Journal of Energy Research and Reviews

Volume 13, Issue 4, Page 9-30, 2023; Article no.JENRR.97687
ISSN: 2581-8368

Techno-Economic Studies of Integration of Solar PV Technology in Telecommunications Sector for Sustainable Development: A Case Study of Budiriro

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Authors' contributions

This work was carried out in collaboration between both authors. Author MM wrote, reviewed and edited the manuscript. Author KTM wrote and reviewed the manuscript. Authors MM and KTM managed the data analysis. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2023/v13i4268

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97687

Original Research Article

Received: 01/02/2023
Accepted: 02/04/2023
Published: 08/04/2023

ABSTRACT

The telecommunications industry in Zimbabwe keeps growing with an increase in the number of users year by year. The demand on the national grid and low power supply means long hours of electricity outages, which prompts Internet Service Providers (ISPs) to use generators as backup power to keep base stations online for uninterrupted provision of internet to consumers. Generator systems increase the operation expenditure (OPEX) of running base stations, produce GHG emissions and in tern attract an additional cost of emission. This causes an increase in the cost of running the business and consequently internet data prices. A case study was conducted in Budiriro. A framework was developed which analysed six combinations (Grid + Generator, Generator only, Generator + Solar, Solar only, Grid + Solar, and Grid only) of power sources based

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on sustainability pillars; Economical, Environmental, and Social, as well as Technical. The six alternatives were simulated in HOMER Pro, a system that evaluates designs for both off-grid and grid-connected power systems, to determine the output (power output, investments, costs, and emissions) of these individual systems. Using a sub-criterion of 15 pairwise combinations, the Analytic Hierarchy Process (AHP) was used to rank these systems, and the best solution was chosen based on the main criteria of the sustainability pillars. The result shows that Grid + Solar PV system provides the best optimal alternative power system to power base stations for the study area, substituting Grid + Generator systems (Existing system). It reduces OPEX by over 1,000 percent offering 37 percent more power and 41.13 tonnes of GHG emissions avoided per year. Socially, power sharing between households and base stations as well as reduction of air and noise pollution. The optimal alternative power source for the base station proposed here in this study will help reduce greenhouse gas emissions, and dependence on grid and operation costs which in turn will reduce data prices, increase internet accessibility at affordable rates and provide a sustainable future for telecommunications businesses in Budiriro.

Keywords: Solar PV; telecommunications industry; sustainability; Budiriro.

1. INTRODUCTION

Telecommunication towers are structures built to carry antennae and auxiliary equipment necessary for mobile network and internet connectivity [1].

A huge number of telecommunication base stations have been erected over the years to be particularly powered by the Zimbabwe national electricity grid. The demand for electricity in other sectors and lack of supply meant these towers needed alternative sources during load shedding, which the industry resorted to the use of fossil fuel. The reason to settle for such a resolution is to keep systems online for consistent internet supply, failure of which can be catastrophic. This is given by an instance when the whole country lost its internet connection for three days, business slowed drastically and the outage cost the country around $17 million [2]. The telecommunications industry has been one of the leading industries in Zimbabwe. However, internet data prices have been increasing at an alarming rate over the last five years which has raised a huge concern to the general public who are barely making a living. Internet Service providers (ISPs) attribute the overall price instability to soaring fuel prices, grid power price increases as well as huge operating costs of alternative power.

Moreover, these operating costs will continue to surge. The telecommunications industry as we know it continues to develop each year. According to [3], approximately 3 percent or 600 TWh of worldwide electrical energy is consumed by telecommunications industries. With the advent of 5G, Fierce Wireless [4] suggests that telecommunications companies expect their operating costs to increase by 5 percent of their 4G counterpart.

To increase internet accessibility in Zimbabwe, there is a need to put an end to the data price inflation by designing alternative energy supply to the base stations that eliminate high OPEX associated with generators which typically increase by 35 percent the total operating cost of a wireless base station (BTS), including skyrocketing fuel and expensive on-site maintenance costs [5]. A huge portion of the energy used by telecommunications companies goes to base stations [6]. Power contributes a quarter of total network costs [7].

According to GSMA, [8] over half of the World's population now have access to the internet. As per the same report, low- and middle-income countries (LMICs) account for 93 percent of the world's population without access to the internet. The main reason is affordability. Reduction of cost as proposed by available research on the deployment of solar will only ensure a decrease in data price costs and a steady increase in internet usage. According to Alsharif [9] case study, Solar PV reduced the OPEX of a telecommunications tower by 84.67 percent. Hence there is potential to pose a significant change in Zimbabwe's local telecommunications industry. Inherently, internet usage simultaneously grows with the population which Zimbabwe is expected to double in a couple of decades.

This paper is focused on identifying, analysing, and proposing energy sources consisting of Solar PV technologies and therefore choosing an optimal alternative source to power base stations to reduce operating costs for ISPs. This will drive data price stabilisation to make the internet which WHO [10], declared as an enabler of the enjoyment of basic human rights, accessible. As well, eradicating the burning of fossil fuels is a big step towards achieving net zero [11]."Global telecommunications network providers are expected to install nearly 121.9 GW of cumulative new distributed renewable energy generation technologies and distributed energy storage systems capacity between 2021 and 2030," [12]. This research will offer significant help to ISPs for such prospects.

By analysing the literature in the area of study, feasibility of deploying solar PV was determined. The methodology looked at six approaches analysed by HOMER Pro through sustainability pillars economic, environmental, social and as well technical capability. The results were then ranked through an AHP of 15 criteria. The results then compare the existing system to the optimal system selected through sustainability performance from the above methodology.

2. Literature Review

According to a dashboard by [13], Zimbabwe has a huge number of off-grid and bad-grid towers powered by diesel. This proportion is 90 percent higher than the regional average of Eastern Africa. However, the country has a policy that gives incentives for off-grid and bad-grids that include finance for solar, PAYG solar, and CAPEX/OPEX subsidy. This gives a great opportunity for ISPs to deploy solar without extra cost on CAPEX.

Essentially, the existing system to power base stations make use of power from two sources namely, grid electricity and backup generators. This backup in some cases both in the study area and some outskirts (beyond the scope of this study) work as the main source of energy during grid outages or as the sole source of power in off-grid base stations.

2.1 Zimbabwe Internet Users

Available data from [14] over the last ten years show an uptrend in the number of internet users. This is shown in Fig. 1. As the internet's importance keeps growing, the projection could mean more and more users of the internet; If over the past years, there were around 25 percent increase, there is a possibility that in the next ten years, there will be probably double the number of internet users. This can only mean an increase in the number of telecommunication towers to cater for the always-rising demand for the internet. This means an increase in the demand for energy from the telecommunications industry. If the existing models continue, the data prices will keep rising as more demand for fuel rises, with prices soaring high to less supply worldwide. Green energy deployment will be the best model to bank on to cater for the exponential growth of internet usage in the coming years.

2.2 Zimbabwe Projected Population

The following data from [15] show a linear increase in the projected population, Fig. 2, which is important in the analysis of existing telecommunication models. This data add justification for the deployment of green energy as internet data will continuously increase. Estimates also show that 63 percent of the total population is aged 13 and above, which is mainly the number of people with potential mobile phones and internet connectivity.

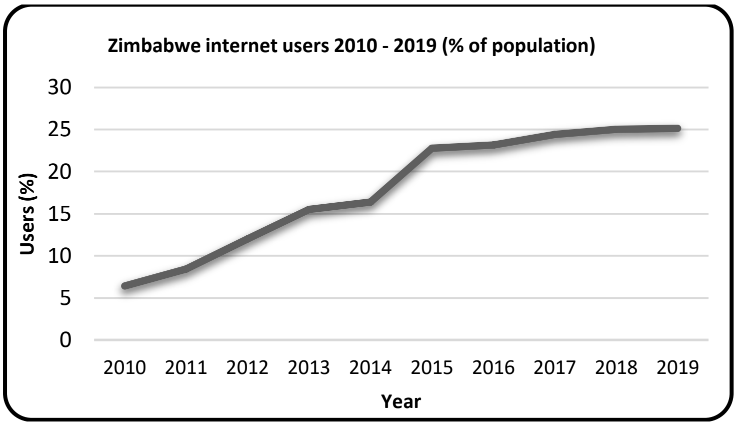

Fig. 1. Zimbabwe internet usage 2010 - 2019

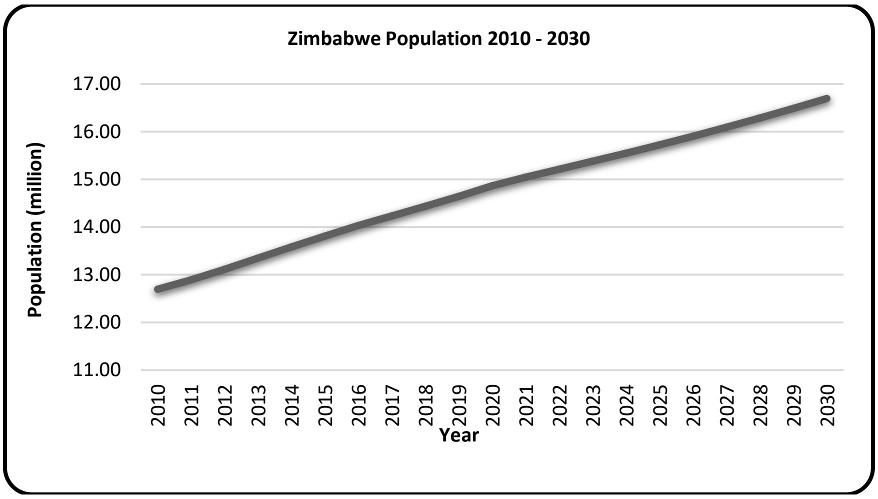

Fig. 2. Zimbabwe population projection

2.3 Zimbabwe Electricity Consumption

As seen in Fig. 3 [16], there is an upward trend establishing. This means that backed by data in Fig 2, there is going to be more demand for energy in the future. More energy demand and little supply will incessantly shoot the energy prices even higher, and the effects will continuously reflect on the data prices. Deploying solar PV to the telecommunication industry will help shun the constant internet data hike.

2.4 Zimbabwe Electricity Generation

Total electricity generated in all the years since 2001 is displayed in Fig. 4 according to [17]. The data shows that there is no consistency in electricity generation. For over thirty years, the country had never surpassed 10 billion kWh mark until 2019. There is almost a high likelihood that the fluctuations will continue while simultaneously, population, demand and consumption keep rising.

2.5 Zimbabwe Fuel Prices

A fuel increase over the years explains the data price hikes as well as project the possibility of extension. The world markets do not show any decrease of fuel in the future. As shown in Fig. 5 [18] and [19], the surge in 2022 prices show how unsustainable it is to be dependent on fossils especially fuel that is imported.

2.6 Zimbabwe Lithium Potential

Zimbabwe is one of the top ten producers of lithium [20]. Zimbabwe holds a significant percentage (1.0 % | 220,000 tonnes) of Lithium reserve in the whole world as shown in Fig. 6. There is ahuge potential for Zimbabwe to integrate renewable energy intelecommunications and other sectors as well. This is because one of the important components for the development of battery energy storage systems is abundantly available.

2.7 Harare – Zimbabwe Monthly PV Data

Renewable energy is energy from a source that naturally replenish within the human timescale. The sun which all renewable energies are dependent on, is a source of energy that does not deplete. This source is abundant in Zimbabwe (5.7 kWh/m2 per day) as show in Fig. 7 by [21]. Further, the idea employed in this research is to make sure the ISPs themselves own and maintain their own renewable energy supply systems unlike paying external suppliers.

Harare, the city in which the study area, Budiriro is located – monthly PV performance data given in Fig. 7.

2.8 Cost Comparison for Running a Generator/Solar PV

Data by [22] gives a comparison of maintenance of diesel fuel generators to that of Solar PV. As shown in Fig. 8, costs saved with solar after 25 years amount to $ 190,019.00.

2.9 Batteries

Because of fluctuations in most renewable energy sources like solar, the storage of the harnessed energy for later use imperative. This allows these energy mixes to balance their supply and demand. Whether from re-appropriation of car batteries or specifically producing battery energy storage systems like stationery energy storage infrastructure.

A Battery Energy Storage System (BESS) is a technology developed for storing electric charge through the manufacture of batteries, or used appropriated lithium-ion electric vehicle batteries [23].

When selecting batteries for Solar Systems, the run time is more important than instantaneous power bursts, hence usage of batteries with higher energy density is advantages. The reasoning being that, PV systems with higher energy density can be less costly mainly during transportation. The energy density is a function of the weight of the battery, and the volumetric energy density (in Whr/litre3) is a function of volume of battery. A battery with a higher energy density will be lighter than a similar capacity battery with a lower energy density [24].

There are quite a number of batteries with distinctions in materials from which the anode and cathode are made and the type of electrolyte. The most common types of solar batteries are categorised into lead-acid batteries and lithium batteries.Fig. 9 shows the breakdown of batteries [25].

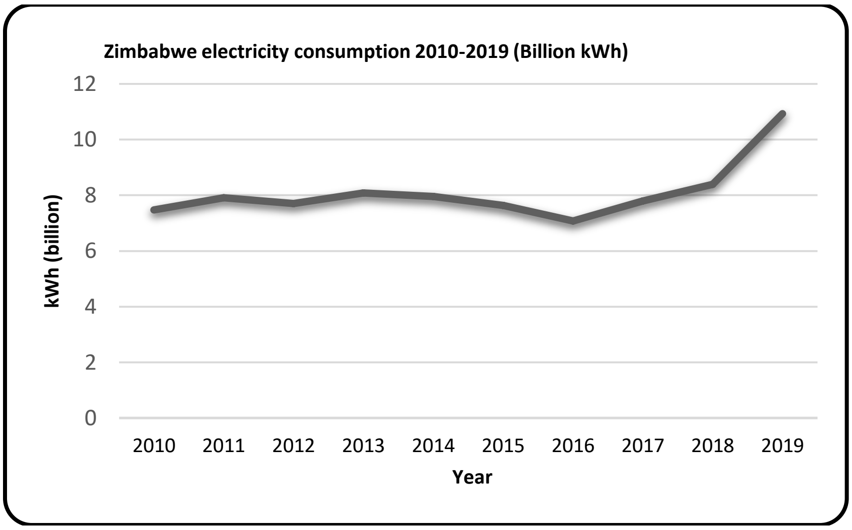

Fig. 3. Zimbabwe electricity consumption 2010 - 2019

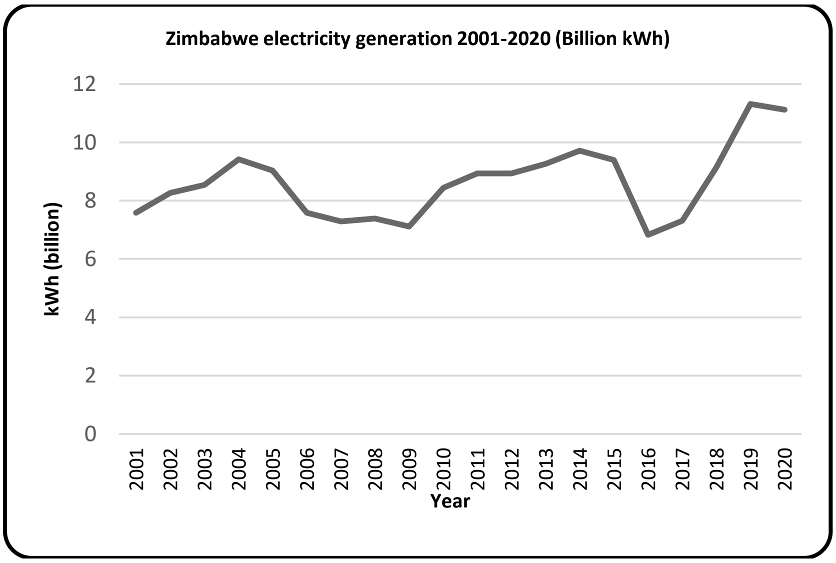

Fig. 4. Zimbabwe electricity generation 2001 - 2020

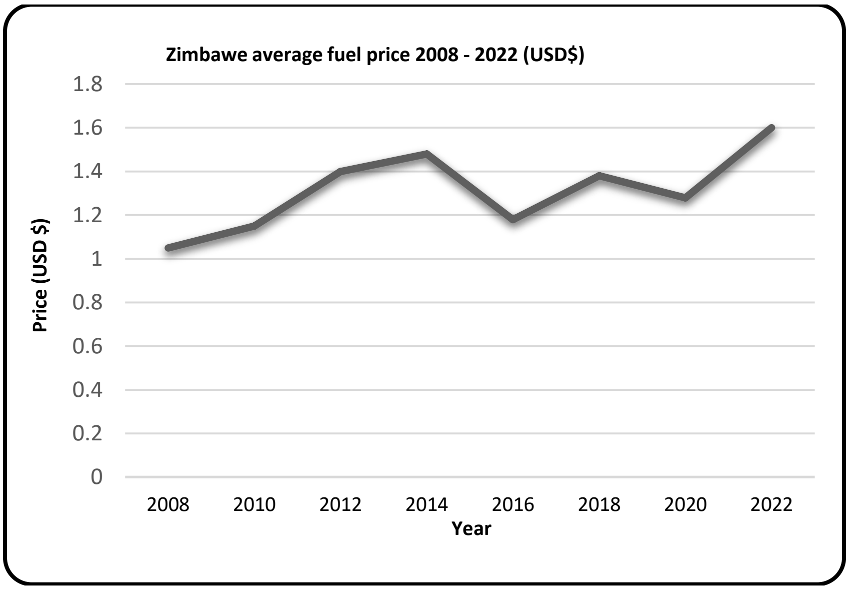

Fig. 5. Zimbabwe average fuel price 2008 - 2022 (USD$)

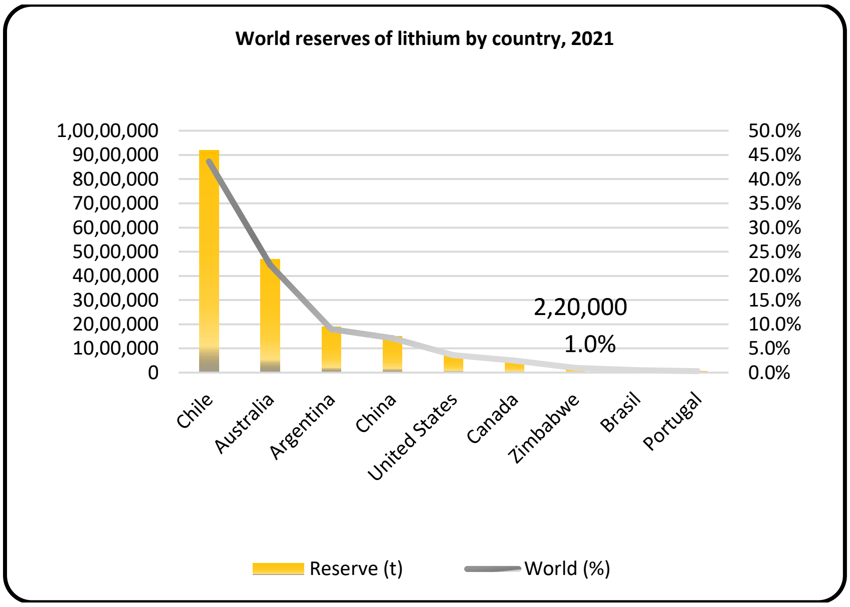

Fig. 6. World reserves of lithium by country, 2021

Further comparisons are made in Fig. 10 of the two leading battery types used for Solar Systems. The comparison uses, Depth of Discharge (DOD) – The, Round Trip – Percentage of energy that can be used to that it took to fully charge the battery, Maintenance – Cost and routines to keep the battery up, Battery life – Time before a need to replace the battery completely, Charge Cycles – Number of times a battery can go from full charged to discharged in its lifecycle, Capacity – Amount of charge that can be hold after charge, and Size per kWh – The weigh per kWh of batteries, for ease of transportation and storage [26-28].

This research focused on Lithium batteries. This is because of the resource availability as discussed in II. - G, a resource that is readily available in Zimbabwe. This makes the deployment of solar more favourable because;

1. Lithium is becoming the preferred choice for batteries is green solutions.
2. Zimbabwe is one of the big producers of lithium, this will reduce production cost of

batteries, Solar PV installations as well as future maintenance – sustainability.

3. The peak sun hours in Zimbabwe average 5 hours a day. Having lithium batteries means the system can be fully charged in a small period of time within the peak sun hours.

2.10 Simulation – HOMER Pro

HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a design, simulation and optimisation software for building cost effective hybrid microgrid and grid-connected systems that combine traditionally generated, renewable power as, storage, and load management [29].

In simulation, HOMER Pro creates from input parameters, viable systems for all possible combinations of energy sources in a design. A number of systems in some cases even hundreds or thousands can be simulated all of which on the basis of required system capacity.

In optimisation, HOMER Pro closely examines the system combinations and sort systems according to the designer's preferred variable. It can optimise for example for the lowest net present cost if that is the designer's main target. The software's interface is shown in Fig. 11.

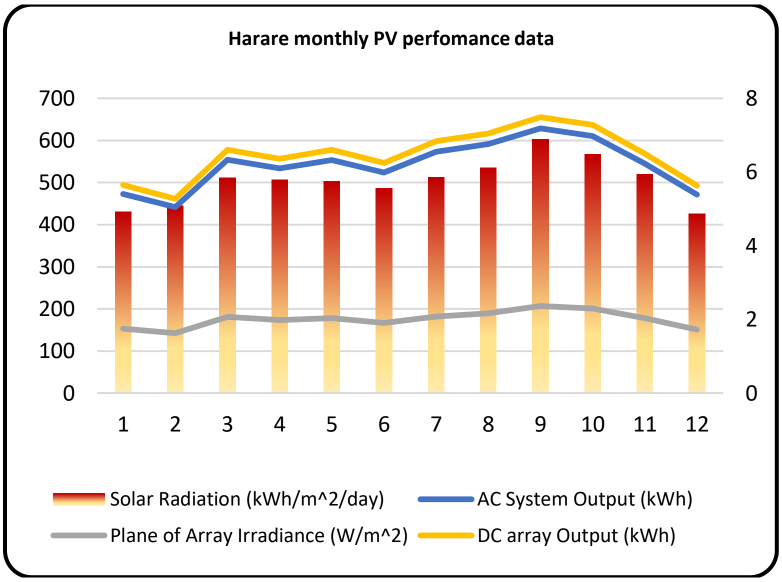

Fig. 7. Harare monthly PV performance data

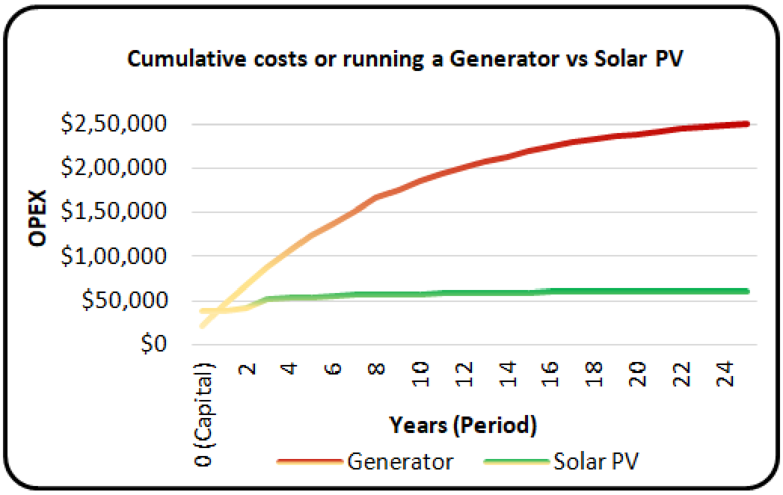

Fig. 8. Cumulative cost or running a generator vs solar PV

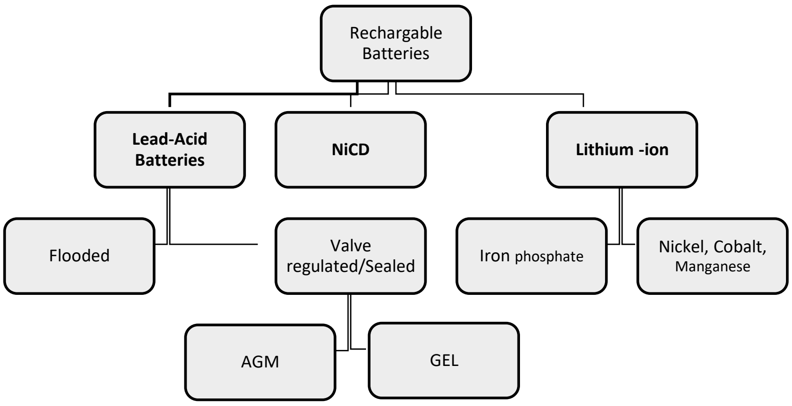

Fig. 9. Types of batteries

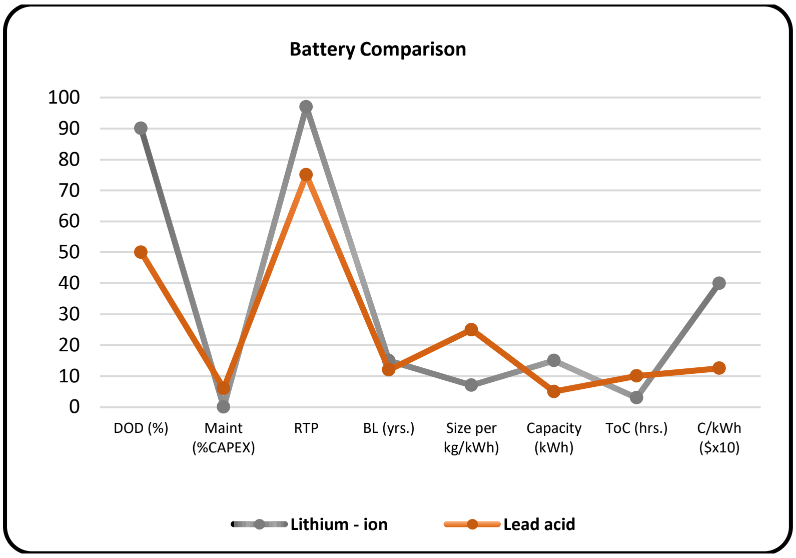

Fig. 10. Battery comparison

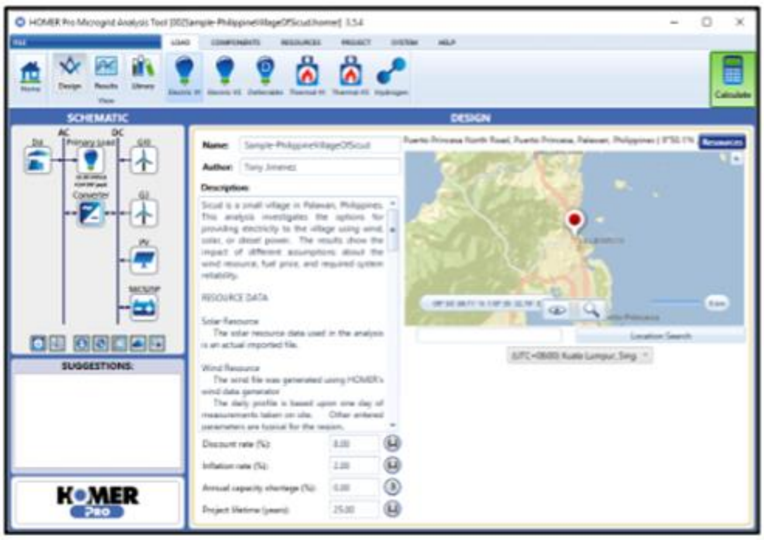

Fig. 11. HOMER Pro interface

3. METHODOLOGY

For the framework to be applicable elsewhere, there is need to assess from a cost perspective the economic feasibility of different approaches that can be applied in the study area through their availability. The process is shown in Fig. 12.

3.1 Scenarios for Integration

The integration of Solar PV on the existing Telecommunication Towers can be approached in three different ways i.e., Base stations built on/near residential houses, Base Stations built near Clinics, Shop, Municipality, Communities and beyond the scope of this research, Base stations built in isolated areas.

3.1.1 Scenario 1 – base stations built on/near residential houses

These base stations built on pockets or spaces intentionally left by municipality or next to households or on the households' land through agreement, Fig. 13.

The benefits that can be realized from this is the fact that households that agree to install the Solar PVs on their roof will share the Power with the telecommunication companies.

They will absolutely pay nothing since the maintenance will be done by these telecommunication companies.

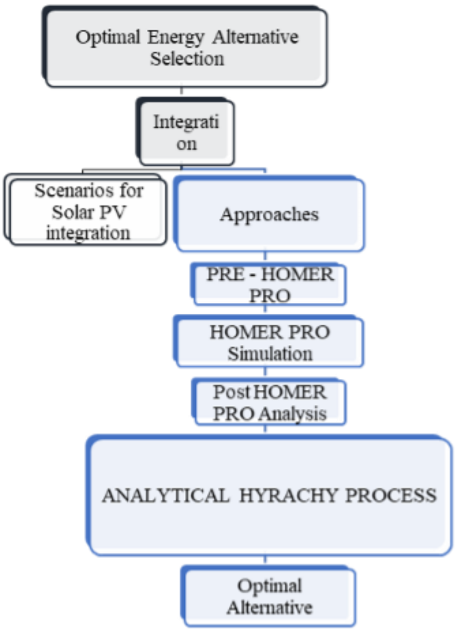

Fig. 12. The research framework

Fig. 13. Telecommunication towers built near houses

3.1.2 Scenario 2 – base stations built near clinics, shops, municipal centres

Base Stations that are built closer to municipal premises like offices, solar powered boreholes as seen inFig. 14, and community halls. These have easy integration since there is a lot of free unutilized area of space both on empty roofs and ground. Solar panels enough to power the community hall and the telecommunication towers can be installed.

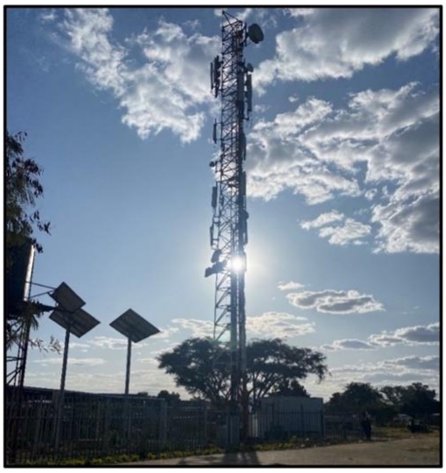

Fig. 14. Telecommunication towers built near municipal facilities

3.2 Approaches for Solar Integration

There are a few combinations of approaches that can be used for the integration of solar for the provision of power into the existing base stations. For a broader perspective, there is also need to analyse how the systems without Solar PV preform as well as their environmental impacts so as to prove the importance of Solar PV deployment in this industry. The different energy systems (approaches) considered are; Existing system (Grid + Generators), Generators only, Generators + Solar PV, Solar PV only, Solar PV + Grid and Grid only.

In the aforementioned approaches, the system setup will consist of power supply (either Solar PV with panels with backup storage in form of batteries/ Diesel gensets/Grid/), charge controllers, inverters, and the load (telecommunication tower).

3.2.1 Approach 0 (A0) – grid + generator (existing system)

The existing system has base stations powered with the Grid (National Grid – Hydro Power + Thermal Power) as the main power source and backup generators that kick in during grid outages. A maximum of 40 percent grid availability per day and the rest will be powered by the generator. A 25-kW generator is used in the study with fuel price set at the existing average at USD $1.74 per litre at the time of simulation, with grid unit power at 0.11 per kWh [19]. GHG emission are calculated based on operation time and percentage efficiency of generators taken to be 25 percent. The system used a maximum of 40 percent of thermal power portion for electricity [34]. This was used to calculate the GHG emission by the grid.The system configuration is shown in Fig. 15.

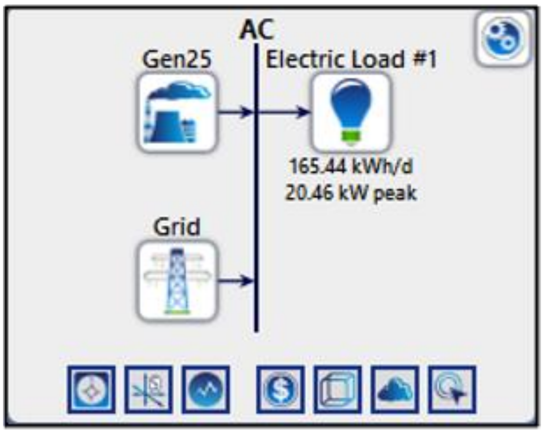

Fig. 15. Grid + Generator (Existing System)

3.2.2 Approach 1 (A1) – generator only

Grid availability is zero and 100 percent generator. A 25-kW generator is used in the study with fuel price set at the existing average at USD $1.74 per litre at the time of simulation [19]. GHG emission are calculated based on operation time and percentage efficiency of generators taken to be 25 percent.

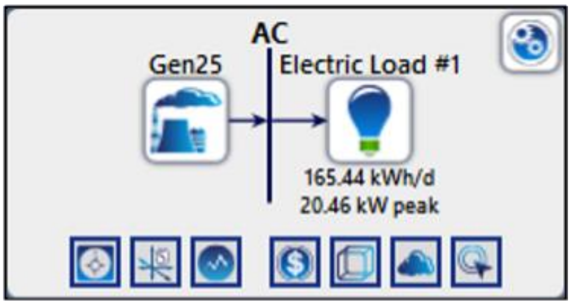

Fig. 16. Generator only

3.2.3 Approach 2 (A2) – generator + solar PV

This approach makes use of Solar PV with generators as backup, Fig. 17. Availability of 60 percent generator and 40 percent availability for Solar PV was used. A 25-kW generator is used in the study with fuel price set at the existing average at USD $1.74 per litre at the time of simulation [19].

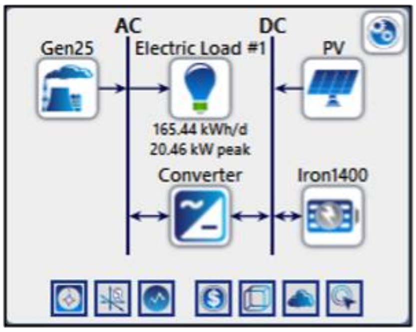

Fig. 17. Generator + solar PV

3.2.4 Approach 3 (A3) – solar PV only

In this approach, Fig. 18, the base stations go totally off-grid aThis system uses 100 percent of Solar PV power. The system size for the Solar PV and battery bank are in Section 3.3.2 andSection 3.3.3.

3.2.5 Approach 4 (A4) – grid + solar PV

In this approach, Fig. 19, Solar PV substitute generators. This essentially means that, solar PV will work during grid power outages as well as during peak hours when power is expensive. The average sun hours in the area are five hours [21], hence the need for a complementary battery pack to increase the reliability of the system during night hours and cloudy days. The input data gave a maximum of 40 percent grid availability per day and the rest will be powered by the Solar PV. The system size for the Solar PV and battery bank sizes are given in 3.3.2 and 3.3.3 respectively, with grid unit power at 0.11 per kWh [19]. The system used a maximum of 40 percent of thermal power portion for electricity [34]. This was used to calculate the GHG emission by the grid.

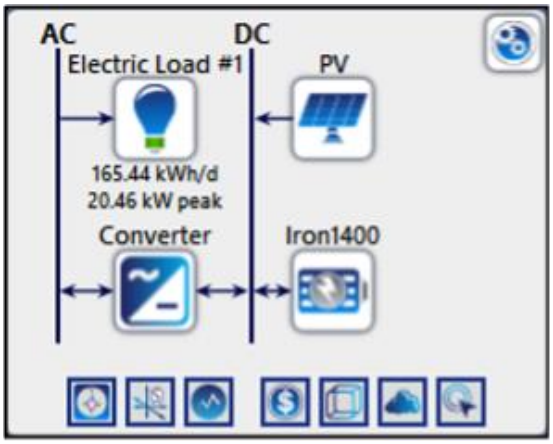

Fig. 18. Solar PV only

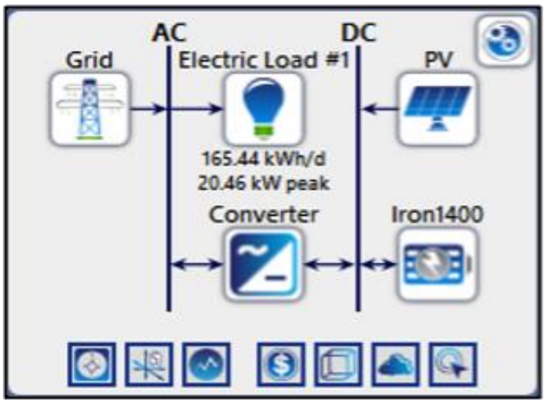

Fig. 19. Grid + solar PV

3.2.6 Approach 5 (A5) – grid only

The grid, if available would provide a 100 percent of the power with grid unit power at 0.11 per kWh [19]. The system used a maximum of 40 percent of thermal power portion for electricity [34].The system is shown in Fig. 20.

3.3 Pre HOMER-Pro Simulation

Before simulation of the proposed approaches, there is base data that needed to be provided for input in the simulation software. This data includes, generator size, grid power provided, PV system size and the battery. A weighting is put on the input parameters based on monthly usage, grid availability and system operation hours.

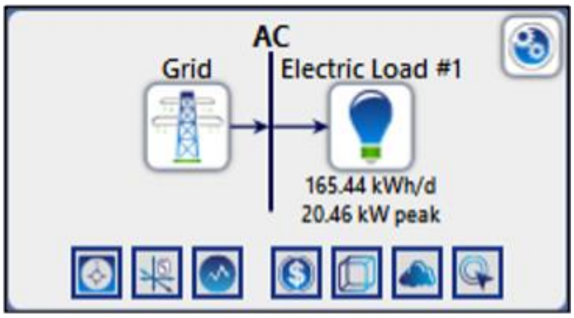

Fig. 20. Grid only

3.3.1 Solar PV system sizing

3.3.1.1 Calculating daily energy use

Energy daily use is approximated from data collected. The data collected has a weekly use of approximately 1,000 kWh per month per base station.

$$Dailyenergyuse = \frac{weeklyuse}{daysinaweek} = \frac{1000}{7} = 142\ kWh/dy \quad (1)$$

3.3.1.2 Calculating power output required by the solar PV system

From the data collected of the study area, the approximate daily hours of full sun are around 5 hrs/dy.

$$PowerOutput = \frac{Dailyenergyuse}{Dailyhoursoffullsun} = \frac{142\frac{kWh}{dy}}{5\frac{hrs}{dy}} = 28.4\ kW \quad (2)$$

3.3.2 Calculating PV system size

This study makes use of a 0.8 derating factor. The system size is obtained by dividing the power output by the derating factor.

$$SolarPVsystem = \frac{Poweroutput}{Deratefactor} = \frac{28.4\ kW}{0.8} = 35.5\ kW \quad (3)$$

A 35.5 kW system will be used as the input system in the simulation of approaches with a Solar PV system.

3.3.3 Battery bank sizing

For the battery bank system, it should last the system at least a day before the next full sun hours. Hence the battery should sustain operation for the next full day. The state of charge used will be 20 percent. Since Solar PV power availability is purely dependent on weather which cannot be controlled by human means. It is not wise to put a 100 percent dependence on it. Hence a 40 percent maximum daily use weighting is placed on it.

$$Dailyuse = 0.4 \times 142\ kWh = 56.8\ kWh \tag{4}$$

$$Batterybanksize = Dailyuse \times \frac{Daysofautonomy}{(1 - stateofcharge)} = 56.8\ kWh \times \frac{1}{(1-0.2)} = 71\ kWh \tag{5}$$

This 71 kWh is the amount of energy our battery bank needs to hold in total when fully charged.

3.3.4 Amp hours required

Assuming a 48 V battery pack,

$$Amphours = 1{,}000 \times \frac{Energystorage}{Batteryvoltage} = \frac{71\ kWh}{48\ V} = 1{,}479.167\ @\ 48V \tag{6}$$

3.3.5 Generator size

From data once used for base stations design and that from the study area collected. We can approximate an average of 30 kVA backup generator. Also, a power factor of 0.85.

$$GeneratorSize = \frac{Generatorrating}{powerfactor} = \frac{30\ kVA}{0.85} = 25.5\ kW \tag{7}$$

3.3.6 Grid considerations

The simulation has to have a weighted Grid data. There have to be a limit on the grid capacity to prevent the systemoptimising towards the grid which might have a relatively cheap power and lower Capital costs. However, the weighting on the grid is fairly applied because of its low reliability due to loadshedding. The maximum capacity is weighted at 3,000 kWh per month.

3.4 Load Profile

The load profile was determined by combining the data collected in the study area and literature.The selected synthetic load in HOMER PRO is a community type of load, Fig. 21, with an average of 165 kWh per day of consumption. This is a bit more than the average BTS consumption with 4kW rating working 24 hours a day. However, with the advent of 5G networks, within the next 10 – 25 years during which this paper is simulating its data on, there is more likelihood that ISP's will have moved to 5G systems. 5G systems need about 68 percent more power than 4G [31]. Hence, thistakes the average daily loads above 160 kWh.

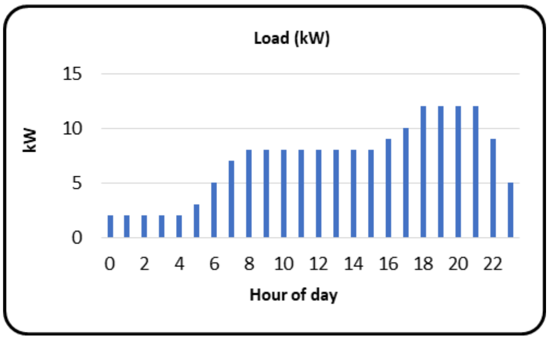

Fig. 21. Load profile

3.5 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making framework which produce priority scales through pairwise comparisons [32] and [33]. AHP start with a focus, which is the main goal – in this case, selecting the optimal energy supply system to power telecommunication base stations, then second level, the main criteria with which the main goal is based and lastly, the sub criteria.

The analysis for this research has criteria based onsustainability pillars [economic, environmental and social], as well as technical, expanded into 15 sub criteria on which a pairwise comparison was performed. The pairwise comparisons were based on both actual measurements on output HOMER Pro simulation data and a scale derived from relative strength of individual sub criteria standing. Fig. 22shows the hierarchy Diagram for selecting the optimal alternative power source for base stations.

Analytic Hierarchy Process (AHP) follows a number of steps which are outlined below,

3.5.1 AHP – step 1: Sub criteria classification

The output simulation results from HOMER PRO are categorised into four sustainability pillars Economical; Capital Expenditure (CAPEX), Operating Expenditure (OPEX), Net Present

Cost (NPC), Levelised Cost of Energy (LCOE), Emission Cost (EC) – Technical; Resource Availability (RA), Capacity (CAP), Reliability (REL), Flexibility (FLEX) – Environmental; Emission (CO2), Land Use (LU), Sustainability (SUS) – Social; Acceptability (AT), Employment Creation (EMP) according to previous research.

3.5.2 AHP – step 2: Pairwise comparison

Here criteria and sub-criteria are compared individually to one another. But firstly, these criteria/sub-criteria are ranked against each other based on actual data or assigned preferred values based on AHP fundamental scale in Table 1.

After preference values are assigned to individual criteria to be compared, the pairwise comparison is made based on the n-by-n matrix in Eq (8).

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{21} & 1 & \dots & a_{2n} \\ . & . & 1 & . \\ 1/a_{n1} & 1/a_{n2} & \dots & 1 \end{bmatrix} \quad (8)$$

In this case, pairwise comparison was performed per each approach (A0 – A5). Before the result of the pair-wise comparison can be accepted, a consistency must be checked. This consistency is checked based on Eq (9),

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (9)$$

Where n is the number of criteria and λ_{max} is the principal eigen value estimated from a summation of products between each element of Eigen vector and sum of columns of the reciprocal matrix. This process referred in Eq (10).

$$\lambda_{max} = \sum_{i=1}^{n} \lambda_{\max p} w_I = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} w_{ij} \quad (10)$$

According to [33] the pair-wise comparison can maintain consistency only when consistency index (C.I.) is equal to or less than 0.10 calculated based on Eq (11) for an average random consistency index (R.I) of n-values given in Table 2.

$$CR. = \frac{C.I.}{R.I.} \quad (11)$$

Where C.R. is consistency ratio by [33]. All of the pair-wise comparisons for all systems maintained a consistency less than the threshold.

3.5.3 AHP – step 3: Pair-wise performance comparison

This step involves getting single value scores of each sub criteria in a pair-wise comparison performed, which are 15 in this study. This was done for all six approaches proposed (A0 – A5). This is done by getting the average of the normalised relative weights pair-wise of each of the individual pair-wise. To obtain normalized relative weights for each paired matrix values, the reciprocal matrix from paired comparison matrix were summed up in each column of the reciprocal matrix and each element of the reciprocal matrix divided with the sum of its column. The average weighted scores from each sub criteria for each approach (A0 – A5) are shown in Table 3.

3.5.4 AHP – step 4: Alternative prioritization

In the final step, the behaviour of these six approaches is analysed by changing priority weights on the main criteria i.e., the sustainability pillars. Many questions are asked, on what systems tops when priority is either given to the economic,environmental and social consciousness, as well as technical.

Table 1. AHP fundamental scale for pair – wise comparisons

AHP Fundamental Scale for Pair-wise Comparisons		
Impact intensity	**Description**	**Definition**
1	Equal Importance	Two criteria contribute equally towards the goal
3	Slightly More Importance	One criteria contribute slightly more than the other criteria towards the goal
5	Strongly More Importance	One criteria strongly contribute more over the other criteria towards the goal
7	Very Strongly Importance	One criteria very strongly contribute more over the other criteria towards the goal
9	Extremely More Importance	One criteria has the highest contribution towards the goal than the other criteria
Intensities of 2,4,6, & 8 are used for intermediate values, while intensities 1.1, 1.2, 3.1,3.2...5.15.2,...,7.1, 7.2,..., etc. are used for criteria that are very close in importance towards a goal.		

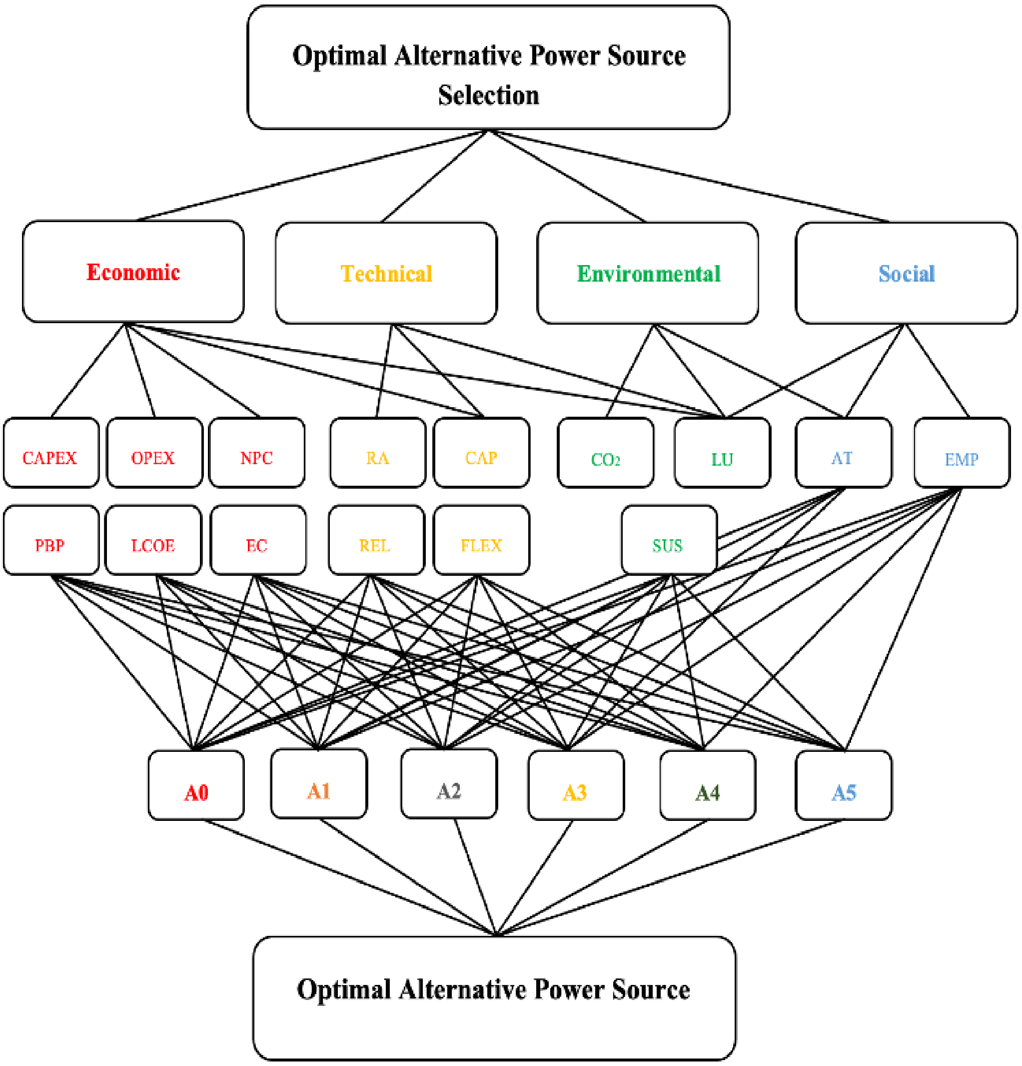

Fig. 22. Analytic Hierarchy for selecting optimal alternative power source

Table 2. Random consistency index

Random Consistency Index (R.I.)								
n	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4
	9	10	11	12	13	14	15	
	1.45	1.49	1.52	1.54	1.56	1.58	1.59	

Table 3. Weighted criteria score for all sustainability pillars

App	**Economical**						**Technical**				**Environmental**			**Social**	
	CAPEX	**OPEX**	**NPC**	**PBP**	**LCOE**	**EC**	**RA**	**CAP**	**REL**	**FLEX**	**CO2**	**LU**	**SUS**	**AT**	**EMP**
A0	0.007	0.006	0.006	0.007	0.007	0.007	0.010	0.010	0.011	0.011	0.013	0.016	0.014	0.021	0.022
A1	0.008	0.006	0.005	0.008	0.007	0.006	0.010	0.011	0.011	0.011	0.011	0.016	0.014	0.021	0.028
A2	0.007	0.006	0.006	0.007	0.007	0.007	0.011	0.011	0.011	0.011	0.014	0.013	0.014	0.021	0.024
A3	0.006	0.009	0.009	0.007	0.005	0.008	0.011	0.009	0.011	0.010	0.017	0.011	0.014	0.021	0.019
A4	0.007	0.008	0.007	0.006	0.008	0.007	0.011	0.011	0.011	0.010	0.014	0.012	0.014	0.021	0.017
A5	0.008	0.007	0.008	0.006	0.008	0.007	0.010	0.009	0.009	0.010	0.015	0.016	0.014	0.020	0.015

4. RESULTS AND DISCUSSION

The proposed approaches for the integration of solar systems into the telecommunications were simulated and the results analysed through Analytic Hierarchy Process. Data from a total of 15 sub criteria was tabulated in a pair-wise comparison to derive their contribution to the selection of the required solution. In return, sustainability pillars, Economical, Environmental and Social, as well as Technical were each prioritised individually (while keeping the other three constant) across all six approaches to observe their behaviour.

4.1 Simulation Results – Post HOMER Pro Analysis

HOMER PRO 3.5.4 was used in this study to simulate the different proposed approaches. The output results are analysed in this section grouped into respective sustainability pillars.

4.1.1 Economic analysis

The simulation of approaches in HOMER Pro gives results of a number of economic measures of viability of hybrid systems. These include but not limited to Initial Capital, Net Present Cost (NPC), Operating cost (in $/year), LCOE, O&M of genset systems (in $/year) and equivalent Cost of Emission (which is computed from local taxes in a country).

Solar PV systems have generally high initial costs over ten percent more than fossil fuel-based systems with generators. Grid only systems have the least initial capital costs, but a relatively higher operating costs around 108 percent per year more than grid coupled with solar. Whereas diesel generators only systems have operating costs between 697 – 1,559 percent per year more than grid only systems and grid + solar systems respectively. In essence, generator only systems will spend between $1,158,025.00 – $1,244,275.00 in its entire lifetime in operation cost only than the two latter systems which more than ten times more than the initial cost of Solar PV installation. This is shown in Fig. 23.

Because of drastic measures to prevent exacerbating the effects of climate change, taxes are set upon fossil fuel burnt or CO2 released into the atmosphere. Apart from the extra cost of maintenance, generator only systems have 618 and 278 percent more extra cost paid in emissions than grid + solar PV systems and grid only systems respectively, as shown in Fig. 24. Generator-based systems have generally lower LCOE than purely solar PV only system ($2,40). Grid + solar PV system ($0.20) and grid only system ($0.11) has the lowest electricity cost per unit. The existing system (grid + generator) has 190 percent more cost per unit of electricity than grid + solar system.

4.1.2 Technical analysis

Solar PV + grid system has 37 percent more energy per year than the existing system (generator + grid) based on the weighted input figures in the simulation results shown in Fig. 25. This means that at a LCOE of $0.20 per kWh, ISPs can sell the extra power back to the grid or share with home owners to subsidise their land use as a rental for the spaces used and still have enough to run their base stations.

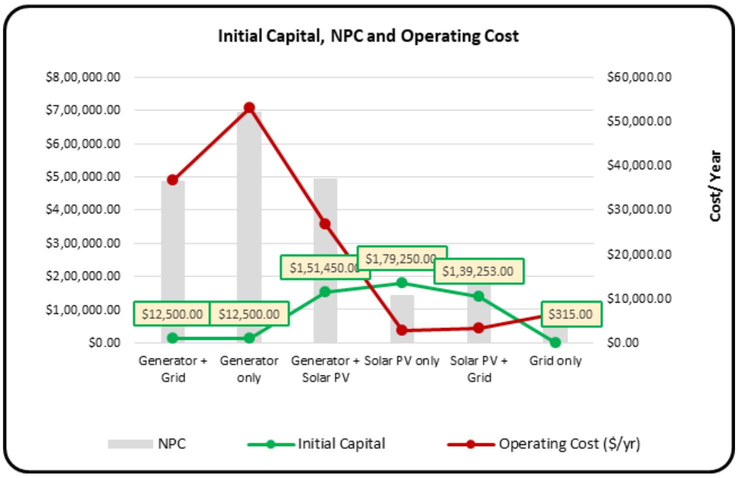

Fig. 23. Initial capital, NPC and operating cost

4.1.3 Environmental analysis

According to a simulation on PV Watt web Solar PV Calculator [31], a 100 m2 of roof space can produce up to 30 kWh of energy per year. This approximate to 3.5 m^2 per kWh of energy space. Fig. 26 gives an overview of land use with Solar PV Systems having around 200 m^2/kW. The same figure compares the amount of CO2 released by the individual approaches. The existing system (Grid + Generator System) has 359 percent emissions in tonnes per year more than that of Grid + Solar PV System.

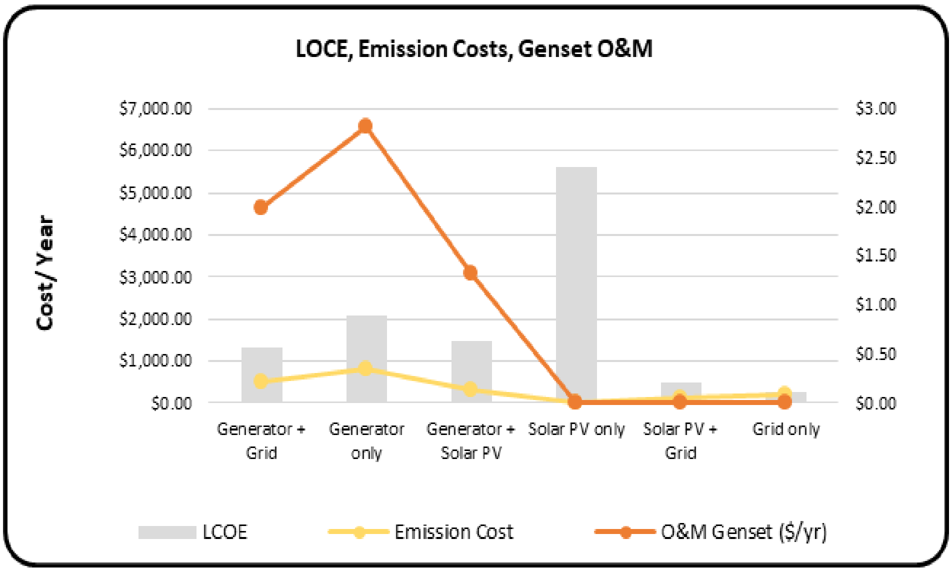

Fig. 24. Genset O&M, emission cost and LCOE

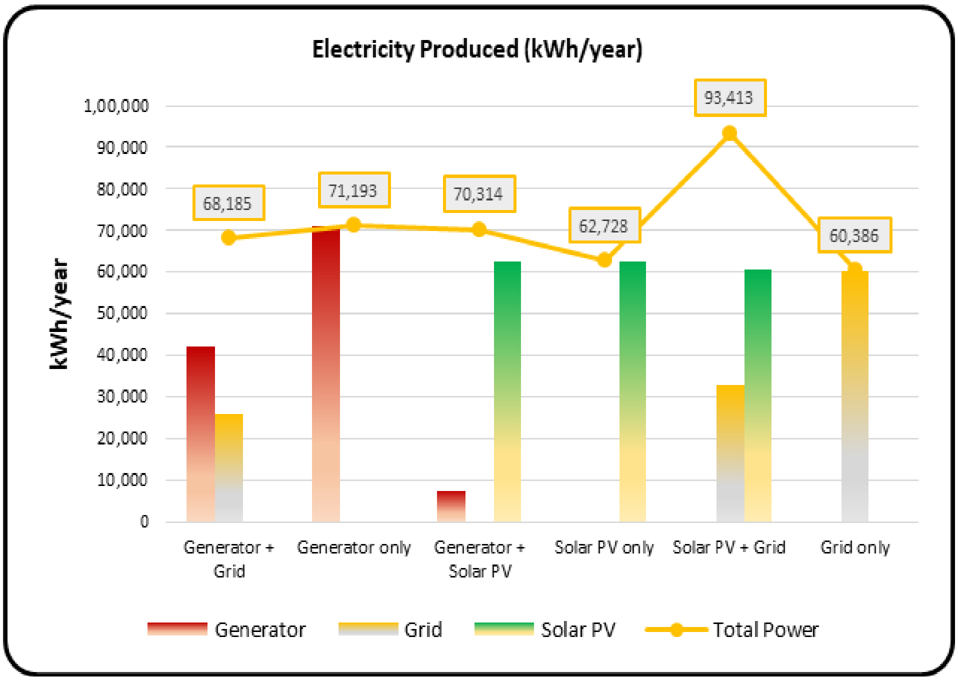

Fig. 25. Electricity production per year of different approaches

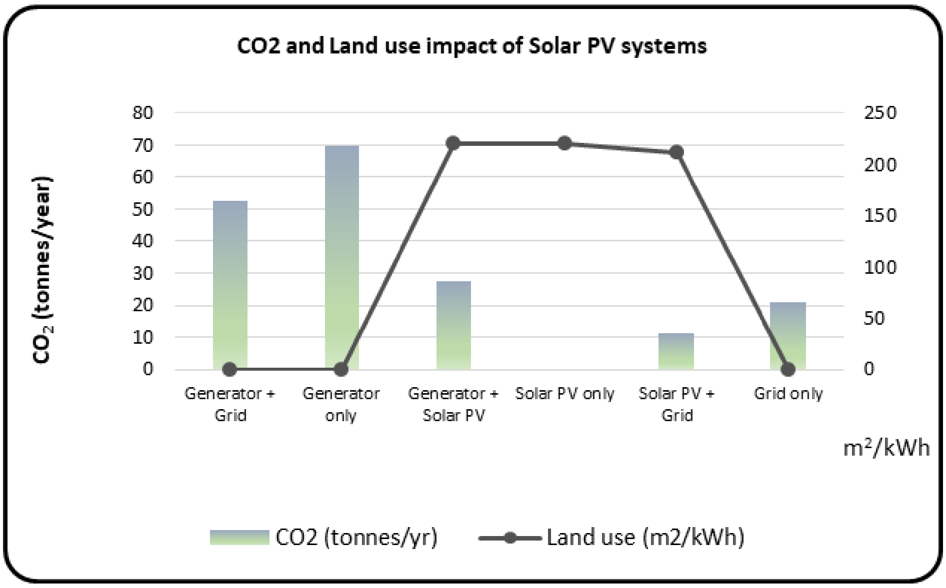

Fig. 26. CO and land use of approaches

4.2 System Selection

From the simulation results as presented in Fig. 27, it is noticed that Grid and, Solar PV + Grid Systems stand out in many sustainability pillars. Other systems are not favourable means of power in the telecommunications industry. In a general sense, hybrid systems with any portion of Solar PV are more preferable than those with generators.

The sustainability performance of all the systems is given in Fig. 28. All the approaches are ranked based on the total percentage weights across all sustainability pillars. Grid only system ranks first, followed by Grid + Solar PV system, with Generators systems ranking lower than systems with Solar PV. From their sustainability performance it is evident that generator systems are visibly less preferrable, hence, cannot be selected as a means of power in the telecommunication industry.

Grid only System in particular, have higher technical preference, and social sustainability. This is mainly because Grid Systems take very minimal land space, produce quiet power in the supplied area as opposed to noisy and vibrating generators. As well, Grid systems means setting up huge companies at macro level in the process, creating employment for the local people. However, their unreliability makes them less preferable. Furthermore, the energy mix in Zimbabwe is currently dominated by hydro. During times of drought or low rainfall, hours of outages drastically increase, up to 24 hours per day in some cases; during that same time, thermal stations, if available, fire up and take the bigger percentage in the energy mix. Though this can supplement the energy demand, firstly – it's not sufficient; secondly – it increases GHG emission. The goal is to reduce and possibly in the near future eliminate fossil fuel use. Reducing dependence on the grid in some other industries, in this case telecommunications, can significantly reduce demand and possibility of emissions by thermal plants as base station power can prioritise using more of Solar PV. Most importantly, grid outages are the reasons for ISPs to turn to generators for back-up power. Hence, to increase reliability of base station power supply by offering redundancy, it therefore leaves Grid + Solar PV system (A4) the optimal alternative power system for powering telecommunications base stations.

Based on the priority results, Grid + Solar PV systems ranks higher on the Economic and Environmental sustainability pillars which are very crucial pillars in modern day business. A system of Grid + Solar PV is not only the best due to redundancy but even feasible as ISP's will only focus on Solar PV installation as the Grid connection already exists. As reported in Fig. 25, Solar PV + Grid have the highest energy production per year. According to the scenarios in Section 3.1, residencies or municipal premises on which ISP's can install Solar PV gain free use of power according to this paper's design proposition; A4 – Grid + Solar PV System can produce sufficient power for this model.

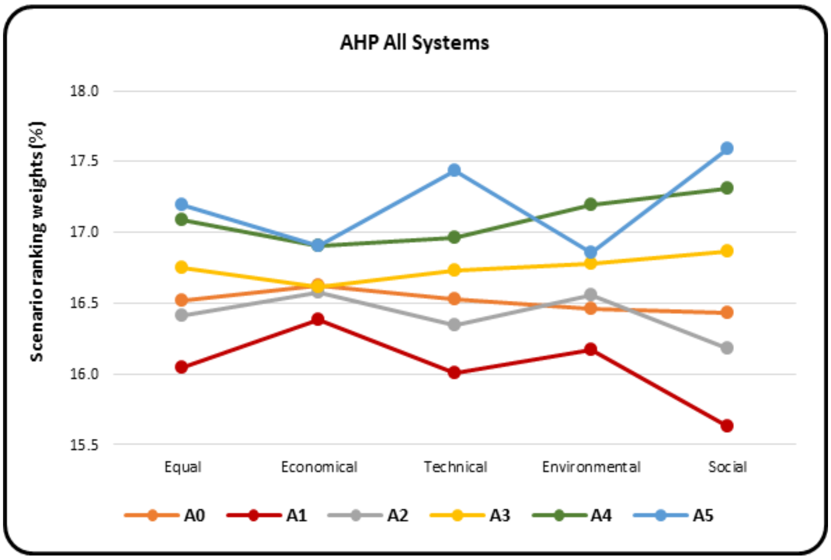

Fig. 27. Analytical hierarchy process (economical 20%, technical 20%, environmental 40% and social 20%)
[A0 – Generator & Grid System; A1 – Generator only System; A2 – Generator & Solar PV System; A3 – Solar PV only System; A4 – Solar PV & Grid System; A5 – Grid only System]

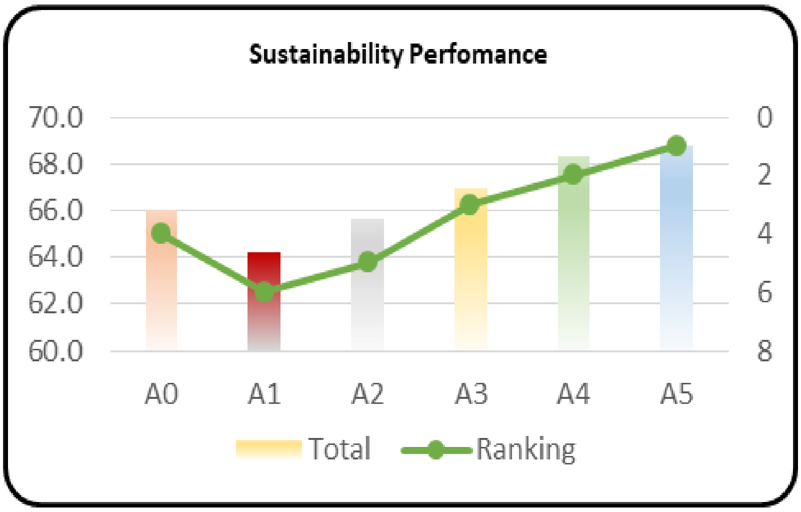

Fig. 28. Analytical hierarchy process combinedprioritisations
[A0 – Generator & Grid System; A1 – Generator only System; A2 – Generator & Solar PV System; A3 – Solar PV only System; A4 – Solar PV & Grid System; A5 – Grid only System]

4.3 The Optimal Alternative System

From the selected approach A4 – Grid + Solar PV, there are a number of potential benefits if adopted by the ISP's.

For energy systems projects, NPC is the best measure of how feasible its implementation is in comparison to others and where a breakdown of sales and net revenue are not given. A system is more preferrable if it minimises NPC. As presented in Fig. 29, Grid + Solar PV (A4) system offer by 170 percent lower NPC over its entire lifecycle than Grid + Generator (A0) system.

Solar PV systems have generally a higher CAPEX than Generator based systems. This is proven in Fig. 30 below with Grid + Solar PV (A4) systems 1,014 percent higher initial capital than Grid + Generator (A0). However, if Solar PV systems are well maintained, they stand as a one-time investment in their lifecycle of 25 years, which is more than that of generator systems, 10 years. This essentially means that midway in the lifecycle of Solar PV, there is a new generator installation.

The reason why the existing system Grid + Generator would cause an increase in data price is because the unit cost of electricity ($0.58 per kWh) is generally higher than the grid ($0.11 per kWh) in the area. By adopting Grid + Solar PV, ISPs reduce the unit cost of electricity by 183% as shown in Fig. 31 to $0.20 per kWh.

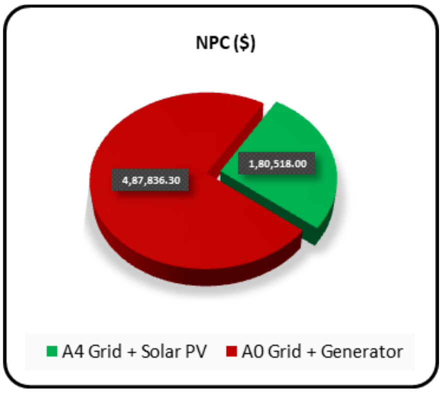

Fig. 29. NPC comparison for grid + generator | grid + solar PV systems

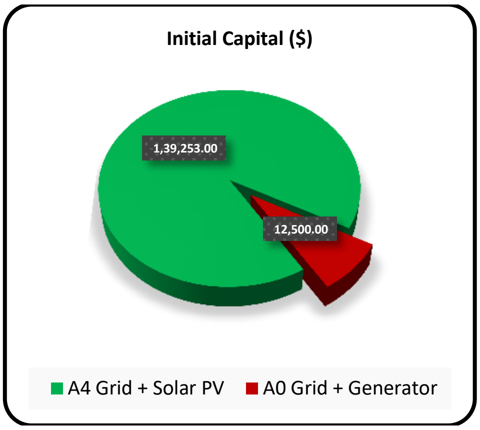

Fig. 30. Initial capital comparison for grid + generator | grid + solar PV systems

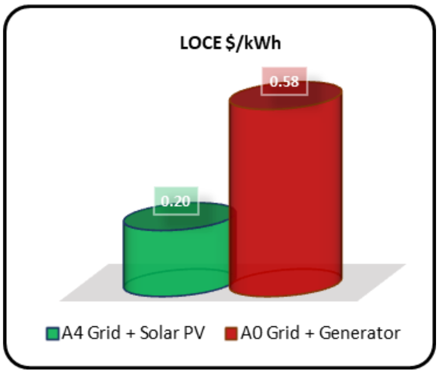

Fig. 31. LCOE comparison for grid + generator | grid + solar PV systems

Operating expenditure for generator-based systems are always high. Though the initial cost is a thousand percent less than those of Solar based systems as of yet, it is still important to note that with cost of running those generators only, it cost more that 100 percent initial cost of solar PV systems over the entire life time. In this case, Grid + Generator system has 1,052 percent more OPEX per year than the proposed approach. The distribution is shown in Fig. 32.

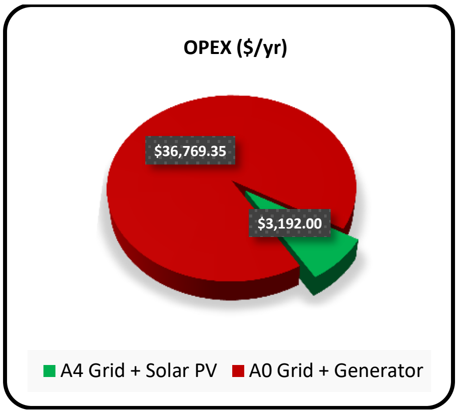

Fig. 32. OPEX comparison for grid + generator | Grid + Solar PV

Setting a cost on carbon is a measure put by governments to reduce emissions by taxing the emitter. To avoid these taxes ISP's can adopt systems with less GHG emissions. By coupling the grid with Solar PV, telecommunications companies can avoid 348 percent additional cost on emission.The distribution is show in Fig. 33.

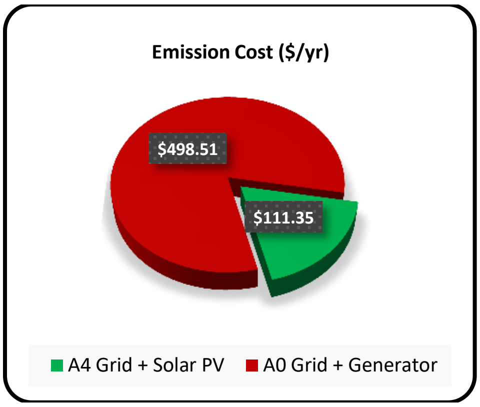

Fig. 33. Emission cost for grid + generator | grid + solar PV

The existing system (Grid + Generator System) has 359 percent emissions in tonnes per year more than that of Grid + Solar PV System. The distribution is show in Fig. 7 for perspective. By adopting the proposed approach there is potential of 41.13 tonnes per year of GHG emissions avoided per base station.

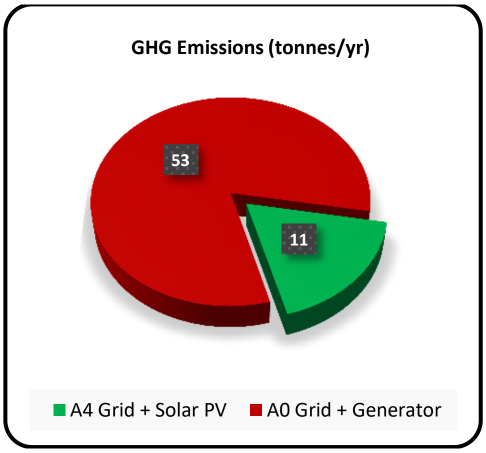

Fig. 34. GHG emissions grid + generator | grid + solar PV

To fully make use of the proposed approach, the installed Solar PV has to provide excess power to share with either the household or municipality on which the Solar PV is installed. At the same power capacity, the simulation results show that the Grid + Solar PV system can produce 37 percent more energy than the existing system as shown in Fig. 35.

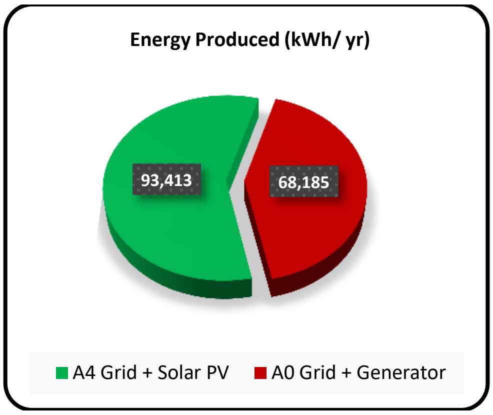

Fig. 35. Energy produced grid + generator | grid + solar PV

5. CONCLUSION

The research's aim was to find a solution for deploying Solar PV by proposing an optimal alternative energy supply system to power telecommunications base stations based on sustainability pillars; Economical, Environmental and Social, as well as Technical. Budiriro was used as a Case Study, a reference, to be able to streamline the research outcomes. The study derived six power system configurations from the available possible power sources in the study area. The systems were then simulated in HOMER Pro and from the simulation results, the systems were ranked through Analytic Hierarchy Process (AHP) by performing pairwise comparisons of 15 sub criteria. After considering a number of factors like reliability, power output and mainly sustainability, Grid + Solar PV system came out as the optimal alternative system to power telecommunications base stations in the study area. The results show that the optimal system reduces OPEX by over 1,000 percent offering 37 percent more power and 41.13 tonnes of GHG emissions avoided per year. The solutions given here within can be applied in similar areas with similar demand and most importantly a sufficient solar irradiation, which is the main resource the study focused on.

The analysed systems are based in a suburb with grid-connected power. Future studies have to look, for low- and middle-income countries (LMICs), at an analysis of power systems for telecommunications towers in isolated areas (off-grid) with dispersed settlements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/97687