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Original Research

Optimal emission plan for independent power producers using generation mix to meet Saudi Arabia environmental goals

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ABSTRACT

The production and use of energy in today's world is heavily reliant on fossil fuels, which is associated with several economic and environmental problems. This study addresses the possibilities of integrating fossil fuel generators with renewable energy systems utilizing various mix-generating scenarios while act as a new emission pricing approach, in line with the current trend towards renewable energy. The suggested carbon incentive scheme includes carbon taxes, carbon permits, and tiers of carbon emissions restrictions (emission factors). The approach seeks to lessen the damaging effects of CO2 emissions on the environment and to compel energy providers to cut back on fossil fuel output and carbon dioxide production. The study, which exclusively analyzes independent Power Producers (IPPs), looks at many desalination facilities in Saudi Arabia that are situated along the Arabian Gulf and Red Sea coasts for 40 years, from 2025 to 2064. The primary objective of the article is to support the best generation mix, taking into account the suggested carbon pricing technique and renewable energy-producing technologies like wind turbines and solar cells, at the chosen locations. The impact of integrating renewable energy on overall costs, including the new price for carbon emissions, is also examined in this study. The impact of various tariffs on supporting the production of renewable energy is covered in the study. The study addresses as well fossil fuel costs. Accordingly, these cost effects on the development of renewable energy sources are investigated additionally. This research has produced a control emission plan for achieving the CO2 limit. The Kingdom of Saudi Arabia's objectives to achieve zero carbon emissions by 2064 are obtained and presented in a case study. In this suggested work, every case study is modeled using the simulation tool HOMER-GRID.

Keywords: Renewable energy, Carbon Incentives, Carbon Taxes, Carbon Permits, Emissions Trading Systems, Optimal Renewable Energy Systems, Renewable Energy in Saudi Arabia, HOMER-GRID.

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1. Introduction

Developing a reliance on renewable energy is regarded as one of the current global concerns facing humanity. The Kingdom of Saudi Arabia's Vision 2030 promotes the Sustainable Energy for All (SE4ALL) initiative's objectives. It includes doubling the proportion of renewable energy in the world's energy mix, as well as the current worldwide trend toward clean and sustainable energy [1-3]. (Tress and al 2019, Jošt and al 2020, Omotoso and al 2022) Utilizing renewable energy sources (RES) to generate electricity can be done on-grid, by building systems disconnected from the grid, or off-grid [4-6]. The majority of hybrid renewable energy systems (HRES) are currently built with an emphasis on financial returns and economic considerations; the environmental benefits of renewable energy are rarely taken into account. Two or more electrical energy sources, at least one of which is renewable, make up a hybrid renewable energy system, or HRES[7]. (Barman and al 2023) [4]. The majority of electricity produced today is mostly derived from fossil fuels. Fossil fuels are

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used extensively in the production of electricity due to the rising energy demand. Over-reliance on fossil fuels has grown to be a serious issue that contributes to their depletion and causes numerous issues with ongoing production [8, 9]. (Barman and al 2023) [4] . Fossil fuel-based electricity generation poses a hazard to both the environment and human survival. As a result, producing clean and sustainable energy now urgently requires reliance on renewable energy sources [10] Vargas-Salgado and al 2023)[5]. Hybrid Renewable Energy Systems (HRES) offer creative ways to replace renewable energy sources in the electrical grid and lessen the growing use of fossil fuels. The National Renewable Energy Laboratory's (NREL) Annual Technology Baseline (ATB) 2017 predicts that onshore wind and utility-scale solar will continue to experience rapid cost declines. Based on recently installed and proposed near-term projects, the most likely mid-range Levelized Costs of Energy (LCOE) for onshore wind is $39/MWh in 2020 and will be $33/MWh in 2030, $31/MWh in 2040, and $28/MWh in 2050. Whereas, utility-scale solar has a mid-range LCOE of $51/MWh in 2020, and it will have $45/MWh in 2030, $41/MWh in 2040, and $37/MWh in 2050 according to [7, 11, 12].

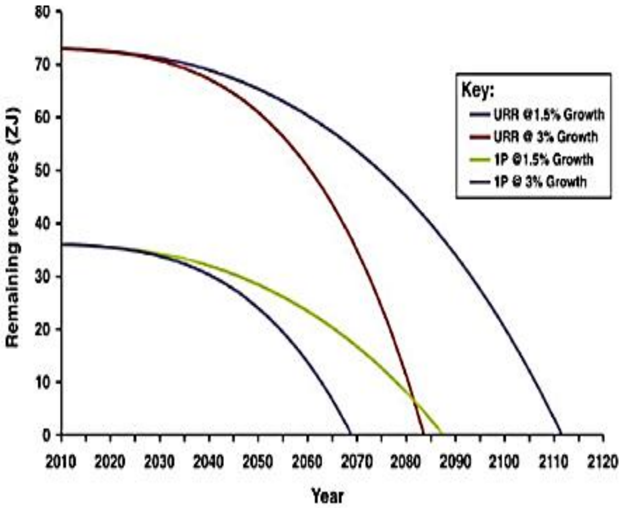

Figure 1. Predicted rates of global fossil fuel depletion [11]

High penetration of unplanned renewable resources can cause negative impacts on the generation mix; as a result, the adequacy between generation and demand will be affected. For instance, the California hourly electric load VS. load less solar and wind (duck curve) for October 22, 2016, is presented in Figure 2 [11].

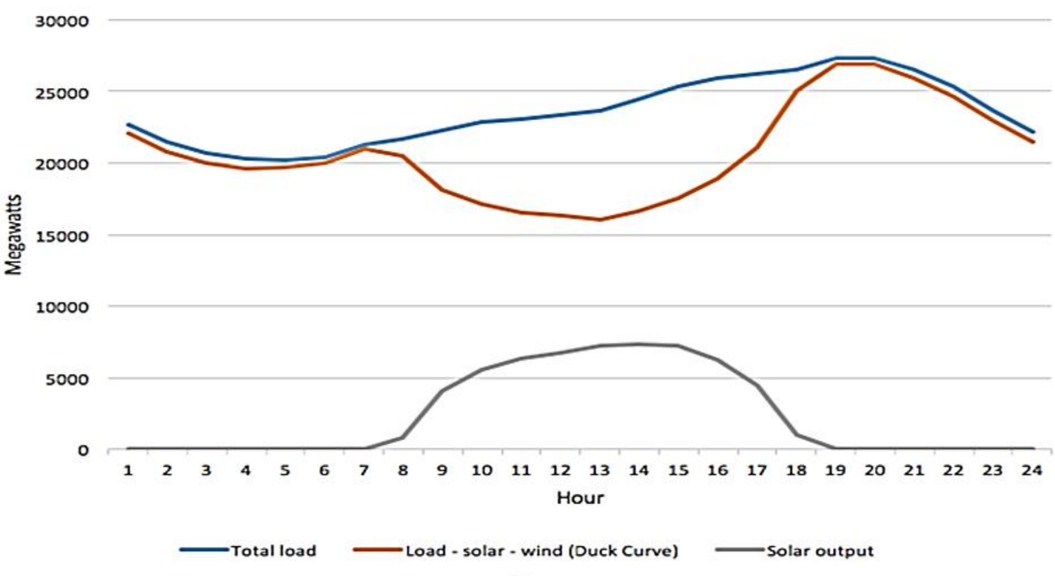

Figure 2. Duck curve in California [11]

2. Related work

These days, the optimal emission plan for independent power producers using generation mix goals is employed in all sizes of producing facilities. It is also utilized in renewable energy systems, including solar and wind power, where output variations can significantly affect the stability of the system. Rahman et al. [12] it was focused on the Kingdom's efforts to mitigate its greenhouse gas emissions, with an emphasis on the power generation that is now in place. The nation has been concentrating on other initiatives, such as the adaptation of combined cycle power plants, carbon capture, utilization, and sequestration (CCUS), renewable and alternative energy sources, and various utility-scale energy efficiency measures, even though the use of natural gas and the number of cogeneration plants have increased in the generation of electricity. The Kingdom will be able to reach its Nationally Determined Contributions with the help of the ambitious and motivating Saudi Vision 2030 renewable energy (RE) targets, which will greatly aid in avoiding greenhouse gas emissions. The use of efficient internal combustion engines, polygene ration, combined heat and power (CHP) systems, the deployment of renewable resources in distribution and micro-grid systems, biomass engines, and ocean thermal energy conversion plants are just a few of the mitigation strategies this study recommended. Within the framework of the Sustainable Development Goals, another study has provided an overview and insight into several measures related to power generation. This includes the examination of various energy modeling techniques, the degree to which they are useful, the general benefits and drawbacks of energy policies based on these methods, and the advancements made thus far in the creation of a mix of reasonably priced and environmentally friendly power sources in emerging nations. It was concluded that there is a great deal of opportunity for power generation from inexpensive and sustainable energy sources because doing so will reduce the effects of greenhouse gases (GHGs) and close the huge gap between supply and demand for electricity [13]. 22 Arab countries, the global hub for fossil fuel production, were examined for their capacity and policies for producing renewable energy now and in the future until 2030. It offers a path forward for these nations' transition to renewable energy production. It has been noted that, among Arab nations, Egypt and Morocco have the largest installed renewable energy capacity in 2020, with installed capacities of 5980 and 3447 MW, respectively. The results also indicated that Djibouti's most ambitious objective is to supply 100% of its electricity from renewable resources by 2035. Lastly, it should be noted that the majority of Arab nations prioritize solar and wind energy, with geothermal energy receiving relatively little attention [14]. According to its findings, PV and wind systems can produce electricity more affordably than fossil fuel-fired power plants in many locations. According to estimates, the country's energy production in 2017 produced specific greenhouse gas emissions of 396–682 g_{CO2}/kWh, which would drop to 341–514 g_{CO2}/kWh if the 2030 RE targets are fulfilled. The kind of fossil fuel used has a big influence on greenhouse gas emissions. Current policy objectives reduce particular greenhouse gas emissions through 2030. Nevertheless, more measures of GHG mitigation will be required. A more aggressive 2030 policy aim ought to be reevaluated as it would more fairly spread the burden over time. In Lubowski, Poland, two-hybrid systems were designed using Homer Grid to give grid-connected households access to two distinct regions. A gas generator, two kW solar panels, two 2.1 kW wind turbines, and one kWh of lithium batteries make up the first system. A gas generator, 1.95 kW photovoltaic panels, 2.1 kW wind turbines, and 1 kWh lithium batteries are all part of the second system. The findings demonstrated that utilizing wind turbines alone is insufficient to improve the system's economic efficiency; instead, a hybrid system is needed. The monthly variations in the likelihood of collecting energy from these sources make combining the two solar and wind energy sources better because they complement each other[15-16].

Okhaifoh et al. [17] the study has worked on reducing the total net current cost (TNPC), Levelized cost of energy (LCOE), and system size as main objectives. A hybrid system in Ivoron Warri, Nigeria consisting of a 2.40 KW PV, a 3.50 kW generator, a 2.04 kW transformer, and two glass mat batteries A 200-amp absorbent (AGM) absorber to feed an initial AC load of 68.55 kWh/day with a peak demand of 10.2 kW. The simulation was done using Homer's Grid for two scenarios containing photovoltaic panels and the other without them. The results showed that the system without PV incurred more costs than the system connected with PV. Moreover, the batteries increased the costs of NPC and COE, as opposed to connecting the system with the network and dispensing with batteries, which reduced these costs.

Several scenarios for hybrid power systems that include in their content PVS/WT/DG/LI BATTERIES or some of them that Vinoth John Prakash and Pradyumna Kumar Dhal have discussed in[18]. They compared fixed systems without tracking (FSWT), tracking systems on a horizontal axis (TSHA), tracking systems on a vertical axis (TSVA), and tracking systems on a dual axis (TSDA). They utilized Homer Pro to simulate powering commercial and residential loads and streetlights on kalpeni Island. After taking into account environmental conditions, the researchers concluded that a PVS system with a vertical axis tracking system (TSVA) and a diesel generator costs a low-level energy cost (LEC) of \$0.222/ per kilowatt-hour is the best result [19].

Xing et. al . [19] showed that the hybrid system consisting of a PV, a gas-based Fuel Cell, a boiler, an ESS, a converter, and a thermostat control unit (TLC) is the optimal generation mix among three different structures. The optimal system achieved an NPC of \$230,2023 and \$0.0409/kWh for COE. The system configuration included the 14 kW PV system, the 15 kW FC, the 2.86 kW inverter, the 100 kW ESS, and the 20 kW TLC. The system emits 2,144 kg of carbon dioxide and 0.0813 kg of carbon monoxide annually [20].

Hybrid power systems can supply the required power to the load at a lower net cost than the basic grid system as discussed in [21]. Among the ten microgrids connected to the national grid in different locations in the United Kingdom analyzed using Homer Pro, the results showed that the most cost-effective generation was for wind turbines. The larger the wind turbine, the lower the current net cost. Although the current net cost of solar power generation is lower than the basic system, it is still higher than wind turbines [20-21].

The scheduling of Hybrid Renewable Energy Systems (HRES) is a differential factor in the cost of generating system power. The paper [21-22] a model for scheduling solar, wind, thermal, and hydro generators by using the Mixed Linear Programming (MILP) method. The results showed that the frequency response of the system is high and the frequency change rate after perturbation is reduced effectively, which reduces the cost of generating the power of the system [21]. Based on the price elasticity of demand (PED), the researchers in the paper [23] divided the load in the village of Sulaymaniyah, north of Saudi Arabia, into two bases. The first basis is if the load has a low price elasticity of demand (PED) and in the second case, the load has a high price elasticity of demand (PED). Particle swarm optimization (PSO), bat algorithm (BA), and social simulation optimization (SMO) are three smart grid optimization controls that have been used to improve Hybrid Power System (HES) design. The study showed that the optimum hybrid system in case of price elasticity of demand (PED) is low in a system consisting of wind with a capacity of 4740 kW and a PV system with a capacity of 8123 kW with a battery of 2715 kWh capacity, a diesel generator with a capacity of 1000 kW and a transformer with a capacity of 8000 kW. The researchers concluded that the COE was reduced to \$0.0392/kWh compared to \$0.473/kWh when the system was conventionally designed [223] From the literature review, the field is still open for presenting an optimal emission plan for independent power producers using generation mi,x, especially in an oil producer country such as Saudi Arabia. In this regard, in keeping with the current trend towards renewable energy, this study explores the potential for integrating fossil fuel generators with renewable energy systems using a variety of mix-generating scenarios and taking a novel approach to carbon pricing into account. Carbon taxes, carbon permits, and levels of carbon emissions restrictions (emission factors) are all part of the proposed carbon incentive program. The strategy aims to reduce the harmful impacts of carbon dioxide emissions on the environment and to force energy suppliers to reduce their use of fossil fuels and the generation of carbon dioxide.

3. Mix generation optimization

On both the Arabian Gulf and Red Sea coasts, several sites were chosen. The Kingdom of Saudi Arabia's western and eastern coasts were selected for the study due to some benefits, the most significant of which are strong winds that can be harnessed to power wind turbines and abundant solar radiation that can be used to generate clean, high-energy solar cells. The Independent Power Producers (IPP) are the focus of the research. The research's concept is to increase the penetration and integration of renewable energy sources into fossil fuel-fired power plants. Solutions that offer low prices, large profitability, and decreased emissions are hybrid renewable energy sources or HRES. These sources consist of at least one renewable energy source. Financial, technical, and environmental challenges are studied in the research. It aims to achieve economic and environmental returns while enhancing integration and modeling the optimal hybrid system for each plant. It also aims to lower emissions. Table 1 shows the Average annual resources; solar GHI; wind speed; Temperature by location using HOMER software and the Average consumption by technology; reverse osmosis (RO), multi-stage flash distillation (MSF), and multi-effect distillation (MED) is illustrated in Table 2. Keeping in mind the recent worldwide shift toward clean and sustainable energy and aligning with Saudi Arabia's 2030 Vision, which places a premium on reducing emissions, increasing the market's proportion of renewable energy, and reducing reliance on fossil fuels. The Minimum Load Ratio is shown in Fig. 3.

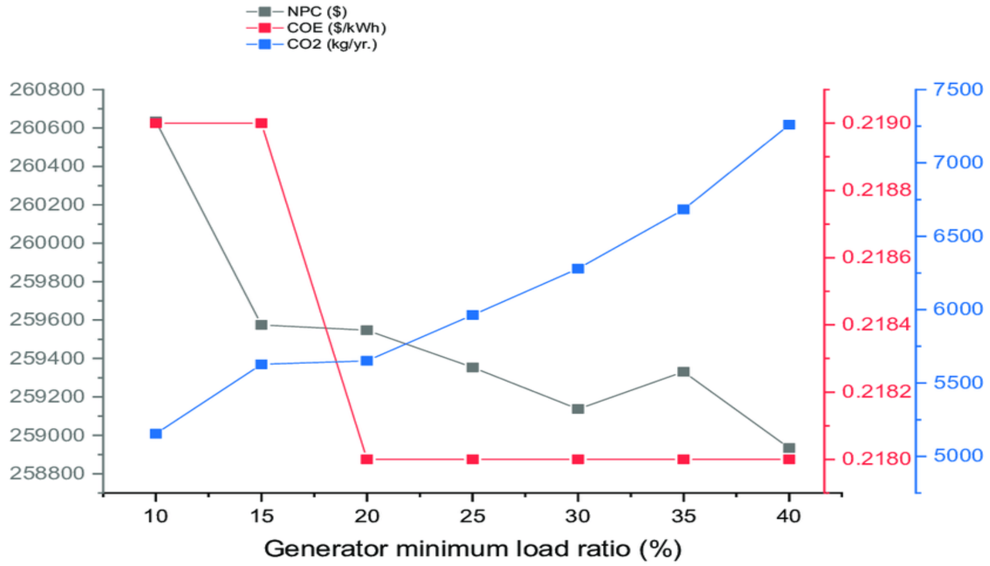

Figure 3. Effect of generator minimum load ratio on NPC, cost of energy (COE), and CO2 emissions [24]

The minimum load ratio of the generator has a clear effect on both the net present cost (NPC), cost of energy (COE), and carbon dioxide emissions; Fig. 3 illustrates this effect. The minimum load ratio is fixed at 25% for all generators in the study because this percentage achieves the study's goal by reducing carbon emissions at relatively appropriate costs[24].

Table 1. Average annual resources by location

Location	Solar GHI Annual average (kwh/m^2/day)	Wind Annual average (m/s)	Temperature Annual average (°C)
Shuaiba Production Systems	5.94	5.01	29.19
Yanbu Production System	6.28	4.98	27.97
Jubail Production System	5.72	5.68	26.49
Ras Al-Khair Production System	5.58	5.51	25.87

Table 2. Average consumption by technology

Technology	Average Electricity Consumption [kwh/m^3]	Average Thermal Consumption [kwh/m^3]	Total Consumption [kwh/m^3]
MSF	3.5 kwh/m^3	9.3 kwh/m^3	12.8 kwh/m^3
MED	0.9 kwh/m^3	46 kwh/m^3	46.9 kwh/m^3
RO	4.15 kwh/m^3	0	4.15 kwh/m^3

In this regard, this section presents a technical model of mix generation optimization, Homer grid simulation, algorithms, and mathematical formulation of the optimization model.

3.1. Mathematical model

The response to demand is studied by improving the integration of renewable energy resources with traditional sources of generation. The researchers compared a set of heuristic algorithms such as artificial bee colony (ABC) and particle swarm optimization (PSO) with a simulation model based on Homer and found that the simulation results are very close. Homer uses a proprietary derivative-free algorithm to search among hundreds of options for the least expensive system [24-25].

The worth of each system component after the system's functioning life has run out is determined in this study, which is known as the salvage cost of the system. Furthermore, the system's penetration of renewable generation is calculated by dividing the total amount of renewable energy produced by the total amount of delivered electrical load. Ultimately, the hybrid power system's running cost is calculated as the yearly sum of all expenses incurred aside from the initial construction cost [25, 26].

Levelized Cost of Energy (COE) as the average cost per kilowatt-hour of useful electrical energy produced by the system, calculated in \$/kWh and expressed using the equation (1):

$$\text{Cost of energy (COE)} = \frac{\mathrm{C_{ann}} - \mathrm{C_b H_S}}{\mathrm{E_s}} \tag{1}$$

where C_{ann} is the total annualized cost of the system in [\$/yr] , C_b is the boiler marginal cost in [\$/kWh] , H_s is the total thermal load served in [kWh/yr] , E_s is the total electrical load served in [kWh/yr].

The total annualized cost is the annual value of the net current cost of the project and is calculated according to equation (2).

$$\mathrm{C_{ann}} = \mathrm{CRF}\ (\mathrm{i}, \mathrm{R_{proj}}) \times \mathrm{C}_{\mathrm{NPC}} \tag{2}$$

C_{NPC} is the total net present cost in [\$] , i is the annual real discount rate [%] , R_{proj} is the project lifetime [yr] , $CRF\ (i, R_{proj})$ is a function returning the capital recovery factor [27].

Equation (3) is used to calculate the capital recovery factor, a ratio that is used to determine the present value of an annuity, which is a series of equal annual cash flows.

$$CRF\ (i, N) = \frac{i\ (1+i)^N}{(1+i)^N - 1} \tag{3}$$

Where, i is the real discount rate, N is the number of years [28]. The salvage value is the residual value in a component of the power system at the end of the project's life. The salvage value can be calculated using the equation (4) as following:

$$\mathrm{S} = \mathrm{C_{rep}} \times \mathrm{R_{rem}}/\mathrm{R_{comp}} \tag{4}$$

Where, R_{rem}, is the remaining life of the component at the end of the project life, R_{rep}, is the duration of replacement cost.

A. PV modelling

In this study, equation (5) is used to calculate the output of the PV array as follows:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right) \left[1 + \alpha_P (T_C - T_{C,STC})\right] \tag{5}$$

Y_{PV} expresses the rated capacitance of PV arrays in the sense of output power under standard operating conditions [kW]. f_{PV} is a derating factor for photovoltaic power and is a scaling factor that Homer applies to photovoltaic panels to calculate the real output under real operating conditions compared to test or standard operating conditions [%]. $\overline{G_r}$ is the solar radiation incident on the photovoltaic array in the current time step [kW/m^2] while $\overline{G_{r,STC}}$ is the solar radiation incident on the photovoltaic panels under standard test conditions [1 kW/m^2]. α_P is the temperature coefficient [%/°C]. T_c is the temperature of the photovoltaic in the current time step[°C], is determined as equation (6). $T_{c,STC}$ is the temperature of the photovoltaic cell under standard test conditions [25°C] [29, 30].

$$T_C = \frac{T_a + (T_{C,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left[1 - \frac{\eta_{mp,STC}(1-\alpha_P T_{c,STC})}{\tau\alpha}\right]}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_P \eta_{mp,STC}}{\tau\alpha}\right)} \quad (6)$$

$T_{c,NOCT}$ is the nominal operating cell temperature [°C]. $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined [20°C]. $G_{T,NOCT}$ is the solar radiation at which the NOCT is defined [0.8 kW/m^2]. $\eta_{mp,STC}$ is the maximum power point efficiency under standard test conditions [%][28].

3.1.1. Wind turbine modelling

The effect of changing the average wind speed value (and hence c) on the shape of the Rayleigh probability density function is shown in equations (7) and (8) [28].

The cumulative distribution function for Weibull statistics can be given by:

$$\mathrm{F(V)} = \mathrm{prob}\ (\mathrm{v} \le \mathrm{V}) = \int_0^{\mathrm{V}} \frac{\mathrm{k}}{\mathrm{c}}\left(\frac{\mathrm{v}}{c}\right)^{\mathrm{k}-1} \exp\left[-\left(\frac{\mathrm{v}}{c}\right)^{\mathrm{k}}\right] \mathrm{dv} \quad (7)$$

$$\mathrm{F(V)} = \mathrm{prob}\ (\mathrm{v} \le \mathrm{V}) = 1 - \exp\left[-\left(\frac{\mathrm{V}}{\mathrm{c}}\right)^{\mathrm{k}}\right] \quad (8)$$

This function can Calculate the probability as well as a number of hours when WT is working during different periods of wind speed $(\mathrm{V_2} \ge \mathrm{v} \ge \mathrm{V_1})$ as equation (9):

$$\mathrm{F(V_2)} - \mathrm{F(V_1)} = \mathrm{prob}\ (\mathrm{V_2} \ge \mathrm{v} \ge \mathrm{V_1}) = \exp\left[-\frac{\pi}{4}\left(\frac{\mathrm{V_2}}{\mathrm{v}}\right)^2\right] - \exp\left[-\frac{\pi}{4}\left(\frac{\mathrm{V_1}}{\mathrm{v}}\right)^2\right] \quad (9)$$

Wind speed measurements are taken using an anemometer, usually at a height of 10 meters above the ground. This makes a difference, as turbines often come at different and very different heights, and it is known that wind speeds vary according to their height from the surface of the earth. To calculate wind speeds at a given altitude the equation (10) is used as follows:

$$\mathrm{U_{hub}} = \mathrm{U_{anem}} \times \left(\frac{\mathrm{Z_{hub}}}{\mathrm{Z_{anem}}}\right)^{\alpha} \quad (10)$$

U_{hub} is the wind speed at the height of the axis of the wind turbine. U_{anem} is the wind speed at the altitude of an anemometer. Z_{hub} is the axis height of the wind turbine. Z_{anem} is the height of an anemometer. α is the power law exponent and is approximately 0.14. The power factor of a wind turbine is referred to as the curve of the expected power output at specified wind speeds under standard operating conditions. If the wind speeds are not within the specified range in the power factor, the turbine does not produce energy [29]. After determining the wind speeds at the wind turbine's height point, the actual power output is calculated for each average speed, considering the actual air density, which is affected by both atmospheric pressure and temperature. The real wind turbine power output is computed according to Equation 11.

$$P_{WTG} = \left[\frac{P}{P_0}\right] \times P_{WTG,STP} \quad (11)$$

P_{WTG} is the actual or real wind turbine power output. $P_{WTG,STP}$ is the power output of a wind turbine at standard temperature and pressure. P is the actual air density. P_0 is the density of air at standard temperature and pressure, which is 1.225 kg/m3[29].

3.1.2. Carbon control methodology

The proposed carbon incentives methodology consists of two main variables, the first being permit incentives and the second being tax incentives. There are other variable parameters such as permissible carbon emissions limits and fuel taxes. Variables change every 5 years starting from 2025 to achieve zero carbon neutrality by 2060. The permissible carbon emissions limits (carbon tolerance) change downward every 5 years. The tax incentives (tax rates) change upward every 5 years. The permit incentives (Emissions Trading System (ETS) prices) change upward every 5 years. This methodology aims to gradually reduce carbon emissions over the coming years and encourage Independent Power Producers (IPPs) to reduce emissions and maximize the financial and environmental benefits of adhering to this methodology. Fig. 4 shows the average carbon permit prices in euros (EU ETS) according to [30-31].

Figure 4. Average carbon permit prices in euros (EU ETS) [30]

The average of carbon permits is determined as equation (12)

$$CarbonPermits_{avg.Ann} = 1{,}3965 * Year - 1{,}7325 \quad (12)$$

$$CarbonPermits_{avg.Ann} = 1{,}3965 * 25 - 1{,}7325 = 33.18 \ \$\, per\ tonne\ of\ CO2 \quad (13)$$

$$CarbonPermits_{avg.Ann} = 1{,}3965 * 30 - 1{,}7325 = 40.1625 \ \$\, per\ tonne\ of\ CO2 \quad (14)$$

Table 3. The proposed permissible carbon limits per KWh

Phase	Year	Carbon Limits (CO2 in kg/ Kwh)	Carbon Tax Rate (in U.S dollar per metric ton of CO2 equivalent)	Tax rate on oil (%)	Tax rate on Natural Gas (%)	Tax rate on coal (%)	Carbon permits prices (average) (in U.S dollar per metric ton of CO2 equivalent)
1	2025	0.750	17.493	0	8.6	139.3	33.18
2	2030	0.650	29.988	0	21.00	193.2	40.1625
3	2035	0.550	29.988	0	21.00	193.2	47.145
4	2040	0.450	46.4625	7.9	37.00	232.00	54.1275
5	2045	0.350	46.4625	7.9	37.00	232.00	61.11
6	2050	0.250	68.9535	25.00	58.8	284.7	68.0925
7	2055	0.150	68.9535	25.00	58.8	284.7	75.075
8	2060	0.050	101.892	49.7	90.1	360.7	82.0575

It sets the permissible carbon emissions limits per kilowatt-hour. If the Independent Electricity Producer (IPP) exceeds the permissible emissions limits, it must pay a carbon tax. If carbon emissions are less than the permissible limit, it gives the right to issue and sell emissions in the form of carbon permits. The carbon emissions factor (CO2 in kg/kwh) can be calculated as equation (15).

$$E_{factor} = \frac{CO2_{kg}}{prod_{kwh}} \tag{15}$$

Where E_{factor} is an emissions factor, $CO2_{kg}$ is CO2 in kg, $prod_{kwh}$ is a production of electricity in kwh. The Variance emission can be determined as equation (16). Accordingly, the carbon tax is calculated as equation (17).

$$VE_{per\ ton} = \left|E_{limit} - E_{factor}\right| * (prod_{kwh}/1000) \tag{16}$$

Where $VE_{per\ ton}$ is a variance emission per ton, E_{limit} is an Emissions limit, E_{factor} is an Emissions factor, $prod_{kwh}$ is a production in kwh.

$$CO2_{Tax} = CO2_{Tax\ Rate}(\%) * VE_{per\ ton} \tag{17}$$

Where $CO2_{Tax}$ is a carbon tax, $CO2_{Tax\ Rate}$ is carbon tax rate, $VE_{per\ ton}$ is a variance emission per ton. The carbon permits can be determined as equation (18).

$$CO2_{permits} = \text{CO2 permits prices} * VE_{per\ ton} \tag{18}$$

If emissions are above the permissible limit, the incentives taxes can be calculated as equation (19). If emissions are less than the permissible limit, the incentives taxes can be calculated as equation (20).

$$Incentives_{taxes} = CO2_{Tax} + Oil_{Tax} + NG_{Tax} + Coal_{Tax} \tag{19}$$

$$Incentives_{permits} = Oil_{Tax} + NG_{Tax} + Coal_{Tax} - CO2_{permits} \tag{20}$$

3.1.3. Simulation model

The Hybrid Optimization Model for Multiple Energy Sources (HOMER) was created by the National Renewable Energy Laboratory (NREL), and an analytical evaluation of the various systems was carried out using the HOMER programme. The programme, which focuses on extremely economical parameters, calculates the appropriate system size, payback period, and energy cost level (LCOE) based on the energy sources to be installed and the investment to be made[10]. According to Homer software, this study presents an optimization model for emission plan. Four different tariffs have been applied for the purpose of studying the feasibility of each tariff. The current tariff is the tariff that is currently applied to the Shuaiba plant systems. The consumption tariff in the other three tariffs are official tariffs that are applied in Saudi Arabia [31-32] a sellback rate of $0.026 as a solution for the purpose of covering the cost of generation is suggested (See Table 4).

Table 4. Energy tariffs in Saudi Arabia (2023)

Tariff Name	Consumption Tariff	Sellback Rate	Monthly fee of Meter	VAT Tax (%)	Grid Emissions Factor (GEF) tCO_2/MWh
Current Tariff	0.0174 $/KWh	0.0054 $/ KWh	8 $	15 %	0.5059 [33]
Industrial Tariff	0.048 $/ KWh	0.026 $/ KWh	8 $	15 %	0.5059 [33]
Commercial Tariff	0.054 $/ KWh	0.026 $/ KWh	8 $	15 %	0.5059 [33]
Governmental Tariff	0.085 $/ KWh	0.026 $/ KWh	8 $	15 %	0.5059 [33]

The interest rate in Saudi Arabia is expected to reach 3.00 percent by the end of the third quarter of 2022, according to global macro models and analyst forecasts from Trading Economics. In the long term, the repurchase rate in Saudi Arabia is expected to trend towards 4.25 percent in 2023. For the purpose of the study, we considered this figure for a period of 40 years, representing the life of the project[34].

The inflation rate in Saudi Arabia is expected to reach 2.60 percent by the end of the third quarter of 2022. In the long term, the expectation of the inflation rate over the next 40 years is considered unstable due to the many unexpected factors affecting the economy that may occur, but the inflation rate in Saudi Arabia is expected to trend to about 2.00% in 2023, according to models of models. Global Macro Econometrics and Analysts Forecasts from Trading Economics. For the purpose of the study, we considered this inflation rate over a period of 40 years, which is the duration of the project [35]

Saudi Arabia aims to reach net zero emissions by 2060. For this regard, a plan that includes a combination of integrating renewable energy generation was proposed, changes in electricity tariffs, and applying the proposed carbon incentives methodology to reduce carbon emissions for a period of 40 years, starting from 2025-2064. The proposed methodology for carbon incentives consists of eight stages, each stage five years from 2025 to 2064 AD [35].

4. Case study

There are 17 production systems belonging to the Saline Water Conversion Corporation (SWCC) extending along the eastern and western coasts of the Kingdom of Saudi Arabia. Among them, two systems on the Red Sea coast, namely the Shuaiba and Yanbu systems, and two systems on the coast of the Arabian Gulf, namely the Jubail and Ras al-Khair systems are chosen as showing in Fig. 5 [36].

Figure 5. SWCC production systems

The details of the operational capacities and techniques used for water desalination are shown for each of the four: Operating Capacity (m^3/day) for Shuaiba production system are presented as; 223000, 455000, 91200, and 400000 for Shuaiba No.1, Shuaiba No. 2, Shuaiba No. 3, and Shuaiba No.4, respectively. For Yanbu production system, the operating Capacity (m^3/day) are 119637, 127800, 566160, and 400000 for Yanbu No.2, Yanbu (Reverse Osmosis), Yanbu No. 3, and Yanbu No.4, respectively, and 137729, 1035000, and 60000 for Jubail No.1, Jubail No. 2, and Jubail (Reverse Osmosis), respectively. Additionally, Operating Capacity (m3/day) for the Ras Al Khair reverse osmosis, and Ras Al Khair No. 1 are 310656, and 740656, respectively. The Shuaiba 1 system contains five backpressure type of Fuji company with 58 MW each and is powered by cracked fuel oil 180 (HFO). The Shuaiba 2 system contains 5 backpressure generators of the type of ABB company with 104 MW each, and they run on Crude oil (LFO). Generator and fuel information for the Shuaiba 2 system, we assumed it on the rest of the other four systems. Tables 5 and 6 show the information and prices of generators and the characteristics and prices of fuel, respectively.

Table 5. Generators data

Production System	Shuaiba 1	Shuaiba 2
Generator types	5 generators backpressure type of Fuji company with 58 MW each	5 generators backpressure type of ABB company with 104 MW each
Capital Cost Factor	750 $/kw [37]	750 $/kw [37]
Replacement Cost Factor	500 $/kw [37]	500 $/kw [37]
Capital Cost	43,500,000.00 $	78,000,000.00 $
Replacement Cost	29,000,000.00$	52,000,000.00 $
O&M Cost	0.010 $/op.hr [37]	0.010 $/op.hr [37]
Consumption	200 liters of fuel/Mwh.	200 liters of fuel/Mwh
Lifetime (hours)	61,000 hours	61,000 hours
Minimum Load Ratio	25 %	25 %

Table 6. Fuel data

Generator Type	backpressure type of Fuji company with 58 MW	backpressure type of ABB company with 104 MW
Fuel Type	cracked fuel oil 180 (HFO)	Crude oil (LFO)
Fuel Price	0.111 $/L [38]	0.218 $/L [38]
Fuel Density (kg/m^3)	979	856
Lower Heating Value of Fuel	42.03	43.51
Carbon Content of Fuel (%)	85 [39]	86 [39]
Sulfur Content of Fuel (%)	3.36	1.89

Frequency Regulation from Renewable Resource Generation shall be activated or deactivated automatically following a request from the TSP. Each Renewable Resource Generation shall be capable of regulating its Active Power in the following frequency range: -

- [60.2Hz, 62.5Hz] through modulation of the Active Power as a function of frequency deviations above 60.2Hz.

- [57Hz, 59.8Hz] through modulation of the Active Power as a function of frequency deviations below 59.8Hz.

The Active Power Droop shall be adjustable between 2% and 8%. The normal set point shall be generally at 4%. Output power shall be limited by the available output power and the minimum output power of the Generating Unit.

The Renewable Resource Generating Unit shall remain connected to the Network and continue stable operation if none of the phases exceeds 120% of nominal voltage for more than 1s. Following the disconnection from the Grid, the Synchronous Generating Unit/Station shall change over to House Load Operation for one (1) hour and, in the case of Synchronous Renewable Resource Generation, for one (1) hour or as long as it is technically feasible based on the Available Active Power.

For each non-Renewable Resource Generating Unit whose performance varies significantly with ambient temperature, the Generator Performance Chart shall show curves for at least two values of ambient temperature so that the TSP can assess the variation in performance overall likely ambient temperatures by a process of linear interpolation or extrapolation. One of these curves shall be for the ambient temperature at which the Generating Unit output equals its Registered Capacity.The TSP shall have control over all System Services, that is, it shall determine what System Services are to be provided, when, and by whom.

Dispatch Accuracy Test shall demonstrate that the Generating Unit meets the relevant Generation Scheduling and Dispatch Parameters. The non-renewable Resource Generation shall pass the test if:

- in the case of Synchronization, the process is achieved within ± five (5) minutes of the registered Synchronization time;
- in the case of Synchronizing Generation (if registered as a Generation Scheduling and Dispatch Parameters), the Synchronizing Generation achieved is within an error level equivalent to ±2.5% of Net Declared Capability;
- in the case of meeting Ramp Rates, the actual Ramp Rate is within ± ten (10) % of the registered Ramp Rate;
- in the case of meeting Load Reduction rates, the actual Load Reduction rate is within ± ten (10) % of the registered Load Reduction rate;
- in the case of minimum base load Generating Units, a variation of + ten (10) % will be acceptable;
- in the case of all other Generation Scheduling and Dispatch Parameters, values are within ± 1.5% of the declared values.

5. Result and discussion

Result of systems associated with a fuel generator contains 8 scenarios, ONLY-GRID, TG-GRID, PV-GRID, WT-GRID, TG-PV-GRID, TG-WT-GRID, PV-WT-GRID, TG-PV-WT- GRID. While the results for systems without a fuel generator contain 4 scenarios, ONLY-GRID, PV-GRID, WT-GRID, PV-WT-GRID. TG stands for turbine generator, PV stands for photovoltaic cells, WT stands for wind turbines. For each production system and for each tariff, capacities, quantities and percentages of production and sales are presented in a table. The net current cost (NPC), energy cost (COE), the impact of carbon incentives on net current cost (NPC) and energy cost (COE) are presented in tables 7-16.

As presented in Table 6, for current tariff for Shuaiba 1, the emissions factors (kg/KWh) for PV-WT-GRID and TG – PV – WT- GRID systems are **0.500902**. The emission factor is **0.309251** (kg/KWh) for PV-WT-GRID in industrial tariff, **0.277093** (kg/KWh) for WT – GRID in commercial tariff, and **0.163514**(kg/KWh) for PV-WT-GRID in governmental tariff with ranking 1. The new energy cost (COE) with incentives is **0.04544**$/KWh for only grid case, **0.04544**$/KWh, **0.04885**$/KWh, and **0.04795** $/KWh for PV-WT-GRID case in industrial, commercial and governmental tariff, respectively (See Table 6).

Table 7. Shuaiba 1 analysis result

Shuaiba 1	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.5059	$0.013	103.5%	0.5059	$0.062	11.65%	0.5059	$0.069	10.35%	0.5059	$0.104	6.58%
TG-GRID	0.5059	$0.018	53.56%	0.6034	$0.060	29.55%	0.6052	$0.060	29.85%	0.6056	$0.060	29.94%
PV-GRID	0.505049	$0.01266	101.8%	0.332674	$0.047	-5.51%	0.3200	$0.05009	-6.44%	0.26422	$0.06048	-9.71%
WT-GRID	0.502604	$0.01280	95.69%	0.344723	$0.052	-3.82%	0.27709	$0.05188	-10.05%	0.21442	$0.06027	-13.28%
TG-PV-GRID	0.5050	$0.018	52.92%	0.5950	$0.060	28.40%	0.59698	$0.06024	28.74%	0.59741	$0.06019	28.85%
TG-WT-GRID	0.5026	$0.019	50.74%	0.5953	$0.060	28.35%	0.59725	$0.06040	28.67%	0.59767	$0.06036	28.79%
PV-WT-GRID	0.5009	$0.013	92.58%	0.3093	$0.045	-8.16%	0.30332	$0.04885	-8.20%	0.16351	$0.04795	-20.05%
TG-PV-WT-GRID	0.5009	$0.019	49.52%	0.5785	$0.060	26.06%	0.5811	$0.06017	26.46%	0.58173	$0.06011	26.62%

For current tariff for Shuaiba 2, the emissions factors (kg/kwh) for PV-WT-GRID and TG – PV – WT- GRID systems are 0.50343. The emission factor is 0.308256 (kg/kwh) for PV-WT-GRID in industrial tariff, 0.28814 (kg/kwh) for WT – GRID in commercial tariff, and 0.163565 (kg/kwh) for PV- WT-GRID in governmental tariff with ranking 1. The new energy cost (COE) with incentives is $0.01264 for only grid case, $0.04945, $0.04876, and $0.04795 for PV-WT-GRID case in industrial, commercial and governmental tariff, respectively (See Table 8).

Table 8. Shuaiba 2 analysis result

Shuaiba 2	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
ONLY-GRID	0.5059	$0.0126	103.54%	0.5059	$0.062	11.65%	0.505900	$0.069	10.35%	0.5059	$0.104	6.58%
TG-GRID	0.5059	$0.0177	56.89%	0.5065	$0.0667	10.90%	0.525955	$0.075	16.82%	0.5351	$0.078	19.55%
PV-GRID	0.5051	$0.0127	101.81%	0.3327	$0.0472	-5.51%	0.320035	$0.050	-6.44%	0.2642	$0.060	-9.71%
WT-GRID	0.5043	$0.0127	99.59%	0.3447	$0.0526	-3.83%	0.2881	$0.053	-8.95%	0.2144	$0.060	-13.29%
TG-PV-GRID	0.5051	$0.0178	56.19%	0.3330	$0.0521	-4.90%	0.3308	$0.055	-1.99%	0.3205	$0.0556	-1.16%

Shuaiba 2	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
TG-WT-GRID	0.5043	$0.0178	55.35%	0.3448	$0.0576	-3.46%	0.2949	$0.058	-6.06%	0.5095	$0.0765	17.02%
PV-WT-GRID	0.5034	$0.0127	97.94%	0.3083	$0.0454	-8.27%	0.3023	$0.049	-8.30%	0.1636	$0.0480	-20.04%
TG-PV-WT-GRID	0.5034	$0.0178	54.67%	0.3085	$0.0501	-7.47%	0.3117	$0.054	-4.28%	0.3029	$0.0544	-3.15%

For Shuaiba MED and RO4, respectively, for current tariff. the emissions factor (kg/kwh) for PV-WT-GRID is 0.502849 and 0.498530. The emission factor is 0.308287 (kg/kwh) and 0.309596 (kg/kwh) for PV-WT-GRID in industrial tariff, 0.275959 (kg/kwh) and 0.288391(kg/kwh) for WT – GRID in commercial tariff, and 0.163396 and 0.160992 (kg/kwh) for PV- WT-GRID in governmental tariff with ranking 1. The new energy cost (COE) with incentives is $0.01264 and $0.01264 for only grid case, $0.04536 and $0.04548, $0.04876 and $0.04889, and $0.04792 and $0.04725 for PV-WT-GRID case in industrial, commercial and governmental tariff, respectively (See Tables 9 and 10).

Table 9. Shuaiba MED analysis result

Shuaiba MED	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.5059	$0.0126	103.54%	0.505900	$0.062	11.65%	0.5059	$0.0685	10.35%	0.50590	$0.1042	6.58%
PV-GRID	0.5050	$0.0127	101.80%	0.332674	$0.047	-5.51%	0.3200	$0.0501	-6.44%	0.26422	$0.0605	-9.71%
WT-GRID	0.5037	$0.0127	98.21%	0.343482	$0.053	-3.95%	0.2760	$0.0518	-10.17%	0.21424	$0.0602	-13.30%
PV-WT-GRID	0.5028	$0.0128	96.59%	0.308287	$0.045	-8.27%	0.3024	$0.0488	-8.30%	0.16340	$0.0479	-20.06%

Table 10. Shuaiba RO4 analysis result

Shuaiba RO4	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.5059	$0.0126	103.53%	0.505900	$0.067	11.65%	0.5059	$0.0685	10.35%	0.50590	$0.1042	6.58%

Shuaiba RO4	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
PV-GRID	0.5050	$0.0127	101.80%	0.332674	$0.047	-5.51%	0.3200	$0.0501	-6.44%	0.26422	$0.0605	-9.71%
WT-GRID	0.5002	$0.0129	90.52%	0.341919	$0.052	-4.10%	0.2884	$0.0529	-8.92%	0.21440	$0.0603	-13.28%
PV-WT-GRID	0.4985	$0.0130	87.61%	0.309596	$0.045	-8.12%	0.3037	$0.0489	-8.16%	0.16099	$0.0473	-20.47%

For Yanbu 2, Yanbu (Reverse Osmosis), Yanbu 3 and Yanbu moving, respectively, for current tariff. the emissions factor (kg/kwh) for PV-WT-GRID is 0.502368, 0.480976, 0.495800 and 0.401633. The emission factor is 0.297783, 0.302783, 0.297010 and 0.270671 (kg/KWh) for PV-WT-GRID in industrial tariff, 0.280432, 0.297010, 0.279712 and 0.259482 (kg/KWh) for WT – GRID in commercial tariff, and 0.158264, 0.154303, 0.158236 and 0.161496 (kg/KWh) for PV-WT-GRID in governmental tariff with ranking 1. (See Tables 11, 12, 13 &14)

Table 11. Yanbu 2 analysis result

Yanbu 2	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.505900	$0.01264	103.54 %	0.505900	$0.06163	11.65 %	0.505900	$0.06853	10.35 %	0.505900	$0.10418	6.58 %
TG-GRID	0.505900	$0.01395	85.50 %	0.510027	$0.06306	13.12 %	0.521904	$0.06734	17.16 %	0.521959	$0.08340	13.43 %
PV-GRID	0.504987	$0.01265	101.77 %	0.312457	$0.04395	-8.07 %	0.296282	$0.04585	-9.38 %	0.252208	$0.05651	-11.25 %
WT-GRID	0.503281	$0.01277	97.21 %	0.346451	$0.05281	-3.64 %	0.289464	$0.05308	-8.80 %	0.215441	$0.06057	-13.16 %
TG-PV-GRID	0.504987	$0.01396	84.18 %	0.315280	$0.04519	-6.70 %	0.318070	$0.04724	-3.98 %	0.302462	$0.05351	-4.96 %
TG-WT-GRID	0.503281	$0.01408	80.86 %	0.390754	$0.05645	1.44 %	0.401774	$0.05963	5.62 %	0.281925	$0.05792	-6.23 %
PV-WT-GRID	0.502368	$0.01278	95.57 %	0.297783	$0.04324	-9.74 %	0.280432	$0.04468	-11.17 %	0.158264	$0.04554	-21.27 %
TG-PV-WT-GRID	0.502368	$0.01409	79.62 %	0.300586	$0.04448	-8.36 %	0.301301	$0.04608	-5.96 %	0.242497	$0.04829	-11.42 %

Table 12. Yanbu (reverse osmosis) analysis result

Yanbu (Reverse Osmosis)	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
ONLY-GRID	0.505900	$0.01264	103.53%	0.505900	$0.06163	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
PV-GRID	0.504987	$0.01265	101.76%	0.312457	$0.04395	-8.07%	0.296282	$0.04585	-9.38%	0.252208	$0.05651	-11.25%
WT-GRID	0.488280	$0.01349	69.02%	0.347621	$0.05298	-3.52%	0.281554	$0.05250	-9.57%	0.218358	$0.06124	-12.83%
PV-WT-GRID	0.480976	$0.01360	60.54%	0.302783	$0.04368	-9.13%	0.285094	$0.04517	-10.61%	0.154303	$0.04474	-21.87%

Table 13. Yanbu 3 analysis result

Yanbu 3	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.505900	$0.01264	103.54%	0.505900	$0.06163	11.65%	0.505900	$0.069	10.35%	0.505900	$0.10418	6.58%
TG-GRID	0.505900	$0.03731	20.82%	0.505900	$0.08630	8.05%	0.505900	$0.060	29.85%	0.505917	$0.12845	5.27%
PV-GRID	0.504987	$0.01265	101.77%	0.312457	$0.04395	-8.07%	0.296282	$0.05009	-6.44%	0.252208	$0.05651	-11.25%
WT-GRID	0.504610	$0.01270	100.36%	0.345051	$0.05273	-3.78%	0.290170	$0.05188	-10.05%	0.216097	$0.06071	-13.09%
TG-PV-GRID	0.502248	$0.03737	20.04%	0.312457	$0.06729	-5.43%	0.296282	$0.06024	28.74%	0.252233	$0.07660	-8.55%
TG-WT-GRID	0.503321	$0.03743	20.22%	0.345051	$0.07735	-2.61%	0.290170	$0.06040	28.67%	0.216097	$0.08298	-9.92%
PV-WT-GRID	0.503697	$0.01272	98.65%	0.297010	$0.04318	-9.83%	0.279712	$0.04885	-8.20%	0.158236	$0.04555	-21.28%
TG-PV-WT-GRID	0.495800	$0.03765	18.59%	0.297010	$0.06643	-6.62%	0.279712	$0.06017	26.46%	0.158236	$0.06551	-15.82%

Table 14. Yanbu moving analysis result

	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect
ONLY-GRID	0.505900	$0.01264	103.50%	0.505900	$0.06163	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
PV-GRID	0.504987	$0.01266	101.73%	0.312456	$0.04396	-8.07%	0.299173	$0.04629	-9.02%	0.252207	$0.05651	-11.25%

	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect	EF (kg/kwh)	COE (with incenti	incentives effect
WT-GRID	0.430840	$0.01626	18.12%	0.430840	$0.05798	4.50%	0.284915	$0.05313	-9.18%	0.228546	$0.06351	-11.76%
PV-WT-GRID	0.401633	$0.01666	5.99%	0.270671	$0.04260	-12.62%	0.259482	$0.04455	-13.18%	0.161496	$0.04607	-20.84%

For Jubail (Reverse Osmosis), Jubail 1 and Jubail 2, respectively, the emissions factor, COE (with incentives), and incentives effect for current tariff, industrial tariff, commercial tariff, and governmental tariff are shown in Tables 15 ,16 & 17. Additionally, the emissions factor, COE (with incentives), and incentives effect for Ras Al-Khair (Reverse Osmosis) and Ras Al-Khair 1 is shown in Table 18 and Table 19.

Table 15. Jubail (Reverse Osmosis) analysis results

Jubail (Reverse Osmosis)	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.505900	$0.01264	103.52%	0.505900	$0.06163	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
PV-GRID	0.505061	$0.01266	101.79%	0.341608	$0.04834	-4.47%	0.322493	$0.05058	-6.14%	0.274359	$0.06294	-8.64%
WT-GRID	0.461694	$0.01403	41.63%	0.247478	$0.04250	-14.87%	0.214231	$0.04204	-18.02%	0.166934	$0.04698	-20.12%
PV-WT-GRID	0.448271	$0.01432	31.39%	0.224919	$0.03998	-17.80%	0.191625	$0.03907	-21.15%	0.125058	$0.03772	-27.27%

Table 16. Jubail 1 analysis result

Jubail 1	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
ONLY-GRID	0.505900	$0.01264	103.53%	0.505900	$0.06163	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
TG-GRID	0.505900	$0.02429	36.01%	0.505900	$0.07328	9.62%	0.505900	$0.08018	8.72%	0.530845	$0.09538	14.09%
PV-GRID	0.505061	$0.01266	101.81%	0.341608	$0.04834	-4.47%	0.322494	$0.05058	-6.14%	0.274360	$0.06294	-8.64%
WT-GRID	0.499656	$0.01284	90.67%	0.234871	$0.04111	-16.48%	0.212398	$0.04163	-18.33%	0.161060	$0.04544	-21.10%
TG-PV-GRID	0.504222	$0.02432	35.27%	0.341608	$0.05965	-3.65%	0.322494	$0.06163	-5.10%	0.306944	$0.06523	-3.02%
TG-WT-GRID	0.499656	$0.02448	33.21%	0.239776	$0.05287	-12.92%	0.212398	$0.05258	-15.09%	0.183515	$0.05177	-16.10%
PV-WT-GRID	0.497978	$0.01287	87.75%	0.223645	$0.03970	-18.02%	0.195100	$0.03930	-20.75%	0.130525	$0.03891	-26.23%

Jubail 1	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect	EF (kg/kwh)	COE (with incentives)	incentives effect
TG-PV-WT-GRID	0.497978	$0.02452	32.52%	0.223645	$0.05083	-14.66%	0.190350	$0.04929	-17.63%	0.151994	$0.04599	-20.52%

Table 17. Jubail 2 analysis results

Jubail 2	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
ONLY-GRID	0.50590	$0.01264	103.54%	0.505900	$0.0616	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
TG-GRID	0.50590	$0.01791	55.99%	0.506227	$0.0668	10.77%	0.524335	$0.07463	16.16%	0.535117	$0.07839	19.33%
PV-GRID	0.50506	$0.01266	101.81%	0.341608	$0.0483	-4.47%	0.322494	$0.05058	-6.14%	0.274360	$0.06294	-8.64%
WT-GRID	0.50507	$0.01267	101.70%	0.232415	$0.0408	-16.80%	0.213915	$0.04180	-18.14%	0.160720	$0.04533	-21.17%
TG-PV-GRID	0.50506	$0.01793	55.31%	0.341793	$0.0534	-4.00%	0.336583	$0.05617	-1.60%	0.329210	$0.05755	-0.18%
TG-WT-GRID	0.50507	$0.01794	55.28%	0.232462	$0.0458	-15.23%	0.218293	$0.04637	-15.20%	0.205366	$0.04699	-14.59%
PV-WT-GRID	0.50340	$0.01271	98.32%	0.221445	$0.0395	-18.32%	0.193555	$0.03908	-20.98%	0.130326	$0.03884	-26.28%
TG-PV-WT-GRID	0.50340	$0.01798	53.93%	0.221497	$0.0444	-16.60%	0.202061	$0.04433	-17.38%	0.163281	$0.04064	-20.52%

Table 18. Ras Al-Khair (reverse osmosis) results

Jubail (Reverse Osmosis)	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
ONLY-GRID	0.50590	$0.01264	103.53%	0.505900	$0.0616	11.65%	0.50590	$0.06853	10.35%	0.505900	$0.10418	6.58%
PV-GRID	0.50507	$0.01266	101.82%	0.343850	$0.0487	-4.20%	0.32892	$0.05159	-5.42%	0.276794	$0.06373	-8.36%
WT-GRID	0.49763	$0.01293	86.59%	0.249081	$0.0431	-14.54%	0.23004	$0.04440	-15.88%	0.174022	$0.04900	-18.93%
PV-WT-GRID	0.49433	$0.01300	81.18%	0.238858	$0.0416	-15.94%	0.20548	$0.04115	-19.11%	0.135298	$0.04061	-25.05%

Table 19. Ras Al-Khair 1 analysis results

Ras Al-Khair 1	Current Tariff			Industrial Tariff			Commercial Tariff			Governmental Tariff		
	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect	EF (kg/kwh)	COE (with incentives	incentives effect
ONLY-GRID	0.505900	$0.01264	103.54%	0.505900	$0.06163	11.65%	0.505900	$0.06853	10.35%	0.505900	$0.10418	6.58%
TG-GRID	0.505900	$0.02858	29.02%	0.505900	$0.07757	9.04%	0.505900	$0.08447	8.24%	0.517017	$0.10711	8.97%
PV-GRID	0.505073	$0.01266	101.82%	0.343850	$0.04874	-4.20%	0.328922	$0.05159	-5.42%	0.276794	$0.06373	-8.36%
WT-GRID	0.504776	$0.01268	101.01%	0.247554	$0.04294	-14.73%	0.228718	$0.04421	-16.05%	0.173834	$0.04893	-18.97%
TG-PV-GRID	0.504247	$0.02862	28.47%	0.343850	$0.06425	-3.22%	0.328922	$0.06683	-4.24%	0.292268	$0.07215	-5.36%
TG-WT-GRID	0.503652	$0.02865	28.25%	0.247554	$0.05840	-11.27%	0.228718	$0.05939	-12.46%	0.188119	$0.06230	-14.23%
PV-WT-GRID	0.502825	$0.01273	97.02%	0.239297	$0.04164	-15.90%	0.207790	$0.04134	-18.84%	0.135761	$0.04069	-24.98%
TG-PV-WT-GRID	0.500874	$0.02873	27.34%	0.239297	$0.05698	-12.14%	0.207790	$0.05619	-14.59%	0.144658	$0.05278	-19.53%

These results are discussed as following points:

- An overview of the Kingdom of Saudi Arabia's objectives to become carbon neutral by 2064 is provided in this case study. Feeding the plant through the electrical network is always preferred. For this regard, carbon incentives are suggested; eight scenarios are included in the results of systems connected to fuel generators: ONLY-GRID, TG-GRID, PV-GRID, WT-GRID, TG-PV-GRID, TG-WT-GRID, PV-WT-GRID, and TG-PV-WT-GRID. There are four situations in the results for systems without a fuel generator: ONLY-GRID, PV-GRID, WT-GRID, and PV-WT-GRID.
- The emissions factors (kg/KWh) for TG – PV – WT – GRID and PV – WT – GRID systems were 0.500902 for the current tariff for Shuaiba 1. The industrial tariff's PV-WT-GRID emission factor was 0.309251 (kg/KWh), the commercial tariff's WT-GRID emission factor was 0.277093 (kg/KWh), and the government tariff's PV-WT-GRID emission factor was 0.163514 (kg/KWh) with ranking 1. The new energy cost (COE) with incentives for the sole grid case was 0.04544$; for the PV-WT-GRID instance, it was 0.04544$, 0.04885$, and 0.04795 $ in the industrial, commercial, and governmental tariffs, in that order.
- The emissions factors (kg/KWh) for the PV-WT-GRID and TG – PV – WT-GRID systems for the Shuaiba 2 current tariff were 0.50343. The emission factor for PV-WT-GRID in the industrial tariff was 0.308256 (kg/kwh), for WT-GRID in the commercial tariff it was 0.28814 (kg/kwh), and for PV-WT-GRID in the governmental tariff with ranking 1 it was 0.163565 (kg/kwh). In the industrial, commercial, and governmental tariffs, the new energy cost (COE) with incentives was $0.01264 for the sole grid scenario, $0.04945, $0.04876, and $0.04795 for the PV-WT-GRID case.
- For the current pricing, Shuaiba MED and RO4, respectively. PV-WT-GRID has an emissions factor of 0.502849 and 0.498530 (kg/kwh). The emission factor for PV-WT-GRID in the industrial tariff was 0.308287 (kg/kwh) and 0.309596 (kg/kwh); for WT-GRID in the commercial tariff, it was 0.275959 (kg/kwh) and 0.288391 (kg/kwh); and for PV-WT-GRID in the governmental tariff with ranking 1, it was 0.163396 and 0.160992 (kg/kwh). In the industrial, commercial, and governmental tariffs, the new energy cost (COE) with incentives was $0.01264 and $0.01264 for the single grid scenario, $0.04536

and \$0.04548, \$0.04876 and \$0.04889, and \$0.04792 and \$0.04725 for the PV-WT-GRID case, respectively.

- For Yanbu 2, Yanbu (Reverse Osmosis), Yanbu 3 and Yanbu moving, respectively, for current tariff. the emissions factor (kg/kwh) for PV-WT-GRID is 0.502368, 0.480976, 0.495800 and 0.401633. The emission factor is 0.297783, 0.302783, 0.297010 and 0.270671 (kg/kwh) for PV-WT-GRID in industrial tariff, 0.280432, 0.297010, 0.279712 and 0.259482 (kg/kwh) for WT – GRID in commercial tariff, and 0.158264, 0.154303, 0.158236 and 0.161496 (kg/kwh) for PV- WT-GRID in governmental tariff with ranking 1.
- For Jubail (Reverse Osmosis), Jubail 1 and Jubail 2, respectively, the emissions factor, COE (with incentives), and incentives effect for current tariff, industrial tariff, commercial tariff, and governmental tariff are shown in Tables 15 ,16 & 17. Additionally, the emissions factor, COE (with incentives), and incentives effect for Ras Al-Khair (Reverse Osmosis) and Ras Al-Khair 1.

From the above result, it may be the best method to force service firms to move to renewable energy is increasing costs of conventional generation by applying high tariffs. One strategy is to reduce service prices while increasing job prospects. Low fossil fuel prices, in contrast to high fuel prices, do not encourage the country's shift to renewable energy with lower emissions or the goal of achieving zero carbon emissions by 2060. Carbon permits are initially more expensive than carbon taxes in order to propel the carbon emissions market forward. Eventually, tax rates grow in an effort to put pressure on electricity-generating companies to reduce their emissions. Long-term systems with a lifespan of ten years or more gain financially from hybrid and renewable energy systems; short-term systems, on the other hand, generally cost more than fossil fuels and the network itself. Photovoltaic is not as good as wind turbines in terms of emissions because of their greater emissions. Wind turbines became more practicable along the Arabian Gulf coast as wind speeds increased, whereas solar panels were more possible along the Red Sea coast as radiation rates increased.

6. Conclusion

A control emission plan has been developed as a result of this study to meet the CO2 limit. The goals of the Kingdom of Saudi Arabia to attain carbon neutrality by 2064 are gathered and showcased in a case study. It is always preferable to feed the plant through the electrical network, even though the low tariff imposed on desalination plants may be economically efficient. This is because the low tariff prevents investment. After all, the cost of energy for turbines, wind generators, and photovoltaic panels is higher than the low tariff. The firm that provides the electrical feed could also suffer losses because they only sell electricity at a nominal price that hardly makes up for their expenses. Due to the high cost of services, such as the high cost of a cubic meter of water for the final customer, the citizen, the high tariff may cause damages. The high tariff is economically costly for the corporations that profit from electricity. However, high tariffs compel service providers to broaden their investment options, look for more cost-effective solutions, and integrate more renewable energy. These actions have a greater positive impact on the economy, the environment, money circulation, labor market opening, investment opportunities, job opportunities, and emissions reduction. The suggested carbon incentives methodology has shown to be effective in cutting costs and emissions at the same time, which enhances the quality of community life overall by lowering the amount of emissions per capita. As a result, it may be the best way to lower the high costs of high tariffs and force service companies to switch to renewable energy at the same time. One is to lower service costs while creating more job opportunities. In contrast to high fuel prices, low fossil fuel prices do not promote the country's shift to renewable energy, lower emissions, Vision 2030, or the aim of achieving zero carbon emissions by 2060. In order to drive the carbon emissions market forward, carbon permits are initially more expensive than carbon taxes. Eventually, tax prices rise in an effort to put pressure on electricity-producing enterprises to lower their emissions. Long-term systems that last 10 years or more yield financial benefits from hybrid and renewable energy systems; short-term systems, on the other hand, will typically cost more than fossil fuels and the network itself. In terms of emissions, photovoltaics is not as good as wind turbines due of their higher emissions. Higher wind speeds at the Arabian Gulf coast made wind turbines more practical, while higher radiation rates around the Red Sea coast made solar panels more feasible.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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Author contributions

Amer A. AL-Ghamdi and Yassir A. Alhazmi jointly contributed to the research and writing of this paper. was primarily responsible for conceptualizing the study, designing the research methodology, analyzing the data, and played a key role in collecting and interpreting the data. Yassir A. Alhazmi contributed to the formulation of the emission optimization model. Both authors collaborated on drafting and revising the manuscript, ensuring its accuracy and relevance to the field of environmental sustainability in the context of power generation in Saudi Arabia.

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