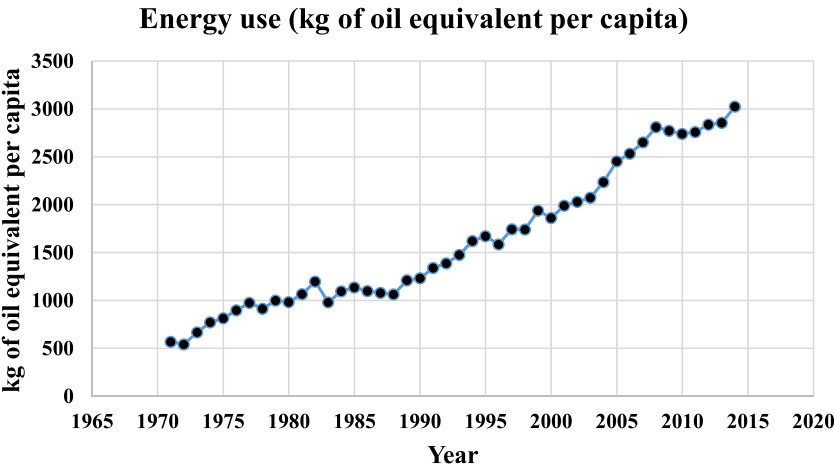


Fig. 3. Growth trend of per capita energy use over the years in Iran.

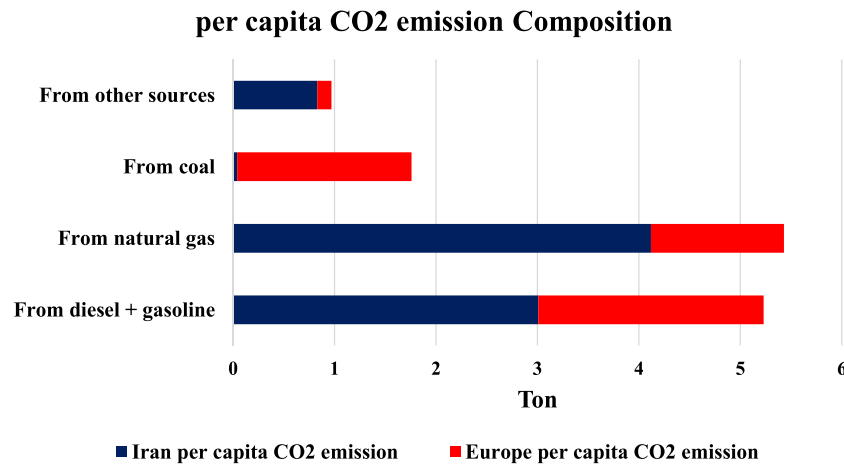


Fig. 4. Composition of CO₂ emission in Iran and European countries.

emissions in the long-term (Apergis et al., 2010; Baek, 2016). Development of renewable energies also can produce the same result, however, only in the short-term (Baek, 2016). About 79% of Iran electricity production in 2015 was from natural gas power plants according to the Ministry of Energy's data. This is while the share of nuclear power plants and renewable was only 1.7% of the total. As per Fig. 5, the share of fossil fuels in power generation has increased in the past three decades and reached the top in 2007. About 97% of Iran power generation was from fossil fuels in this year. However, the figure shows a slight decline trend afterward. Industry and building sectors are the major electricity consumers in this country. Moreover, Iran exports electricity to the neighboring countries, particularly, Iraq. Therefore, Iran needs practical policies to cut CO₂ emission intensity in power generation to meet the Paris agreement's target.

Trade level refers to the level of imports and exports per year in a country. Since it bears a close relationship with Gross Domestic Product (GDP), the factor generally forges a strong relationship with CO₂ emissions. As a result, any rise in the trade level can simply result in a higher level of CO₂ emission in some particular countries, such as China, India, Turkey, and Malaysia (Halicioglu, 2009; Jayanthakumaran et al., 2012; Ozturk and Acaravci, 2013; Shahbaz et al., 2016). Technological progress also could have a major impact on the amount of CO₂ emission. Development of energy infrastructure has brought about lower CO₂ emissions in both developed and developing societies (Liou and Wu, 2011). Energy Intensity (EI) has been suggested as a measure of technological progress in the literature which directly influences the amount of CO₂ emission. As a result, a low EI implies a high level of energy-efficient and innovative energy systems in society (Donglan et al., 2010; Yue et al., 2013; Zhang and Tan, 2016). Iran also suffers from a high energy intensity. The energy intensity level of primary energy in Iran was 7.794 MJ per PPP GDP in 2015 according to the World Bank Data. Considering that a large proportion of Iran's GDP is supplied from crude oil export, and Iran has not an energy-intensive industry, the energy intensity is drastically high in this country. Moreover, due to the reduction in crude oil price and the US sanctions against Iran after 2011, Iran has faced a reduction in oil export revenue, but the energy intensity was in increase between 2011 and 2015. This is mainly because of a dramatical increase in the energy consumption of Iran during this period. Fig. 6 shows the per capita GDP of Iran between 1971 and 2014.

In fact, the increase in energy use between 2011 and 2014, alongside the promotion of fuels quality standards have slightly reduced the CO₂ intensity per energy use in this country. Fig. 7

illustrates the trend of CO₂ intensity in Iran between 1971 and 2014. Adoption of constructivism policies like electrification, supply natural gas to the majority of residential buildings, utilization of electric water pumps instead of diesel engines, and production of vehicles fuels in compliance to the Euro Standards have triggered a slight decline trend in the CO₂ intensity during the post-war years. However, as per Fig. 7, these policies already became inefficient and only may stabilize the level of CO₂ intensity per energy consumption in this country. Actually, Iran needs to adopt more flexible policies regarding the renewable energies and CO₂ capture facilities if have a strong desire to lower the CO₂ intensity and meet the Paris Agreement's target.

Determinants of CO₂ emissions are various and sundry and encompass a wide range of socioeconomic and technological factors. Inasmuch as there is a consensus among the researchers on these driving forces, determinants of CO₂ emissions may vary from region to region because of their particular economic structure and energy system. With reviewing the possible driving forces of CO₂ emissions in the literature and scrutiny of their historical trends in Iran, this paper finds population, CO₂ intensity, GDP per capita, share of fossil fuels in electricity production, and per capita energy use as the major driving forces of CO₂ emissions in this country. Through regression analysis, these factors will be used as predictors for the development of forecasting models to estimate CO₂ emission by 2030. The next section provides a brief overview over the possible approaches adopted for forecasting CO₂ emission in the last two decades.

2.2. Common approaches for forecasting CO₂ emissions

Numerous approaches have been adopted for forecasting CO₂ emissions in the short-term and long-term. These approaches mainly forecast the future trends based on the historical data and encompass a wide range of regression models and machine learning tools combined with scenario analysis.

A number of studies have applied decomposition-based approaches to forecasting CO₂ emissions. These papers suggest a variety of forecasting models, including the STIRPAT model (Noorpoor and Kudahi, 2015; Wen and Liu, 2016), Kaya model (O'Mahony, 2013), and the IPAT model (Qiang et al., 2015). However, given the major improvements in environmental policies and considerable development in modern technologies, in addition, due to the complex nature of CO₂ production from various resources and abundance of the driving forces, traditional approaches seemingly fail to accurately forecast CO₂ emissions.

Electricity production from oil, gas and coal sources

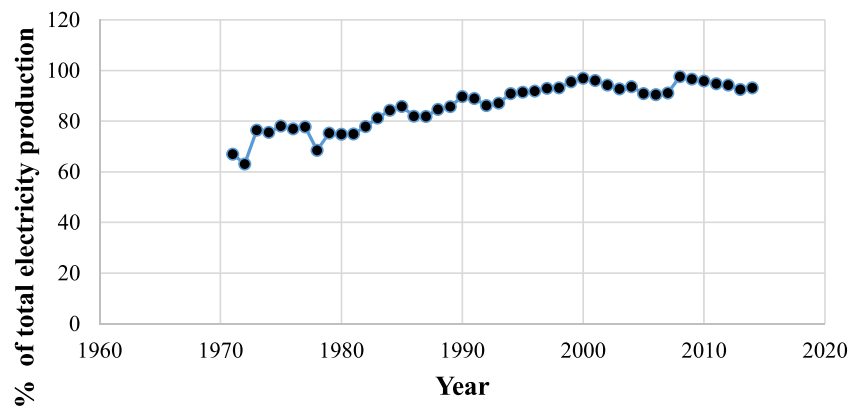


Fig. 5. Growth trend of electricity production from fossil fuels in Iran.

GDP per capita

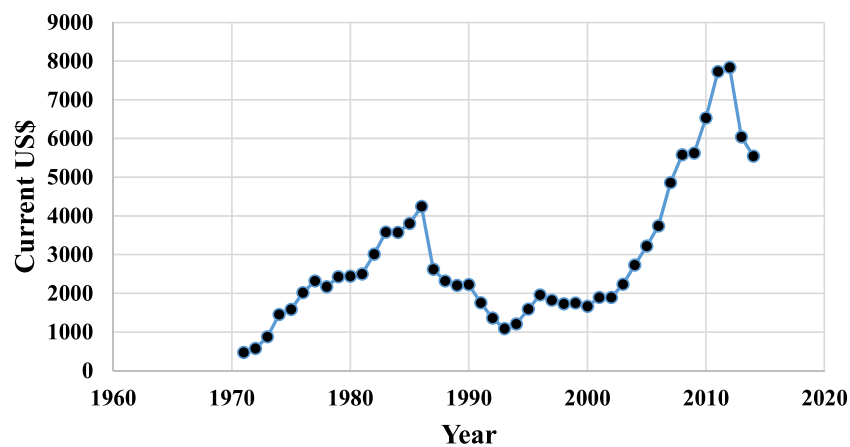


Fig. 6. Iran's per capita GDP between 1971 and 2014.

CO₂ intensity per energy consumption

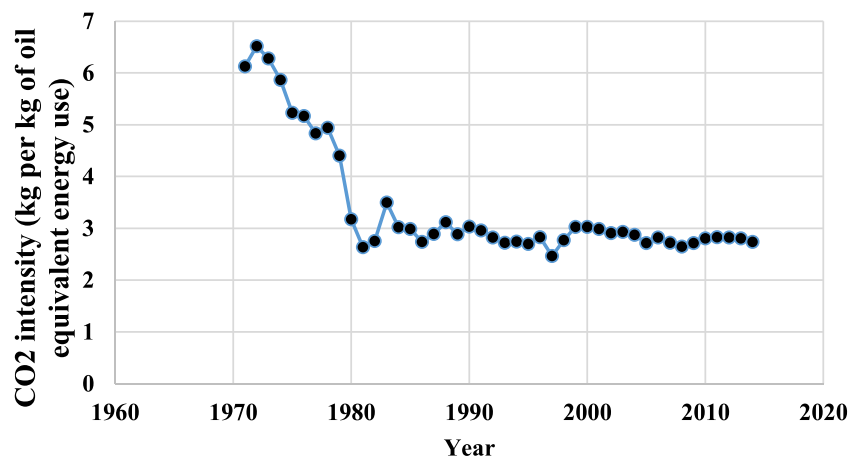


Fig. 7. Iran's CO₂ intensity between 1971 and 2014.

Forecasted results from the traditional models may exhibit different trends from the historical data. As a result, novel and innovative methodologies are needed to efficiently address the issue (Guo et al., 2018).

Scenario analysis has received considerable attention for this purpose. With the consideration of possible solutions and alternatives for the future, scenario analysis reduces the uncertainty of outcomes and make a better projection about the future trends

of CO₂ emissions. A large number of studies have applied scenario analysis to forecasting CO₂ emissions. As an illustration, a combination of the scenario analysis and a system dynamic model was applied to forecasting CO₂ emissions in China by 2020 (Xiao et al., 2016). Scenario analysis also has been applied to scrutinize the long-term solutions for reducing energy utilization and CO₂ emissions of the steel industry in China (Karali et al., 2016). Another study has adopted the methodology in a combination with a linear programming model to prioritize alternative solutions to the problem of global warming (Tokimatsu et al., 2017).

Machine learning tools, in particular, artificial neural network (ANN) models have been widely used in the forecasting processes. These methodologies best suit to the cases which there are non-linear relationships between target and response variables (Guo et al., 2018). Combining the ANN and a bees algorithm, Behrang et al. (2011) have speculated about the state of global CO₂ emissions in 2040. Using a Back-Propagation Neural Networks model combined with a genetic algorithm (GA), Sun et al. (2016) also forecast future values of CO₂ emissions for a province of China. Fang et al. (2018) offer a novel methodology for forecasting of CO₂ emissions in China by 2020. The approach is a compound of Gaussian Process Regression (GPR) and genetic algorithm and has a good performance in terms of accuracy.

A number of researchers also put efforts into the forecasting of CO₂ emissions in Iran. Davoudpour and Ahadi (Davoudpour and Ahadi, 2006) have proposed a scenario-based econometric model to forecast annual energy demand and CO₂ emissions of Iran between 2000 and 2011. From scenario analysis, possible impacts of pursuing energy efficiency measures and price adjustment policy on the total energy demand and CO₂ emissions have been appraised during the 2000s. Under a business-as-usual (BAU) scenario, the yearly growth rate of CO₂ emissions has been obtained 6.8%; while, with the implementation of a management scenario, the country most likely could have lowered the rate to a half extent. Köne and Büke (2010) have applied regression analysis to forecast CO₂ emissions from the top 25 CO₂ emitting countries by 2015 and 2030. Based on the analysis, CO₂ emission in Iran almost has followed a linear increasing trend in the majority of times. With the application of a grey box model and an Autoregressive Integrated Moving Average (ARIMA) model, Lotfalipour et al. (2013) have forecasted Iran's CO₂ emissions by 2020. With superior performance, the grey box model has estimated that Iran's CO₂ emissions will cross the border of 925 million tons by 2020. Azadeh et al. (2017) have performed a regression analysis in an effort to forecast CO₂ emissions from Iran's industrial sector based on the socioeconomic indicators. Heydari et al. (2019) have proposed a novel methodology, combining a General Regression Neural Network model with a Grey Wolf Optimization approach, for forecasting of CO₂ emissions from fossil fuel consumption in Iran, Italy, and Canada.

3. Methodology

This research applies multiple regression (MR) models (Ostertagová, 2012) in order to forecast Iran's CO₂ emissions based on the historical data derived from World Bank Open Data. Two models have been developed using Matlab: MLR and MPR. Moreover, using proForecaster 2.1, this paper adopts various forecasting approaches, i.e. expert neural net, hybrid forecasting method, quadratic growth, linear exponential smoothing, single exponential smoothing, damped exponential smoothing, triple exponential smoothing, linear growth, moving average, polynomial growth, and double moving average, in order to forecast the predictors' trend between 2015 and 2030. It is worth to mention that the model selection is based on the mean absolute percentage error (MAPE) of the forecasting approaches. This paper

splits the dataset according to 70/30 rule. That means 80% of the dataset is used for the training set and 20% for the validation set. Fig. 8 elaborates the forecasting steps in this paper. The next section explains the development procedure of regression models in summary.

3.1. Regression analysis

Multiple regression (MR) model is a type of regression models when there are more than one predictors for a response variable. As one of the extrapolation methods, regression analysis assumes that the past is a proxy for the future. Therefore, this paper assumes that future values of CO₂ emission most likely follow the pattern of historical data. The general form of a multiple regression model is:

$$Y = X\beta + e \quad (1)$$

In this equation, the response vector Y and error vector e are two n -length column vector, β is a column vector of length $k + 1$, and X is a n by $k + 1$ matrix.

The MR estimates the regression parameters using the least square error (Tabasi et al., 2016). The approach firstly computes the sum of the squared errors, then seek for the best estimators minimizing the sum as follow:

$$e = Y - X\beta \quad (2)$$

$$e^T e = (Y - X\beta)^T (Y - X\beta) \quad (3)$$

Normal equations will be derived by making Eq. (3) equal to 0,

$$X^T X \beta = X^T Y \quad (4)$$

By multiplying both sides of Eq. (4) by $(X^T X)^{-1}$, an unbiased estimator of β will be calculated as below:

$$\hat{\beta} = (X^T X)^{-1} X^T Y \quad (5)$$

Therefore, the mean estimated values of Y are calculated by the following equation:

$$\hat{Y} = X\hat{\beta} = X(X^T X)^{-1} X^T Y = HY \quad (6)$$

The symmetric matrix of H (hat matrix) converts Y to \hat{Y} . Finally, the following equation computes the error terms:

$$\bar{e} = Y - \hat{Y} = (I - H)Y \quad (7)$$

Eqs. (8) and (9) represents the general form of MLR and second-degree MLP equations respectively.

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik} + u_i, \text{ for } i = 1, 2, 3, \dots, n \quad (8)$$

$$y_i = \beta_0 + \beta_1 x_{i1}^2 + \beta_2 x_{i2}^2 + \dots + \beta_k x_{ik}^2 + u_i, \text{ for } i = 1, 2, 3, \dots, n \quad (9)$$

Coefficient of determination is defined as follow:

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y})^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (10)$$

As well, residual sum of squares (RSS) is calculated from the following equation:

$$RSS = \sum_{i=1}^n (y_i - \hat{y})^2 \quad (11)$$

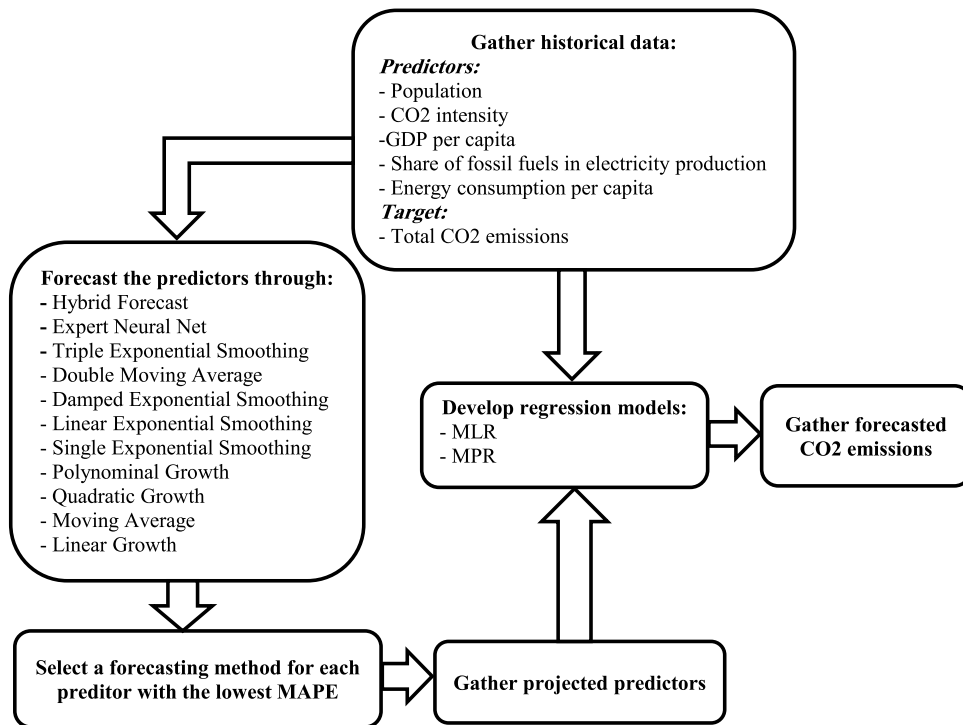


Fig. 8. Forecasting process flowchart.

4. Prediction scenarios

Iran's CO₂ emissions have been in a substantial increase after 1980. As per Fig. 9, between 1975 and 1980, the figure has followed a declining trend, though considerable increased afterward and reached the top in 2015. Additionally, there is a great deal of uncertainty about the future of Iran's CO₂ emissions, as the government still have not brought forward specific proposals to tackle the problem of increasing CO₂ emissions. Further, the abovementioned issues also will expose the future of Iran's CO₂ emissions to considerable uncertainties. Thus, any possible scenario should take these uncertainties into consideration in order to provide an accurate prediction from upcoming CO₂ emissions. This paper presents two scenarios in order to forecast Iran's CO₂ emissions between 2015 and 2030: business as usual (BAU) and Sixth Development Plan (SDP).

4.1. BAU scenario

The BAU scenario considers an insignificant change in the currently available composition of the indicators. In fact, the indicators represent the same trends with their historical data in this scenario. Table 2 contains the relevant information and assumptions regarding the indicators in the BAU scenario.

4.2. SDP scenario

On March 19th, 2017, the Iranian Parliament approved the Sixth Development Plan which describes the structural policies of Iran between 2016 and 2021. However, despite the Paris Agreement, Iran has not set any target regarding CO₂ emissions in the next 5 years. Instead, the Parliament has set three high targets regarding renewables, per capita GDP, and energy intensity as below:

- Increase of renewable shares in primary energy consumption by 1% each year;

- Increase of per capita GDP (in comparison to constant prices in 2004) by 7.6% each year; and
- Reduction of energy intensity by 3% each year.

In addition to assumptions of the BAU scenario, the STP takes the three targets into consideration in order to forecast the CO₂ emissions by 2030. Though the two first targets influence the MLP model straightforwardly, the third target makes an alteration in both per capita GDP and per capita energy use. The scenario applies the relevant impacts to both determinants and accordingly estimates the amount of yearly CO₂ emissions.

5. Results

Using the MPR, a polynomial function has been derived from the historical data, which represents a strong correlation between the predictors and response variable:

$$y = -1.4e - 11x_1^2 + 1.7e - 3x_1x_2 + 1.2e - 7x_1x_3 + 9.4e - 7x_1x_4 + 4.1e - 6x_1x_5 + 1341x_2^2 - 4x_2x_3 - 325.3x_2x_4 + 50x_2x_5 + 1.7e - 4x_3^2 + 3.2e - 2x_3x_4 - 2.2e - 3x_3x_5 - 29.2x_4^2 + 1.9e - 1x_4x_5 - 1.7e - 2x_5^2 - 5.6e - 3x_1 - 51051.3x_2 + 3.7x_3 + 5649.9x_4 - 170.9x_5 - 17426.4 \quad (12)$$

where, x_1 is the total population, x_2 represents CO₂ intensity in kg per kg of oil equivalent energy use, x_3 is per capita GDP in US\$, x_4 is the share of electricity production of fossil fuel sources, and x_5 represents per capita energy use in kg of oil equivalent. R^2 for the training set is 0.99 and RSS is 13 927 877.94. For the validation set, R^2 is 0.98 and the RSS is 14 865 647.54. This implies that the model best fits the predictors and correlations between the estimated and actual data concentrate in close proximity of the ideal fit.

Eq. (13) represent the function derived from the MLR methodology.

$$y = 3.9e - 3x_1 + 42256.6x_2 + 6.7x_3 - 274.7x_4$$

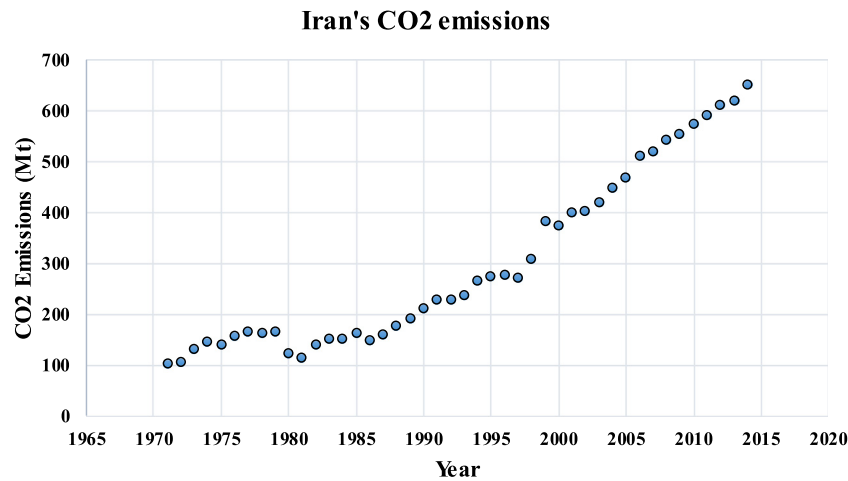
Fig. 9. Iran's CO₂ emissions over the years (Bank, 2019a).

Table 2

Information and assumptions regarding the indicators in the BAU scenario.

Indicator	Information	Assumption
Population	Population has increased by 4.53 million every five years on average	During the periods of 2015–2020, 2021–2025, and 2026–2030, the population will increase by 5.04, 4.2, and 4.3 million based on a triple exponential smoothing forecasting.
CO ₂ intensity	Overall CO ₂ intensity has reduced by 55% during the period of 1971–2014, however, experienced some fluctuations as follow: <ul style="list-style-type: none"> • 1971–1975: reduced by 14.6% • 1975–1980: reduced by 38.5% • 1981–1985: increased by 13.4% • 1986–1990: increased by 10.8% • 1991–1995: reduced by 8.9% • 1996–2000: increased by 7% • 2001–2005: reduced by 9% • 2006–2010: reduced by 0.6% • 2011–2014: reduced by 2.5% 	CO ₂ intensity probably continues a slight decline trend in this period. A hybrid forecast approach estimates the following figures for the parameter: <ul style="list-style-type: none"> • 2015–2020: reduces by 0.52% • 2021–2025: reduces by 0.38% • 2026–2030: reduces by 0.39%
GDP per capita	Per capita GDP also has experienced serious fluctuations as follows: <ul style="list-style-type: none"> • 1971–1975: increased by 237.3% • 1975–1980: increased by 21% • 1981–1985: increased by 52.3% • 1986–1990: reduced by 47.7% • 1991–1995: reduced by 9.4% • 1996–2000: reduced by 15.2% • 2001–2005: increased by 70% • 2006–2010: increased by 74.7% • 2011–2014: reduced by 31.1% 	A hybrid forecast model forecast a declining trend as follows: <ul style="list-style-type: none"> • 2015–2020: reduces by 11.4% • 2021–2025: reduces by 17.6% • 2026–2030: reduces by 22.1%
Electricity production from fossil fuels	Share of electricity production from fossil fuels was in increase by a rate of 7.1% during this period; however, the figure has declined in the following periods: <ul style="list-style-type: none"> • 1976–1980: 2.15% reduction • 2001–2005: 5.17% reduction • 2011–2014: 1.54% reduction 	A linear exponential smoothing approach estimates an insignificant change in the share of electricity production from fossil fuels.
Per capita energy use	Per capita energy use has significantly increased during this period. Every five years, the figure has risen by 17% on average.	According to a hybrid forecasting approach, per capita energy use is assumed to increase by 17% every five years.

$$+ 184.7x_5 - 354818.4 \quad (13)$$

This model also represents a high coefficient of determination ($R^2 = 0.99$) for the training set. RSS for this case is 5 163 798 853 which is significantly higher than the MPR model. For the validation test, R^2 is 0.97 and the RSS is 556 489 634. Therefore, as the result of a lower RSS, the MPR allows a tighter fit of the model to the historical data. Fig. 10 represents validation of the MPR and MLR models against the historical data. Table 3 contains predicted values for the determinants and response variable during the period of 2015–2030.

Table 4 contains results of MPR and MLR models for prediction of total Iran's CO₂ emissions under three scenarios' assumptions. The MLR model has forecasted higher CO₂ emission values in comparison to the MPR. Though, due to its lower RSS, the MPR results probably are more accurate compared to the MLR. Based on the BAU and SDP scenarios, the MLR model forecasts Iran's total CO₂ emissions in 2030 with values of 730 594.9 and 315 738.91, kt respectively; while the MPR model offers values of 876 263.3 and 211 096.59, and 207 918.21 kt for the BAU and SDP scenarios.

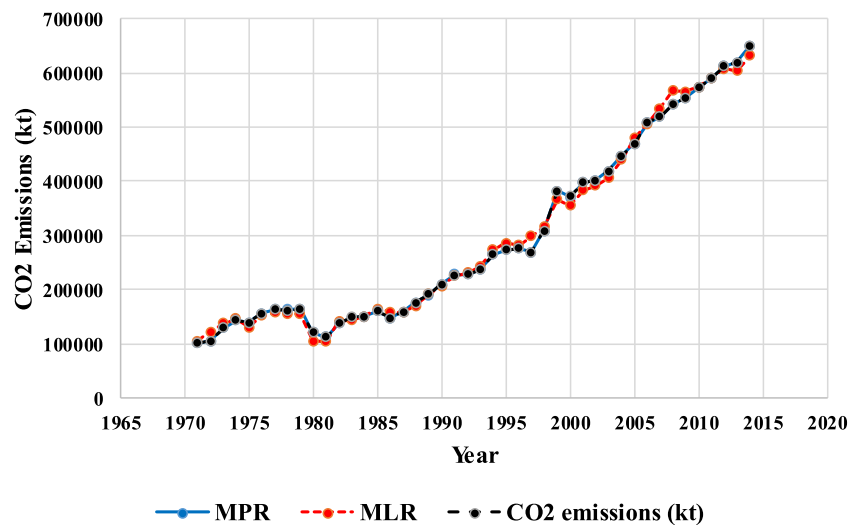


Fig. 10. Validation of both MPR and MLR models with the historical data.

Table 3

Predicted values of determinants between 2015 and 2030.

Scenario	BAU				SDP				Forecasting method	MAPE
Year	2017	2020	2025	2030	2017	2020	2025	2030		
Population (million)	81.16	84.44	89.67	95.10	81.16	84.43	89.68	95.10	Triple exponential smoothing	0.001
CO ₂ intensity	2.48	2.74	2.73	2.71	2.48	2.74	2.73	2.71	Hybrid forecast	0.05
GDP per capita	5415	4715	3730	2745	5962	8599	12402	17888	Hybrid forecast	0.124
Electricity production from fossil fuels	93.18	93.27	93.27	93.27	90.18	87.18	82.18	77.18	Hybrid forecast	0.042
Energy use per capita	3326.64	3072.34	3192.08	3313.47	2864.41	2112.44	1495.05	1028.73	Linear exponential smoothing	0.005
Energy intensity	0.62	0.64	0.85	1.21	0.48	0.25	0.12	0.06	Polynomial growth	0.037

Table 4

Predicted values for CO₂ emissions of Iran in 2030.

Year	CO ₂ emission based on the MPR model (kt)		CO ₂ emission based on the MLR model (kt)	
	BAU	SDP	BAU	SDP
2017	671450.23	632172.20	671450.23	610771.18
2020	719903.70	500128.42	659336.90	487395.84
2025	795419.90	352754.92	694451.80	387452.21
2030	876263.30	211096.59	730594.90	315738.91

Fig. 11 illustrates the forecasted trends for Iran's total CO₂ emissions in the period of 2015–2030 based on the proposed scenarios for the MLR and MPR models respectively. From both models, It can be found that the BAU scenario ruins any chance of meeting the Paris Agreement target; therefore, Iran cannot fulfill its associated commitments if does not implement practical measures in this regard. However, with a full implementation of the SDP scenario, Iran most likely could fulfill the 4% reduction target in the first year of implementation. Whereas, both MLR and MPR models represent that the total CO₂ emissions most likely will increase by 5% each year. Hence, as per figure, there is a strategic gap in the implementation of the SDP which is mainly due to the ambitious targets of this plan.

6. Discussion

Iran is able to meet its commitment to the Paris Agreement based on the SDP scenario. Implementing the plan most likely could have met the 4% reduction target by the end of 2015 and the 12% reduction target by the end of 2018. However, the BAU scenario represents an increasing trend for Iran total CO₂ emission in the coming years.

Reviewing effectivity of previous development plans (i.e., Fourth and Fifth Development Plans) reveals that the government

was unable to meet their shaped targets. As well regarding the SDP, the government still has not implemented any practical action to follow the relevant targets. In addition to the deficiency of government in the implementation of such plans, the relevant targets are ambitiously shaped and need a comprehensive set of practical measures to attain them. Therefore, the country needs to set about reversing previous policies and shape more attainable and practical targets in order to meet its commitment to the Paris Agreement.

Share of renewable energies in Iran energy mix was only 0.97% in 2014. The figure has risen by solely 0.2% by 2017; while according to the SDP scenario, the figure should have been about 4% in 2017. This is while Iran's CO₂ emission also has risen by 3.38% during this period. The BAU scenario also estimates a 1%–4% increase in Iran's CO₂ emissions between 2014 and 2017. This implies that Iran actual performance in following targets of the Paris Agreement bears a close resemblance to the BAU scenario rather than the SDP. Considering that renewables and nuclear power plants account for only 1.7% of Iran primary energy consumption, the associated target was also expressed in the previous plans, and the share scarcely has risen in the recent years, it is beyond expectation that government can raise the figure by 1% in each year in the future. Additionally, during the recent years, the parliament has considerably reduced the government's

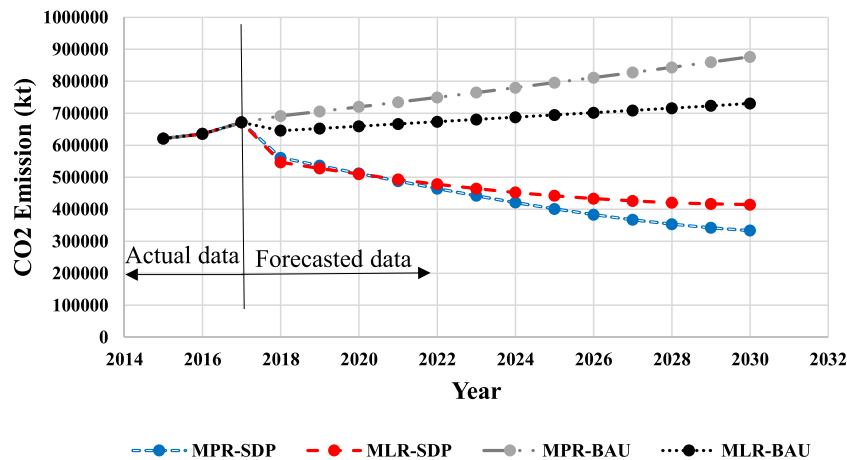


Fig. 11. Scenario-based prediction of Iran's total CO₂ emission in 2030 based on the MLR and MPR models.

development budget which is to the contrary of major targets of SDP in the diverse sectors. Further, natural gas is a major source of electricity production in Iran. Owing to its abundance and low price in this country, as well as, the high capital intensities of power generation with renewables, it is improbable that the government widely turn attention toward renewable energies at the moment. Though the share of natural gas in electricity production has increased during the recent years, the share of renewables has not significantly changed in this period. In fact, the government follows a policy to phase out oil and coal power plants and confine to natural gas as the main fossil source for electricity production. Though advantages of this policy outweigh its disadvantages, the government must concurrently invest in renewable energies if intend to meet the target of the Paris Agreement.

The US sanctions also pose serious obstacles to the implementation of the SDP. Iran is an example of oil-dominant economies that has provided cheap energy to different sectors, for decades (Moghaddasi and Pour, 2016; Raeeni et al., 2019). Inasmuch as a large proportion of Iran's annual GDP is supplied from crude oil export revenue, and Iran's oil production and the export rate have significantly reduced due to the sanctions, it is highly unlikely that the country can meet the 7.6% GDP growth target based on the currently available situations. While under the SDP's assumption Iran's GDP per capita should have reached about \$5700 in 2017, the figure was \$5415 in reality. The BAU scenario also estimates a declining trend for Iran's GDP in the coming years. Therefore, Iran's real performance in terms of wealth production also is near to the BAU scenario rather than the SDP.

Recent production capacity increases in the energy-intensive industries along with insignificant changes in their efficiency have brought about a rise in the energy intensity of Iran since 1973 (Farajzadeh and Nematollahi, 2018). As energy efficiency measures are time-consuming and capital-intensive, the development budget of government has been reduced recently, and most of the energy-intensive industries of Iran are governmental or quasi-governmental, improvement of energy intensity by 3% each year seems likely remote; considering that, the target has been also expressed in the previous development plans. This is while energy intensity in Iran has risen by 6% between 2014 and 2017. While the SDP scenario considers a declining trend for energy intensity in Iran, the figure has considerably increased under the BAU assumptions. Therefore, from this perspective also the BAU scenario is more probable for Iran.

As Iran is highly dependent on oil export revenues and the US sanctions have drastically cut the net income, as well as, Iran CO₂ emissions show great sensitivity to the GDP, the prospect

of reaching the SDP's targets seems really dim and the BAU scenario seems more probable. To fulfill its commitment to the Paris Agreement, Iran needs to formulate more get-at-able development plans and consider all the possible internal and external stakeholders in the formulation procedure. However, formulation of sustainable development policies does not necessarily result in sustainability. Though set the targets, the current practice of the development plans in Iran has failed to provide applicatory road maps to achieve these targets and only confined to make generalizations about the targets. As a result, the country usually falls behind the development schedule in the majority of times. In fact, the government vastly need to reduce economic interventionism and shape effective decentralization and diversification policies to widely involve the private sector in economic activities if tends to obtain the best results from the SDP. Additionally, ratification and implementation of carbon tax and energy price adjustment policies are of necessity for the reduction of energy and CO₂ intensity in this country, and accordingly, fulfillment of the Paris Agreement target.

7. Conclusion

With a drastic increase in total CO₂ emissions, Iran has become one of the most CO₂ emitting countries after the revolution in 1979. As one of the signatories of the Paris Agreement, the country has a commitment to lower its greenhouse gas emissions and counter the effects of climate change problems. In 2015, the Parliament has ratified the SDP in order to shape the overall development policies of Iran in the next five years. However, the SDP's concentration is on the economic aspects of development and rarely the environmentally or sustainability-related policies. This paper aims to speculate about the possible state of Iran in 2030 in terms of CO₂ emissions and its commitment to the Paris Agreement. Through regression analysis, two forecasting models, MLR and MLP, have been adopted to make an estimate of Iran annual CO₂ emissions based on the population, CO₂ intensity, per capita GDP, share of electricity production from fossil fuels, and per capita energy use. The coefficient of determination for both models has been found to be above 0.99; however, RSS for the MPR model was much lower in comparison.

From a scenario-based analysis, it was found that Iran cannot meet its commitment to the Paris Agreement based on the BAU scenario; however, full implementation of the SDP scenario could have met both 4% and 12% reduction targets by end of 2018. While energy intensity will drastically increase by 2030 based on the BAU scenario, the SDP shows a huge decline in the figure if fully be implemented. Analysis shows that the BAU scenario will

result in about 30% increase in the total CO₂ emissions of Iran by 2030; on the other hand, implementation of the SDP may result in about 60% reduction in the figure. This deviation implies possible strategic gaps in the implementation of the SDP. Therefore, with the unsuccessfulness of previous development plans and the SDP by the end of 2017, as well as, ambitiously shaped policies of these plans, further studies are needed to scrutinize the strategic gaps in the implementation of the development plans. In addition, due to the situation of Iran in the global community, it is beyond expectation that Iran can meet the SDP targets; therefore, future studies need to concentrate on development of carbon tax systems, diversification of net income, optimal privatization path, renewable energies, and CO₂ capture technologies to shape more pragmatic scenarios in order to alleviate climate-change-related problems in this country.

Acknowledgments

The authors would like to acknowledge Soft Technologies Research Institute (STRI), university of Tehran for the esteemed financial support.

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