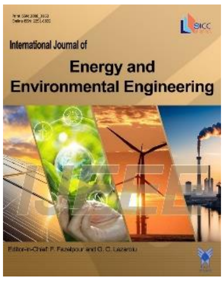

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Analysis of Greenhouse Gas Emissions from a Combined Cycle Power Plant using RETScreen

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Original Research

Abstract

Population growth and increasing energy demand have intensified fossil fuel consumption, resulting in higher greenhouse gas (GHG) emissions and environmental impacts. This study evaluates the environmental performance of the Saravan combined cycle power plant in Guilan Province, Iran, under two proposed seasonal fuel mix scenarios using RETScreen Clean Energy Management Software. Scenario 1 represents normal winter conditions, with natural gas used for ten months (March–December) and gasoil for two months (January–February), achieving total annual GHG emissions of 4,814,379 tCO_2 and a projected 30-year reduction of 71,882,453 tCO_2. Scenario 2 reflects severe winter conditions, with natural gas for eight months (April–November) and gasoil for four months (December–March), resulting in 5,018,646 tCO_2 of annual emissions and a projected 30-year reduction of 32,780,122 tCO_2. The analysis demonstrates that strategic seasonal adjustments in fuel usage—prioritizing natural gas when available and supplementing with gasoil during peak cold months—can substantially reduce GHG emissions while maintaining reliable electricity production. Furthermore, risk assessment indicates that the optimized seasonal fuel mixes provide economic benefits, with estimated savings from carbon shadow pricing of $119,804,088 for Scenario 1 and $54,633,537 for Scenario 2 over 30 years. Implementing such optimized seasonal fuel strategies enhances both environmental performance and operational flexibility, offering an effective approach for sustainable electricity generation and climate change mitigation in fossil fuel-based combined cycle power plants.

Keywords: Greenhouse effect, Fossil fuel, Environmental performance, Analysis risk, Carbon shadow price

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1. Introduction

The provision of sustainable and accessible energy sources has emerged as a fundamental challenge for human societies in recent decades [1]. The increasing global population has increased energy consumption, prompting significant concerns among many countries regarding GHG emissions and the environmental damage associated with fossil fuels [2–5]. Although diverse sources of electricity generation have been developed in recent years, fossil fuels remain the main source of energy in many countries [6,7].

Historically, the dependence on fossil fuels has significantly contributed to GHG emissions, impacting global warming and climate change [8,9]. The combustion of these fuels in power plants results in the emission of carbon dioxide, nitrogen oxides, sulfur dioxide, and particulate matter, which significantly threatens human health and the environment [10–13]. Air pollution represents a significant environmental impact on fossil power plants [14].

Iran possesses 32.1 trillion m^3 of gas and 157.8 billion barrels of oil, categorizing it as one of the richest countries in terms of fossil fuel resources. Moreover, approximately 88% of the country's electricity is generated from fossil fuels [15]. Fossil power plants in Iran are among the major sources of pollution and emit nitrogen oxides and sulfur dioxide as a result of the chemical composition of fuel, which includes a high sulfur content (2.5–3.5%) and high nitrogen level (approximately 26%). Therefore, it is crucial to continuously monitor fuel consumption and pollutant emissions to minimize fossil fuel use, lower energy production costs, and enforce environmental policies [14,17].

Performance assessment in combined cycle power plants, particularly through analytical tools such as RETScreen, effectively contributes to reducing pollutant emissions and increasing efficiency. Several studies have addressed this issue from different perspectives. Iweh *et al.* (2023) used RETScreen Expert to evaluate a 211.75 MW solar PV project in Yaoundé, Cameroon. Their results showed an annual electricity generation of about 304 GWh and a GHG reduction potential of 61,004 tCO_2 per year. The project was economically feasible, with a cost of energy of $0.075/kWh, a benefit-cost ratio of 4.5, and a payback period of approximately 9 years, demonstrating the viability of large-scale solar deployment in Cameroon. [18]. Kofi *et al.* (2021) analyzed the financial advantages associated with a hybrid grid-connected solar and gasoil generator system utilizing RETScreen in Ghana. Their findings demonstrated that the integration of renewable energy sources, particularly solar energy, with other energy systems results in substantial decreases in electricity expenses. This system design provides multiple advantages, such as enhanced reliability, decreased emissions, and substantial cost savings [19]. In another study, Pan *et al*. (2017) analyzed four potential scenarios regarding energy supply forms in the RETScreen. The results indicated that implementing a combined heat and power system utilizing natural gas alongside a biomass system was essential to meet energy demand and decrease energy imports, resulting in an annual reduction in GHG emissions of 1.978 million tons [20]. Electricity is an essential commodity in today's global economy and the foundation of technological advancement. According to the US Energy Information and Administration (2022), renewable energy, nuclear power, and fossil fuels are the three primary types of energy used to generate electricity [21]. Islam *et al.* (2023) used RETScreen to evaluate the feasibility of a 100 MW solar PV project in Rajshahi, Bangladesh. The results indicated an annual generation of 140,155 MWh, a power generation cost of $0.09/kWh, and a reduction of 78,797.7 tCO_2 per year, demonstrating that the project is technically, economically, and environmentally viable. [22]. The Iranian Ministry of Energy has revised its policy concerning the development of combined cycle power plants [16]. Since few studies have addressed this issue in Guilan Province, Iran, this study aims to assess the environmental performance of a combined cycle power plant located in Rasht, Guilan Province, Iran, in the RETScreen. This software facilitates a more precise analysis of technical, geographical, and climatic factors. The utilized information comprises design data, specifications for the combustion system chimney, and related parameters.

2. Data and methods

2.1. Case study site

The Saravan combined cycle power plant, located in the southeastern Rasht, Iran, was put into operation in 1997 to increase Iran's electricity generation capacity. Boasting a nominal capacity of 1,350 MW, the power plant occupies a land area of 56 hectares next to Rasht Industrial Town [23]. The power plant was developed in two phases: the first phase involved the installation and operation of six Siemens V94.2 gas units, each rated at 143.8 MW with an efficiency of approximately 33%. The second phase incorporated three steam units, collectively providing 148.2 MW, operating in a combined cycle configuration [24,25]. Figure 1 shows the geographical location of the Saravan combined cycle power plant in the RETScreen.

2.2. Meteorological data

Meteorological data were obtained from reliable databases, including the Iran Meteorological Organization and NASA, and included average temperature, relative humidity, atmospheric pressure, wind speed, and solar radiation measured at stations in Rasht [26,27].

These data were used to analyze the influence of ambient climate conditions on the operational performance of the power plant, particularly the gas turbines. Ambient temperature plays a critical role: lower temperatures increase air density, which improves the volumetric flow rate through the turbines, enhances combustion efficiency, and increases overall system efficiency [26]. Similarly, variations in humidity and wind speed can affect the cooling performance and intake air properties, while solar radiation data may be relevant for auxiliary systems or integrated renewable components. By incorporating meteorological data into the simulation models, more accurate predictions of turbine output, fuel consumption, and pollutant emissions can be achieved under varying climatic conditions.

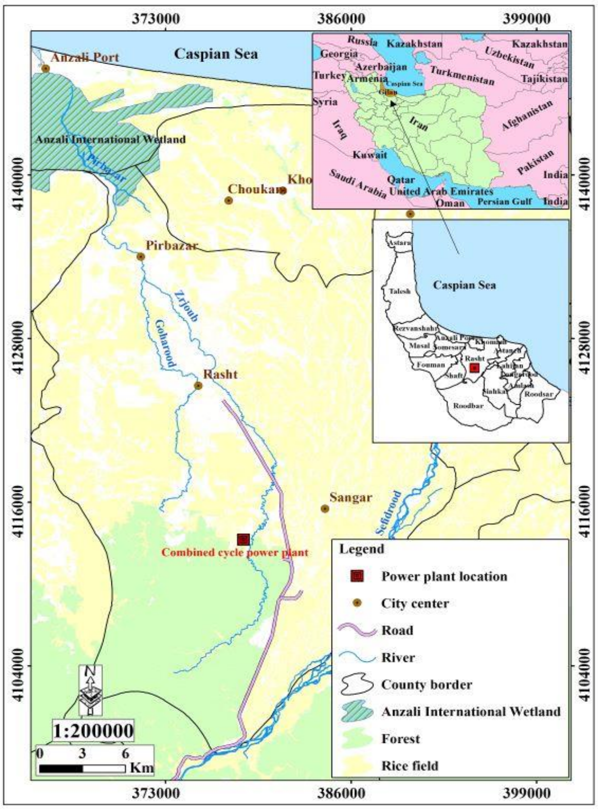

Figure 1. Geographical location of Saravan Combined Cycle Power Plant

Table 1. Location and annual climate data of the Saravan combined cycle power plant

Parameter	Value	Unit
Mean temperature	16.5	°C
Relative humidity	83.5	%
Precipitation	641.5	mm/year
Solar radiation	3.85	kWh/m²/day
Wind speed	4.6	m/s
Atmospheric pressure	1017.8	kPa
Cooling demand	1396	kWh/m²/year
Heating demand	507	kWh/m²/year

3. Methodology

3.1. Data collection and preparation

In Iran, natural gas is predominantly methane (85–88%), with minor fractions of ethane (2–5%), propane (0.7–2%), butane (0.3–1.2%), and trace non-hydrocarbon components such as CO_2, N_2, and H_2S [28–30]. These compositions are consistent across central, southern, and northern gas fields [28]. Gasoil, used as a backup fuel, consists of C_{12}–C_{20} hydrocarbons, including paraffins, cycloparaffins, and aromatics, with sulfur content ranging from a few hundred to 7000 ppm, which significantly affects pollutant emissions during combustion [31]. The Gilan combined cycle power plant primarily operates on this methane-rich natural gas, with gasoil as backup. Detailed fuel compositions, together with combustion parameters such as burner type, exhaust temperature, flow velocity, stack height, and operational data, were used as inputs for emission modeling [32,33].

3.2. Calculation of GHG emissions and air pollutants

The formulas in RETScreen version 9.1.0.24 were used to calculate GHG emissions on the basis of fuel type and fuel mix. Eq. 1. was used to calculate the GHG reduction [34].

$$\Delta_{GHG}=(e_{base}-e_{proposed})E_{proposed}(1-\lambda_{proposed})(1-e_{credit}) \quad (1)$$

In this equation:
e_{base}: Base case GHG emission factor
$e_{proposed}$: Proposed case GHG emission factor
$E_{proposed}$: Proposed case annual electricity generation
$\lambda_{proposed}$: Electrical energy loss in transmission and distribution for the proposed project (in an off-grid system, it is equal to zero)
e_{credit}: Credit cost of GHG reduction for a fuel source.
Eq. 2. was used to calculate the baseline GHG emission factor (the system's GHG emissions) [35].

$$e_{base} = \left(e_{CO_2}\, GWP_{CO_2} + e_{CH_4}\, GWP_{CH_4} + e_{N2O}\, GWP_{N2O}\right)\frac{1}{\eta}\,\frac{1}{1-\lambda} \quad (2)$$

In this equation, e_{CH_4}, e_{CO_2}, and e_{N2O} represent the emission factors, and e_{CH_4}, e_{CO_2}, and e_{N2O} denote the source fuel. GWP_{CH_4}, GWP_{CO_2}, and GWP_{N2O} are the global warming potentials, and η is the fuel conversion efficiency. In addition, it indicates energy loss in transmission and distribution. In accordance with standards, GWP_{CH_4}, GWP_{CO_2}, and GWP_{N2O} were considered equal to 21, 1, and 310, respectively. In cases that involve multiple fuel types or sources, the GHG emission factor is determined as proposed by the Ministry of Natural Resources of Canada [34].

3.3. Pollutant emissions associated with the utilization of secondary fuel

The studied power plant is of the combined cycle type and utilizes two fuel types; thus, the equation 3 was employed to assess the GHG emission coefficient:

$$e_{proposed} = \sum_{i=1}^{n} f_i \, e_{proposed} \quad (3)$$

In this equation, n denotes the number of sources available, and f_i represents a fraction of the final electricity consumption generated by fuel/source I [14].

3.4. Scenario definition

In order to evaluate the environmental performance of the Saravan combined cycle power plant under realistic operating conditions in Iran, two proposed fuel consumption scenarios were developed. These scenarios reflect the actual operational practice of power plants in the country, where natural gas is the dominant fuel due to its abundance and low cost, while gasoil oil is used only during periods of gas shortage. In the first proposed scenario, representing normal operating conditions, the plant operates on natural gas for ten months of the year and switches to gasoil in January and February when gas supply and pressure decline, resulting in a fuel share of 84% natural gas and 16% gasoil. In the second proposed scenario, which represents severe winter conditions, the plant relies more heavily on gasoil to maintain stable electricity generation, operating on natural gas for eight months and gasoil for four colder months (December to March), corresponding to 67% natural gas and 33% gasoil.

These two proposed scenarios provide a realistic representation of the annual operating pattern of Iranian power plants compared with idealized hybrid mixes and enable a more accurate assessment of greenhouse gas emissions and environmental impacts in RETScreen analysis. Similar approaches have been reported in recent studies: Motahari et al. (2023) [36] applied life cycle assessment to a combined cycle power plant to quantify fuel-related environmental burdens; Ghodrati et al. (2020) [23] examined the water–energy–carbon nexus in Iranian CCPPs under seasonal fuel constraints; Yousefi et al. (2023) [37] highlighted the sensitivity of integrated LCA results to fuel-switching conditions; Mohtaram et al. (2020) [38] optimized combined cycle plants for emission reduction and cost control; and Khan

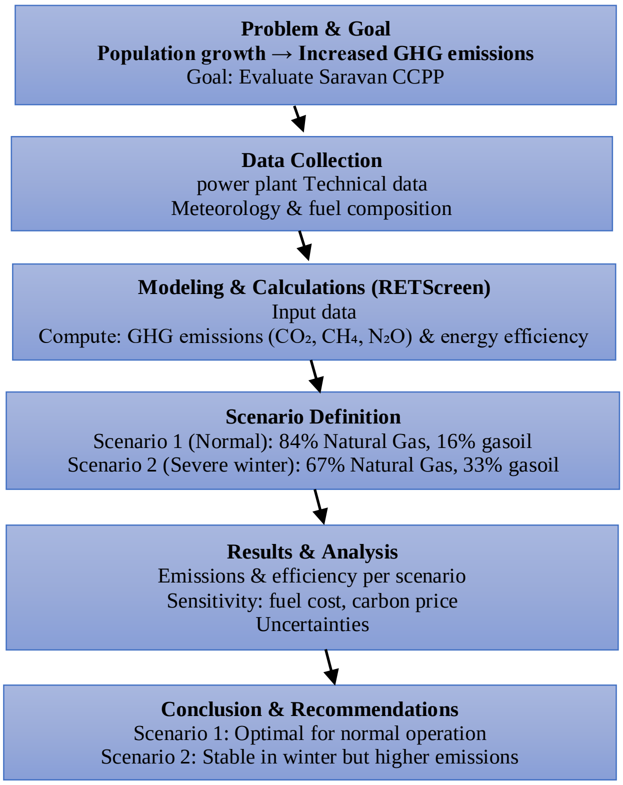

Figure 2. Research flowchart of the Saravan combined cycle power plant analysis using RETScreen

et al. (2023) [39] emphasized the role of RETScreen in scenario analysis and GHG assessment. In addition, Pye et al. (2020) [40] underlined that achieving net-zero energy systems requires flexible scenario-driven approaches. Similarly, international investigations (Marseglia et al., 2020) emphasize that scenario-based analyses and fuel switching strategies substantially affect efficiency, emission factors, and long-term environmental outcomes [41]. Collectively, these studies confirm that scenario-based modeling of seasonal fuel mixes is an effective method for assessing and mitigating environmental impacts in combined cycle systems under Iranian operating conditions. Figure 2 illustrates the research flowchart, summarizing the methodological steps from data collection, input into RETScreen, definition of the two scenarios, through to results analysis and conclusions.

4. Results

4.1. Energy analysis

The Saravan combined cycle power plant, with a nominal capacity of 1350 MW and an annual production of 10,734,414 MWh, is assessed as a project demonstrating favorable performance in energy production. The power plant's operating efficiency is estimated at approximately 79.5%, reflecting effective equipment utilization and optimal management practices. This efficiency rate is notably satisfactory compared with the global standards for combined cycle power plants. The energy analysis revealed that the expenses for periodic repairs, maintenance, and upgrades of control systems amount to approximately $140 million, whereas the annual fuel cost exceeds $3 billion. The power plant employs a dual-fuel system, utilizing natural gas with a capacity of 143.8 MW and gasoil with a capacity of 148.2 MW. Such a system enhances operational flexibility and enables responsiveness to potential fuel supply disruptions. Table 2 presents the results of the energy analysis for the studied power plant.

4.2. Analysis of GHG emissions

The analysis of GHG emissions for natural gas and gasoil indicated that natural gas is an environmentally superior option compared with gasoil, effectively contributing to the reduction of environmental impacts and GHG emissions. Natural gas generates approximately 49.6 kg of CO_2, 0.0009 kg of CH_4, and 0.0006 kg of N_2O per GJ of energy. On the other hand, gasoil produces 70 kg of CO_2, 0.002 kg of CH_4, and 0.0006 kg of N_2O. The overall emission factor of this power plant is 40.8% for natural gas and 25.3% for gasoil. Although this factor is greater for natural gas, it is important to note that natural gas emits significantly fewer GHGs than gasoil does. Furthermore, the transmission and distribution losses for both fuels are 7%, indicating that energy is lost during the transfer from the source to the end user. The GHG emissions from the studied power plant are equal to 0.473 and 1.075 tons of carbon dioxide per unit of energy for natural gas and gasoil, respectively. This suggests that natural gas emits substantially fewer GHGs than gasoil does. Table 3 presents the GHG emissions categorized by fuel type in the studied power plant.

Based on the two proposed seasonal fuel mix scenarios for the Saravan combined cycle power plant, Table 4 presents the fuel consumption and associated greenhouse gas (GHG) emissions. In Scenario 1, representing normal operating conditions, the plant utilizes 84% natural gas and 16% gasoil, reflecting the use of gasoil only during the two colder months (January–February) when natural gas supply is limited. This results in total annual GHG emissions of approximately 4,814,379 tCO_2. In Scenario 2, representing severe winter conditions, the plant relies more heavily on gasoil, with a 67/33 share of natural gas to gasoil during the year, including four colder months (December–March). Consequently, total annual GHG emissions increase to about 5,018,646 tCO_2.

The data in Table 4 highlight that adjusting the seasonal fuel mix can significantly influence GHG emissions while maintaining total energy production at 10,743,772 MWh per year. Natural gas consistently contributes lower emissions per unit of energy compared with gasoil, emphasizing the environmental benefits of maximizing gas utilization when available. These results provide a realistic representation of the power plant's annual operational pattern and serve as the basis for further environmental and economic assessments in the study.

According to Table 5, gasoil and natural gas emit 70.0 kg and 49.6 kg of carbon dioxide per GJ of energy, respectively. In addition, they emit 0.0020 and 0.0009 kg/GJ of methane, respectively. Although these figures may seem small, the substantial greenhouse effect of methane makes a significant difference. The results also revealed that the emissions of nitrogen oxide (N_2O) are 0.0006 kg/GJ for both fuels.

Table 2. Energy analysis for the Saravan combined cycle power plant

Title	Value	Unit
Power plant capacity	1,350	Megawatt
Annual electricity production	10,734,414	MWh
Repair cost	140,641,322	Dollar
Fuel cost	3,292,043,040	Dollar

Table 3. GHG emissions by fuel type in the studied power plant

Fuel type	CO_2 (kg/GJ)	Methane (kg/GJ)	N_2O(kg/GJ)	Total emission factor (%)	Transmission and distribution(%)	GHGs emission (tons of CO_2)
Natural gas	49.6	0.0009	0.0006	40.8	7.0	0.473
Gasoil	70.0	0.0020	0.0006	25.3	7.0	1.075

Table 4. Analysis of fuel consumption and GHG emissions

Fuel type	Scenario 1 – Normal Operating (MWh)	GHG emissions (tCO_2)	Scenario 2 – Severe Winter (MWh)	GHG emissions (tCO_2)
Natural Gas	9,025,571	3,851,274	7,198,327	3,073,284
Gasoil	1,718,201	963,105	3,545,445	1,945,362
Total	10,743,772	4,814,379	10,743,772	5,018,646

Table 5. Comparison between gasoil and natural gas in terms of GHG emissions and energy consumption

Fuel type	CO_2(kg/GJ)	Methane (kg/GJ)	N_2O(kg/GJ)	Fuel consumption	GHGs (tons of CO_2)
Gasoil	70.0	0.0020	0.0006	11,274,120	2,849,571
Natural gas	49.6	0.0009	0.0006	11,274,120	2,022,491
Total	59.8	0.0015	0.0006	22,548,240	4,871,061

The total greenhouse gas emissions amount to 2,849,571 tons of carbon dioxide for gasoil and 2,022,491 tons for natural gas. The total greenhouse gas emissions for both fuels are 4,871,061 tons of carbon dioxide.

The environmental performance of the Saravan combined cycle power plant was evaluated under two proposed seasonal fuel mix scenarios, reflecting both normal operating and severe winter conditions. The carbon shadow price is used in this analysis to represent the estimated economic cost of emitting one ton of CO_2, providing a monetary valuation of GHG reductions.

Scenario 1 – Normal Winter Conditions (March–December NG, January–February Gasoil): In this scenario, the plant operates using 84% natural gas for ten months and 16% gasoil for two months, reflecting the limited use of gasoil during the coldest months. The weighted electricity generation efficiency is 36.0%, with transmission and distribution (T&D) losses of 7%, resulting in a weighted GHG emission factor of 0.569 tCO_2/MWh. Total annual GHG emissions are 4,814,379 tCO_2, with a projected 30-year reduction of 71,882,453 tCO_2 based on strategic seasonal fuel management. Considering a carbon shadow price of \$50/tCO_2 over 30 years with a 3% annual escalation rate, the estimated GHG reduction savings amount to \$119,804,088.

Scenario 2 – Severe Winter Conditions (April–November NG, December–March Gasoil): This scenario represents severe winter conditions, with 67% natural gas for eight months and 33% gasoil for four months, ensuring stable electricity generation during periods of higher fuel demand. The weighted electricity generation efficiency is 33.0%, with T&D losses of 7% and a weighted GHG emission factor of 0.672 tCO_2/MWh. Total annual GHG emissions are 5,018,646 tCO_2, with a projected 30-year reduction of 32,780,122 tCO_2 and GHG reduction savings of \$54,633,537. These results demonstrate that seasonal adjustment of the fuel mix can substantially reduce greenhouse gas emissions while maintaining electricity production reliability. Scenario 1, which prioritizes higher natural gas usage for most of the year, provides the largest absolute reduction in GHG emissions, whereas Scenario 2 illustrates that even under severe winter conditions, meaningful reductions are achievable through strategic seasonal fuel management. Table 6 compares the two optimized seasonal fuel scenarios for the Saravan combined cycle power plant. It shows the fuel mix, electricity generation efficiency, GHG emission factors, annual emissions, and estimated savings from emission reductions. Scenario 1 uses more natural gas under normal winter conditions, while Scenario 2 uses more gasoil to maintain stable generation in severe winters.

4.3. Risk analysis

A sensitivity analysis was conducted to evaluate the economic and environmental uncertainties associated with the operation of the Saravan combined cycle power plant under the two optimized seasonal fuel mix scenarios. The initial construction costs were estimated to range from 2.9 to 4.8 billion USD, with an average of approximately 3.8 billion USD, while fuel costs under the proposed seasonal fuel mix scenarios were calculated at around 6.5 billion USD, subject to market fluctuations. The economic valuation of GHG reductions

Table 6. Comparison of proposed seasonal fuel mix scenarios for the Saravan CCPP

Parameter	Scenario 1 – Normal Winter	Scenario 2 – Severe Winter
Fuel Mix (NG/Gasoil)	84/16 (10 months NG, 2 months Gasoil)	67/33 (8 months NG, 4 months Gasoil)
Weighted Electricity Generation Efficiency (%)	36.0	33.0
Weighted GHG Emission Factor (tCO_2/MWh)	0.569	0.672
Annual GHG Emissions (tCO_2)	4,814,379	5,018,646
Projected 30-Year GHG Reduction (tCO_2)	71,882,453	32,780,122
GHG Reduction Savings (\$)	119,804,088	54,633,537

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was based on a carbon shadow price of 50 USD/tCO_2, allowing emission reductions to be translated into monetary savings. From an environmental perspective, the projected 30-year greenhouse gas (GHG) reductions under the two proposed scenarios are 71,882,453 tCO_2 for Scenario 1 – Normal Winter (84% natural gas / 16% gasoil, March–December NG, January–February gasoil) and 32,780,122 tCO_2 for Scenario 2 – Severe Winter (67% natural gas / 33% gasoil, April–November NG, December–March gasoil), as summarized in Table 7. This analysis demonstrates that significant GHG reductions can be achieved through strategic seasonal fuel mix adjustments, with Scenario 1 providing the largest reduction under normal conditions, while Scenario 2 ensures stable electricity production and meaningful emission reductions even during the harshest winter months.

5. Discussion

The evaluation of the Saravan combined cycle power plant using RETScreen demonstrates that strategic optimization of the seasonal fuel mix significantly improves both environmental performance and energy efficiency. Two proposed seasonal scenarios were analyzed:

Scenario 1 – Normal Winter Conditions (March–December NG, January–February Gasoil): In this proposed scenario, the plant uses 84% natural gas and 16% gasoil, reflecting limited use of gasoil during the coldest months. The weighted electricity generation efficiency is 36.0%, with a weighted GHG emission factor of 0.569 tCO_2/MWh. Total annual GHG emissions are 4,814,379 tCO_2, resulting in a projected 30-year reduction of 71,882,453 tCO_2 and an estimated GHG reduction savings of $119,804,088. This scenario prioritizes natural gas utilization, achieving the largest absolute reduction in GHG emissions.

Scenario 2 – Severe Winter Conditions (April–November NG, December–March Gasoil): In this proposed scenario, the plant adjusts the fuel mix to 67% natural gas and 33% gasoil, using gasoil during the four coldest months to ensure stable electricity generation. The weighted electricity generation efficiency is 33.0%, with a weighted GHG emission factor of 0.672 tCO_2/MWh. Total annual GHG emissions are 5,018,646 tCO_2, resulting in a projected 30-year reduction of 32,780,122 tCO_2 and estimated savings of $54,633,537. Even under severe winter conditions, meaningful GHG reductions are achievable through strategic seasonal fuel management.

These results confirm that adjusting the seasonal fuel mix can substantially reduce greenhouse gas emissions while maintaining electricity production reliability. The findings align with previous studies emphasizing the advantages of combined cycle systems in utilizing waste heat from gas turbines to improve overall thermodynamic efficiency and reduce emissions (Sing et al., 2011; Ganjehkaviri et al., 2014) [42,43]. Ahmad et al. (2021) reported that natural gas combined cycle plants outperform coal-fired and biomass systems due to efficient utilization of excess turbine heat [44].

Adjusting the seasonal fuel composition further mitigates GHG emissions without compromising operational flexibility, as highlighted by Breuer et al. (2021) and Machado *et al.* (2021) [45,46]. Similarly, Tarannum *et al.* (2021) conducted a life cycle impact assessment of natural gas and coal-fired power plants in Bangladesh, evaluating the potential of CO_2 capture. The study found that CO_2 emissions from sub-critical and super-critical coal plants could be reduced by over 80% with capture technologies.

Table 7. Risk analysis of key parameters for Saravan Combined Cycle Power Plant

Parameter	Unit	Value	Minimum	Maximum
Initial costs	USD	3,881,972,013	2,911,479,010	4,852,465,017
Fuel costs – proposed model	USD	6,584,086,080	4,938,064,560	8,230,107,600
Projected 30-Year GHG Reduction – Scenario1	tCO_2	71,882,453	53,911,840	90,000,000
Projected 30-Year GHG Reduction – Scenario2	tCO_2	32,780,122	24,585,092	41,000,000
Carbon shadow price	USD/ tCO_2	50	37,5	62,5

It also highlighted the importance of utilizing captured CO_2, for example through construction materials, emphasizing strategies to mitigate future fossil fuel emissions [47]. Bori et al. (2022) reported that upgrading fossil fuel plants to combined cycle technology in Nigeria led to significant reductions in GHG emissions and air pollutants [48].

The regional climate of Guilan Province, with a mean temperature of 16.5°C, enhances air density and improves gas turbine combustion efficiency, corroborating findings by Khajehpour et al. (2021) regarding the influence of ambient temperature on thermodynamic performance [49]. The optimized seasonal fuel mix aligns with national energy policies promoting combined cycle expansion and supports global climate objectives, including the Paris Agreement targets adopted at COP21, which aim to limit global warming to well below 2°C and pursue efforts to restrict it to 1.5°C [16, 17 , 50].

In summary, these results emphasize the importance of integrating technical, environmental, and economic considerations when planning seasonal fuel strategies for combined cycle power plants. Implementing the two proposed seasonal fuel mix scenarios can achieve substantial long-term reductions in greenhouse gas emissions while maintaining reliable and efficient electricity production. Tools such as RETScreen provide a comprehensive framework to model different seasonal fuel scenarios, assess GHG reductions, and support informed decision-making, enabling the optimization of seasonal fuel strategies for both environmental and operational benefits.

6. Conclusion

The assessment of the Saravan combined cycle power plant demonstrates that strategic optimization of the seasonal fuel mix can achieve substantial reductions in greenhouse gas (GHG) emissions while maintaining reliable electricity generation. Under Scenario 1 – Normal Winter Conditions (84% natural gas / 16% gasoil, March–December NG, January–February gasoil) – total annual GHG emissions are 4,814,379 tCO_2, resulting in a projected 30-year reduction of 71,882,453 tCO_2. Scenario 2 – Severe Winter Conditions (67% natural gas / 33% gasoil, April–November NG, December–March gasoil) – achieves meaningful emission reductions of 5,018,646 tCO_2 annually, corresponding to a 30-year reduction of 32,780,122 tCO_2, even under harsher winter conditions.

These findings confirm that adjusting the fuel composition seasonally is an effective strategy to balance emission mitigation with energy supply reliability. By prioritizing higher natural gas usage when available and strategically using gasoil during peak cold months, the plant can maximize environmental benefits without compromising operational performance. Implementing these two proposed seasonal fuel mix scenarios provides a practical pathway for long-term GHG reduction, aligning with both national energy policies and international climate commitments. Tools such as RETScreen enable detailed modeling of seasonal fuel scenarios, assessment of GHG reductions, and evidence-based decision-making, supporting sustainable and efficient electricity production in combined cycle power plants.

Authors Contribution
All authors have contributed equally to prepare the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that there is no conflict of interests regarding the publication of this paper.

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