COST COMPARISON OF STAND-ALONE WIND AND PV SYSTEM IN NIGERIA.

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A PROJECT PRESENTED TO

THE DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF BENIN
P.M.B 1154, BENIN CITY, EDO STATE.

IN PARTIAL FULFILMENT FOR THE AWARD OF B.ENG IN ELECTRICAL/ELECTRONICS ENGINEERING.

JULY 2021

CERTIFICATION

I, **OGUME JIMROX ODEZI (ENG1503851)** hereby declare that this thesis is my original authorial work, which I have worked out by my own. All sources, references and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

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DEDICATION

I dedicate this project work to God almighty for His mercy and strength to accomplish this project work.

ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to God Almighty for the grace, knowledge and patience to complete this project and to my project supervisors Engr. Prof. S. O. Igbinovia and T. A. Aika**,** for their amazing support and advice towards the completion of the project.

A special thanks to the Department of Electrical/Electronic Engineering for imparting me with the knowledge and understanding that helped improve my understanding in this field of study.

Finally, I would like to thank my parents, Mr. and Mrs. P. Ogume, for their love, encouragements and financial support throughout my academic program.

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ABSTRACT

With the advent of renewable energy solutions in the energy sector of developed and developing nations, a cost evaluation of the different available options is necessary. In this project, a cost comparison of a 10kW wind and solar PV system was examined.

This thesis uses the Life Cycle Costing (LCC) methodology to evaluate the cost of solar and wind power systems for a period of 25 years, to determine which is more cost effective.

The cost of installing a 10kW wind turbine system was evaluated to be ₦25,753,268.75 while that of solar PV system for the same amount power was evaluated to be ₦26,068,916.76 for a period of 25 years.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Electricity has gone from being a luxury into a necessity in our daily lives and is essential to ensure the quality of life for billions of people around the world. An increasing population and the rapid development of technology in today´s society has led to an increase in electricity demand.

Increase in electricity generation is then required to balance the electricity demand by different energy sources. Electricity generation through natural resources such as natural gas and coal are leaving a great impact on our global climate with greenhouse gases (GHG) and has led to climate awareness around the world (Shamil, 2017). There is therefore a need for future energy technologies to be focused on clean and renewable energies as they mitigate the issue of global warming and other climate concerns.

The imperativeness of electricity to any nation cannot be over emphasized. Renewable energy technologies can help countries (developed and developing countries alike) meet their policy goals for secure, reliable and affordable energy to expand electricity access and promote development. Solar PV systems and wind turbines are the two dominant renewable energy sources.

With the growth of global population, the issues involving consumption of natural resources have become intense, and the environmental problems have become more serious in many parts of the world. Electricity production constitute a big portion of total greenhouse gas emission in the world (USEPA, 2013). The growing concern on achieving environmental sustainability and at the same time making economical savings has become a necessity in our society.

This global climate awareness and the diminishing of the natural resources have resulted in the fact that the electricity production is turning more and more towards renewable energy sources (RES). According to International Energy Outlook (2016), the electricity generation by renewable energy sources in the world will increase to 11 trillion kWh by 2040 compared from 4.9 trillion kWh in 2012.

1.2 Problem Statement

Renewable energy systems must be both energy efficient and cost competitive with fossil fuel power-generating stations if they are to emerge as a prominent mode of electricity production (Keoleian and Lewis, 1997). This work address the question of cost competitiveness between solar and wind energy system for 10kWp of energy.

1.3 Aims and Objectives

The aim of this project is to perform the life cycle costing of solar PV system and wind turbine system for 10kWp rating and compare which is more cost effective over a period of 25 years.

The objective include:

1. to obtain data on wind and PV systems
2. analyze the data
3. Make recommendation base on the data.

1.4 Methodology

The following methodology is applied in this study to fulfil the objectives given above.

1. Gathering and assessing the data through literature and public data.

2. Simulating and making the techno-economic analysis of the model.

3. Discussion of the results.

1.5 Scope of Study

The scope of study is to assume 25 years of lifetime for Solar PV and wind turbine system. This project work is limited to 10kW of energy in Nigeria. The results obtained here will eventually be different for different energy values and will vary from location to location depending on factors such as wind speeds and solar irradiation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Renewable Energy

According to IRENA (2013), renewable energy is energy that doesn’t run out. It is energy that can be used without reducing its availability in the future. This includes natural forces (heat, radiation, motion) and chemical energy from biomass (biofuels). Biomass is included because it can be replaced in the human time-frame.

True renewable energy sources are energy supplies that are refilled by natural processes at least as fast as we use them. All renewable energy comes, ultimately, from the sun. We can use the sun directly (as in solar heating systems) or indirectly (as in hydroelectric power, wind power, and power from biomass fuels).

The enormous potential of renewable energy sources can meet many times the world energy demand. They can enhance diversity in energy supply markets, contribute to long-term sustainable energy supplies, and reduce local and global atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy services, particularly in developing countries and rural areas, create new employment opportunities, and offer opportunities to manufacture much of the equipment locally (IEA, 1997).

Renewable energy includes but is not limited to the following according to IRENA (2015):

- Solar energy: this is radiant light and heat from the sun that is harnessed using a range of ever evolving technology.
- Wind energy: the use of air flow through wind turbines to mechanically power generators to generate electricity.
- Tidal energy: a form of hydropower that converts the energy of the tides into electricity or other useful forms of power.
- Geothermal energy: this is thermal energy generated and stored in the earth. Thermal energy is the energy that determines the temperature of a matter.
- Hydroelectricity energy: this is the energy derived from the power of falling water or fast running water, which may be harnessed for useful purposes.
- Biomass energy: biomass contain stored energy because plant absorb energy from the sun through the process of photosynthesis. When biomass is burned, this energy is released as heat.

2.1.1 Global Trend of Renewable Energy

According to IRENA (2020), at the end of 2019, global renewable generation capacity amounted to 2 537 GW. Hydropower accounted for the largest share of the global total, with a capacity of 1 190 GW. Wind and solar energy accounted for most of the remainder, with capacities of 623 GW and 586 GW respectively. Other renewables included 124 GW of bioenergy and 14 GW of geothermal, plus 500 MW of marine energy.

Renewable generation capacity increased by 176 GW (+7.4%) in 2019. Solar energy continued to lead capacity expansion, with an increase of 98 GW (+20%), followed by wind energy with 59 GW (+10%). Hydropower capacity increased by 12 GW (+1%) and bioenergy by 6 GW (+5%). Geothermal energy increased by just under 700 MW.

Solar and wind energy continued to dominate renewable capacity expansion, jointly accounting for 90% of all net renewable additions in 2019.

2.1.2 Renewable Energy Potential and Trend in Nigeria

As at 2001, about 25% of the 774 local government areas of Nigeria were not connected to the national grid and today, more than 80% of these areas are still not connected; a national projection based on 13% Gross Domestic Product growth rate revealed that energy demand will increase from 5746 MW in 2005 to 297900 MW in 2030 while supply should increase from 6440 MW to above 300,000 MW within the same period of years. To accomplish this, requires an additional 11,686 MW every year to meet demand. Nigeria currently generates an estimated 3000

MW due to fluctuations in the availability and poor maintenance of generating equipment. Thus, Nigeria still has a long way to go in achieving energy sufficiency. Furthermore, the present generation mix needs augmenting with the aim of maximizing sustainable energy production.

Various research carried out identified that great prospects exist for wind energy utilization for power generation. Moreover, wind speeds are generally weak in the south except for the coastal regions and offshore, which are windy. Offshore areas from Lagos through Ondo, Delta, Rivers, Bayelsa to Akwa Ibom States were reported to have potentialities for harvesting strong wind energy throughout the year. Inland, the wind was reported strongest in the hilly regions of the North, while the mountainous terrains of the middle belt and northern fringes demonstrated high potential for great wind energy harvest. It was however observed that, due to varying topography and roughness of the country, large differences may exist within the same locality. Also, results from The Nigerian Metrological Agency based on the outcome of using 40 years (1968 − 2007) available average wind data from the whole forty-four wind stations across the states of the federation showed that the country's wind regime is found to lie majorly between poor to moderate regimes, with the southern states having their mean wind profile at 10 m height in the range between 3.0 − 3.5 m/s, depending on the states, and Northern states capable with mean wind speeds of between 4.0 − 7.5

m/s. This means that, Nigeria has good wind resources over most part of the country. Although, wind speeds in the southern states are low, they can however be employed for standalone power generating systems using small scale wind turbines. This if employed, will be a major breakthrough for rural and sub-rural areas not connected to national electricity grid.

According to the statistics from the International Energy Agency (IEA), total Nigerian primary energy supply was 118,325 Kilotonne of Oil Equivalent (ktoe) - excluding electricity trade - in 2011, biomass and waste dominated with 82.2%. Renewable energy sources only accounted for a small share of the energy supply. For instance hydropower only accounted for 0.4%. Wind and solar are also utilized, but at an insignificant level at present.

In order to bring a solution to these problems, the Federal Government of Nigeria (FGN), in its Power Sector Reform Roadmap (2013), set the ambitious targets to increase installed hydro to 5,690 MW, thermal to over 20,000 MW and renewable 1000 MW capacities by 2020. The targets also aim at diversifying Nigeria’s energy mix to reduce its natural gas dependence. A 10 MW pilot wind plant has been built in Katsina and is awaiting commissioning. One major hydropower plant is now under development, the Zungeru 700 MW plant in Niger State. A number of smaller hydropower plants are also being planned such as Gurara (30 MW) or

Kashimbilla (40 MW). The 3,050 MW Mambilla hydropower plant project is currently being reviewed. In addition, the Nigerian Electricity Regulatory Commission (NERC) has issued licenses for 8 solar projects totaling a capacity of 868 MW and a 100 MW wind park. Furthermore, investors are increasingly enthusiastic about developing large solar plants in the country.

"Despite the potential for renewable energy to contribute to solving Nigeria’s deficient grid infrastructure, there is no grid-based renewable energy electricity production at the moment (apart from large scale hydro), and the perception that renewables are a high-risk investment still prevails. Fourteen solar PV companies signed power purchase agreements (PPAs) with the bulk electricity trader in 2016, with a combined capacity of 1 GW, but as of 2019 none of them have yet reached financial close.

2.2 Wind Energy

Wind power technologies transform the kinetic energy of the wind into useful mechanical power. Wind is created by the unequal heating of the Earth’s surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical power that runs a generator to produce clean electricity. Today’s turbines are versatile modular sources of electricity. Their blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which spin a shaft connected to a generator that makes electricity.

Wind power technologies come in a variety of sizes and styles and can generally be categorized by whether they are horizontal axis or vertical axis wind turbines (HAWT and VAWT), and by whether they are located onshore or offshore. The power generation of wind turbines is determined by the capacity of the turbine (in kW or MW), the wind speed, the height of the turbine and the diameter of the rotors.

Most modern large-scale wind turbines have three blades rotating around the horizontal axis (the axis of the drive shaft). These wind turbines account for almost all utility scale wind turbines installed. Vertical-axis wind turbines exist, but they are theoretically less aerodynamically efficient than horizontal-axis turbines and don’t have a significant market share.8 In addition to large-scale designs, there has been renewed interest in small-scale wind turbines, with some innovative design options developed in recent years for small-scale vertical-axis turbines.

Horizontal-axis wind turbines can be classified by their technical characteristics, including:

- rotor placement (upwind or downwind);
- the number of blades;

- the output regulation system for the generator;
- the hub connection to the rotor (rigid or hinged; the so-called “teetering hub”);
- gearbox design (multi-stage gearbox with high speed generator; single stage gearbox with medium speed generator or direct drive with synchronous generator);
- the rotational speed of the rotor to maintain a constant frequency (fixed or controlled by power electronics); and
- wind turbine capacity.

2.2.1 Main Components of a Wind Turbine

Today, the most common design of WT is the horizontal axis wind turbine (HAWT). That is, the axis of rotation is parallel to the ground. The principal subsystem of a typical HAWT includes the rotor, drive train, generator, nascelle and yaw system, tower and foundation, and control system.

Rotor

The rotor consists of the hub and blades of the wind turbine. The blades transform the kinetic energy into rotational energy, using the same aerodynamic principles as an airplane wing. They can be rotated around their longitudinal axis, called pitch, to maximize the energy yield from the wind. The blades are mounted to the hub.

Drive Train

The drive train consists of the other rotating parts of the WT downstream of the rotor. These typically include a low-speed shaft, a gearbox, and a high-speed shaft. Other drive train components include the support bearings, one or more couplings, a brake, and the rotating parts of the generator.

The gearbox transforms the rotational energy from the hub, which is usually in a high torque with low speed format, into low torque – high speed format required by the generator.

Hydraulic system

The pitch mechanism in a WT is usually driven by oil pressure. An oil pump, control valves and actuators are needed to rotate the blades into their designated position. A mechanical rotor brake is often also hydraulically actuated.

Generator

The generator in a WT is located on the high-speed side of the gearbox, and converts rotational energy into electrical energy. It consists of a rotor creating a rotating magnetic field, which itself then induces a voltage in the stator. There are different types of generators; common types used in wind turbines are synchronous generators, as well as single or double fed asynchronous generators.

A synchronous generators produce current, which alternates with the same frequency as the rotor rotates.

Asynchronous generators rotate slightly faster than their output current oscillates.

Nascelle and Yaw System

This part includes the WT housing, the machine bedplate or main frame, and the yaw orientation system, required to keep the rotor shaft properly aligned with the wind. The main frame provides for the mounting and proper alignment of the drive train components. The nascelle cover protects the contents from the weather.

Tower and foundation

The principal types of tower design currently in use are the free-standing types using steel tubes, lattice towers, and concrete towers. The stiffness of the tower is a major factor in WT system dynamics because of the possibility of coupled vibrations between the rotor and the tower.

Control system

The control system supervises operational data and supports control of the turbine operation. It can detect some abnormalities during operation, for example when a sensor detects a high temperature and triggers an alarm or shuts down the generator rotation. Furthermore, it controls the pitch system to maximize the energy production.

A WT control system includes: sensors (speed, position, temperature, current etc), controllers (mechanical mechanisms, electrical circuits), power amplifiers (electrical amplifiers, hydraulic pumps, and valves), actuators (motors, pistons, magnets, and solenoids), and intelligence (computers and microprocessors).

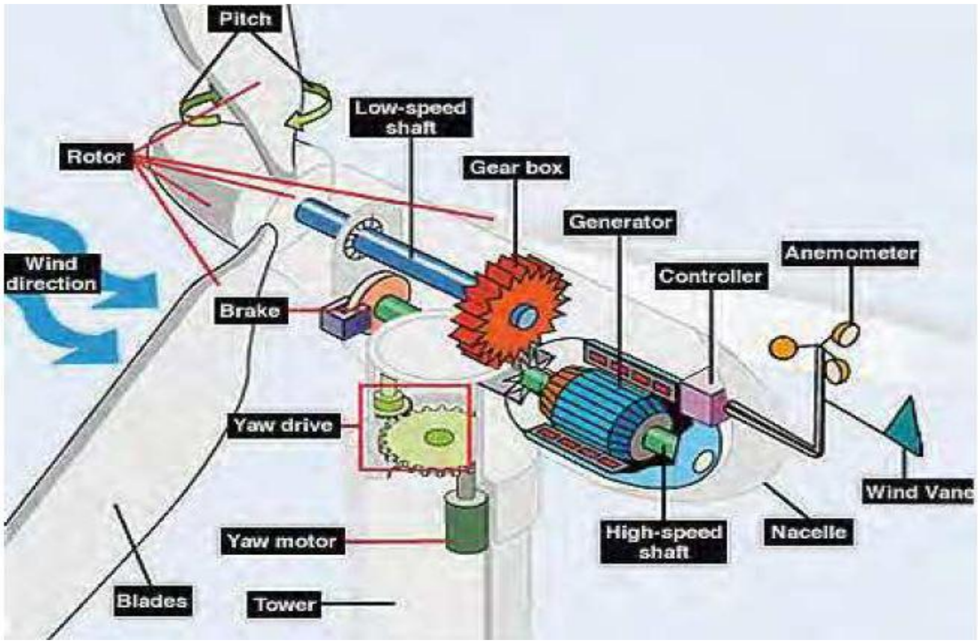

Figure 2.1: Components of a wind turbine

The turbine size and the type of wind power system are usually related. Today's utility-scale wind turbine generally has three blades, sweeps a diameter of about 80 to 100 metres, has a capacity from 0.5 MW to 3 MW and is part of a wind farm of between 15 and as many as 150 turbines that are connected to the grid.

Many different design concepts of the horizontal-axis wind turbine are in use. The most common is a threebladed, stall- or pitch-regulated, horizontal axis machine operating at near-fixed rotational speed. However, other concepts for generation are available, notably gearless "direct drive" turbines with variable speed generator designs have a significant market share. Wind turbines will typically start generating electricity at a wind speed of 3 to 5 metres per second (m/s), reach maximum power at 15 m/s and generally cut-out at a wind speed of around 25 m/s.

2.2.2 On-grid and Off-grid Wind Turbines

Wind turbines can be used for either on-grid or off-grid applications. Most medium-size and almost all large-size wind turbines are used in grid tied applications. One of the obvious advantages for on-grid wind turbine systems is that there is no energy storage problem. As the contrast, most of small wind turbines are off-grid for residential homes, farms, telecommunications, and other applications. However, as an intermittent power source, wind power produced from off-grid wind turbines may change dramatically over a short period of time with little warning. Consequently, off-grid wind turbines are usually used in connection with batteries, diesel generators, and photovoltaic systems for improving the stability of wind power supply.

2.2.3 Onshore and Offshore Wind Turbines

Onshore wind turbines have a long history on its development. There are a number of advantages of onshore turbines, including lower cost of foundations, easier integration with the electrical-grid network, lower cost in tower building and turbine installation, and more convenient access for operation and maintenance.

Offshore wind turbines have developed faster than onshore since the 1990s due to the excellent offshore wind resource, in terms of wind power intensity and continuity. A wind turbine installed offshore can make higher power output and operate more hours each year compared with the same turbine installed onshore. In addition, environmental restrictions are more lax at offshore sites than at onshore sites. For instance, turbine noise is no long an issue for offshore wind turbines.

2.2.4 Small Wind Turbines

Small wind turbines are generally considered to be those with generation capacities of less than 100 kW. These smaller turbines can be used to power remote or off-grid applications such as homes, farms, refuges or beacons. Intermediate-sized wind power systems (100 kW to 250 kW) can power a village or a cluster of small enterprises and can be grid-connected or off-grid. These turbines can be coupled with diesel generators, batteries and other distributed energy sources for remote use where there is no access to the grid. Small-scale wind systems remain a niche application, but it is a market segment that is growing quickly. They are emerging as an important component of renewable electrification schemes for rural communities in hybrid off-grid and mini-grid systems.

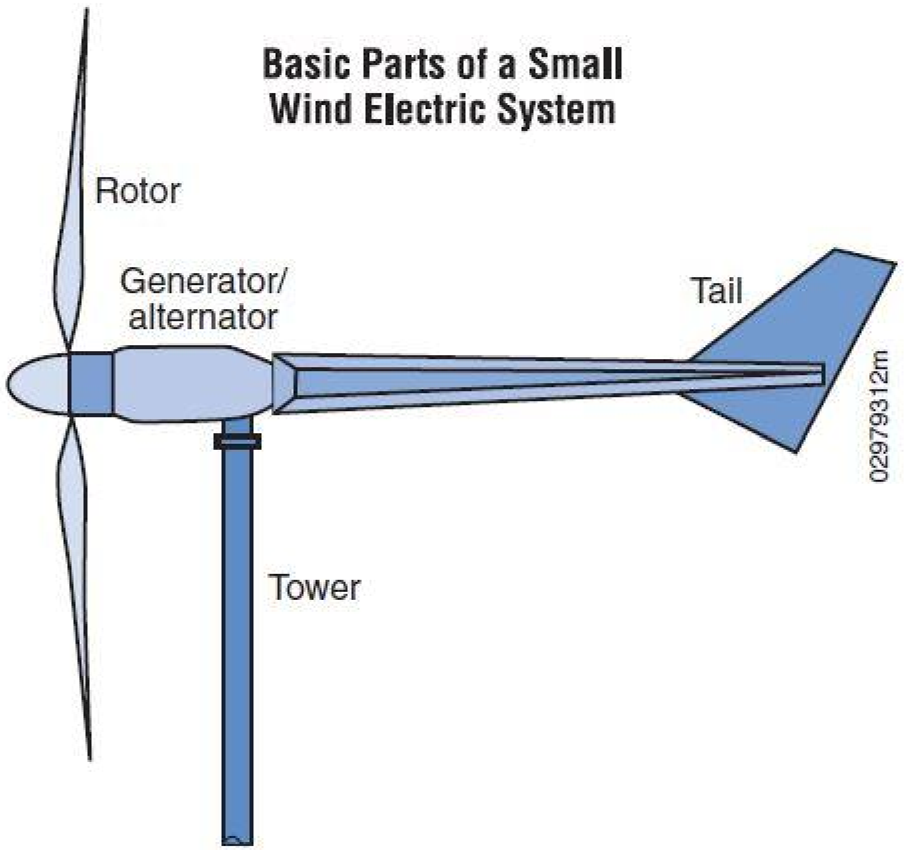

Figure 2.2: Basic Parts of a small wind turbine

Small wind turbines can meet the electricity needs of individual homes, farms, small businesses and villages or small communities and can be as small as 0.2 kW. They can play a very important role in rural electrification schemes in off-grid and mini-grid applications. They can be a competitive solution for off-grid electrification and can complement solar photovoltaic systems in off-grid systems or mini-grids.

Although small wind turbines are a proven technology, further advances in small wind turbine technology and manufacturing are required in order to improve performance and reduce costs. More efficient installation and maintenance techniques will also help improve the economics and attractiveness of small wind turbines.

A typical home uses approximately 10,000 kilowatt-hours (kWh) of electricity per year (about 830 kWh per month). Depending on the average wind speed in the area, a wind turbine rated in the range of 5 to 15 kW would be required to make a significant contribution to this demand (DOE, 2007).

Although the wind power industry appears to be booming in recent years worldwide, achieving continuous cost reduction in wind power generation continues to be a challenge and a key focus for the wind industry. Wind power is characterized by low variable costs and relatively high fixed costs. The main factors governing wind power economics are:

- Investment costs, including wind turbines, foundations, and grid connection
- Operation and maintenance (O&M) costs, including regular maintenance, repairs, insurance, spare parts, and administration
- Wind turbine's electricity production cost, which highly depends on the wind turbine capacity, wind farm size, and average wind speed at the chosen site
- Wind turbine lifetime

- Discount rate.

Among these, the most important factors are the wind turbines' electricity production and their investment costs. The trends towards lager wind turbines and larger wind farms help reduce both investment and O&M costs per kilowatt-hour (kWh) produced. Though the price of electricity from wind has fallen approximately 90% over the last 30 years because of the developments of wind technology, it is still more expensive than those from coal or natural gas. With reduced power consumption, the prices of fossil fuels (e.g. coal and natural gas) have greatly decreased, putting even more pressures on the wind power industry to continuously drive down wind power costs for staying competitive in the present challenging economic times (Wei Tong, 2010).

2.2.5 Wind Turbine Capacity Factor

Due to the intermittent nature of wind, wind turbines do not make power all the time. Thus, a capacity factor of a wind turbine is used to provide a measure of the wind turbine's actual power output in a given period (e.g. a year) divided by its power output if the turbine has operated the entire time. A reasonable capacity factor would be 0.25–0.30 and a very good capacity factor would be around 0.40. In fact, wind turbine capacity factor is very sensitive to the average wind speed.

2.2.6 Energy Yield of Small Wind Turbines

Wind turbines rely on wind to produce electricity. Wind is one of the most ancient techniques that have been in use in order to generate usable mechanical or electrical power. Wind moves from one location to another based on the pressure level between these two locations; hence wind speed is mainly affected by the pressure.

Wind speed always varies and cannot be anticipated, which makes it more desirable to describe the wind speed using statistical methods. One of the most common functions in use to determine the probability of a certain wind speed is the Weibull distribution function (Ahmed et. al, 2013).

Wind energy systems are one of the most cost-effective renewable energy systems. Depending on your wind resource, a small wind energy system can lower your electricity bill by 50% to 90%, help you avoid the high costs of extending utility power lines to remote locations, prevent power interruptions, and it is nonpolluting (DOE, 2007)

2.2.7 Stand-alone Wind turbines

The most common type of stand-alone small wind electric system involves the use of a wind generator to maintain an adequate level of charge in an electrical storage battery. The battery in turn can provide electricity on demand for electrical applications such as lights, radios, refrigeration, telecommunications, etc., irrespective of whether or not the wind is blowing. A controller is also used to ensure that the batteries are not damaged by overcharging (when surplus energy is dissipated through a dump load) or excessive discharge, usually by sensing low voltage. Loads connected to the battery can either be DC or AC (via an inverter).

Small wind battery charging systems are most commonly rated at between 25-100 W for a 10m/s wind speed, and are quite small with a rotor diameter of 50 cm to 1 m. These systems are suitable for remote settlements in developing countries.

Larger stand-alone systems, incorporating larger wind electricity generators and correspondingly larger battery banks (at an increased cost) are also available, these may include other renewable energy technologies, such as PV, as well as diesel generators to ensure that the batteries are always charged and that power availability is high.

Less common is the stand-alone system which does not incorporate a battery back. This involves the use of a wind turbine with, at least, a diesel generator, which will automatically supply power when required. This has the advantage of not requiring a battery bank but the required control systems are complex.

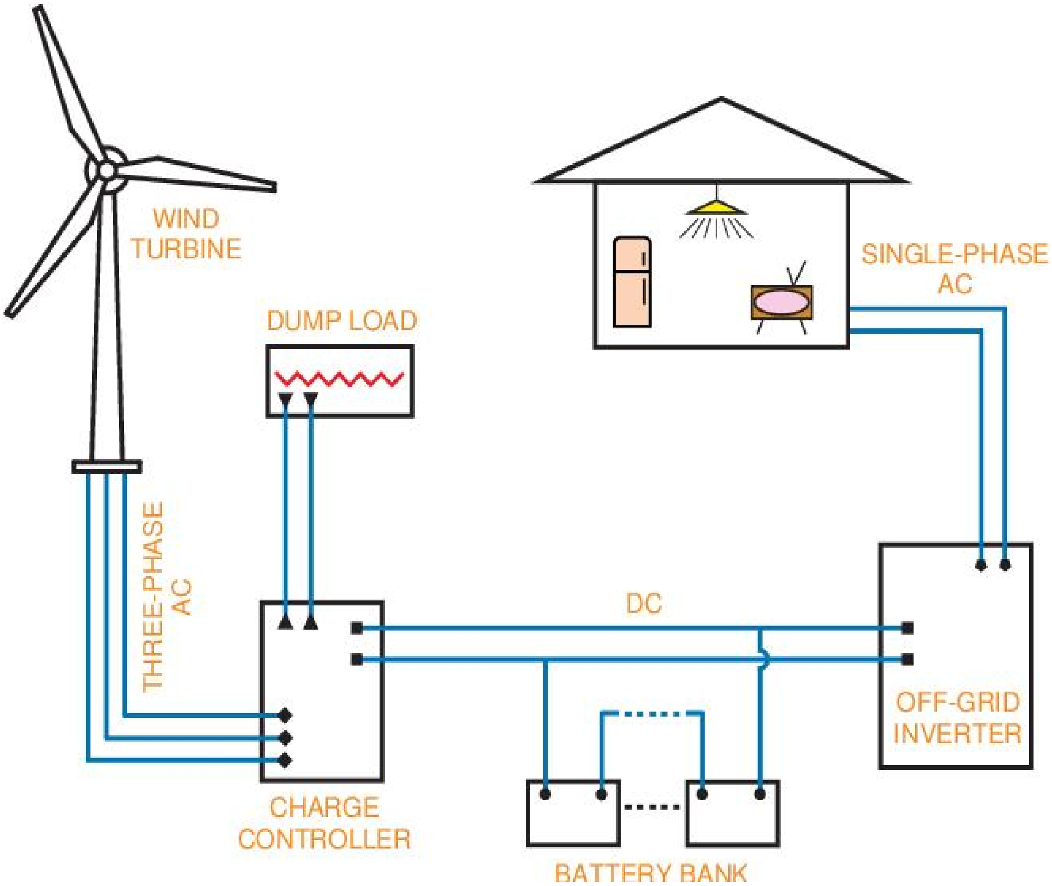

Figure 2.1 Stand-alone Wind Turbine System

The generators for small wind turbines are usually three-phase alternating current generators and the trend is to use the induction type, although some models utilize single-phase generators or direct current output.

After running the three phase AC wire through a slip ring and down to the receiving end, a three-phase rectifier is used to convert the AC to rectified DC for battery charging, especially in solar hybrid power systems. The rectifier should be mounted to a heat sink for cooling, with the option of adding a computer fan that is activated by a bimetal thermal switch for active cooling.

The DC end of the rectifier is then connected to the batteries. This connection should be as short as possible to avoid power losses, typically with a shunted digital wattmeter in between for monitoring. The batteries are then connected to a power inverter, which converts the power back to AC at a constant frequency for grid connectivity and end use.

For a site suitable for wind energy, an off-grid wind turbine-battery power system is a good alternative for supplying energy need. Reliability of the power supply is crucial, hence, sizing of the components, wind turbine and the battery bank is very important. There are different wind turbines with different ratings and power curves. For an off-grid turbine battery power system, for every different chosen wind turbine the minimum required number of batteries in the battery bank would be different for reliable and continuous supply. It is the usual case in practice that either the battery bank is chosen as undersized such that the consumer suffers from no power from time to time or the battery bank is chosen as oversized without any calculation and this results in high initial costs for the consumer.

Like other renewable energy technologies, wind is capital intensive, but has no fuel costs. The key parameters governing wind power economics are the:

- Investment costs (including those associated with project financing);
- Operation and maintenance costs (fixed and variable);

- Capacity factor (based on wind speeds and turbine availability factor);
- Economic lifetime; and
- Cost of capital.

Although capital intensive, wind energy is one of the most cost-effective renewable technologies in terms of the cost per kWh of electricity generated.

2.3 Solar Energy

Photovoltaics, also called solar cells, are electronic devices that convert sunlight directly into electricity. The Photovoltaic effect is when two different (or differently doped) semiconducting materials (e.g. silicon, germanium), in close contact with each other generate an electrical current when exposed to sunlight. The sunlight provides the electrons with the energy needed to leave their bounds and cross the junction between the two materials. This occurs more easily in one direction than in the other and gives one side of the junction a negative charge with respect to the other side (p-n junction), thus generating a voltage and a direct current (DC). PV cells work with direct and diffused light and generate electricity even during cloudy days, though with reduced production and conversion efficiency. Electricity production is roughly proportional to the solar irradiance, while efficiency is reduced only slowly as solar irradiance declines.

The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest growing renewable energy technologies and it is expected that it will play a major role in the future global electricity generation mix. Solar PV systems are also one of the most “democratic” renewable technologies, in that their modular size means that they are within the reach of individuals, co-operatives and small-businesses who want to access their own generation and lock-in electricity prices (IRENA, 2019).

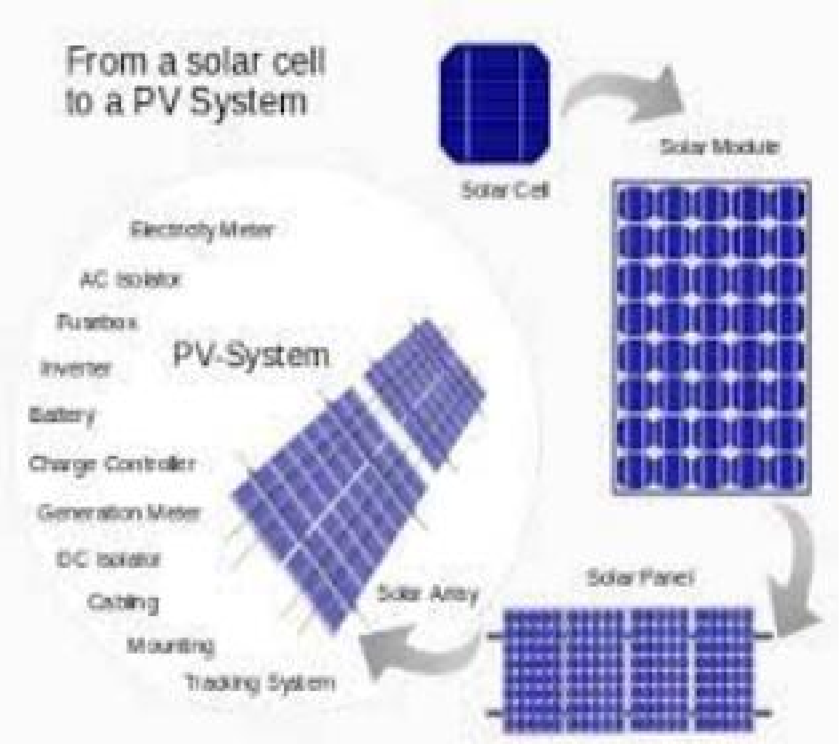

Figure 2.2: From solar Cells to Solar Panels

Photovoltaic system is a favorable technology for tropical climate economies. The components of a photovoltaic system is leads to massive cell production as of today, namely wafer-based crystalline (single crystal and multi-crystalline silicon), compound semiconductor (thin-film), or organic. The key components of a PV power system are various types of photovoltaic cells (often called solar cells) interconnected and encapsulated to form a photovoltaic module (the commercial product), the mounting structure for the module or array, the inverter (essential for grid-connected systems and required for most off-grid systems), the storage battery and charge controller (for off-grid systems but also increasingly for grid-connected ones).

Solar power is a renewable resource that is available everywhere in the world. Solar PV technologies are small and highly modular and can be used virtually anywhere, unlike many other electricity generation technologies. Unlike conventional power plants using coal, nuclear, oil and gas; solar PV has no fuel costs and relatively low operation and maintenance (O&M) costs. PV can therefore offer a price hedge against volatile fossil fuel prices. PV, although variable, has a high coincidence with peak electricity demand driven by cooling in summer and year round in hot countries.

A PV system consists of PV cells that are grouped together to form a PV module, and the auxiliary components (i.e. balance of system - BOS), including the inverter, controls, etc. There are a wide range of PV cell technologies on the market today, using different types of materials, and an even larger number will be available in the future. PV cell technologies are usually classified into three generations, depending on the basic material used and the level of commercial maturity:

- First-generation PV systems (fully commercial) use the wafer-based crystalline silicon (c-Si) technology, either single crystalline (sc-Si) or multi-crystalline (mc-Si).
- Second-generation PV systems (early market deployment) are based on thin-film PV technologies and generally include three main families: 1) amorphous (a-Si) and micromorph silicon (a-Si/µc-Si); 2) Cadmium-Telluride (CdTe); and 3) Copper- Indium-Selenide (CIS) and Copper-Indium- Gallium-Diselenide (CIGS).
- Third-generation PV systems include technologies, such as concentrating PV (CPV) and organic PV cells that are still under demonstration or have not yet been widely commercialized, as well as novel concepts under development.

Solar PV systems operate in the presence of direct or diffuse solar irradiation. The higher the level of solar resource, the lower the LCOE will be. Siting solar PV systems in areas with high solar resources, usually expressed as annual mean figures in kWh/m2/year or as kWh/m2/day, will therefore minimize the cost of electricity from solar PV. The global solar resource is massive. Around 885 million TWh worth of solar radiation reaches the Earth’s surface each year (IEA, 2011). The solar resource varies significantly over the day, week and month depending on local meteorological conditions. However, most of the annual variation is related to the Earth's geography.

Global Horizontal Irradiation (GHI) is the total amount of shortwave radiation received from above by a horizontal surface. This is expressed as W/m2 and includes both direct normal irradiance (DNI) and diffuse horizontal irradiance (DIF). In Nigeria, the average solar resource is around 3.5-7.0 kW h/m2/day. Tracking can also increase the yield, but with considerable additional expense.

2.3.1 Stand-alone PV System

Stand-alone PV system is a system that are not connected to the electricity grid. Stand-alone systems are typically small and supported by one array of balance of system. It is usually preferred to be installed in the rural area to satisfy the energy demand only without generating profit. At which point, if the demand is high, there are cases to which it become a stand-alone solar farm, with the availability of land space and initial investment. Stand-alone systems vary widely in size and application from wristwatches or calculators to remote buildings or spacecraft. If the load is to be supplied independently of solar insolation, the generated power is stored and buffered with a battery.

The balance of system for a stand-alone PV system is as shown in Figure 3.1 below. The whole system is usually connected to one string (one string usually holds 20 PV modules) due to its small generation. The generated DC current walkthrough the charge controller, which plays the important role in preventing battery from being overcharged and also it dissipating excess power from load resistance. Then, there is fuse and isolation switch that protect PV from accidental shorting our wires and automate switch off when it is not required. The fuse and isolation switch are optional to the complete system but implementing it can save energy and improve battery life.

Battery bank are typical for a stand-alone system since it store excess energy generated and allow flexible time of usage during nighttime. Then, the electricity is directed to the DC load demand before going to the inverter and convert into AC current for the AC load.

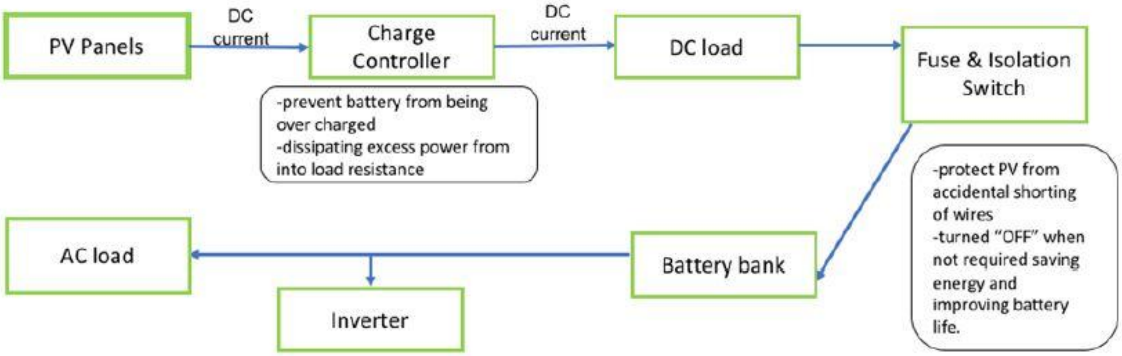

Figure 2.3: Solar-alone PV system components

2.4 Life Cycle Costing

Today, in the global economy and due to various other market pressures, the acquisition decisions of many engineering systems, particularly the expensive ones, are not made based on initial procurement costs but rather on their life cycle costs. Past experiences indicate that often engineering system ownership costs exceed acquisition costs. In fact, according to various studies, the engineering system ownership cost (i.e., logistic and operating cost) can vary from 10 to 100 times the original acquisition cost.

The life cycle cost of a system may be defined simply as the sum of all costs incurred during its life span (i.e., the total of acquisition and ownership costs). The term *life cycle costing* was used for the first time in 1965 in a report entitled "Life Cycle Costing in Equipment Procurement". This report was prepared by the Logistics Management Institute, Washington, D.C., for the assistant secretary of defense for installations and logistics, U.S. Department of Defense, Washington, D.C. Life cycle costing requires that all potential costs be calculated by taking into consideration the time value of money. In modern society, interest and inflation rates are utilized to take into consideration the time value of money. The approach used for estimating the total life cycle cost of equipment procurement (Dhillon, B. S, 2010).

LCC accounts for all relevant costs (only) over a defined period of time (the period of analysis). LCC encourages analysis of business needs and then communicating this to the project team. Costs of ownership (through construction, purchase or renting) of alternative options are evaluated over their whole life. Total cost of ownership/occupation is optimized by balancing initial capital and running costs. Analysis of risks and costs of loss of functional performance due to failure or maintenance are included. LCC promotes realistic budgeting for operation, maintenance and repair. LCC encourages discussion and recording of decisions about the durability of materials and components at the outset of the project. LCC makes it more probable that the best value for money solution is adopted. LCC provides data on actual performance and operation compared with predicted performance for use in future predictions and benchmarking (RICS, 2016).

At the same time, another assessment involving whatever costs in developing a project is very important. This analysis is named Life Cycle Cost Assessment (LCCA). This analysis is helpful in helping investors in deciding which methods or alternatives are more viable and cost-effective. It evaluates all processes within the project from the start of the project to the end of its life, but in terms of cost. For example, the PV system project, all costs involved from PV panel production until it is disposed (Fuller, 2005). Besides that, there are several economic analysis that lies within LCCA. For example, Life Cycle Cost (LCC), Levelized Cost of Energy

(LCOE), Net savings (NS), Savings of Investment Ratio (SIR), Net Present Value (NPV), Internal Rate of Ratio (IRR) and Payback Period (PB). These economic analysis is used in this project to evaluate the photovoltaic.

The life-cycle design (LCD) framework was developed to guide the environmental improvement of a product system while also optimizing performance, cost and legal requirements. The objective of LCD is to minimize aggregate life-cycle environmental burdens and impact, including energy consumption, solid waste generation and human and ecological health effects related to air and waterborne pollutant emissions.

According to Wikipedia, Life-cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds. The life-cycle cost (LCC) of a project it the total amount of all costs incurred by the project from its initial design stages to its decommissioning.

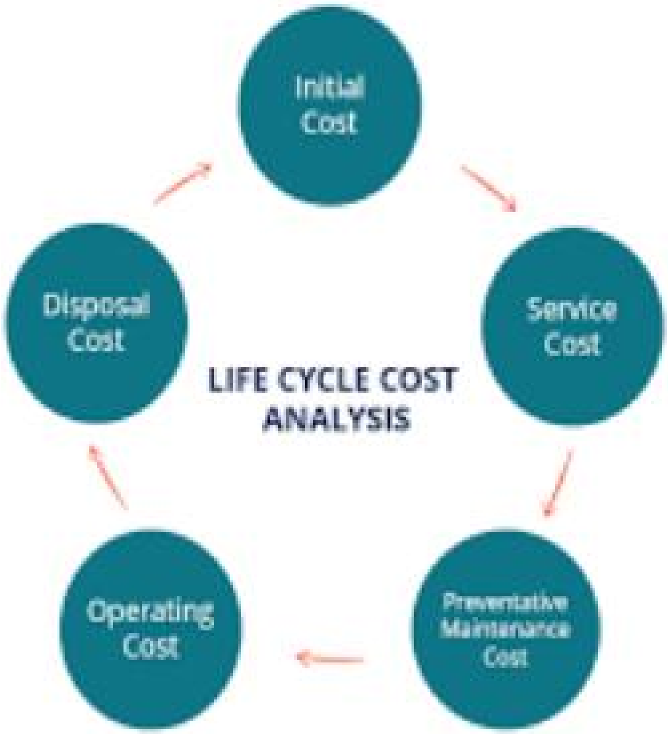

Figure 2.4: Life Cycle Cost (LCC) process

To determine what the life-cycle cost of a project will be, firms carry out life-cycle cost analysis (LCCA). A LCCA takes into account all costs, from the cost of construction, cost of fuel or repairs to the cost imposed by emissions from the project. The analysis takes into account all known and projected costs. Costs such as the social cost from pollution are difficult to quantify and therefore the LCCA is not exact. The LCCA of a project allows firms to compare different projects to determine which is the cheapest in the long term.

Over the years, a large number of life cycle cost models have been developed that include both general and specific models. No single life cycle cost model has been accepted as a standard model in the industrial sector. There could be many reasons for not having a standard model, including the inclinations of users, the nature of the problem, the existence of many different cost data collection systems, and many different types of equipment, devices, or systems. Nonetheless, irrespective of the types of models used in performing life cycle cost analysis, they all must be effective in representing equipment, systems, or subsystems, transparent and visible.

Sherif and Kolarik, 1980 classified life cycle cost models under two categories: analytical models and heuristic models. Analytical models typically consist of a set of mathematical relationships which are designed to describe a certain aspect of a system. Usually, they are accompanied by a set of underlying assumptions. These assumptions tend to restrict or limit the model's ability to reflect the actual system's performance. The magnitude of this limitation is usually directly related to the complexity of the system. A wide variety of analytical models have been documented in LCC and related areas. These range from models covering very specific aspects of a system to models which address total system LCC. Heuristic models (ill-structured analytical models) usually use rules of thumb or strategies that are intuitively appealing, but are not guaranteed to produce optimum solutions. They can however be incorporated to simulation models. Heuristic models are usually tailored to specific applications rather than to broad problem classes and are not documented in the literature to the same extent as analytical models.

The LCCA is usually presented in the form of the levelized cost of energy (LCOE) for a project. The LCOE measures these costs over the lifetime of a plant and determines how much it costs to produce an amount of energy (usually per MWh)· The LCCA of a project can be used to compare the lifetime costs of one project compared to another.

Various types of information are required to perform life cycle costing studies. These include the acquisition cost of the item, the useful operational life of the item in years, the annual maintenance cost of the item, transportation (delivery) and installation costs of the item, discount and escalation rates, the annual operating cost of the item, taxes (e.g., tax benefits from depreciation, investment tax credit), and the salvage value or disposal cost of the item.

In any case, prior to starting a life cycle costing study, it is considered useful to seek answers to questions on topics such as the following (Dhillon, B. S, 2010):

- goal of the estimate;
- assumptions and ground rules;
- treatment of uncertainties;
- required data;
- required details of the analysis and analysis-related constraints;

- involved personnel and the responsibility of the cost analyst;
- controlling and auditing the life cycle costing process by the seller's and purchaser's management;
- estimating procedures to be followed;
- life cycle cost analysis users;
- life cycle cost analysis format;
- life cycle costing time schedule;
- required accuracy and precision of the analysis; and
- fund limitations.

2.5 Related Works

Otasowie and Ezomo, 2014, performed a life cycle cost analysis of diesel generator and National grid in Nigeria. The BTS cost analysed was cost of BTS power equipment acquisition, operation and maintenance. The load demand of BTS was accessed using the load demand of diesel generator and National grid. The life cycle cost was used to compare diesel generator and the National grid. The methodology used in this work was to visit a BTS and access the load demand. The demand was now used to compute the life cycle cost for generator set and the National grid system. From the LCC analysis conducted to assess the economic viability, the result of this study shows that the generator set should be encouraged to power remotely located BTS.

(Mohanlal Kolhe et al 2002) in a paper economic viability of stand-alone solar photovoltaic system in comparison with diesel powered system in India, stated that the cost of PV systems decreases and diesel cost increase, the break even points occur at higher energy demand.

(Bejamin O. Agajelu et al 2013) in a paper Life cycle cost analysis of a Diesel/Photovoltaic hybrid power generating system state that the economic analysis shows that the hybrid system has the least life cycle cost and cost of energy out of the three power systems considered.

(Bala E.J, et al 2008) in a paper assessment of diesel generator and solar PV for use in the Global System for mobile communication (GSM) phone industry in Nigeria showed that the solar PV is less costly to be deployed in the phone industry for period over five years.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

For the calculation of the estimated economic cost, LCC is the most common and most sophisticated method. As a cost-oriented approach, LCC focuses on all resources consumed by the project during its lifetime. Through LCC, these resources are quantified as costs and are accumulated to find the total cost of the device over its economic life. Different from the cost of a project, which only calculates the cost of construction and installation, LCC includes the initial investment, operating and maintenance costs, replacement costs and disposal costs. Therefore, the calculation of LCC includes both current costs and the predicted/anticipated future costs. When calculating future costs, the net present value and internal rate of return are very important parameters. Meanwhile, these two parameters are also important parameters for comparison of various alternative investments (Fan, 2014).

As stated in chapter two (2), LCC models can be analytical or heuristical. An analytical approach is used to analyze and compare the LCC of wind and solar PV system for 10kw power demand over a period of 25 years. The major disadvantage of this approach is the model’s ability to reflect the actual system performance is limited due to the assumptions made when developing the model.

3.2 LCC Formulation

LCC is comprised of five (5) basic steps. While the steps are generally sequential, the sequence can be altered as per the project requirements. The steps describes as follows:

Step 1: Establish framework design & Define analysis period.

A detailed framework is produced alongside the available alternatives. This is because the LCCA analysis involves the use of time value of money.

Step 2: Determine activity timing.

It means determining the timing of all activities that need to be done to run LCCA. For example, provide a questionnaire, visit a case study site, collect case study data, analyze data, and present reports. Case study data from experts were collected online.

Step 3: Estimate costs.

The third step in this analysis is to identify and estimate all costs involved in each phase. Among the costs involved will be the cost of materials, equipment, electricity, labor and so on.

Step 4: Compute life cycle costs.

Once, all data is available, the LCCA calculation can be done in the fourth step. These data are calculated using several economic analyses; life cycle cost (LCC), levelized cost of energy (LCOE), net savings (NS), savings to investment ratio (SIR), net present value (NPV), internal rate of return (IRR) and payback period (PB).

Step 5: Analyze results & Evaluate alternatives.

In the last step is to analyze all the results. Through this, where the cause of high cost contributors can be identified. In addition, comparisons between alternatives can determine which alternatives are best and can save more cash. At the same time, alternative evaluations are also carried out, through this alternative which will bring more processes that are most viable and cost-effective for a project.

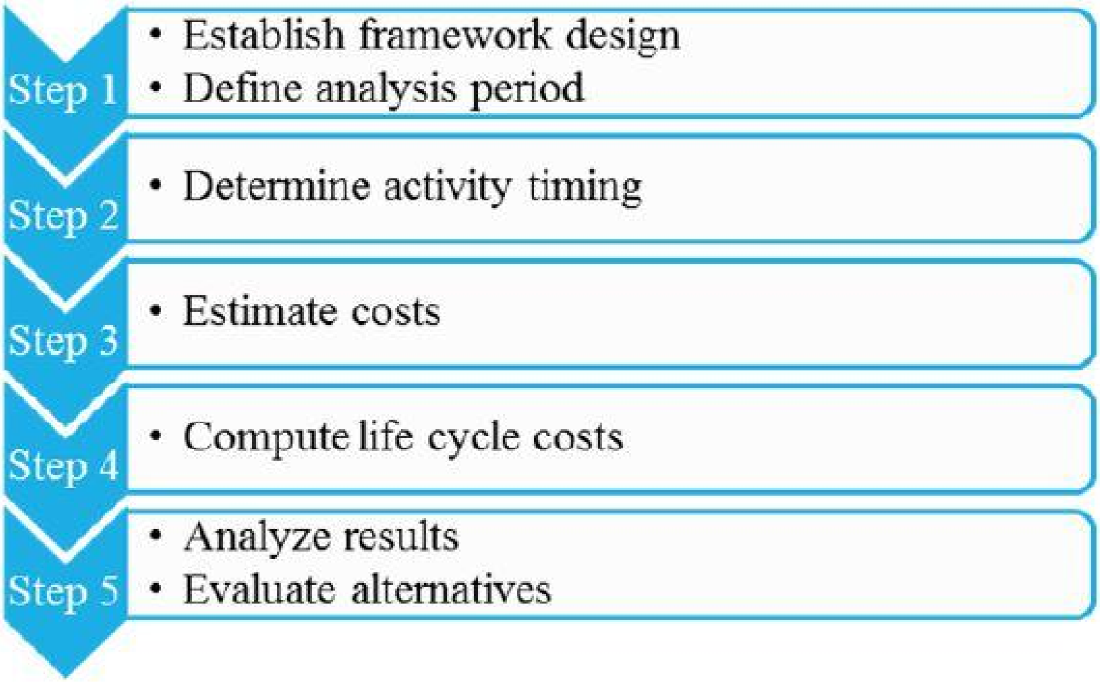

Figure 3.1: LCC Methodology

Life Cycle Cost (LCC)

Life cycle costs are tools for estimating the overall cost of the project including start-up costs, fuel costs, operating and maintenance costs, repair costs, replacement costs, waste values, finance charges, and other non-financial benefits.

$$LCC = C_I + C_{OMR} + C_{rep} + C_O - C_{res} \quad \text{………………………………..…(3.1)}$$

Where

LCC is the life cycle cost

C_I is the investment cost

C_{OMR} is the operating, maintenance and repair cost

C_{rep} is the replacement cost

C_O is other costs

C_{res} is the waste value.

Investment cost (CI) refers to the initial investment of power plants such as land, photovoltaic modules, transmission, system design and installation costs. Operational, maintenance and repair costs (C_{OMR}) refer to operator's pay, inspection, insurance, property taxes and repair costs. The replacement cost (Crep) is the total cost for replacement of equipment required during the life of the system. Other costs (C_O) include energy, water and other associated costs during the life of the system. The residual value (Cres) refers to the resale value and the residual value; this value is the net value of the system in the last year for the life cycle period.

All LCC costs are usually totaled to a present day value known as net present value (NPV). Net present values are calculated based on interest and inflation rates. The inflation rate is used to transform anticipated future costs to baseline current dollar value, and a discount rate is used to discount the future expenditure because of “time value of money”.

Let i = interest rate

j = inflation rate

$$F_{PW} = \frac{(1+j)^n}{(1+i)^n} \quad \text{……………………………………………………………} 3.2$$

Where F_{PW} is called the present worth factor.

The present worth, PW is calculated as:

$$PW = F_{PW} \times C_O \quad \text{...}3.3$$

Where C_O is the cost of the object.

If the annual recurrent expenditure or future expenditures (cash flows) are fixed in size and regularly occur over a specific number of periods, the situation is known as an annuity. Then, the present Value (PV) is calculated as:

$$PV = F_n \times \frac{(1+i)^n - 1}{i(1+i)^n} \quad \text{...}3.4$$

Where F_n is the constant cash flows in year n, i is the interest rate.

The project case studies include a stand-alone PV system and a stand-alone wind turbine system both of 10kW capacity. The data from each case studies is obtained by expert opinions. All of the data that have been obtained is being analyzed and interpreted by LCC and identification of the most viable and cost-effective system between the two is determined.

The total initial investments, total operating and maintenance cost were computed based on an exchange rate of ₦410.97 to a dollar as at 10/07/2021. Inflation rate was taken at 15.79% and the interest rate was taken at 4.5%. Battery lifetime was estimated at 5 years and at the end of each lifetime span replacement was conducted (Jakov, 2011).

Table 1: Wind turbine system assumptions

S/N	ASSUMPTION	DATA SOURCE
1.	Installation cost was taken at 30% of the capital cost	Ragheb, 2017
2	Other costs include costs such as taxes, financing, system design, regulatory taken at 18% on initial investment	NREL, 2016
3.	Operation and Maintenance cost was taken at 2% system cost per year	(Jakov et. al., 2011), (Suresh and Sudhakar, 2013)
4.	Waste (residual) value was assumed to be 20% of initial investment cost.	This is estimated because the residual does not occur yet at the base date.

Table 2: Solar PV system assumptions

S/N	ASSUMPTION	DATA SOURCE

1	Testing and installation cost was assumed to be 3.75% of the total capital cost	(Mustafizur et. al., 2016)
2	Other costs include local permit, inspection fees, and taxes on solar panels taken at 22% of total initial investment cost.	IRENA, 2020
3	Operation and Maintenance cost was taken at 1% of system cost per year.	"Online". Operational costs of solar panel system. https://www.powerfromsunlight.com Accessed July 23, 2021.
4.	Waste (residual) value was assumed to be 20% of initial investment cost.	This is estimated because the residual does not occur yet at the base date.

Wind turbine system.

Table 3.1: Total Inital investment for wind turbine system

S/N	ITEMS	QUANTITY	UNIT	TOTAL

			COST(₦:K)	COST(₦::K)
1.	10kW Wind Turbine (HAWT) R&X	1	1,148,085.00	1,148,085.00
2.	10kW Regulator/charge controller (Flexmax MPPT)	1	113,162.50	113,162.50
3.	Pole (Tower) 1.5m/length & Guy Wires	6.5	30,000.00	195,000.00
4.	Battery (24V, 150A) (Lithium Polymer Battery)	6	168,303.50	1,009,821.00
5.	Gr-257 Growatt inverter (10KVA)	1	618,073.00	618,073.00
6.	Transportation			50,000.00
	Sub-total			3,134,141.5
	Installation cost (30% of capital cost)			940,242.45
	Total initial investments			4,074,383.95

Operating and Maintenance cost:

Turbine maintenance – 2% of turbine cost per year = ₦(0.02 x 1,148,085.00) = ₦22,961.70 per year

Present value = ₦22,961.70 x $\frac{(1+0.045)^{25}-1}{0.045(1+0.045)^{25}}$ = ₦340,480.68 for lifetime.

Other costs

18% of total initial investment

Other costs = 0.18 x ₦4,074,383.95 = ₦733,389.11

Waste value:

Resale value of wind turbine = 20% of initial investment = 0.2 x ₦ 4,074,383.95

= ₦814,876.79

Solar PV System

Table 3.3: Total Initial Investment for PV system.

S/N	ITEMS	QUANTITY	UNIT COST(₦:K)	TOTAL COST(₦::K)
1.	250W solar cells (Miratec	40	57,000.00	2,280,000.00

	Monocrystalline)			
2.	10kW Regulator/charge controller (Flexmax MPPT)	1	113,162.50	113,162.50
3.	Stand (ground install racks)	20	2,057.50	41,150.00
4.	Battery (24V, 150A) (Lithium Polymer Battery)	6	168,303.50	1,009,821.00
5.	Gr-257 Growatt inverter (10KVA)	1	618,073.00	618,073.00
6.	Transportation			50,000.00
	Sub-total			4,112,206.00
	Installation cost (3.75% of capital cost)			154,207.73
	Total initial investments			4,226,413.73

Operating and Maintenance Cost:

Solar PV system maintenance – 1.0% of cost per year = ₦ (0.01 x 2,280,000.00) = ₦22,800.00

Present value = ₦22,800.00 x $\frac{(1+0.045)^{25}-1}{0.045(1+0.045)^{25}}$ = ₦338,082.96

Other costs

22% of total initial investment.

Other costs = 0.22 x ₦4,226,413.73 = ₦929,811.02

Waste value:

Resale value of solar PV system = 20% of total initial investment = 0.2 x ₦4,226,413.73 = ₦845,282.75

Total Replacement Cost (same for both systems).

Battery Replacement (four (4) times over lifespan):

1. Present worth factor, at 5th year, $F_{PW} = \frac{(1+0.1579)^5}{(1+0.045)^5}$ = 1.67
2. Present worth factor, at 10th year, $F_{PW} = \frac{(1+0.1579)^{10}}{(1+0.045)^{10}}$ = 2.79
3. Present worth factor, at 15th year, $F_{PW} = \frac{(1+0.1579)^{15}}{(1+0.045)^{15}}$ = 4.66
4. Present worth factor, at 20th year, $F_{PW} = \frac{(1+0.1579)^{20}}{(1+0.045)^{20}}$ = 7.78

Cost of battery = ₦1,009,821.00

Present worth of 5th, 10th, 15th, and 20th year's replacement

= (1.67 + 2.79 + 4.66 + 7.78) x ₦1,009,821.00 = ₦17,065,974.9

Controller replacement (two (2) times over lifespan):

1. Present worth factor, at 9th year, $F_{PW} = \frac{(1+0.1579)^9}{(1+0.045)^9} = 2.52$
2. Present worth factor, at 18th year, $F_{PW} = \frac{(1+0.1579)^{18}}{(1+0.045)^{18}} = 6.34$

Cost of controller = ₦226,325.00

Present worth of 9th and 18th year's replacement

= (2.52 + 6.34) x ₦226,325.00= ₦2,005,239.50

Inverter replacement (once over lifespan):

Present worth factor, at 13th year, $F_{PW} = \frac{(1+0.1579)^{13}}{(1+0.045)^{13}} = 3.80$

Cost of inverter = ₦618,073.00

Present worth of 13th year replacement = 3.80 x ₦618,073.00 = ₦2,348,677.40

Table 3.4: Total Replacement

S/N	ITEMS	COST (₦:K)
1	Battery Replacement – 4 times over lifespan	17,065,974.90
2	Inverter replacement – once over lifespan	2,348,677.40
3	Controller replacement – 2 times over lifespan	2,005,239.50

	Total Replacement Cost	21,419,891.80

CHAPTER FOUR

DATA ANALYSIS

4.1 Analysis of Result

The LCC of the solar PV and wind Turbine system have been evaluated using (3.1) and the results shown below.

Table 4.1: Summary of LCC of Solar and Wind Turbine System

costs	Wind turbine (₦:K)	Solar PV system (₦:K)
Total Initial Investment cost	4,074,383.95	4,226,413.73
Operating and Maintenance cost	340,480.68	338,082.96
Replacement cost	21,419,891.80	21,419,891.80
Other Costs	733,389.11	929,811.02
Waste Value Cost	814,876.79	845,282.75
LCC	25,753,268.75	26,068,916.76

From the above analysis, the life cycle of wind turbine is lower that of the solar PV system. This is under the assumption of a fairly constant wind speed for the wind turbine system. Other assumptions made in the course of the analysis include:

- The project is a commercial project.

- All the materials required by the project are imported from China.
- The same means of transportation is used for both project.

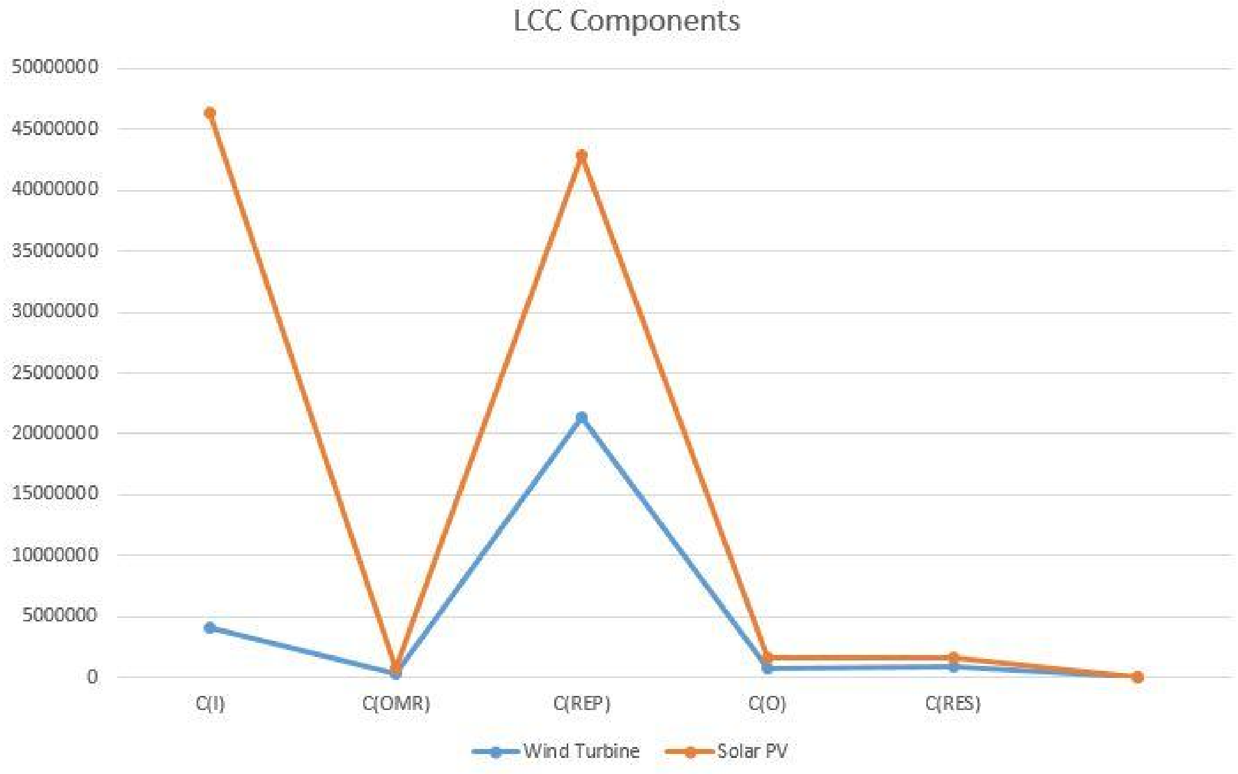

Figure 5: Plot showing the component of LCC for wind and solar PV system

The total initial investment cost of solar PV system is fairly higher than that of the wind turbine for 10kW power. The case is usually different for different power requirement and scale of the project. All things being equal, this initial investment cost affects other cost associated with the system.

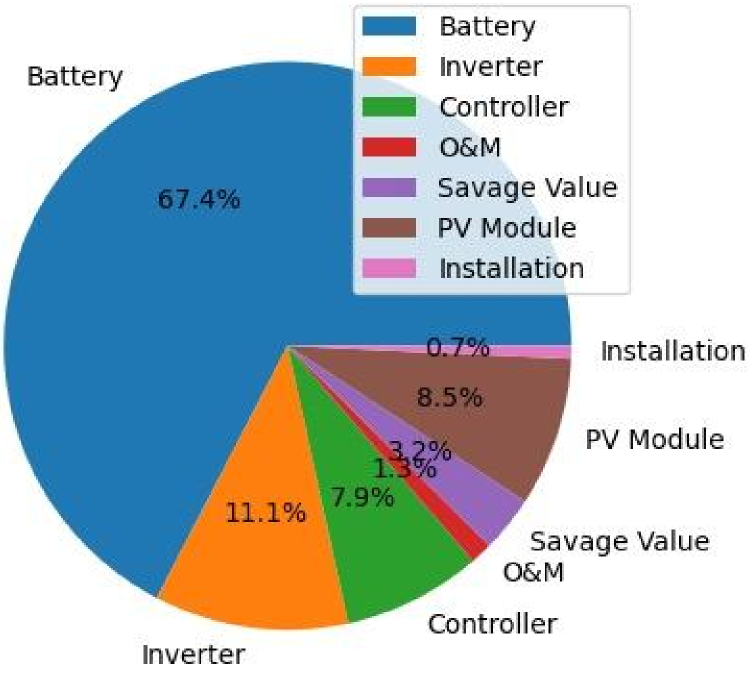

Figure 6: Percentage-wise cost of Solar PV system parameters

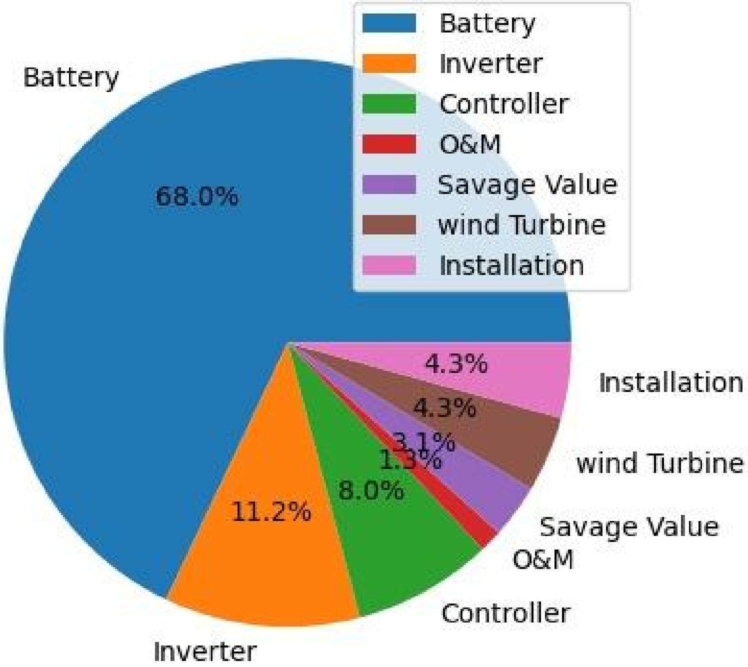

Figure 7: Percentage-wise cost of Wind Turbine System Parameters

4.2 Recommendations Based on Data.

For locations where wind resource is readily available, it is more cost effective to install a 10kW wind turbine than a 10kW solar PV system. Factors like solar irradiance and wind speeds are very important in the decision making of which system to install since the electricity produced is directly dependent on them.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The LCC of solar PV system is lower than that of the wind turbine system. This majorly due to the lower initial investment cost of installing a PV system when compared to the wind turbine system. Wind turbines generally have higher maintenance cost than PV system due to wear and tear of moving parts. Since both systems are stand-alone, that is, off-grid, they require batteries which incure basically the same operation and maintenance cost.

5.2 Recommendation and Future Work

Renewable Energy (RE) systems cost data in Africa are not systematically collected or made available to policy makers, resulting in difficulties in setting realistic policy support levels that are efficient and effective. The collection of representative real-world project costs in Africa is extremely challenging due to the small scale and fragmented nature of the industry in Africa, as well as confidentiality issues. Also, data quality and coverage are highly variable, and collecting data on cost breakdowns is extremely difficult. This makes data analysis time-consuming and sometimes limits the conclusions that can be drawn.

Systematic cost data collection and comparison is not the norm in Africa meaning that there is often a lack of information on costs and their evolution over time.

Future research should be focused on a coordinated effort to collect the installed costs of Renewable Energy (RE) systems in Africa (Nigeria inclusive), across all market segments, is required to improve policy making and to share experiences among countries and regions. This will improve the efficiency of policy support and accelerate deployment, by targeting efficient cost structures in new markets.

Future research should also be focused on developing software particularly tailored for life cycle costing (LCC) of energy systems. Such a software may include Machine Learning technique to develop and predict more accurate models for LCC of different energy systems for Renewable Energy Sources (RES). A large amount of resources are spent on constructing new facilities and maintaining the existing ones. The total cost of ownership can be minimized by focusing on reducing the facilities life-cycle costs (LCCs) rather than the initial design and construction costs. With the developments of machine learning in predictive analytics, deeper level of knowledge on LCC can be attained.

REFERENCES

1. https://data.worldbank.org/indicator/FR.INR.RINR?locations=NG

2. https://energypedia.info/wiki/Nigeria_Energy_Situation (accessed July 10, 2021)

3. https://energyeducation.ca/encyclopedia/Life-cycle_cost(accessed June 28, 2021)

4. https://en.wikipedia.org/wiki/Life-cycle_cost_analysis (accessed July 1, 2020)

5. https://en.wikipedia.org/wiki/Small_wind_turbine (accessed July 10, 2020)

6.https://nairametrics.com/2017/11/13/wind-energy-choice-energy-generation-nigeria (accessed July 2, 2021)

7. https://www.statista.com/statistics/383132/inflation-rate-in-nigeria/

8.https://www.powerfromsunlight.com/operational-costs-solar-panel-system (accesed 23rd july 2021)

9. APEC Energy Working Group April 2019, Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) Framework of Photovoltaic Systems in the APEC Region. ISBN: 978-981-14-1313-1

10. Bala E.J. elecetra.(2008) Assessment of Diesel Generator and Solar PV for Use in the Global System Mobile (GSM) Phone Industry in Nigeria. Nigerian Journal of Solar Energy Vol.19-21 Pp. 94-98.

11. Benjamin O. Agajelu et al. Life cycle Cost Analysis of a Diesel/Photovoltaic Hybrid Power Generating System. Industrial Engineering letters 2013 Vol. 3. No. 1 Pp. 19-30

12. Dhillon, B. S. Life cycle costing for engineers, 1947.

13. Fuller, Sieglinde K. 2005. Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123.

14. Gregory A. Keoleian and Geoffrey McD. Lewis, Application of Life-cycle Energy Analysis to Photovoltaic Module Design

15. Iain Staffell and Richard Green, How does wind farm performance decline with age? , 2014

16. IRENA (International Renewable Energy Agency), Renewable Energy Technologies: Cost Analysis Series, Vol 1: Power Sector, Issue 4/5, 2012.

17. IRENA (International Renewable Energy Agency), Renewable Energy Technologies: Cost Analysis Series, Vol 1: Power Sector, Issue 5/5, 2012.

18. IRENA (International Renewable Energy Agency), Renewable Power Generation Costs in 2019, 2020

19. Jakov Šimunović, Frano Barbir, Gojmir Radica, Branko Klarin, Techno-economic analysis of PV/wind turbine stand-alone energy system, 2011.

20. Jiawei Fan, Life Cycle Assessment And Life Cycle Cost of Photovoltaic Panels on Lake Street Parking Garage, 2014.

21. Md. Mustafizur Rahman, A.K.M. Sadrul Islam, Sayedus Salehin, Md. Abdullah Al-Matin, Development of a Model for Techno-economic Assessment of a Stand-alone Off-grid Solar Photovoltaic System in Bangladesh, 2016.

22. NREL (National Renewable Energy Laboratory), Distributed Wind Soft Costs: A Beginning, 2016

23. Otasowie, P.O and Ezomo, P. I, Life Cycle Cost Analysis of Diesel Generator Set and National Grid in Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 5(5):363-367 (ISSN: 2141-7016).

24. RICS professional guidance, UK. Life cycle costing 1st edition, April 2016

25. Suresh P. V and Sudhakar K., Life Cycle Cost Assessment of Solar-Wind-Biomass Hybrid for Energy Centre, MANIT, Bhopal, 2013.

26. U.S Energy Information Administration, International Energy Outlook 2016, vol. 0484, no. May. 2016. Available: http://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf (Accessed 10 February 2020.

27. Wei Tong, Kollmorgen Corporation, Virginia, USA. WIT Transactions on State of the Art in Science and Engineering, Vol 44, © 2010 WIT Press.

28. William J Kolarik and Yosef S Sherif Life Cycle Costing: Concept and Practice, USA, 1980