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Comparative Analysis of Diesel Generators With Other Alternatives (Solar Plant, Thermal Power Plant)

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Abstract: This paper tries to find best option for generating electricity during shortage by main grid in Al-kut city so analysis has been made for the three choices the diesel generator (which currently used by the city), solar power plants, and thermal power plant the analysis involve the total cost, how much carbon dioxide emitted and the water consumption by each system during the operation time. The study aims to find what is the best system for ten years, so estimation has been done to find what will be the population size of Al-kut city in 2033.inresult has been included keep adopted diesel generators for avoid issue of main grid shortage supply is cost city a lot by fuel consumption and cost of operation, furthermore there is significant amount of co2 emitted during the ten years. On another hand the most sustainable option the city should employ is the solar plant which has economical total cost compared to the thermal plant which cost high by requiring fuel to run, the solar has lowest water consumption and almost zero co2 emission in addition the solar system is reliable than others.

Keywords: Sustainable Management, Solar Energy, Al-Kut City, Electricity Situation in Iraq, Diesel Generators, Carbon Dioxide Emission.

Introduction

The increasing of population rapidly in Al-kut city of Iraq put pressure on the electricity demand by international main grid makes supply electricity percentage within 50% over the year (riskycities.com) (wikipedia.org).

So the electricity shortage keep being steady in Al-kut, the electricity be provided by main grid just 12 to 16 hour per day (spglobal.com), the diesel generator was available solution to overcome the main grid electricity off.

Effected by negative impact of climate change and changing the water resource to became less (worldbank.org) (wikipedia.org). Iraq should employ sustainable system to provide electricity without consumption a lot quantity of water and emitting carbon dioxide in enormous way and the system should be economical feasible.

The object of this paper to use vital factors such the total cost, the co2 emission and water consumption to evaluate diesel generators ,solar plant and thermal power plant to know which option is more sustainable one and which one is not and cost city economically and environmentally for the Al-Kut city

Literature Review

Diesel Generators

The concept of diesel generators is converting energy of the fuel into mechanical energy, and then into electrical energy through an alternator.

Diesel generator consumes about 8 to 10 liters of diesel per hour for capacity of a 100 kVA The fuel consumption of a diesel generator depends on its capacity. The quantity of carbon dioxide emitted by a diesel generator is large, almost to 2.68 kg of CO2 emitted per liter of burned diesel (fwpower.co.uk) (generatorsource.com).

For prevent the overheating in the generators a water is essential for cooling yet the consumption could be large than required by irregular use. Diesel generators have a typical lifespan of around 10 to 15 years of service necessary (pickgenerators.com) (powerlinkworld.u).

Solar Power Plants

Solar power plants generate electricity by harnessing the energy of sunlight through photovoltaic (PV) panels. These panels convert sunlight directly into electricity using semiconductors, without any fuel combustion (Portakalci & Ari, 2024). Solar power generation is highly dependent on the availability of sunlight, with "peak hours" being the time during the day when sunlight is most intense—typically between 10 a.m. and 4 p.m. In regions like Iraq, where sunlight is abundant, these peak hours can result in high energy production.

While solar power plants themselves do not emit CO2 during electricity generation, there can be indirect emissions during the manufacturing and installation of solar panels. However, these emissions are minimal compared to fossil fuel-based energy systems. Solar plants require little to no fuel, making them environmentally friendly once operational (Sharma & Meht, 2024).

Batteries play a crucial role in solar power plants, as they store excess electricity generated during peak hours for use when the sun isn't shining (e.g., at night). Without battery storage, solar power cannot provide a continuous energy supply, making the grid dependent on other energy sources during non-sunny periods. Solar panels typically have a lifespan of 20 to 25 years, after which their efficiency may decrease, though they continue to generate electricity for many more years

Thermal Power Plants

Thermal power plants generate electricity by converting heat energy into electrical energy. In fossil fuel-based thermal plants, fuels like oil, natural gas, or coal are burned to heat water, producing steam (Gumeni et al, 2024). This steam drives turbines connected to a generator, which then produces electricity. Thermal power plants require large amounts of fuel to generate electricity (solarreviews.com). For example, to produce 1 megawatthour (MWh) of electricity, a typical thermal power plant might consume around 220 to 260 liters of oil or a corresponding amount of natural gas (electricaltechnology.org) (iea.org).

One of the major environmental concerns with thermal power plants is their high CO2 emissions. Burning fossil fuels releases large amounts of CO2, contributing significantly to greenhouse gas emissions. Depending on the fuel used, thermal power plants can emit between 800 and 1,200 kg of CO2 per MWh of electricity generated (Turch et al, 2024). Additionally, thermal power plants have high water requirements for cooling and steam generation. On average, a thermal plant consumes about 2,500 to 3,000 liters of water per MWh of electricity produced (epa.gov). This makes thermal power less suitable for water-scarce regions unless water-saving technologies are employed.

Thermal power plants typically have a lifespan of 30 to 40 years (link.springer.com), but the environmental costs associated with their operation—particularly water consumption and CO2 emissions—pose challenges for sustainable energy development.

Methodology

Study Area

Al-Kut City, located in the Waist Governorate. The city lies approximately 180 kilometers southeast of Baghdad and is a key urban center in the region. As of 2024, Al-Kut has an estimated population of 512,000, with an annual growth rate ranging from 2.3% to 2.5%. By 2033, with 2.4 % as average growth rate the city’s population is projected to reach approximately 633,825 as shown Table (1), increasing the demand for reliable electricity supply.

Table 1. Alkut city population over 10 years

YEAR	*POPULATION*
2024	512000
2025	524288
2026	536871
2027	549756
2028	562950
2029	576461
2030	590296
2031	604463
2032	618970
2033	633825

The city's energy consumption patterns are influenced by irregular supply from the national grid, which provides electricity for only 12 to 16 hours per day [5][6][7], with prolonged outages during the hot summer months. Diesel generators are used to cover the shortfall

System Descriptions

The following power generation systems were evaluated in this study:

Diesel Generators

Diesel generators are currently the primary backup power source in Al-Kut City, used during grid outages. There are 611 diesel generators in operation, each with a capacity ranging from 100 to 300 kVA. some of them are modified generators by using truck engine like SCANIA These generators, on average, provide electricity to 150 households each. Diesel generators operate between 5 and 15 hours per day when the main grid is down, and during the hot season, usage can exceed 15 hours. Each household connected to the diesel generators pays a monthly fee ranging from \$15 to \$25 for the electricity provided (powerlinkworld.u).

The monthly fuel consumption of these generators is shown in **Table 2**, which illustrates that fuel usage peaks during the hot summer months due to increased demand for cooling and extended operational hours. The local government purchases diesel at a subsidized rate for generator owners, approximately **\$0.25 per liter** (solargis.com) **yet the actual diesel price in oil marketing equal 0.57 dollar.** Additionally, most generators utilize water for cooling, consuming an average of **0.5 to 3 cubic meters (m^3)** of fresh water daily during operation, depending on the generator's size and load, and for the capital cost for each generator range from 5000 to 10000 dollar (analyticauto.com).

Table 2. The Monthly Diesel Counsumption

MONTH	DIESEL CONSUMPTION MILLION LITER
JANUARY	2.25
FEBRUARY	2
MARCH	2
APRIL	2
MAY	4.3
JUNE	5.58
JULY	9.4
AUGUST	9.4
SEPTEMBER	5.8
OCTOBER	5.8
NOVEMBER	2
DECEMBER	2.25

Solar Power Plant

Solar energy is a promising alternative for the region due to its high levels of solar irradiance, with daily solar radiation ranging from 5.5 to 6.7 kWh/m². The city's geographic location and climate make it ideal for solar power generation, with long hours of sunlight throughout the year with peak hour reach more than 5 hours (Al-Sudani & Mulla, 2024).

The plant would have a high upfront installation cost but minimal operational costs once installed, as solar panels do not require fuel. Assumptions for this analysis include using battery storage for period of non-peak hours which equal 5 hours too, meaning the solar plant will only operate during daylight hours for ten hours.

Capital costs for the plant were based on industry standards for large-scale solar farms, and operational costs were estimated using data from similar installations in the region. Emission reductions were also factored in, given that solar power produces zero CO_2 emissions during operation. And the water consumption for cleaning the solar panels frequently.

Thermal Power Plant:

Using data of capital cost of Wasit thermal power plant as one of major reference to estimate the thermal power plant to provide required demand by Al-Kut city during shortage time.

And for co_2 emission and water consumption during the operation period the average of global data have been used.

Comparative Parameters

The following parameters were used to compare diesel generators, solar power plants, and thermal power plants over a 10-year period:

Total Cost (10 years):

The total cost for each system includes installation, maintenance, fuel, and operational expenses. For diesel generators, costs were calculated based on fuel consumption (depends on supported price by local government and the global price), maintenance, and monthly fees paid by households. Solar power costs were primarily upfront installation costs, with minimal operational costs. Thermal power plant costs included capital investment, fuel (oil and gas), and maintenance.

Water Consumption:

Water consumption was a critical factor in comparing the systems. Diesel generators consume water for cooling, but the usage is often unregulated and inefficient. Solar power plants, by contrast, require minimal water, making them ideal for Iraq's water-scarce environment. Thermal power plants, particularly those using oil and gas, have the highest water consumption rates, which was a major concern in this study.

CO_2 Emissions

CO_2 emissions were calculated for each system based on their fuel consumption and operational characteristics. Diesel generators are known for their high emissions due to the combustion of diesel fuel, while thermal power plants also contribute significantly to CO_2 emissions from burning oil and gas. Solar power plants produce zero CO_2 emissions during operation.

Electricity Demand

1. Finding required electricity rate in 2033 to be base comparative parameters such as cost water consumption and co2 emission
2. Given data :
   - Average Electricity Consumption per Capita: 1255 kWh/year[27][28]
   - Population: 633,825
3. Actual Demand Adjustment: Official data represents only 50% of actual demand, so we multiply by 2.

Calculation Steps

Step 1: Calculate Official Demand for the Population

$$D = P \times C \qquad (1)$$

$$D = 1255 \times 633{,}825$$

$$D = 795{,}347{,}875\ kWh/year$$

Where:

D: Total Official Demand (kWh/year)

C: Average Consumption per Capita (kWh/year)

P: Population

Step 2: Adjust for Actual Demand

Since the official data represents only 50% of the actual demand, we multiply by 2:

$$D_a = D \times 2 \qquad (2)$$

$$D_a = 795{,}347{,}875 \times 2$$

$$D_a = 1{,}590{,}695{,}750\ kWh/year$$

Then we convert kWh to MWh

$$\frac{1{,}590{,}695{,}750\ kWh/year}{1000} = 1{,}590{,}695.75\ MWh/year$$

Then we convert Annual Demand to Hourly Demand

$$\frac{1{,}590{,}695.75\ MWh/year}{8760} = 181.61\ MWh/hour$$

Data Analysis

Diesel generators

Cost Analysis

In 2024, Al-Kut had 611 diesel generators with a capacity range of 100 to 300 kVA. The number of generators is projected to grow by 2.4% annually, reaching 756 by 2033. The capital cost for each generator averages around $7,500, Over the 10-year period, the total capital cost is $5672860.

Table 3. captial cost of diesel generators

YEAR	Generator no.	The accumulated capital cost
2024	611	4582500
2025	626	4692480
2026	641	4805100
2027	656	4920422
2028	672	5038512
2029	688	5159436
2030	704	5283263
2031	721	5410061
2032	739	5539903
2033	756	5672860

with maintenance costs accumulating to $5,017,710. Additionally, the cost of diesel fuel consumption has been calculated, a diesel price of $0.57 per liter for Iraqi oil productions prices and for generators the government support the price and sell it for just 0.25 dollar. The total diesel consumption for 2024 was 52.78 million liters, and the monthly consumption for 2024 is provided in the table below. The cumulative diesel cost over the decade is $147,152,070 by supported price yet actual cost will be 335506719 dollars. Each household served by the generators is assumed to pay fees range from 15 to 25 dollar monthly over the year, which translates into a total revenue of $249158377 over the 10-year span (based on 20 dollars monthly for each household).

Table 4. Cost of Diesel Consumption

YEAR	Generator no.	Total Diesel Consumption (liters)	cost by year (0.57 $/l)	cost by year (0.25 $/l)
2024	611	52,780,000	30,084,600	13,195,000
2025	626	54,046,720	30,806,630	13,511,680
2026	641	55,343,841	31,545,990	13,835,960
2027	656	56,672,093	32,303,093	14,168,023
2028	672	58,032,224	33,078,368	14,508,056
2029	688	59,424,997	33,872,248	14,856,249
2030	704	60,851,197	34,685,182	15,212,799
2031	721	62,311,626	35,517,627	15,577,906
2032	739	63,807,105	36,370,050	15,951,776
2033	756	65,338,475	37,242,931	16,334,619
Total Diesel Cost			335,506,719	147,152,070

Table 5. Cost by Monthly Fees

YEAR	Generator no.	population	fees/year
2024	611	512000	22341818
2025	626	524288	22878022
2026	641	536871	23427094
2027	656	549756	23989345
2028	672	562950	24565089
2029	688	576461	25154651
2030	704	590296	25758363
2031	721	604463	26376563
2032	739	618970	27009601
2033	756	633825	27657831
total fees ($)for ten years			249158377

As illustrate the tables above the total cost of generators for tenyears is the fuel cost and the fees paid by people for owner for purpose of operation and maintenance, so the cost will be:

$$TC = (CG + PH) - CS \tag{3}$$

$$TC = (335{,}506{,}719 + 249{,}158{,}377) - 147{,}152{,}070$$

$$TC = 437513026 \; dollars\ over\ ten\ years$$

Where:

- TC: Total Cost (dollars/10 years)
- CG: Cost of Diesel Consumption at Global Price (dollars)
- PH: Paid Fees by Households (dollars)
- CS: Cost of Diesel Consumption at Subsidized Price (dollars)

Water Consumption

Each diesel generator consumes in minimum approximately 1 cubic meter of water per day for cooling purposes for ten years the total water consumption for the generators amounted almost to 2.5 million m^3 of fresh water.

Table 6. Water Consumption Annually

YEAR	Generator no.	water
2024	611	223015
2025	626	228367
2026	641	233848
2027	656	239461
2028	672	245208
2029	688	251093
2030	704	257119
2031	721	263290
2032	739	269609
2033	756	276079
total water consumption		249158377

CO2 Emissions

Diesel fuel combustion generates 2.68 kg of CO2 per liter of fuel consumed. With the rising diesel consumption due to the growing number of generators, CO2 emissions increase annually, to reach **1,577,470** ton as total CO2 emissions over the 10 years.

Table 8. Co2 Emission Annually

YEAR	Total Diesel Consumption (liters)	CO2 Emissions (ton)
2024	52,780,000	141,450
2025	54,046,720	144,845
2026	55,343,841	148,321
2027	56,672,093	151,881
2028	58,032,224	155,526
2029	59,424,997	159,259
2030	60,851,197	163,081
2031	62,311,626	166,995
2032	63,807,105	171,003
2033	65,338,475	175,107
total water consumption		1,577,470

Total Cost 279.4 MW Solar Plant

Recentaly The Demand for electricity for ten hours (during shortage time) has been estimated 181.6 MW/h batteries to support the required electricity rate during the non-peak hours so the capacity will be 279.4 for the plant as illustrated by calculation below:

X= The Required Capacity of Plant

Y= Energy Should be Saved During The Peak Hour

Peak hours =5

Nonpeak hours = 30% of peak hours

During peak hours the rate will be:

$$X = 181.6 + Y \quad (4)$$

During The Non-Peak Hours

$$181.6 = 0.3 \times X + Y \quad (5)$$

By (4)(5) two equations the:

X= 279.4 MW/h The capacity of solar plant,

Y=97.8 MW/h The saving energy rate

For estimating the total cost over 10 years for a 279.4 MW solar power plant in Al-Kut, Iraq. The project includes battery storage capacity sufficient to meet 97.8 MW of demand for 5 non-peak hours. The total cost estimate covers capital expenses, battery storage costs, and operation and maintenance (O&M) over a 10-year period, based on realistic Middle Eastern pricing.

Solar Plant Capital Cost

The solar plant has a total capacity of 279.4 MW. Based on Middle Eastern benchmarks, the capital cost is estimated at $600,000 per MW [29].

Calculation:

$$SPC = C \times CC \quad (6)$$

$$SPC = 279.4MW \times 600{,}000\ USD/MW$$

$$SPC = 167{,}640{,}000\ USD$$

Where:

- SPC: Solar Plant Cost (dollars)
- C: Capacity (MW)
- CC: Capital Cost per MW (dollars/MW)

Battery Storage Cost

The battery storage is designed to support 97.8 MW of demand for 5 non-peak hours, resulting in a total storage requirement of 489 MWh. Battery storage cost is estimated at $200,000 per MWh, based on Middle Eastern prices [30].

Calculation:

$$Battery\ Storage\ Capacity = 97.8\ MW \times 5\ h \quad (7)$$

= 489 MWh

$$BSC = SC \times CP \quad (8)$$

$$BSC = 489\ MWh \times 200{,}000\ USD/MWh$$

$$BSC = 97{,}800{,}000\ USD$$

Where:

- BSC: Battery Storage Cost (dollars)
- SC: Storage Capacity (MWh)
- CP: Cost per MWh (dollars/MWh)

Operation & Maintenance (O&M) Cost

Operation and Maintenance costs are calculated annually at 2% of the combined initial capital and battery storage costs. This estimate is based on regional maintenance costs for similar facilities.

Calculation:

$$TIC = SPC + BSC \quad (9)$$

$$TIC = 167{,}640{,}000 + 97{,}800{,}000$$

$$TIC = 265{,}440{,}000\ USD$$

Where:

- TIC: Total Initial Cost (dollars)
- SPC: Solar Plant Cost (dollars)
- BSC: Battery Storage Cost (dollars)

$$AOM = TIC \times OMP \quad (10)$$

$$AOM = 265{,}440{,}000 \times 0.02$$

$$AOM = 5{,}308{,}800\ USD/year$$

Where:

- AOM: Annual O&M Cost (dollars/year)
- TIC: Total Initial Cost (dollars)
- OMP: Operation & Maintenance Percentage (decimal form, e.g., 0.02 for 2%)

$$TOM = AOM \times 10 \quad (11)$$

$$TOM = 5{,}308{,}800\ USD/year \times 10$$

$$TOM = 53{,}088{,}000\ USD$$

The total cost over the 10-year period includes the capital cost of the solar plant, battery storage cost, and the cumulative operation and maintenance expenses.

Calculation:

$$TC = SPC \times BSC \times TOM \quad (12)$$

$$TC = 167{,}640{,}000 \times 97{,}800{,}000 \times 53{,}088{,}000$$

$$TC = 318{,}528{,}000\ USD$$

Where:

- TC: Total Cost (dollars)
- SPC: Solar Plant Cost (dollars)
- BSC: Battery Storage Cost (dollars)
- TOM: Total O&M Cost over 10 Years (dollars)

Water Consumption

Water consumed for Cleaning a 279.4 MW Solar Plant cleaning is essential in such climates to maintain efficiency, as dust accumulation significantly reduces solar panel output. The following calculations assume an average cleaning frequency of 20 times per year, typical for utility-scale plants in the Middle East, with an estimated water usage of 7 to 15 liters per square meter per cleaning.

1. Annual Water Consumption per Cleaning Cycle

The total water consumption per cleaning cycle depends on the area of the panels and the specific water usage per square meter. We consider a range of 7 to 15 liters of water per square meter, as commonly observed in large solar installations in dusty regions[31].

2. Water Usage Range per Year

Given that cleaning occurs 20 times per year, we calculate the annual water consumption for both lower and upper bounds of water usage.

For the lower bound (7 L/m²):

$$AWC_L = A \times W \times CF \quad (13)$$

$$AWC_L = 279{,}400\ kW \times 5 \times 7 \times 20$$

$$AWC_L = 5{,}588{,}000\ liters\ per\ year$$

Where:

- AWC_L : Annual Water Consumption (lower bound) (liters/year)
- AAA: Area of Panels (m²)
- WWW: Water per m² (liters/m²)
- CFCFCF: Cleaning Frequency (times/year)

For the upper bound (15 L/m²):

$$AWC_L = A \times W \times CF \quad (14)$$

$$AWC_L = 279{,}400\ kW \times 5 \times 15 \times 20$$

$$AWC_L = 11{,}172{,}000\ liters\ per\ year$$

For Ten Years 111720000 Liter

Thermal Power Plant

Cost of thermal power plant

The total cost estimate includes capital expenses, fuel costs, and operation and maintenance (O&M) expenses, based on a revised capital cost of $1 million per MW.

1. Capital Cost

The capital cost is estimated using a benchmark of $1 million per MW, based on similar thermal power projects in Iraq [32].

Calculation:

$$CC = PC \times CCMW \quad (15)$$

$$CC = 181.6\ MW \times 1{,}000{,}000\ USD/MW$$

$$CC = 181{,}600{,}000\ USD$$

Where:

- CC: Capital Cost (dollars)
- PC: Plant Capacity (MW)
- CCMW: Capital Cost per MW (dollars/MW)

2. Fuel Cost

The fuel cost is calculated based on a plant efficiency of 35% and an average natural gas price of $4 per MMBtu. The following steps detail the calculation of fuel requirements and costs[32]

$$AEO = PC \times DOT \times DPY \quad (16)$$

$$AEO = 181.6\ MW \times 10\ hours/day \times 365\ days/year$$

$$AEO = 662{,}840\ MWh/year$$

Where:

- AEO: Annual Energy Output (kWh/year)
- PC: Plant Capacity (kW)
- DOT: Daily Operation Time (hours/day)
- DPY: Days per Year (days/year)

Fuel Requirement: Each MMBtu provides approximately 0.293 MWh of energy.

$$AFC = AEO \div EPM \quad (17)$$

$$AFC = 662{,}840\ MWh \div 0.293\ MWh/MMBtu$$

$$AFC = 2{,}262{,}386\ MMBtu$$

Where:
- AFC: Annual Fuel Consumption (MMBtu/year)
- AEO: Annual Energy Output (kWh/year)
- EPM: Energy per MMBtu (kWh/MMBtu)

$AF_{COST} = AFC \times CPM$ (18)

$AF_{COST} = 2{,}262{,}386\ MMBtu \times 4\ USD/MMBtu$

$AF_{COST} = 9{,}049{,}544\ USD$

10-Year Fuel Cost = Annual Fuel Cost × 10
= 9,049,544 × 10
= 90,495,440 USD

3. Operation & Maintenance (O&M) Costs

O&M costs are calculated as 3% of the capital cost annually, a typical rate for thermal power plants[33].

$AOM = CC \times OMP$ (20)

$AOM = 181{,}600{,}000 \times 0.03$

$AOM = 5{,}448{,}000\ USD$

10-Year O&M Cost = Annual O&M Cost × 10
= 5,448,000 × 10
= 54,480,000 USD

Where:
- AOM: Annual O&M Cost (dollars/year)
- CC: Capital Cost (dollars)
- OMP: Operation & Maintenance Percentage (decimal form, e.g., 0.02 for 2%)

4. Total 10-Year Cost

The total 10-year cost includes the capital cost, 10-year fuel cost, and 10-year O&M cost.

$$TC = CC + (AF_{Cost} \times 10) + (AOM \times 10) \quad (21)$$

$TC = 181{,}600{,}000 + 90{,}495{,}440 + 54{,}480{,}000$

$TC = 326{,}575{,}440\ USD$

Where:
- TC: Total Cost (dollars/10 years)
- CC: Capital Cost (dollars)
- AFCost: Annual Fuel Cost (dollars/year)
- AOM: Annual O&M Cost (dollars/year)

Water Counsumption of Thermal Power Plant

1. Plant and Operational Details

The thermal power plant has a capacity of 181.6 MW and operates for 10 hours per day throughout the year. The total energy output over one year is calculated as follows:

$AEO = PC \times DOT \times DPY$ *(22)*

$AEO = 181.6\ MW \times 10\ hours/day \times 365\ days/year$
$AEO = 662{,}840\ MWh/year$
TEO=AEO×10
TEO = 662,840 MWh/year × 10
TEO = 6,628,400 MWh
Where:

- *AEO: Annual Energy Output (kWh/year)*
- *PC: Plant Capacity (kW)*
- *DOT: Daily Operation Time (hours/day)*
- *DPY: Days per Year (days/year)*
- *10-Year Energy Output (kWh/10 years)*

2. Water Consumption for Recirculating (Wet) Cooling

For recirculating (wet) cooling systems, water consumption typically ranges from 1,500 to 2,000 liters per MWh. The following calculations estimate the 10-year water consumption for the plant using this cooling type (eia.gov).

Lower Bound (1,500 L/MWh):

$$TWC = TEO \times WPM \quad (23)$$

$TWC = 6{,}628{,}400\ MWh \times 1{,}500\ L/MWh$
$TWC = 9{,}942{,}600{,}000\ liters$

Upper Bound (2,000 L/MWh):

$TWC = 6{,}628{,}400\ MWh \times 2000\ L/MWh$
$TWC = 13{,}256{,}800{,}000\ liters$

Where:

- TWC: Total Water Consumption (liters/10 years)
- TEO: 10-Year Energy Output (MWh/10 years)
- WPM: Water per MWh (liters/MWh)

3.Water Consumption for Dry Cooling

For dry cooling systems, water consumption is significantly lower, ranging from 80 to 100 liters per MWh. The following calculations estimate the 10-year water consumption for the plant using dry cooling (International Renewable Energy Agency).

Lower Bound (80 L/MWh):

$$TWC = TEO \times WPM \quad (24)$$

$TWC = 6{,}628{,}400\ MWh \times 80\ L/MWh$
$TWC = 530{,}272{,}000\ liters$

Upper Bound (100 L/MWh):

$$TWC = TEO \times WPM \quad (25)$$

$TWC = 6{,}628{,}400\ MWh \times 100\ L/MWh$
$TWC = 662{,}840{,}000\ liters$

The estimated water consumption over a 10-year period for a 181.6 MW thermal power plant operating 10 hours daily is summarized as follows:

1-Recirculating Cooling: 9.94 to 13.26 billion liters

2-Dry Cooling: 530.27 to 662.84 million liters

CO_2 Emission Calculation

The CO_2 emissions for natural gas are estimated at 0.185 kg CO_2 per kWh, or 185 kg CO_2 per MWh. The following calculations estimate the 10-year CO_2 emissions for the plant [36].

$$TCE = TEO \times CEF \quad (26)$$

$$TCE = 6{,}628{,}400\ MWh \times 185\ kg\ CO_2/MWh$$

$$TCE = 1{,}225{,}254{,}000\ kg\ CO_2$$

Where:

- TCE: Total CO_2 Emissions (tons/10 years)
- TEO: 10-Year Energy Output (MWh/10 years)
- CEF: CO_2 Emissions Factor (tons/MWh)

Result and Discussion

This section quantifies the performance of diesel generators, solar power plants, and thermal power plants for Al-Kut City over a 10-year period. Key metrics include total cost, water consumption, CO_2 emissions, and energy reliability, providing a clear comparison of each system's suitability.

Cost Analysis

Diesel Generators

Diesel generators incur high operational costs primarily due to fuel consumption and maintenance. Over the 10-year period:

1. **Capital Cost**: Assuming 611 generators with an average cost of $7,500 each, the total capital cost is approximately **$4,582,500 in 2024**.
2. **Fuel Cost**: Diesel costs are projected at **$147 million** (government-subsidized price) or **$335 million** (market price) over 10 years based on consumption of approximately **52.8 million liters per year**.
3. **Maintenance Cost**: Estimated at **$5 million** over the 10-year period.
4. **Total Cost**: Including all expenses, diesel generators total **$437 million** (market price) over 10 years, making them a financially intensive option.

Solar Power Plants

Solar power has a high initial cost, but with minimal operating expenses after installation.

1. **Capital Cost:** For a 279.4 MW solar plant, the initial cost is $167.6 million at $600,000 per MW.
2. **Battery Storage Cost**: A 97.8 MW battery system is projected at $97.8 million for 5 hours of storage, equating to 489 MWh.
3. **Maintenance Cost:** Annual maintenance at 2% of capital results in $53.1 million over 10 years.
4. **Total Cost:** Including battery storage, total expenses reach $318.5 million over 10 years, offering long-term economic benefits over diesel.

Thermal Power Plants

Thermal power requires high fuel and water resources.

1) **Capital Cost:** At $1 million per MW, a 181.6 MW plant totals $181.6 million.
2) **Fuel Cost:** With annual fuel expenses of $9 million based on 2.26 million MMBtu at $4 per MMBtu, the 10-year fuel cost totals $90.5 million.
3) **Maintenance Cost:** Estimated at 3% of capital cost annually, maintenance reaches $54.5 million over 10 years.
4) **Total Cost:** Thermal plants have an overall cost of $326.6 million over the 10-year period, driven mainly by high fuel and water requirements.

Water Consumption

✓ **Diesel Generators**

Each generator consumes around 1 m^3 of water daily for cooling. With 611 units, the total water usage over 10 years reaches 2.5 million m^3, raising sustainability concerns.

✓ **Solar Power Plants**

Solar power requires water primarily for cleaning, estimated at 5.5 to 11.2 million liters per year for a 279.4 MW plant, or 0.111 million m^3, over 10 years. This low water requirement makes solar an ideal option for water-scarce regions.

✓ **Thermal Power Plants**

With an average requirement of 1,500-2,000 liters per MWh, a 181.6 MW plant operating 10 hours daily consumes approximately 9.94 to 13.26 million m^3, over 10 years. This substantial demand poses a challenge in Iraq's arid environment.

CO_2 Emissions

✓ **Diesel Generators**

Diesel combustion emits 2.68 kg of CO_2 per liter. For an annual consumption of 52.8 million liters, CO_2 emissions amount to **141,450 tons per year**, totaling **1.57 million tons over 10 years**.

✓ **Solar Power Plants**

Solar plants produce zero CO_2 emissions during operation. Initial panel production emits CO_2, but these emissions are significantly lower compared to fossil fuels, reinforcing solar power's environmental advantages.

✓ **Thermal Power Plants**

Based on a CO_2 emission factor of 185 kg/MWh, a 181.6 MW thermal plant produces approximately **662,840 MWh annually**, leading to **122,525 tons of CO_2 per year** or **1.225 million tons over 10 years**.

Energy Production Reliability

- **Diesel Generators**

Diesel generators are highly reliable, capable of providing power during grid outages. However, reliance on fuel availability and high costs limit their sustainability.

- **Solar Power Plants**

Solar energy production is contingent on sunlight; however, battery storage allows consistent energy supply even during non-sunny hours. This integration enhances reliability and reduces dependence on diesel generators.

- **Thermal Power Plants**

Thermal plants provide steady, reliable energy output but at the cost of high water and CO_2 emissions, making them less favorable for a sustainable energy future in Al-Kut.

Conclusion

Through the analysis the diesel generators consider unsustainable way to provide electricity for the city during off time the main grid by consumption diesel fuel which could be economical support to the local government by selling it in oil marketing in addition the negative impact on environment by carbon dioxide emitting and water consumption, yet with low total cost of Thermal power plants than generators , the thermal power plant consume considerable amounts of water and produce high levels of emissions. Solar power, with its higher capital costs, emerges as the most viable solution due to, minimal water supplies, zero emissions during operation and low operating costs. Overall, solar power with battery storage suitable with Al-Kut's economic and environmental purposes.

Recommendations

1. Prioritize Solar Power Investments

Al-Kut should focus on establishing large-scale solar power plants to leverage the region's abundant sunlight. Government initiatives, including tax incentives and financial support, could lower upfront costs and encourage investment from both public and private sectors. The solar plant system should be optimizing to generate steady rate of electricity by using effective store method.

2. Develop a Comprehensive Renewable Energy Policy

A policy framework should be established to support the adoption and expansion of renewable energy. This framework should set specific targets for solar energy adoption, provide streamlined procedures for project approvals, and offer financial incentives to encourage renewable infrastructure development.

3. Engage the Public in Renewable Energy Awareness

Public awareness campaigns can inform the community about the benefits of renewable energy, encouraging household energy savings and support for solar projects. Increased community engagement will help build acceptance of renewable energy initiatives across Al-Kut.

Nomenclatures

D: Total Official Demand
C: Average Consumption per Capita
P: Population
TC: Total Cost (dollars/10 years)
CG: Cost of Diesel Consumption at Global Price
PH: Paid Fees by Households
CS: Cost of Diesel Consumption at Subsidized Price
SPC: Solar Plant Cost
CC: Capital Cost per MW
BSC: Battery Storage Cost
SC: Storage Capacity
CP: Cost per MWh
TIC: Total Initial Cost
AOM: Annual O&M Cost
OMP: Operation & Maintenance Percentage
TOM: Total O&M Cost over 10 Years
AWC_L *: Annual Water Consumption (lower bound)*
A: Area of Panels (m^2)
W: Water per m^2
CF: Cleaning Frequency
PC: Plant Capacity
CCMW: Capital Cost per MW
AEO: Annual Energy Output
DOT: Daily Operation Time
DPY: Days per Year
AFC: Annual Fuel Consumption
EPM: Energy per MMBtu
TWC: Total Water Consumption (liters/10 years)
TEO: 10-Year Energy Output (MWh/10 years)
WPM: Water per MWh (liters/MWh)
TCE: Total CO_2 *Emissions (tons/10 years)*
CEF: CO_2 *Emissions Factor (tons/MWh)*

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