A study of off grid environment friendly power suppling solution to telecom towers in NEOM

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***Abstract*— In todays standers, having telecom coverage is essential at all times therefor there must be a telecom antenna covers the users at any geographical area. NEOM is a mega project for new futuristic city in Saudi Arabia that will have cutting edge technologies and features including environmental sustainable features such as clean carbon free energy. The challenge for telecom companies was to cover all the construction areas while having no grid connection and the power supply must be as environmental friendly as possible.**

In this thesis the study conducted on possible solutions technically and how much it effective economically and environmentally compared with typical solutions. The solutions are standalone power source for telecom tower, to cover the construction area till permanent on grid solution reach the area. Three types of possible solutions proposed:

1- Solar with Batteries, environmentally friendly solution.

2- Solar with Diesel Generator, as a hybrid solution.

3- Diesel Generator with batteries, as a hybrid solution.

The thesis compares each solution with a typical dual diesel generator as primary source from economic point of view and environmental point of view.

For each solution the Life Cycle Cost (LCC) calculated as base of economical comparison and CO2 emissions as base of environmental comparison. Two matrices been calculated to combine the economic and environmental comparison factors to showcase the suitability of each solution; the first one is called Unit of energy that is the sum of the cost of CO2 emissions in addition to LCC, the second was called Cost-CO2 emissions magnitude that calculates the magnitude of a vector that represented by the LCC and CO2 emissions in two dimensions plane.

The result shows that using single factor of comparison such as LCC will result in favoring the typical solution which is the cheapest (0.97M SAR in 10 years) but most harmful for the environment (1,017 ton CO2 emissions in 10 years) and using CO2 emissions will result in favoring the solar with batteries (No CO2 emissions in 10 years) which is the most expensive solution (2.47M SAR in 10 years).

Applying the unit of energy and Cost-CO2 emissions metric result in favoring the hybrid solutions, solar and diesel generator on first place (1.15M SAR and 272 Ton of CO2 in 10 years) then diesel generator with batteries in second place (1.12M SAR and 579 Ton of CO2 in 10 years).

Keywords*— *Batteries,CO2 emission, Comparison, Cost, Deisel, Energy, Hybrid, LCC, Life Cycle Cost, NEOM, Power source, Renewable, Rural Area, Solar, Stand alone, Telecom Tower.

I. INTRODUCTION

NEOM city is part of 2030 Saudi Arabia vision. The city is located in the northwest of Saudi Arabia is planning to construct a power system that will shift the dependence on fossil fuels and achieve 100% renewable energy to energize the city and also provide clean energy for the country. The location is considered as one of the wealthiest natural resources in the region of solar energy and wind energy. NEOM's objective is to be a self-sustainable city and a center of renewable carbon-free energy [1]. Telecom services provided by telecom towers is requirement for today's lifestyle, the services including 2G, 3G, 4G and 5G connection which is providing cellphones and any SIM card device calls, messages and internet services. Telecom operators accomplish telecom coverage through constructing telecom towers to allow the antenna to user's connection; the idea of building high towers is to cover bigger areas and to allow microwave connection between tower to the telecom network because microwave connection required line of sight connection.

Power supplied for telecom towers is usually designed for maximum possible consumption. The maximum consumption usually varies between 4KW to 150KW depending on the number of operators, the telecom configurations each operator uses, and other accessories such as Air conditioning, lights, sockets, and sensors. A typical power supply solution for telecom towers in rural areas where the electrical grid connection is not feasible is to install a dual diesel fuel generator; it is the second optimal solution after grid connection, and it is reliable due to duality in case of one generator failure or maintenance time, it is cost efficient due to availability in the market, the only downside is the environmental effects related to air and noise pollution and the operational cost due to fueling.

For the NEOM situation, telecom coverage is needed for the current population (mostly construction workers), and the challenge telecom operators face is to implement a solution with as minimum environmental pollution as possible till the electrical grid infrastructure is ready and the solution must be reliable with zero failures due to sensitivity of the work. Therefore, using specific renewable solutions such as solar systems only is not feasible.

The selected solutions are combination of solar panels, batteries, and generators to ensure the reliability of the power system; there are three proposed solutions:

1- Solar system with Batteries.

2- Solar system with a diesel generator.

3- Diesel generator with lithium batteries.

This thesis aims to study the benefits of suggested solutions technically and economically compared with typical solutions.

II. LITERATURE REVIEW

As NEOM Project the name formed via combining Greek and Arabic words, the name 'NEOM' is intended to represent a 'new future' for people across the globe. First announced in late 2017 as a sustainable project on an unprecedented scale, situated in a topographically diverse region along the Red Sea shoreline, NEOM will be able to benefit from renewable resources while preserving access to the lucrative trade route passing through the Suez Canal. The central location along global transportation and trade routes presents an opportunity for developing tourism, commerce, and technology, to achieve the sustainable goals set by Saudi Vision 2030 and communicated by the Saudi government, NEOM should become a testing ground for innovative technological solutions. Namely, the plan to reach net-zero carbon levels can be accomplished by shifting to renewable energy sources, which requires the construction of offshore wind turbines and solar power plants [2], more than 2,800 staff from 86 countries already living and working onsite [3].

Since the early 2000s the Global System for Mobile Communication GSM and Long-term evolution LTE evolve and expanded to covers most of the geographic areas using telecom towers, In general, electrical load of telecom towers ranges from 2 to 12 kW [4], outdoor towers are installed on roof of a building or in open ground which cater larger geographical area. Outdoor towers use many different type of antenna structures such as (i) ground-based tower, (ii) ground-based pole, (iii) guyed masts, (iv) mini pole, (v) rooftop, (vi) solar street pole, (vii) slim tower, (viii) fake trees, (ix) decorative or camouflage sites. Among various options, ground-based towers/poles installed on the ground and rooftop towers/poles installed on roofs of the buildings are popular. In a typical telecom tower, about 60 percent of the electricity is used by active equipment and the remaining electricity is used by passive equipment such as DC power systems 11% and cooling equipment 25% and others including radio frequency (RF) load and feeder load (line loses) each about 1% [5], one of the main challenges was to electrify off grid towers in rural areas, most of the literature on this subject focuses on three factors: economic efficiency, reliability and environmental effect and usually the studies are about comparing the possible solutions or optimizing proposed solution.

For Existing solutions, since the past two decades, conventional power supply options including the grid, batteries, and diesel generators have dominated the telecom towers' electricity supply. Telecom towers have also been powered by alternative electricity supply options such as photovoltaic panels, wind turbines, and fuel cells. However, in order to increase the reliability of power supply to telecom towers, hybridization of conventional and renewable energy systems have also been considered [5]. Typical solutions include diesel generators, renewable energy systems (e.g., PV or wind systems), hybrid power supply systems (i.e., PV-wind, PV-diesel, PV-wind-diesel, and PV-fuel cell systems), and energy storage solutions that were specific to the electrochemical type of energy storage classification such as batteries, hydrogen systems, and hybrid energy storage systems [6].

Diesel generators were among the earliest technologies used as backup or primary power supply solutions for telecom tower in areas with poor or no access to the main grid, The key advantage of deploying diesel systems is that the system can be tailored according to the load demand [6].

Multiple solar photovoltaic cells are connected in series/parallel to absorb sunlight and convert the naturally available plenty of solar energy into DC electrical energy to charge the battery bank and drive the telecom load. The solar PV power output is heavily affected by various factors such as the geographical position, solar PV panel rating, panel material, tilting of PV panel and the generation technology [7].

A wind turbine generates electrical energy into two steps: first, it converts the wind power into mechanical energy and then transforms into electricity. The electrical power produced by WT mainly relies on wind velocity, weather system, and hub height [7].

The battery bank is an energy storage device that enhances the power supply reliability providing backup supply during the absence or unpredictable fluctuation of renewable energy generation [7].

The hybrid power supply system is designed to utilize a combination of two or more power supply solutions (e.g., PVs and diesel generator) in order to achieve a more feasible, reliable, and environmentally friendly power supply arrangement. In particular, in terms of reliability, the deployment of a hybrid power supply system is able to reduce the intermittency of power supply and, accordingly, the need for a larger size of energy storage solution (e.g., batteries or hydrogen storage system) [6].

For Choosing methods, One interesting method is Fuzzy AHP (Analytic Hierarchy Process) which sit a system of point for each option in terms of cost, air pollution, noise pollution and reliability where 0 is worst and 9 is best then taking the average of the point and compare each option [8].

Other more complex technic is Monte-Carlo based simulations are performed to evaluate wireless network performance in terms of throughput, energy efficiency (EE), energy efficiency gain (EEgain), average energy savings, radio efficiency varying system bandwidth (B) and BS transmission power (PTX) considering the dynamic behavior of traffic intensity and renewable energy (RE) generation profile [9].

Optimization technic, a lot of optimization technic focused on techno-economic and environmental effect such as joint transmission coordinated multipoint (JT-CoMP) user association technique is integrated for achieving higher throughput and Energy Efficiency performance Monte-Carlo based simulation or evaluating EE, EE index (EEI), and energy saving performances [10], for hybrid system HOMER stands for Hybrid Optimization Model for Electric Renewables used it is developed by National Renewable Energy Laboratory (NREL) of the USA [4]. This software is used to optimize the system with appropriate design, size and planning of multiple energy resources including solar photovoltaic array with user defied input parameters [11], HOMER adopts two major dispatch strategies such as cycle charging (CC) and load following (LF) to control the operation of DG and battery storage system during shortfall of solar PV system power supply to load [12] [9]. Under LF strategy, DG produces only enough power to meet the electricity demand of load and it is not to charge the battery [13].

The gap this thesis trying to cover is applying life cycle cost of the solution while previous literature using mostly installation cost only ignoring the equipment replacement cost, also combining the environmental factor with the total cost to have single comparison point.

III. Methodology

To compare possible solutions in term of economics and environment factors, each solution must have reliable output for the same required load and must be sustainable for the same period of time, those constrains will be part of the assumptions on this thesis.

Each solution is designed to cover the maximum required load with high reliability, the required equipment for each designed is the base of economic and environmental analysis, where each equipment having it cost of installation, expected life cycle and CO2 emissions.

A. Economic analysis

To evaluate the cost of each solution a Life Cycle Cost (LCC) analysis was conducted, LCC is the total present value of all the costs that occur during the life cycle of a project. [14]

In this work, the used equipment such as batteries, PVs and generators will be replaced when it’s expected life cycle is due with the same equipment and its present time will be calculated till the assumed period of project time is over, the operational cost and accessories such as cabling and circuit brakers will be assumed and included. The LCC computed as follows:

$$LCC = C_P + \sum_{t=1}^{n} \frac{C_t}{(1+d)^t} \qquad (1)$$

- t indicates the year when each cost occurs.
- C_P is the initial cost.
- C_t are all the relevant costs that occur during the year t, fuel and equipment replacement in this case.
- n is the study period.
- d is the discount rate used to compute the present value of future costs [14].

B. Environmental Analysis

There are a lot of environmental factors such as CO2 emissions, noise pollution, manufacturing wastes, row material extracting impact, leakage and old equipment replacement. In this thesis the focus will be on CO2 emissions during the life cycle of the solution and will be used as metric to compare it with other solutions.

For each solution based in the required equipment, CO2 emissions for the project period is calculated based on the equipment manual. The calculation computed by:

$$CO2\ emissions = D \times HiD \times 365\ days \times n \times CO2 \qquad (2)$$

- D is consumed liters of diesel in hour.
- HiD is hours in a day the diesel based equipment is used.
- n is the study period.
- CO2 is CO2 emissions per one liter of diesel.

C. Comparison metric

Since the energy output will be fixed to caver the telecom tower required load for all the solutions, we have two parameters for comparison: Present value cost and CO2 emissions, to have single metric to compare the systems a combined metric of energy and CO2 emissions applied, two options of comparison metric were applied:

1) Option 1

Unit of energy (UoE) where CO2 emission will be converted to cost using Social Cost of CO2 where The social cost of carbon dioxide (SC-CO2) measures the monetized value of the damages to society caused by an incremental metric tons of CO2 emissions [15] SC-CO2 estimate is $185(693.75 SAR) per ton of CO2 [15]and included in total cost then divided by total energy produced by the system to have single unit of energy contains how much unit of cost that include total system cost and CO2 emission cost, as shown below:

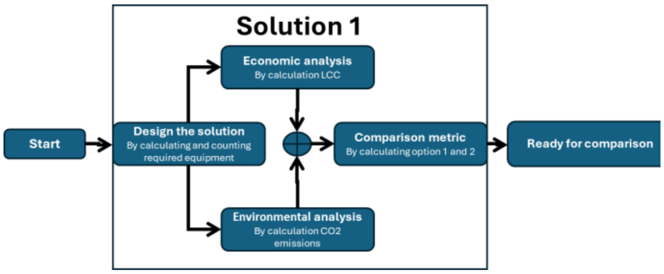
$$UoE = \frac{(CO2\ ton \times 693.75\ SAR) + LCC}{Energy\ Unit} \qquad (3)$$

2) Option 2

Cost-CO2 emissions magnitude, where total cost and total CO2 emissions will be represented in flat plane in x-axis and y-axis respectively, then by Pythagorean theorem the magnitude will be the used metric, as shown below:

$$\text{Magnitude} = \sqrt{(LCC)^2 + (CO2\ \text{emissions}\ )^2} \qquad (4)$$

In both options the more cost or environmental efficient the solution the lower the output is, the best solution will be the smallest number. Below block diagram summarize the applied methodology in each system:



IV. Factors and Assumptions

A. Load

Telecom load vary from 2 to 12 KW during the day [4] depending om maximum required load and the traffic of users using the same tower, in order to fix the required load the average (6 KW) is consider the maximum load that the solution needs to cover 24 hours, and other accessories such as air conditions, sensors, lights and sockets are estimated to be 2 KW which conclude the total required load is 8 KW.

B. Period

NEOM eventually will have permanent clean power source to cover the entire city, the estimate in this thesis that it will take 10 years till the permanent power source is implemented, therefore all the solutions will be measured economically and environmentally for 10 years.

C. NEOM Environment

Situated at the latitude of 29° N and longitude of 35° E, the location of NEOM is characterized by a high average level of solar irradiance, the highest daily irradiance value of 8.085 kWh/m2/d is collected in June. Whereas the least daily irradiance of 3.542 kWh/m2/d is received in December. the average daily horizontal solar radiation is around 5.85 kWh/m2 [16], therefore the radiation will be assumed to be 5.85 kWH/m2 and the optimal angle for the solar system is 29 degrees south. Sunshine duration throughout the year ranges from 9 to 11 h/day with few cloudy days [17].

D. Currency and discount rate

The used currency is Saudi Arabian Riyal (SAR) which is equivalent of 3.75 USD with discount rate if 4.20% as per Saudi Central Bank (SAMA) [18].

E. Installation, Operation and Fuel cost

For operational and maintenance, it will be assumed that telecom operator of the telecom tower will have fixed price contract regardless of the type of power source, therefore operational and maintenance cost will be neglected. For Installation, were assumed to be 20% of capex cost. For fuel price, in Saudi Arabia the price of Diesel is 1.15 SAR/liter or 0.3$/liter [19], it will be assumed fixed price the 10 years.

V. Solutions

will contain required equipment, fuel usage, cost, expected life cycle, CO2 emission and LCC analysis for each system, the baseline will be considered as the typical solution (Dual Diesel Generator), the result will be compared in comparison section.

A. Dual Diesel Generator (Typical solution):

Diesel generators were among the earliest technologies used as primary power supply solutions for telecom tower in areas with poor or no access to the main grid, The common failure figure that is often reported is 0.5%, or 5 out of 1000 start attempts fail. This is enough to put an extra set of diesel generators in place to increase reliability, particularly for applications where 100% reliability is needed [6]. Hence the dual diesel generator solution is the go-to solution, the system component are:

- 2 Desal Generators, for 8 KW applications the optimal sizing available is 11.8 KVA / 11.8 KW cost 31,100 SAR per generator [4] with life cycle of 8760 Hours, 2.7 kg CO2 emissions per liter [20]and 4.3 Liter of diesel per hour based on FG Wilson P11-6S generator data sheet [21].
- Automatic switching System (ATS), to insure 12-hour operation per generator every day and switching off in case of failure to the other generator or backup battery system, cost estimated as 10,000 SAR with life cycle of 10 years.
- Fuel Tank with capacity of 2,000 liter cost estimated as 8,000 SAR.
- Backup battery system, for 8 KW to insure 4-hour backup time for 48 – 54 DC volt system:

$$\frac{8{,}000\ W}{54\ v} \times 4h = 592.6Ah \approx 6\ string\ \times 100Ah \quad (5)$$

one string cost 13,263 SAR [22] with life cycle of 4 years.

- Cables, Circuit breakers and alarming system/sensors are neglected.

1) Cost Analysis

$$Gnerator\ cost = (2 \times 24{,}000) \times 1.20 = 57{,}600\ SAR\ every\ two\ year$$

$$Backup\ Battery\ cost = (6 \times 13{,}263) \times 1.20 = 95{,}439{,}6\ SAR\ every\ 4\ year$$

$$Deisel\ cost = \frac{4.3\ L}{h} \times 24h \times 365\ day \times 1.15\frac{SAR}{L} = 43{,}318.2\ SAR\ Every\ year$$

$$ATS\ cost = 10{,}000 \times 1.20 = 12{,}000\ SAR$$

$$Fuel\ Tank\ cost = 8{,}000 \times 1.20 = 9{,}600\ SAR$$

Year	Installed equipment	Annual cost SAR	Present Value SAR
0	ATS + Tank + Generator + Batteries + Fuel	235,051.80	235,051.80
1	Fuel	43,318.20	41,572.17
2	Generator + Fuel	117,958.20	108,640.74
3	Fuel	43,318.20	38,288.40
4	Generator + Batteries + Fuel	213,451.80	181,062.68
5	Fuel	43,318.20	35,264.02
6	Generator + Fuel	117,958.20	92,155.62
7	Fuel	43,318.20	32,478.53
8	Generator + Batteries + Fuel	213,451.80	153,588.28

9	Fuel	43,318.20	29,913.07
10	Fuel	43,318.20	28,707.36
LCC		976,722.66	

Table 1: Dual Diesel Generator (Typical solution) LCC

2) Environmental Analysis

$$Deisel\ Consumption = \frac{4.3\ L}{h} \times 24h \times 365\ day \times 10\ year = 376{,}680\ Liter$$

$$CO_2 emissions = 376{,}680\ \ Liter \times 2.7 \frac{Kg}{Liter} = 1{,}017{,}036\ Kg$$

B. Solar with Batteries:

In this system, a solar panel will be installed with a battery bank. It is known that solar panels cannot work for 24 hours continuously and can work only in sunlight for a maximum of 9-11 hours per day. Here, the energy required for the other 16 hours will be generated in the availability of sunlight and will be stored in the battery bank [8]. the system component are:

- Battery system, for 8KW to be powered for 15 hour a day and added to it 1 days to confirm sustainability with 54v , needed system is

$$\frac{8{,}000\ W}{54\ v} \times 39h = 4{,}296.3Ah \approx 22\ string\ \times 200Ah$$

one string cost 26,527.5 SAR [22].

- Solar panels, the requirement is to power the telecom tower and fully charge the battery system in 9 hours, requires load

$$8{,}000W + \frac{(22\ string \times 200Ah \times 54v)}{9} = 34{,}400W$$

with efficiency of 20% of converting solar radiation to energy, single panel output vary between 150 to 400 W therefore used panel is 300 W and 12 v which means every 4 panels will be in series, required number of panels

$$\frac{34{,}400W}{300W} = 114{,}67 \approx 116$$

panels with life cycle of 25 years and 967.5 SAR per panel [22].

- Automatic switching System (ATS), to insure switching to battery system in case of voltage drop which indicate low solar radiation due to nighttime, cloudy day or fault in the system, cost estimated as 10,000 SAR with life cycle of 10 years.
- Voltage regulator, cables, circuit breakers and other accessories are neglected.

1) Cost Analysis

$$Battery\ system\ cost = (22 \times 26{,}257.5) \times 1.20 = 693{,}198\ SAR\ every\ 3\ year$$

$$Solar\ panels\ cost = (116 \times 967.5) \times 1.20 = 134{,}676\ SAR$$

$$ATS\ cost = 10{,}000 \times 1.20 = 12{,}000\ SAR$$

Year	Installed equipment	Annual cost SAR	Present Value SAR
0	Batteries + Panels + ATS	839,874.00	839,874.00
1		0.00	0.00
2		0.00	0.00
3	Batteries	693,198.00	612,708.84
4		0.00	0.00
5		0.00	0.00
6	Batteries	693,198.00	541,565.50
7		0.00	0.00
8		0.00	0.00
9	Batteries	693,198.00	478,682.81
10		0.00	0.00
LCC			2,472,831.14

Table 2: Solar with Batteries LCC

2) Environmental Analysis

This system is CO2 free emission.

C. Solar with Diesel Generator

This system is similar to the above system and there is only one difference as compared to the above i.e. a diesel generator. In this case, it has been assumed that there may be a case of any emergency such as low sunlight, clouded weather, and other similar cases, the diesel generator will provide the power and it will work for an average of 4 hours per day [8]. the system component are:

- Battery system, for 8KW to be powered for 11 hour a day with 54v , needed system is

$$\frac{8{,}000\ W}{54\ v} \times 11h = 1{,}629.63Ah \approx 9\ string\ \times 200Ah$$

one string cost 26,527.5 SAR [22].

- Solar panels, the requirement is to power the telecom tower and fully charge the battery system in 9 hours, requires load

$$8{,}000W + \frac{(9\ string \times 200Ah \times 54v)}{9h} = 18{,}800W$$

with efficiency of 20% of converting solar radiation to energy, single panel output vary between 150 to 400 W therefore used panel is 300 W and 12 v which means every 4 panels will be in series, required number of panels

$$\frac{18{,}800W}{300W} = 62.67 \approx 64$$

panels with life cycle of 25 years and 967.5 SAR per panel [22].

- Desal Generators, required load is

$$8{,}000W + \frac{9\ string \times 200Ah \times 54v}{4h} = 32{,}300W$$

the optimal sizing available is 30KVA / 24 KW cost 70,900 SAR per generator [4]with life cycle of 8760 Hours, 2.7 kg

CO2 emissions per liter [20]and 6.9 Liter of diesel per hour based on FG Wilson P33-3U generator data sheet [21].

- Automatic switching System (ATS), to insure 12-hour operation per generator every day and switching off in case of failure to the other generator or backup battery system, cost estimated as 10,000 SAR with life cycle of 10 years.
- Fuel Tank with capacity of 2,000 liter cost estimated as 8,000 SAR.
- Voltage regulator, cables, circuit breakers and other accessories are neglected.

1) Cost Analysis

$$Battery\ system\ cost = (9 \times 26{,}257.5) \times 1.20 = 283{,}575.6\ SAR\ every\ 4\ year$$

$$Solar\ panels\ cost = (64 \times 967.5) \times 1.20 = 74{,}304\ SAR$$

$$Gnerator\ cost = 70{,}900 \times 1.20 = 85{,}080 SAR\ every\ 4\ year$$

$$Deisel\ cost = \frac{6.9\ L}{h} \times 4h \times 365\ day \times 1.15 \frac{SAR}{L} = 11{,}585.1\ SAR\ Every\ year$$

$$ATS\ cost = 10{,}000 \times 1.20 = 12{,}000\ SAR$$

$$Fuel\ Tank\ cost = 8{,}000 \times 1.20 = 9{,}600\ SAR$$

Year	Installed equipment	Annual cost SAR	Present Value SAR
0	Batteries + Panels + ATS + Generator + Tank + Fuel	476,150.10	476,150.10
1	Fuel	11,585.10	11,118.14
2	Fuel	11,585.10	10,670.00
3	Fuel	11,585.10	10,239.92
4	Batteries + Generator + Fuel	380,246.10	322,547.66
5	Fuel	11,585.10	9,431.07
6	Fuel	11,585.10	9,050.94
7	Fuel	11,585.10	8,686.12
8	Batteries + Generator + Fuel	380,246.10	273,604.36
9	Fuel	11,585.10	8,000.01
10	Fuel	11,585.10	7,677.55
LCC			1,147,175.86

Table 3: Solar with Diesel Generator LCC

2) Environmental Analysis

$$Deisel\ Consumption = \frac{6.9L}{h} \times 4h \times 365\ day \times 10\ year = 100{,}740\ Liter$$

$$CO_2 emissions = 42{,}340\ Liter \times 2.7 \frac{Kg}{Liter} = 271{,}998\ Kg$$

D. Diesel Generator with batteries

This system is similar to the solar system but single diesel generator replacing the solar panels. In this case the diesel generator will provide the power for an average of 12 hours per day. the system component are:

- Battery system, for 8KW to be powered for 12 hour a day with 54v , needed system is

$$\frac{8{,}000\ W}{54\ v} \times 12h = 1{,}777.78Ah \approx 9\ string\ \times 200Ah$$

one string cost 26,527.5 SAR [22].

- Desal Generators, required load is

$$8{,}000W + \frac{9\ string \times 200Ah \times 54v}{12h} = 16{,}100W$$

the optimal sizing available is 17.5KVA / 17.5 KW cost 47,730 SAR per generator [4]with life cycle of 8760 Hours, 2.7 kg CO2 emissions per liter [20] and 4.9 Liter of diesel per hour based on FG Wilson P16.5-6S generator data sheet [21].

- Automatic switching System (ATS), to insure 12-hour operation per generator every day and switching off in case of failure to the other generator or backup battery system, cost estimated as 10,000 SAR with life cycle of 10 years.
- Fuel Tank with capacity of 2,000 liter cost estimated as 8,000 SAR.
- Cables, Circuit breakers and alarming system/sensors are neglected.

1) Cost Analysis

$$Battery\ system\ cost = (9 \times 26{,}257.5) \times 1.20 = 283{,}581\ SAR\ every\ 4\ year$$

$$Gnerator\ cost = 47{,}730 \times 1.20 = 57{,}276\ SAR\ every\ 4\ year$$

$$Deisel\ cost = \frac{4.9\ L}{h} \times 12h \times 365\ day \times 1.15 \frac{SAR}{L} = 24{,}681.3\ SAR\ Every\ year$$

$$ATS\ cost = 10{,}000 \times 1.20 = 12{,}000\ SAR$$

$$Fuel\ Tank\ cost = 8{,}000 \times 1.20 = 9{,}600\ SAR$$

Year	Installed equipment	Annual cost SAR	Present Value SAR
0	Batteries + ATS + Generator + Tank + Fuel	527,290.20	527,290.20
1	Fuel	58,429.20	56,074.09
2	Fuel	58,429.20	53,813.90
3	Fuel	58,429.20	51,644.82
4	Batteries + Generator + Fuel	505,690.20	428,956.90
5	Fuel	58,429.20	47,565.42
6	Fuel	58,429.20	45,648.20
7	Fuel	58,429.20	43,808.25
8	Batteries + Generator + Fuel	505,690.20	363,867.10
9	Fuel	58,429.20	40,347.86

10	Fuel	58,429.20	38,721.55
LCC		1,697,738.29	

Table 4: Diesel Generator with batteries LCC

2) *Environmental Analysis*

$$Deisel\ Consumption = \frac{4.9\ L}{h} \times 12h \times 365\ day \times 10\ year = 214{,}620\ Liter$$

$$CO_2 emissions = 214{,}620 Liter \times 2.7 \frac{Kg}{Liter} = 579{,}474\ Kg$$

VI. COMPARISONS

New the full picture is clear in terms of LCC SAR and CO2 emissions for each solution, below table contains a summary with percentage of the difference between the solution with typical solution:

Solution	LCC (SAR)	CO2 emissions (Ton)
Dual Diesel Generator (Typical solution)	976,722.66	1,017.04
Solar with Batteries	2,472,831.14	0.00
Solar with Diesel Generator	1,147,175.86	272.00
Diesel Generator with batteries	1,119,744.97	579.47

Table 5: Combined result of LCC and CO2 emissions

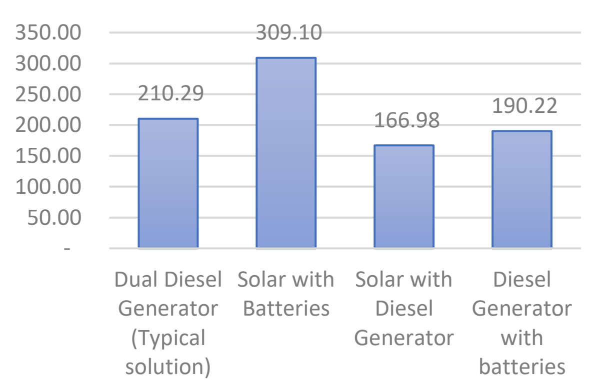
A. *Unit of energy metric UeE*

Using CO2 Social cost to combined CO2 emissions with LCC and comparing the systems, below used function:

$$Unit\ of\ energy\ metric = \frac{(CO2\ ton \times 693.75\ SAR) + LCC}{Wh}$$

Applying the role above gave the below result (SAR/W):

Figure 1: Unit of energy metric



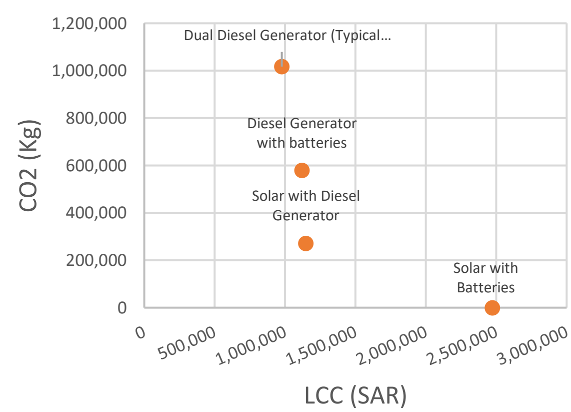
B. *Cost-CO2 emissions magnitude*

Cost-CO2 emissions magnitude, where total cost and total CO2 emissions will be represented in flat plane in x-axis and y-axis respectively, then by Pythagorean theorem the magnitude will be the used metric, as shown below:

$$\text{Magnitude} = \sqrt{(LCC)^2 + (CO2\ Kg)^2}$$

Below figure represents Cost-CO2 emissions magnitude:

Figure 2: LCC and CO2 emmsion plane



SOLUTION	COST-CO2 EMISSIONS MAGNITUDE / MILLION
DUAL DIESEL GENERATOR (TYPICAL SOLUTION)	1.41
SOLAR WITH BATTERIES	2.47
SOLAR WITH DIESEL GENERATOR	1.18
DIESEL GENERATOR WITH BATTERIES	1.26

Table 6: Cost-CO2 emissions magnitude result

Based on previous analysis, one dimensional comparison will favor the extreme solution, in telecom tower scenario if the comparison by price the conclusion based on Life Cycle Cost analysis typical solution is superior and in CO2 emissions analysis Solar system is superior but combining the two, the result was hybrid solution such as solar with generator is the best feasible solution because the used metrics shows solar with generator gives 166.98 SAR/W which is 21% less than typical solution and Generator with Batteries 190.22 SAR/W which is 10% less than typical solution but Solar only gives 309.10 SAR/W 47% more then typical solution (210.9 SAR/W), similar result were found using LCC-CO2 emissions as XY plan were best solution were Solar with Generator resulting in 16% less than typical solution and in second place Generator with batteries resulting in 11% less than typical solution and solar only gives 75% increase compared to typical solution.

VII. CONCLUSION

Since the early 2000s telecom tower coverage is essential and getting more critical with the technology advancement and the case of electrifying the rural areas with no feasible grid connection, telecom tower become the source of CO2 emissions emitted by telecom providers, therefore the telecom industry is trying to contribute to reduce the environmental harem and continue expanding as business requirement.

In NEOM case, an ambitious mega project to construct a modern city with zero CO2 emissions, telecom towers must be built there to cover the required telecom demand for the construction period, the challenge is there is no grid connection, and the stand-alone power source must cover the telecom tower demand with sustainable and clean as possible energy till the clean governmental or simi governmental grid connection bult.

In this paper, a comparison between four possible solutions been done, the approach was first to find Life Cycle Cost for 10 years for each system and second to find total CO2 emissions for 10 years for each system then to find a metric to combined cost of the solution with CO2 emissions, two metric been calculated and both shows the same result, the first one was to convert CO2 emissions to Saudi Arabian Riyal (SAR) and adding it on top of Life Cycle Cost of each system, the second metric was to combined Life Cycle Cost and CO2 emissions in XY plane and calculate the magnitude of the resulted victor.

The result of one dimensional comparison such as LCC was in favor of Dual Diesel Generator (Typical solution) and in terms of CO2 emissions the Solar with Batteries was CO2 free, but combining the two the result was in favor of hybrid solutions were solar with generator gives 166.98 SAR/W which is 21% less than typical solution in first metric and 16% less than typical solution in second metric, in the second place Generator with Batteries 190.22 SAR/W which is 10% less than typical solution in first metric and 11% less than typical solution in second metric, standalone solar with batteries were the worst solution due to over design to insure sustainability.

In conclusion, Hybrid solutions is the best feasible solution for temporary standalone power source for telecom tower in terms of techno, economic and environment efficiency, the recommendation is to expand on configurations of hybridization to get the optimal configuration and to compare the long term effects of it compared to typical cost efficient solution or extreme clean energy solutions.

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