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Article

CO_2 emission from the electricity sector in Iran; calculation, prediction and reduction policies

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ABSTRACT

Fossil fuel power plants produce a significant amount of CO_2 emissions, and this pollutant causes global warming, respiratory and heart diseases, and other significant issues. Electricity interprets as a primary and rising demand in each energy system; thus, in this paper, carbon dioxide (CO_2) emission reduction was selected as the objective value for 2025. Power plant fuel consumption was surveyed to calculate the CO_2 emission caused by each fuel. Also, Esfahan province (an industrial province in Iran) was investigated as the study case. Forecasting the fuel consumption for 2025 was run by two parameters: population and Gross Domestic Production (GDP), which were forecasted by the report of the Iran Statics Center and the Gaussian Process Regression (GPR) method, respectively. The CO_2 emission of power plants was obtained using the coefficients of each fuel. Based on Iran's commitment to the Paris Agreement, a 4% reduction of CO_2 emissions is the main objective. Thus, this study aims to reach this goal by implementing four scenarios: a) adding renewable energies, b) adding renewable energies and improving the generation efficiency, c) adding renewable energies and decreasing the grid losses, and d) combining the three scenarios mentioned above. According to these scenarios, reformation strategies compensated 10.5% of the required power, which was satisfied by renewable energies, and finally, this province can gradually satisfy a 4% reduction until 2025.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) report, which is related to an increase of 1.5 °C the earth's temperature after the industrial revolution, expresses the combustion impacts of fossil fuels in greenhouse gases emission [1, 2]. Today, climate-changing problems, global warming, rising numbers of respiratory and heart diseases, etc., have raised concerns in the countries. The Paris Agreement was signed in 2015 to balance the number of pollutants from human activities and ensure sustainable development in the second half of this century and limit the temperature increase up to 2°C [3, 4]. Due to the increase in population, the limitations of energy sources, and the environmental effects of fossil fuels, societies are moving towards alternative energies [5]. The pollutants emission generally is derived from five sectors: transportation, power plant, industrial, commercial-residential, and agricultural. As shown in Figure 1, the power plant sector produces a significant amount of emissions. This sector contains three parts: generation, transmission, and distribution, which major contribution to pollution emissions such as CO_2, Methane (CH_4), Nitrogen Oxide (NO_x), Sulfur Oxide (SO_x), etc. are related to generation [6]. Several theories mentioned a relationship between environmental pollution and economic growth [5-7]. On the other hand, the quality of the environmental parameter is affected by renewable energy development. Thus, more than ever, societies are moving to use renewable energy resources to satisfy ecological indicators. Finally, a U-shaped relationship between renewable energy resources and economic growth, or in other words, GDP per capita, will be derived [8, 9]. As a result of the new technologies development and increasing the number of consumers, electricity demand has been rising. Lack of fossil fuel sources, fuel price, and combustion's harmful environmental effects are potential challenges during power generation. A solution to this problem is Distributed Energy Planning (DEP) [10]. According to the IEA report, five factors can affect DEPs, which are: Distributed Generation (DG) Technology, limitations on new transmission lines, increase in the electricity consumers with high reliability, privatization, competition in the electricity market, and climate change concerns [11]. IEA forecasted a reduction of 1.4 to 13 GT in the CO_2 emission caused by power generation, which means about 90%, until the year 2050 [12]. Iran is one of the most important oil and natural gas exporting countries. Statistics show that more than 98% of Iran's energy consumption is provided through these sources, which has led to severe problems such as air pollution, and the effects of this pollution are more visible in metropolitan areas [13-14]. Along with this, statics showed a share of 1.97% in global CO_2 emission in the year 2018, which made this developing country the seventh CO_2 producer country around the world [15]. Furthermore, Iran's Energy balance sheet (2016) reports that annual CO_2 emissions released in the electricity sector are higher than any other pollutant [16].

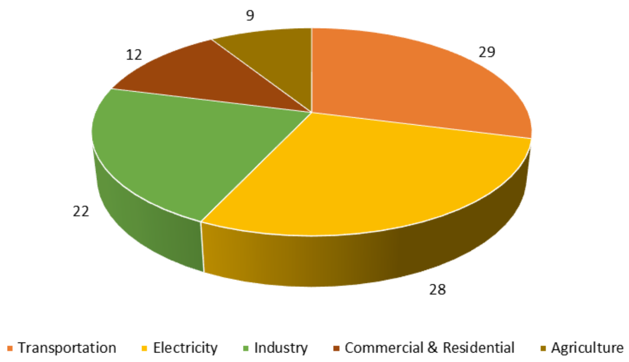

Figure 1. The contribution of each energy sector in the pollutant emissions

Most of the CO_2 emissions in 2016 for Iran are related to natural gas, diesel, gasoline, Mazut, and coal, respectively. Figure 2 illustrates the importance of CO_2 and the share of other pollutants, as well. As can be seen, following CO_2, NO_x has a larger share in air pollutants [17]. In order to achieve sustainable development goals and control pollutants, consumption management and utilization of renewable energy sources are required. The high potential of renewable sources, like solar and wind, can help apply sustainable programs and strategies [14]. Investment in renewable energy sources has been conducted so that solar power plants' installation had a growth rate equal to 50 between 2007 and 2017 [12]. About 195 countries signed the Paris Agreement, including Iran, and each country made its commitments. Based on the Bill expressed in the Iranian parliament, this country would decrease at least 4 percent of its emission by 2030 [18]. Hence, this paper is focused on the 4 percent reduction of CO_2 emission.

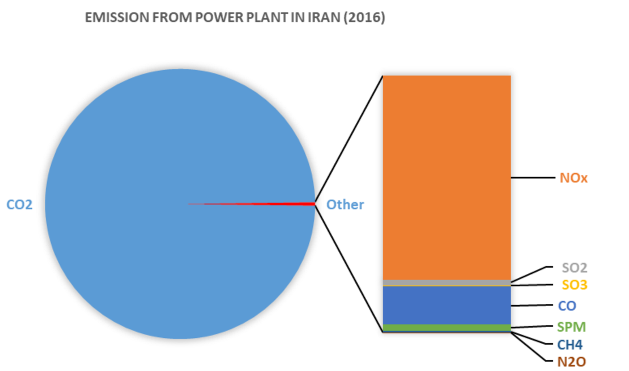

Figure 2. The contribution of each pollutant

2. Literature review

The amount of fuel consumption due to the fuel type is determined by achieving the number of pollutants caused by the power plants. According to references [19] and [20], the most influencing parameters on fuel consumption in power plants are GDP and population. Two main study areas focused on this research are demand forecasting and CO_2 emission reduction strategies. A comprehensive study of 50 countries worldwide, including Iran, has investigated the impact of GDP, population growth, and renewables installation on air pollution [21]. It has concluded that the two first criteria have a positive effect on CO_2 emission. According to [22], a novel self-adapting intelligent Grey model is a better approach than competing natural gas forecasting methods. The logistic model has been applied in [23] for long-term natural gas consumption forecasting in China. For getting the parameters of the logistic model Levenberg-Marquardt algorithm is adopted. In [24], the Autoregressive–Moving-Average model with exogenous inputs (ARMAX) model has been developed for residential and commercial energy demand forecasting in Iran. Alcaraz and Villalvazo [25] presented the natural gas estimation shortage with econometric analysis based on panel data and analyzed the natural gas interconnection shortage and GDP. In 2017, Scarpa and Bianco [26] investigated long-term natural gas consumption, considering heating degree days, natural gas prices, and GDP per capita. To obtain this goal, they used the regression algorithm and the Kalman filter method. The relationship between price and income with natural gas consumption has been shown by Liu et al. [27]. The generalized least square method was used in this study. Wang et al. [28] studied the natural gas consumption model with high accuracy by a MAPE value of 2.32% with a hybrid model based on the Particle Swarm Optimization-Wavelet Neural Network (PSO-WNN). In [29], Artificial Neural Networks (ANN), Multiple Linear Regression (MLR), and Support Vector Regression (SVR) was presented for forecasting natural gas consumption in Istanbul with these criteria: seasonal index, temperature, price of natural gas, population and 12 years history of natural gas consumption. In [30,31], electricity consumption forecasting in a building is done by using the GPR method. Sharifzadeh et al. [32] did a comparative study of ANN, SVR, and GPR for forecasting residential electricity demand. Further, the Gaussian process quantile regression is used in [33] to predict Power load probability density. In some cases, the GPR method is preferred in forecasting wind forecasting because it is flexible to provide uncertainty representations [34, 35].

Researchers have proposed some methods to decrease CO_2 emissions [36, 37]. Dominkovic et al. [38] studied southeast Europe to make a 100% renewable energy system for 2050 to achieve a zero-carbon energy community. For getting this object, biomass, and other renewable energies have been used. Also, improving energy efficiency is considered a reformation strategy for decreasing CO_2. Daví-Arderius et al. [39] expounded on the impact of electricity losses on CO_2 decrement. Construction of DGs near the consumers and covering different generations with renewable energy are the two essential policies suggested in this research. Technical progress, energy structure, and economic level are the variables considered in [40] to analyze their impact on CO_2 emission in China. Also, it is concluded that technological advances have about a 1% effect on China's CO_2 emission. Also, 14 years (2000-2014) of research in China indicated that technological developments had a remarkable impact on CO_2 emission [41]. The South Asian Association for Regional Cooperation (SAARC) countries has been weighted and ranked based on the CO_2 emission issue by Grey Relational Analysis (GRA) [42]. The results have shown substantial pollution problems in India with the first rank; hence, renewable energy installation and adoption of ISO14001 certification were introduced to solve this problem. Toward reduction of carbon emission, reference [43] offered three assortments that contain adding a clean energy supply, development in energy conservation, and negative emission strategies like using CCS technology.

3. Methodology: GPR

GPR is a non-parametric probabilistic kernel method that can model arbitrary complex systems [32]. This method combines arbitrary variables with a number describing the joint Gaussian distribution [33]. GPR models a probability distribution by functions and can be parameterized with statistical functions like mean *m(x)*, which is the expected value of *f(x)*, and covariance *κ(x-x')* that defines the similarity between data points. It can be shown as:

$$y = f(x) \sim GP(m(x), \kappa(x - x')) \quad (1)$$

where *x* and *y* are the input and output in the training dataset, respectively, and *f(x)* is called the latent variable. For simplification, mostly *m(x)* is considered to be 0.

A variety of covariance functions can be used. Some of the most common ones are squared exponential *(SE)* (Eq2), Matern (*MA*) (Eq3), and rational quadratic (*RQ*) (Eq4).

$$\kappa_{SE}(x - x') = \theta_f^2 exp(\frac{\|x-x'\|^2}{\theta_l^2}) \quad (2)$$

$$\kappa_{Ma}(x - x') = \sigma^2 \frac{2^{1-v}}{\Gamma(v)} (\sqrt{2v}\frac{x-x'}{l})^v \kappa_v(\sqrt{2v}\frac{x-x'}{l}) \quad ,v,l > 0 \quad (3)$$

$$\kappa_{RQ}(x - x') = \sigma^2 (1 + \frac{x-x'}{2\alpha l^2})^{-\alpha} \quad ,\alpha, l > 0 \quad (4)$$

The *SE* function is infinitely differentiable, so the GPR is so smooth using it, and it is too strict for physical action [34]. θ_f and θ_l are parameters that control the length scale.

K_v in Matern covariance was modified Bessel function. The function becomes simple when *v* is half floating-point *v=p+1/2,* where *p* is an integer. *V* is mostly considered to be *v=5/2* and *v=3/2*.

Along with this, two effective methods were proposed to evaluate machine learning algorithms' performance; Holdout-test, which mostly applies to large datasets, and cross-validation (CV), which is called K-fold validation. This approach divides the dataset into parts and estimates each fold's accuracy to prevent overfitting the output. Also, by increasing the number of folds, more reputable outputs can be derived.

4. Fuel consumption forecasting

The energy system of Isfahan province for 2016 is shown in Figure 3, illustrating its high dependency on fossil fuels. Furthermore, the importance of conversion and grid losses are apparent in this figure. As mentioned before, GDP and population are the essential parameters for estimating energy consumption. GDP was achieved using the GPR method, and the population was obtained by the combined method from the report of Iran's Statics Center [44]. In this research, the estimation of GDP is based on historical data from 2006 to 2016. As a result, future data up to 2025 was achieved by applying the GPR algorithm to the current data.

4.1 Population forecast

Population forecasting is conducted by the combined method, which utilizes inner population structure (i.e., mortality, age-sex composition, and fertility pattern) and outer impacting factor population structure (i.e., immigration) to forecast population. This method is the most common approach in population modeling and forecasting [44]. Figure 4 illustrates the population curve for 19 years.

4.2 GDP forecast

Real data on provincial GDP from 2006 to 2016 is derived from the energy balance sheet [17]. The GPR method was used by applying a 10-fold validation method for the years 2016 to 2025. The results obtained from the GPR are presented in Figure 5.

4.3 Natural gas and diesel consumption forecast

Natural gas and diesel fuel consumption are shown in Figure 6 and Figure 7, respectively. As shown in Table 1, most of Isfahan's power plants are non-renewable and consume four fuel types, including diesel, coal, natural gas, and Mazut. The consumption of Mazut has gradually been discarded in recent years due to its high combustion pollutants. Therefore, in the present study, its value for the future was considered to be zero. Besides, coal usage for power generation is decreasing with a high slope and is used under particular conditions [45]. Therefore, the coal consumption for future power plants is considered to be zero too. Natural gas and diesel consumption are forecasted by applying the GPR approach with the three mentioned covariance functions and calculating R-squared for each one.

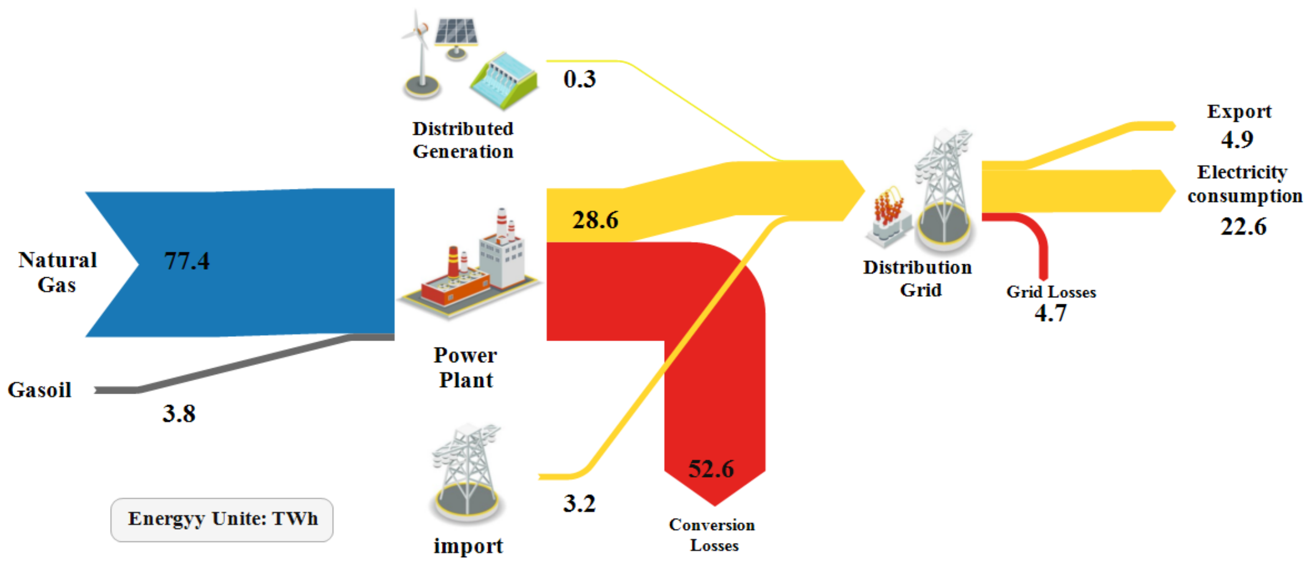

Figure 3. The electricity system of Isfahan province

The best-fitted covariance function is selected by comparing R-squared, Matern with R-squared equal to 0.96 and 0.88.

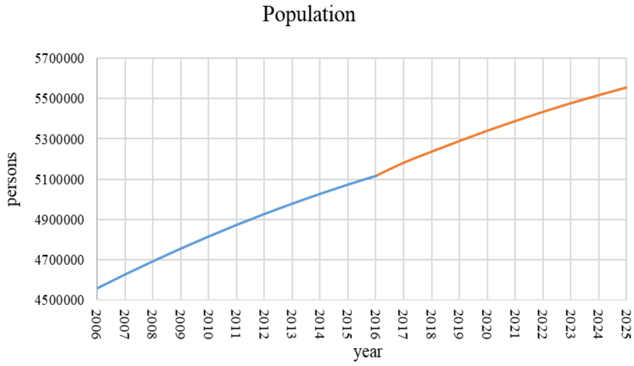

Figure 4. The population of Isfahan province (blue: historical data; orange: forecast data)

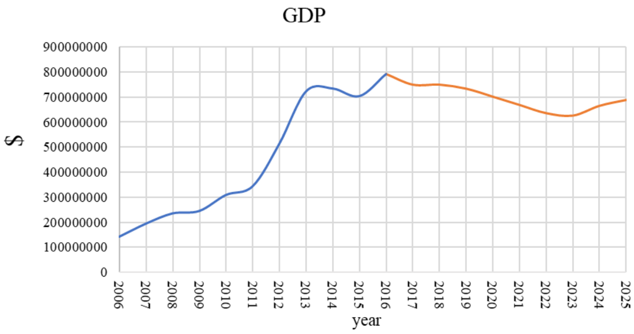

Figure 5. GDP of Isfahan province (blue: historical data; orange: forecast data)

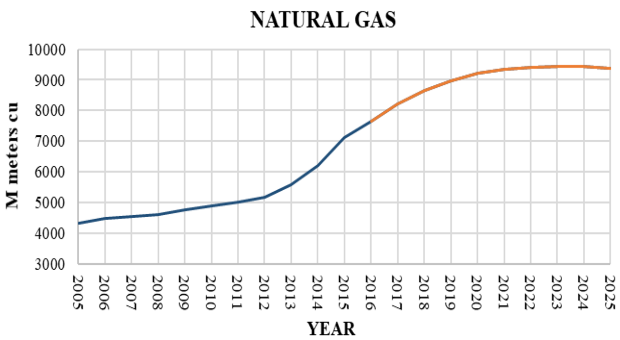

Figure 6. Natural gas consumption forecast of powerplants (blue: historical data; orange: forecast data)

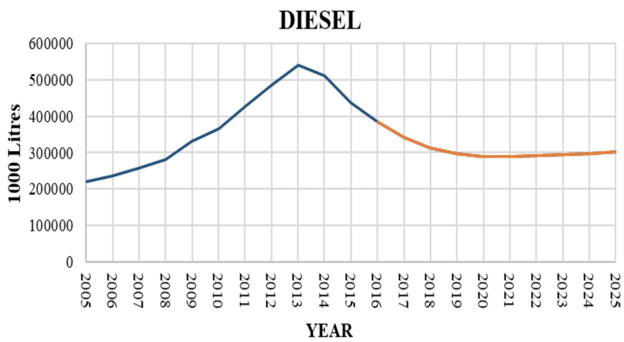

Figure 7. Diesel consumption forecast of powerplants (blue: historical data; orange: forecast data)

Table 1. List of power plants in Isfahan province

Name	Type	Capacity (MW)	Efficiency (%)
Zob Ahan	steam	249	26.4
Zob Ahan	Gas	26	-
Fulad	steam	210	27..9
Fulad	Gas	108	31
Shahid Montazeri	steam	1616	38.3
Islam Abad	steam	835	37.1
Hessa	Gas	87.6	28
Kashan	Gas	324	31.7
Chehel Sotun	Gas	954	32
Zavareh	Combined-cycle	484	50.4
Distributed Generation	Gas	126.7	39.7

5. CO_2 emission calculation

The difference in the heating value of the fuels and the efficiency of machines' burning fuels affect each fuel's emission per equal amount. In order to calculate the coefficient of CO_2 for the electricity sector caused by natural gas, the total volume of CO_2 produced by the natural gas electricity sector is divided into the total consumption of natural gas [46]. The accrued coefficient is 0.0022 tons per 1000 liters. Using the same approach, the coal and diesel emission coefficient is calculated as 0.0011 and 2.905 tons per 1000 liters, respectively. Finally, according to the data presented in the energy balance sheet and estimated values, the CO_2 emission of three more essential fuels in the electricity generation sector has been calculated, shown in Figure 8.

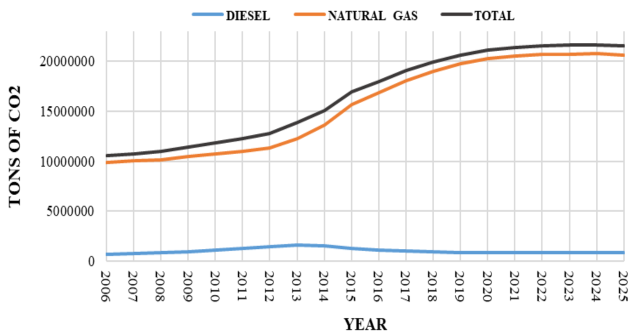

Figure 8. CO_2 emission trend

6. Emission reduction scenarios

As represented in previous sections, CO_2 is becoming a critical problem in societies; therefore, CO_2 emission was considered an objective function. This research aimed to Achieve a 4% reduction in CO_2 by the implementation of four scenarios as follows:

S1. Adding the photovoltaic
S2. Adding the photovoltaic and reforming the generation sector
S3. Adding the photovoltaic and reforming the grid
S4. Adding the photovoltaic and reforming the generation sector and the grid

In the first step, total CO_2 production caused by power plants until the year 2025 was calculated, then 4% of this amount was considered as the criteria of reduction for these scenarios equals 860890 Tons. In the second step, fuel consumption for the power plants (natural gas & diesel) was calculated using the coefficients of CO_2 emission. Finally, according to fuel consumption and total energy production, one coefficient is obtained using Eq5, which satisfies the reduction of CO_2 emission.

$$Generation\ coeffcient = \frac{TEP(t)}{PEC(t)} \quad (5)$$

TEP(t) and *PEC(t)* represent the Total Energy Production and Primary Energy Consumption, respectively in t^{th} year. For this amount of electrical energy, the following scenarios are explained:

In scenario (1), renewable power plants would be replaced with fossil fuel to generate the calculated electrical power replacement. Based on solar radiation and ambient temperature, Isfahan has a high potential for PV energy generation [47]. According to the Iran Renewable Energy and Energy Efficiency Organization announcement, the estimated capacity of photovoltaic for Isfahan province is 3220 MW [48]. So, these potentials can cover the rest power with less CO_2 emission.

In scenario (2), an improvement in the efficiency of the fossil fuel plants was considered; thus, a ratio of needed power would be satisfied during generation. PV would be replaced with the rest of the required electricity. Enhancements in efficiency include converting the gas turbine powerplant to a combined cycle powerplant or improving the powerplant components and equipment types.

Transmission and distribution losses play an essential role in grid optimization, and these can help the grid reach the optimum point. Therefore, in scenario (3), with activities like reforming the distribution grid, installation of the low-loss transformers, changing the defective counter, etc., the grid losses would reach a minimum amount, and this will cause a decrease in fuel consumption of powerplants or on the other point of view, with constant fuel consumption, the grid has extra power for feeding the demands.

Eventually, in the last scenario, three scenarios were combined and expressed the amount of renewable power to improve efficiency and decrease the grid's losses.

7. Results and discussion

Referring to Figure 8, the total CO_2 emission in 2025 will be 21,522,259 Tons for Isfahan province, and it is aimed to reduce 4% of CO_2 emission, which means 860,890 Tons of reduction. Based on Eq5, the generation coefficient in 2016 is 2852.3 and 1.30 for natural gas and diesel, respectively.

This coefficient is variable for each year due to power plant efficiency and fuel alternation. Powerplant efficiency trend analysis of 2005 compared to 2016 showed 2.73% growth in the BAU scenario. Reducing 4% of CO_2 emission by just decreasing fuel usage requires 1,086,303 MWh energy generation descending, as expressed in Eq 5. In other words, 124.01 MW must be supplied using the appropriate sources. The scenarios mentioned above compensate for it by providing energy with different strategies.

The capacity factor is the annual generation of a power plant divided by the product of the capacity and the number of hours over a given period (Eq6). The photovoltaic capacity factor is an average of 20% for Isfahan province. Therefore, the equated power that should be provided by renewable energies can be calculated using the capacity factor formula.

$$Capacity\ factor = \frac{P_{real}}{P_n} \times 100 \quad (6)$$

where P_{real} and P_n are the real output power and nominal power, respectively.

Table 2 shows a summary of the results of the calculations for different scenarios. This research aims to clarify the importance of power plant efficiency and grid losses in the contribution of CO_2 emission reduction. These two factors can help renewable energies, as shown in Figure 9, to provide an environmental-friendly energy system.

8. Conclusion

In this paper, Isfahan province power plants' CO_2 emission up to 2025 was estimated by considering the most affecting factors on consumers' electricity consumption (GDP and population). GP regression with a different covariance function was applied to the consumption trend from 2005 to 2016. The comparison was based on the best R-squared validation. Finally, considering the air pollution reduction program, which aimed to reduce 4% of CO_2 emissions, four scenarios were discussed. The scenarios were based on altering renewable energies to recent infrastructures with a constant rate of technological improvements and alternative rate that impacts the promotion of efficiency and transfer losses. The main conclusions that can be drawn from this study are as follows:

- Matern covariance function can produce more satisfactory results for the fuel consumption trend.
- Diesel consumption has decreased with a high slope in recent years, and it will be reduced more within the upcoming years.
- The primary fuel of power plants is natural gas in Isfahan province. By descending other fuels like coal and diesel in power plants, natural gas compensates for it, and its consumption will be increased.

Table 2. The results and summary

	Generation Coefficient		PV Capacity (MW)	$Power_E$* (MW)	$Power_L$** (MW)	Efficiency growth (%)	Grid losses (%)
	Ngas	Diesel					
S1	2852.3	1.3	620.05	0	0	1	**14.5**
S2	2931.02	1.34	603.05	3.4	0	2.7	**14.5**
S3	2852.3	1.3	574.05	0	9.2	1	**7.1**
S4	2931.02	1.34	557.05	3.4	9.2	2.7	**7.1**

- By applying reformatory developments on existing instruments that include power plants, transport, and distribution networks, pollution will decrease, and the share of demand for renewable plant installation will be reduced.
- The impact of reforming strategies is undeniable, especially for renewable installation issues like investment, land limitation, and low potential.

Further research can mostly focus on econometric aspects of renewable power plant installation and technological development costs.

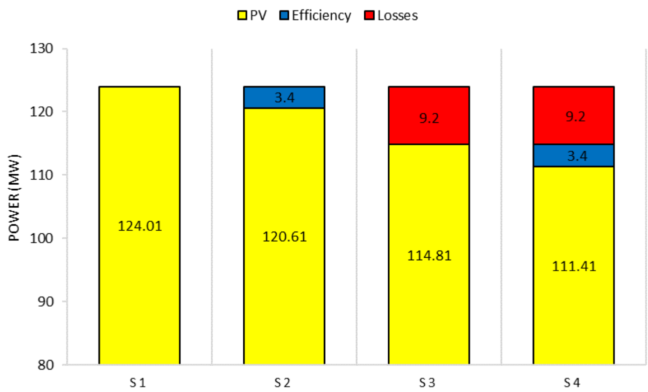

Figure 9. Comparison of scenarios

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

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