Degree Project

Level: master’s

An Environmental and Health Benefit and Cost analysis of Renewable Energy in Nigeria

A comparison between the investment in solar energy plant and hydropower plant

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Abstract: This study analyses the environmental and health benefits associated with the use of renewable energy sources, focusing on the costs and savings involved. The research employs a comprehensive cost-benefit analysis approach, comparing the costs associated with generating energy from a 10 megawatts solar energy power plant versus a 10 megawatt hydropower plant. The data used in this research was gathered from a variety of sources, including government reports, academic studies, and industry publications. The analysis ensued a positive net benefit for both power plants, while the economic useful life of developing and implementing the solar plant is shorter, the long-term benefits of these technology outweighs that of the hydro power plant. The data indicates that renewable energy technologies can significantly reduce greenhouse gas emissions and air pollution, leading to substantial improvements in public health and environmental quality. Overall, this research indicates that investing in renewable energy sources is not only an environmentally responsible choice, but also a viable decision for the society.

Keywords: Environment, Health, Solar Energy and Hydropower

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1. Introduction

The absence of and the insufficient supply of power is one of the biggest obstacles preventing Nigeria development. According to World Bank press release (The World Bank Group, 2021) the country's lack of reliable power is major constraint to the citizens and organizations, resulting in annual economic losses of $26.2 billion (₦10.1 trillion) which is estimated to be about 2 % of Nigeria's GDP. Nigeria has an estimated population of 200 million (United Nations, 2022), about 85 million people lack access to electricity, leaving the country's electricity access rate at 57 % (World Bank, 2021). In light of the current situation, the Nigeria government has set three significant and perhaps lofty goals for the provision of electricity by 2050. These three goals pertain to the expansion of renewable energy sources, decrease of emission and increased access to electricity. The National goal for universal access to electricity is for over 90% of the population including those in rural and urban areas (Roche et al., 2020). The focus of this paper is to therefore develop an analysis that encompasses the environmental and health benefits and cost of a 10 megawatts (MW) solar energy power plant (SEPP) and a 10 MW hydropower plant in Bauchi state, Nigeria.

According to the United States Agency for International Development (USAID, 2022), Nigeria has abundant hydro, solar, wind, oil and gas energy resources, and its existing power plants has the capacity to produce 12,522 MW of electricity. However in most days, it can only deploy about 4,000 MW due to aging infrastructures, transmission and distribution constraints in addition to operational and maintenance inefficiencies. Also, according to the International Energy Agency (IEA, 2019), 80% of power generation in Nigeria comes from fossil fuel, at this rate, "Nigeria's greenhouse gas (GHG) emissions are projected to grow to around 900 million tonnes by 2030" (Remtang et al., 2021). Additionally, reports on air pollution, gas flaring, oil spillage, pipe vandalism continues to negatively impact residents of the producing communities and the environment. The Nigeria National Oil Spill Detection and Response Agency (2022) reported 822 oil spills in 2020 and 2021, resulting to a total of 28,003 barrels of oil leakage into the environment. For a sustainable development Nigeria must therefore replace the use of fossil fuel with more renewable energy.

According to the International Hydropower Association (2022) hydro power is the most sought-after renewable energy in Nigeria, while solar energy is the most accessible sources of energy in Nigeria (International Renewable Energy Agency, 2021). For these reasons, this paper will serve the purpose of estimating and comparing the environmental and health impact of a 10 MW solar energy power plant and a 10 MW hydro power plant using a cost-benefit analysis (CBA). The main objectives are to monetize the environmental and health benefits derivable from these renewable energy power plants, to compare these benefits with the investments and operational costs and calculate the net present value (NPV).

This analysis is done for Bauchi state in northern Nigeria because it holds significant potential for renewable energy development (Mshelia, 2021). However, this paper is delimited by the following reasons; first, the plant size, Bauchi state has a potential for larger renewable power plant, but the choice for a 10 MW power plant is as a result of the unavailability of data coverage for larger plants. Secondly, the benefit transfer approach amongst other desirable approaches is the only suitable method to monetize the estimated impacts for this analysis and lastly, the research focuses only on the environmental and health impacts rather than a comprehensive CBA which would include the economic, financial and the social costs and benefits for example, energy security, job creation, price stability, loss of space (land for the solar plant and river in the case of hydropower) and recycling cost of obsolete plant. Despite these limitations, this paper will serve as a benchmark for further analysis of larger renewable power plant, in other states and in Nigeria as a whole.

The next section describes the background of energy provision and sources of electricity in Nigeria. In section 3, the conceptual foundations are discussed followed by the reviews of previous literature on CBAs of renewable energies in some developing countries and methodology of this paper. Section 6 presents the case study, the impact category, monetizes the costs and benefits, and computes the NPV and a sensitivity analysis for both projects. Finally, section 7 draws up a conclusion and suggests recommendation based on the attained results.

2. Background of the current provision and use of electricity in Nigeria

The Long-Term Vision for Nigeria (LTV-2050) is that by 2050, Nigeria is a country of low-carbon, climate-resilient, high-growth circular economy that reduces its current level of emission by 50 %, moving towards having net-zero emissions across all sectors of its development in a gender-responsive manner (Department of climate change, 2021). According to a renewable energy report (Sterling X Stars, 2022), Nigeria is currently a lower middle-income country, with nearly half of all electricity consumed in Nigeria being self-generated, indicating a significant unmet demand. Small-scale diesel and gasoline generators have a combined capacity of nearly 14 gigawatts (GW), this production creates local air pollution which negatively impacts the human health.

Nigeria has a variety of commercially viable natural energy sources in both renewable and non-renewable forms. The main non-renewable energy sources include crude oil, coal, lignite, tar sands, natural gas, and nuclear materials, while the key renewable energy sources are the sun, wind, hydro, biomass, and tidal waves. Despite this vast energy endowment, the country's inability to obtain inexpensive and dependable electricity is impeding industrial production and economic expansion, (USAID, 2022). All manufacturing companies in Nigeria rely on self-generated electricity to power their operations and to maintain power backup in the case of a power outage due to the country's severe energy shortage (Anudu, 2022). Energy poverty -which refers to the lack of access to modern energy services-, needs to be eradicated for future sustainable growth in a low carbon development scenario to be envisioned. For Nigeria's economy to grow, everyone needs access to sustainable energy.

2.1 Renewable energy resource in Nigeria

Nigeria is a signatory to the 2015 Paris Agreement, committed to keeping the rise in temperature below 2°C by 2050, in other to do this, it is important to attain a net zero greenhouse gas (GHG) emission (Bureau et al., 2021). When fossil fuels are burned to produce power and heat, they release a significant amount of greenhouse gases that cover the earth and trap solar energy. According to the UN press release, fossil fuels, such as coal, oil, and gas, account for more than 75 % of all greenhouse gas emissions and almost 90 % of all carbon dioxide emissions.

Furthermore, the traditional power sector in Nigeria faces obstacles such as lack of gas in power plant and inadequate grid infrastructure, which has made it necessary to transition away from using gas-fired power plants and towards using renewable energy as well as to substitute on-grid electricity with off-grid renewable alternatives. According to the Intergovernmental Panel on Climate Change (2012), renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Renewable energy sources are plentiful and are all around us. In this analysis the focus will be on solar energy and hydropower.

2.1.1 Solar energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the earth is about 10,000 times greater than the rate at which humans consumes energy. Solar technologies can deliver heat, cooling, electricity and fuels for a host of applications. It converts sunlight into electrical energy through mirrors that concentrate solar radiations. For several years after installation, solar farms offer an easy way to provide safe, renewable, and locally produced energy (Foster et al., 2009).

In 2022, Nigeria boasted a total generated capacity of about 42 GW, this is consistent with the country's installed solar capacity's growing trend from the 15 MW recorded in 2012 and the 19 MW in 2018. According to a report by the department of climate change in Nigeria (2021) in 2050 the renewable energy master plan seeks to install 500 MW of solar PV capacity. About 427,000 MW of photovoltaic and concentrated solar power is theoretically possible (Netherlands enterprise agency, 2021). As more enterprises and industries use the solar technology to power their operations, the commercial and industrial solar sector is also expanding. However, small solar and solar home systems dominate the market (Remteng et al., 2021).

2.1.2 Hydro power

Water traveling from higher to lower elevations is used as a source of energy in hydropower. Reservoirs and rivers are two sources of it. Hydropower plants that use reservoirs rely on the water that has been stored there, whereas runoff plants use the river's current to generate energy (Wagner and Mathur, 2010).

Nigeria is blessed with numerous huge rivers and waterfalls, as well as an estimated 1,800m^3 of renewable water resources per person annually. The Niger River, Benue River, and the Lake Chad basin are the key water sources with the greatest hydroelectric potential. The installed hydroelectric capacity is currently 2,062 MW (Nchege and Okpalaoka, 2023). According to study by the international hydropower association (2022) hydropower has an overall exploitable potential of about 14,120 MW, producing more than 50,800 GWh of electricity annually.

According to Remteng et al. (2021) cooperation between the ministries of power and water resources was formed with the goal of renovating a number of existing hydroelectric plants. These plants include the 700 MW Zungeru and 40 MW Kashimbila hydropower plants currently under development, as well as the Gurara 1 (30 MW), Tiga (10 MW), Oyan (10 MW), Challawa (8 MW), and 6 MW Ikere plants.

2.1.3 Other renewable resources in Nigeria

Large wind turbines situated on land (on shore) or in the water (offshore) are used to generate electricity from wind by capturing the kinetic energy of flowing air. Although onshore and offshore wind energy technology have advanced recently to maximize the amount of electricity produced, with higher turbines and greater rotor diameters, wind energy has been used for thousands of years. Wind energy generation currently has a 10 MW installed capacity in Nigeria; it was finished in early 2021 and is situated in Katsina State, this is considered a step forward in Nigeria's wind energy industry.

Bioenergy is made from various organic resources, known as biomass, including wood, charcoal, dung, and other manures for the production of heat and power, as well as agricultural crops for the creation of liquid biofuels. Energy emissions of greenhouse gases from burning biomass are produced, albeit at a lower rate than from burning fossil fuels like coal, oil, or gas. However, given potential adverse environmental effects connected to large-scale expansions in forest and bioenergy plants, and the ensuing deforestation and land use change, bioenergy should only be employed in limited applications.

Geothermal energy makes use of the thermal energy that is available from the earth's interior. Geothermal reservoirs can be heated using wells or other methods. Hydrothermal reservoirs are those that are naturally sufficiently hot and permeable, whereas enhanced geothermal systems are those that are naturally adequately hot but improved by hydraulic stimulation.

3. Conceptual Foundations

One of the ways to view CBA is as a framework for evaluating the relative efficacy of policy options. Boardman et al. (2018) defines CBA as a policy method that quantifies in monetary terms the value of all consequences of policy to all member of the society. The idea behind this reasoning is simple; it is a functional technique for measuring whether the benefits of a particular action are greater than the costs, judged from the view point of the society at large (Bergmann and Hanley, 2012). There are several economic theories associated with a CBA, for the case of this study the focus is on welfare, opportunity cost, market failure and willingness to pay.

3.1 Welfare economics

Welfare economics is a branch of economics that focuses on assessing and maximizing the overall well-being of individuals in society. It seeks to determine how policy measures, actions and inceptives impact the welfare of people, such inceptives that could motivate individuals and organisations towards embracing green energy includes renewable portfolio standards (RPS), renewable energy certificates or credits (RECs), net metering. Welfare economics plays an important role in evaluating the benefits and costs associated with the adoption and promotion of renewable and sustainable energy sources. In the context of welfare economics, the definition of welfare typically includes not only monetary measures but also factors that contribute to people's overall well-being, such as health, environmental quality, and even social equity. Therefore, when analysing the implications of renewable energy, welfare economists consider a wide range of factors beyond just financial costs and benefits. In this study, the benefits of green energy includes reduced pollution and greenhouse gas emissions, improved air quality, enhanced public health, and reduced dependence on fossil fuels. By conducting a CBA within the framework of welfare economics, policymakers and decision-makers can evaluate the overall impact of renewable energy initiatives on society and make informed choices that maximize social welfare.

3.2 Opportunity cost

Opportunity cost is a concept that relates to the choices individuals or society make when faced with limited resources. It refers to the value of the next best alternative that is forgone when a particular choice is made. In the context of renewable energy, opportunity cost can be understood by considering the trade-offs involved in adopting green energy sources. For example, investing in green energy infrastructure requires substantial financial resources, which could be used in other sectors or projects. The opportunity cost in this case is the potential benefits and values that would be obtained if those resources were allocated to the next best alternative, such as investing in a healthcare or educational project. Additionally, the opportunity cost also relates to the transition from traditional energy sources to green energy. The understanding opportunity cost helps make informed decisions by considering the trade-offs and alternative uses of resources. It provides a framework for evaluating the benefits and costs associated with different choices and helps in assessing the efficiency of resource allocation.

3.3 Market failure

The theory of market failure refers to a situation where the free market fails to efficiently allocate resources and produce optimal outcome. There are various causes of market failure, including externalities, public goods, market power and information asymmetry. Externality is a resulting factor from the use of fossil fuel, it occurs when the actions of individuals or firms have unintended effects on others that are not reflected in market prices. These effects can be positive or negative. For instance, pollution from the use of fossil fuel has adverse effects on the health and well-being of nearby residents, without any form of accountability in developing countries like Nigeria. Externalities and market failures are often interconnected. Externalities, such as pollution, is an example of a market failure because they are costs that are not accounted for in the market price. When externalities exist, the market fails to allocate resources efficiently because the social costs or benefits are not taken into consideration. To address such market failure, governments often intervene through regulations, taxes, subsidies, or other policy instruments. The focus of this study is to estimate the environmental and health benefits associated with the use of renewable energy, thereby improving resource allocation and achieving better outcomes for society.

3.4 Willingness to pay

Willingness to pay refers to the amount of money individuals or society as a whole is willing to spend or pay for a good, project or policy. It is a measure used to estimate the economic value that people place on certain benefits or improvements resulting from the implementation of renewable energy sources. It allows policymakers and researchers to weigh the costs of implementing renewable energy against the expected benefits, which includes reduced greenhouse gas emissions, improved air quality, and energy security. By estimating the willingness to pay, a CBA provides insights into the economic value that renewable energy brings to society. It also helps in decision-making processes by comparing the costs and benefits of different energy options and determining the overall social desirability of investing in renewable energy.

4. Literature review

Current literature covers socio-economic and environmental as well as non-technical analyses related to renewable energy. For instance, Guno and Agaton (2022) investigated the socio-economic and environmental benefits of solar irrigation systems in Philippines. The study revealed the environmental benefits of solar irrigation in terms of the reduction in GHG emissions of up to 26.5 tons CO_2eq/ha/year and the avoidance of emissions of air pollutants such as carbon monoxide, nitrogen oxides, sulphur oxides, and particulate matter. The project valuation method indicates that, on average, the solar irrigation system is a good investment with a positive net present value of USD 4517/ha.

In another study by Ahmad et al. (2022) a CBA of a 100 MW solar photovoltaic project commissioned by the Pakistani government was conducted. This analysis is from a developer point of view, with the aim of determining the NPV and payback period. The cost consists of the investment and maintenance cost, while the benefit includes the $18.4/MWh electricity price and a 95,570 tonnes of GHG, but the GHG was not monetized. The paper uses RETScreen, a software for energy modelling, financial analysis and GHG reduction analysis, the software is a suitable tool because of the extensive database from this project. Using a 10 % discount rate, the analysis arrived at a positive NPV and a payback period of 5.6 years

Berrade et al. (2019) evaluated the potential of installing micro hydropower (MHP) in Morocco. The study conducted a technical and economic cost benefit analysis of the MHP while also considering the environmental aspect of the installation. The cost-benefit analysis was performed considering two case scenarios; the expected and the worst case scenario. The revenue gained offset the cost incurred, arriving at a positive net present value in both scenarios. The project is considered profitable as a result of the positive NPV.

In Indonesia, Nashrulloh et al. (2021) studied the technological and economic factors for evaluating the feasibility indicators of a small hydropower plant. The technological considerations aid in assessing the technical planning for installations that could be constructed inside the dam. The economic aspect assesses the internal rate of return, NPV, and payback duration of a renewable hydropower energy infrastructure. The analysis aimed to get a comprehensive insight from potential hydropower energy and conduct a feasibility study based on techno-economic analysis to develop renewable energy. The results showed a payback period of 8 years, a positive NPV of 64,005 USD.

Based on the literature review conducted in this paper, it can be deduced that there is a growing body of evidence supporting the positive economic and environmental impacts of renewable energies, specifically on solar energy and hydropower in different developing countries. This section emphasizes the importance of prioritizing the adoption and utilization of renewable energies as a means to address environmental and health challenges while promoting sustainability. Without a complete CBA, it will be premature to draw definitive conclusions about the social NPV’s, hence further research and policy initiatives are therefore warranted to support the scaling up of renewable energy projects in developing countries like Nigeria and to ensure the realization of the full potential of these clean and sustainable energy sources.

5. Methodology

This section provides a detailed account of the approaches and techniques used to conduct the study. It serves as a road map for readers to understand how the research was designed and executed, ensuring transparency and reproducibility.

5.1 Cost benefit analysis

A Cost-Benefit Analysis is a technique used to evaluate the costs and benefits of a project or decision. It allows decision-makers to compare the costs of implementing a project with the benefits it is expected to generate over a specific time period. One important concept in CBA is net present value; the NPV is a financial metric that takes into account the time value of money. It calculates the present value of all future cash flows associated with the project, both costs and benefits, by discounting them to their present value using an appropriate discount rate. The discount rate accounts for the fact that money received or spent in the future is worth less than money received or spent today. A CBA also takes into account the sensitivity analysis.

Sensitivity analysis is a tool used in CBA to assess the impact of changes in key assumptions or variables on the results of the analysis. It helps to identify which factors have the most significant influence on the project's costs and benefits. By varying these factors, analysts can understand the level of uncertainty associated with the results and make informed decisions. The purpose of sensitivity analysis is to show how sensitive predicted net benefits are to change assumptions (Boardman et al., 2018). There are several types of sensitivity analysis that can be used in CBA or other types of economic analysis. Some of the commonly used ones includes: One-way sensitivity analysis, tornado diagram, multi-way sensitivity analysis, threshold analysis, scenario analysis and the Monte Carlo sensitivity analysis.

A Monte Carlo sensitivity analysis is suitable for this CBA due to the level of uncertainty, the discount rate and the transferred monetary values used. The Monte Carlo sensitivity analysis is a statistical technique used to assess the impact of uncertainty or variability in input parameters on the output of a model or simulation. In this method, uncertain input parameters are randomly sampled from their probability distributions, and the model or simulation is run repeatedly using these sampled values. Each run produces an output, and by analysing the distribution of these outputs, we can understand the sensitivity or importance of each input parameter. Monte Carlo sensitivity analysis allows us to quantify the effects of different input parameters on the model's outputs and assess the robustness or sensitivity of the model to changes or variations in these parameters. Overall, Monte Carlo sensitivity analysis is a tool for understanding and managing uncertainty in complex models or simulations by exploring the range of possible outcomes under various input conditions (Thomopoulos, 2014).

When conducting a CBA with two or more project that have different life span, drawing up a conclusion based on the NPV’s alone is flawed, therefore, this study utilizes the equivalent annual net benefit (EANB) method to further determine, the most viable project. EANB is an approach used to express the net benefits of a project over a specific time period in annual terms. It allows decision-makers to compare projects that have different durations or timeframes. EANB is calculated by dividing the total net benefits of a project over its lifetime by the project's economic life or duration in years. This provides decision-makers with a standardized measure that can be used to compare projects with different time horizons (Boardman et al., 2018).

5.2 Monetary valuation

Monetary Valuation in CBA refers to the process of assigning a monetary value of cost and benefits associated with a particular project or policy. It involves quantifying both the monetary costs and the monetary benefits. Several approaches are currently been used by economist to arrive at the monetary value of environmental and health impact from the use of green energy. According to a report by the National economic research association (1998), the most widely used approaches includes that of the value of life-year (VOLY), value of statistical life (VOSL) and willingness to pay, other approaches includes cost of illness or damage avoided, stated preference approach, revealed preference method, benefits mapping (BenMap) and the Benefit transfer approach. While debates over existing approach for monetary valuation of social cost and benefits continues, the search for simpler technique remains.

Valuing the environmental and health impacts of renewable energies in Nigeria is challenging because it requires the estimation for the economic value of improvements in health & productivity, air quality, environmental quality, surveys and value of life. Due to the lack of data in the scope of this study the most efficient approach is the benefit transfer method. The benefits transfer approach is a method used in CBA to estimate the value of a specific project or policy by utilizing existing data from previous studies. In the case of renewable energy, it aims to transfer data and findings from similar projects or policies to estimate the benefits of the proposed renewable energy project. This approach is particularly useful when there is limited data available for the specific project being assessed. In summary, the benefits transfer approach in a CBA of renewable energy involves using existing data from previous studies on similar projects to estimate the benefits of the proposed project. According to van Kooten (2021) it helps overcome data limitations and provides a more accurate estimation of the potential benefits, allowing for a comprehensive assessment of the project's economic viability.

6. Case study

The proposed location for the project is the village of Zongoro in Ganjuwa local government area (LGA), in the state of Bauchi. About 20 km separate Bauchi Township from the site, the site is proposed, mainly because of the area's high levels of sunshine and water body availability compared to other region. Figure 1 shows an abstract view of the map of Nigeria and a more close up view of Bauchi state and it local government areas.

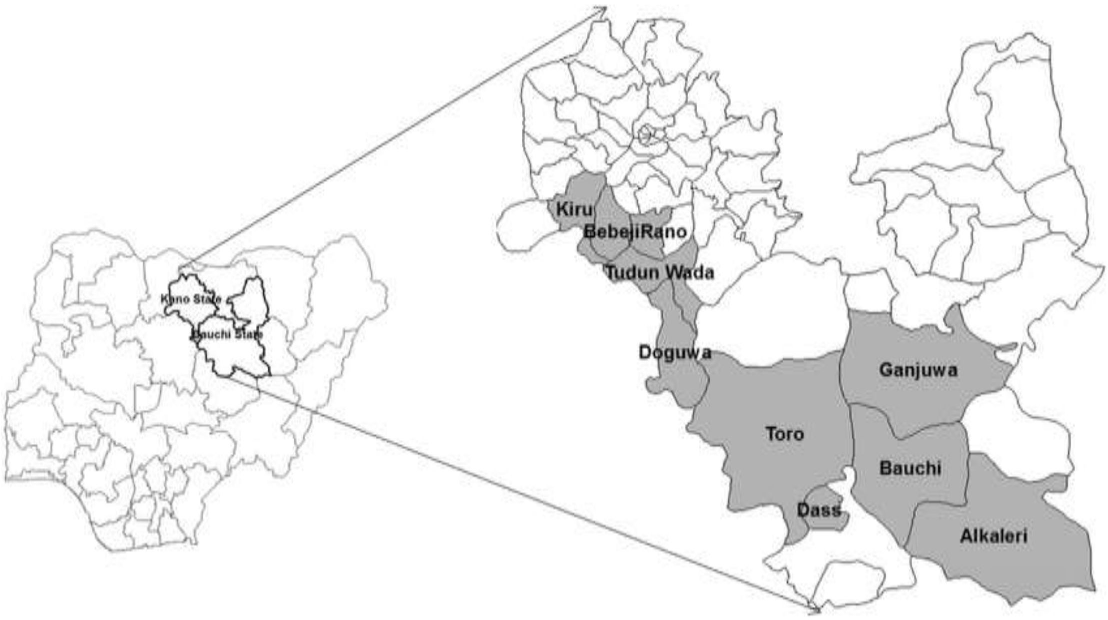

Figure. 1 Maps showing Ganjuwa in Bauchi State.

The project's location is suitable because of its climatic, topographical, and overall physical environment, including co-visibility impact because it is located outside of any natural protected habitat, or tourist attracted area. Additionally, the proposed site is close to an existing 132 kV national utility power grid for simple interconnection.

In Nigeria, the economic useful life of a solar or hydropower facility might change based on a number of variables, including the value quality of the equipment used, maintenance procedures, operational effectiveness, and climatic circumstances. Hydropower plants often last longer than solar plants, on average. The usable life of a solar power plant in Nigeria is estimated to be about 25 years, according to a study by Diemuodeke et al. (2021). However, with the right upkeep and equipment improvements, this lifespan can increase. On the other hand, a hydropower plant in Nigeria has a lifespan that is considerably longer, generally 50 years or more Yuguda et al. (2020). This is so because hydropower facilities are less prone to wear and tear than solar plants, since they have fewer moving parts compared to solar power plant.

According to Boardman et al. (2018) the choice of a discount rate is one of the most important aspects of CBA, as it plays a significant role in determining the present value of the net benefits and costs over the useful life. Unlike the European Union (EU), Nigerian does not have a specific discount rate for renewable energy, the government instead uses a standardizes discount rate of 12 % when analysing the economics of infrastructure projects, this rate is based on the nominal interest rate of the nation, and acts as a benchmark for both the private sector and public sector. Empirical behavioural evidence suggests that individuals apply lower rates to discount events that occur farther in the future i.e they have decreasing time aversion (Boardman et al., 2018). From the foregoing, a high discount rate can underestimate the expected NPV of the solar power plant due to its shorter life span as compared to the hydropower plant; it is desirable to therefore test the sensitivity of one’s result to change in parameters used in discounting. Considering 12 % discount rate is not an official discount rate designed for renewable energies and is appears to be high compare to countries with an already established discount rate, for this analysis, a 4 % discount rate as established by the European Council for an energy efficient economy (2015) will be used to conduct the CBA and a 12 % discount rate will be used to test the sensitivity in a Monte Carlos simulation. In summary, the choice of the discount rate is critical in CBA as it governs the evaluation of costs and benefits over time, incorporates the concept of time value of money, comparison between projects, and help in assessing the long-term implication of investments.

CBA has some inherent uncertainty, according to Broadman et al. (2018), accounting for future risk is to analyses the robustness of uncertainty by performing a sensitivity analysis, which would project how NPV changes when inputs factors changes. This research carried out a Monte Carlos analysis on microsoft excel by making random draws (RAND()) on the benefits parameters (health cost savings and green-house gas), while assuming a minimum and maximum limit and then performed the simulation 1000 times which provided range of NPV's which in turn was used to estimate the mean, min, max and standard deviation values.

6.1 Measuring costs and benefits

The society is impacted both favourably and unfavourably by investments in renewable energy. Positive effects include decreases in regional and local air pollutants like SO_2 and NOx (caused by the displacement of electricity generation from fossil fuel sources) as well as local air pollutants like particulates. Reduced CO_2 emissions are credited with reducing global harm, also some negative effect can also occur. These impacts are mainly not priced by markets due to the problem of market failures. This section describes the environmental and health impacts of both the solar and hydro power plant respectively as seen in Table 1 and 2 below, followed by how these impacts can be measured in monetary equivalents (dollar value) focusing solely on the benefits as the research only accounts for the investment and maintenance costs.

Table 1: Environmental and health impacts of a 10 MW SEPP

Impact category	Positive impacts	Negative impacts
Health Impact	• Beyond its effects on global warming, carbon emissions can seriously harm a person's health, especially the heart and lungs. Adoption of solar energy can result in cleaner air, • which can lower the risks of heart disease, asthma attacks, and early deaths by reducing the amount of carbon and other pollutants entering the environments	• Numerous hazardous substances are utilized during the production of PV cells, the majority of which are for cleaning and purifying the semiconductor surface. Hydrochloric acid, sulphuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone are some of the chemicals utilized in this process.
Environmental Impact	• Solar photovoltaic panels are sources of clean energy because they don't emit any greenhouse gasses while they are producing power, despite the fact that some emissions may occur during production and transportation. • Every kilowatt-hour of power generated by solar panels as opposed to a fossil fuel like natural gas can lessen the carbon footprint of the final consumer. • Lesser greenhouse gas emissions in the atmosphere due to the global adoption of solar energy would aid in reducing the consequences of climate change.	• Solar energy does not produce greenhouse gas emissions; however there are emissions connected with other phases of the solar life cycle, such as production, transportation of materials, installation, maintenance, decommissioning and dismantling.

Source: *Rabaia et al. (2021*)

Table 2: Environmental and health impacts of a 10 MW hydropower plant

Impact Category	Positive impacts	Negative impacts
Health Impact	• Hydropower is a clean energy source that helps to reduce the use of fossil fuels, which in turn lowers air pollution and slows the effects of climate change. • It offers endlessly available renewable energy. • A hydroelectric plant also doesn't deplete the environment's water supply. This is because anything taken out eventually returns in full, making its water footprint minimal.	• The natural flow of a river system is disrupted most significantly by storage hydropower or pumped storage hydropower plants. This results in altered animal migration routes.
Environmental Impact	• The volume and flow rate of the water released (after generating power) can be precisely and gradually managed. This entails having continuous flow control, which lowers the risk of floods during periods of heavy rain.	• A dam and reservoir can alter the silt loads, river flow characteristics, natural water temperatures, and water chemistry. The ecology and physical properties of the river may be impacted by all of these changes. Native flora and animals that live in and near the river may be negatively impacted by these changes.

Source: *Bergmann and Hanley (2012*).

6.1.1 Project cost

i) Investment cost: In accordance with the newly commission solar power station in Kano state, Nigeria, the investment cost of a 10 MW SEPP is an estimate of $15 million. The plant consists of over 21,000 solar PV panels, two 6MVA transformers and 52 inverters, a state-of-the-art warehouse and storage building, a control room building, office and workshop building amongst other (Nigeria Sovereign Investment Authority, 2023). Also, in line with newly commissioned 10 MW hydropower plant in Kano Nigeria 2022, the project cost for a 10 MW hydropower plant is estimated to be $40 million. The cost estimation is divided into the construction of temporary works (river division, transportation for construction, power supply for construction, houses for construction and construction management), construction civil works (water retaining structure, drainage and energy dissipation structure, water conductor structure, power generation structure, substation structure, fish passage, headwork of the irrigation channel, treatment project of the slope near the dam bank, transportation and housing), electrometrical equipment and installation (power generation equipment and installation, substation equipment and installation and the public utility installation) hydro mechanical structure and installation and lastly, fees, permits and reserved funds (Energy, Capital and Power, 2023). Table 3 shows the initial cost of investment of the power plant being compared in this analysis.

Table 3: capital cost of the proposed renewable energy power plant

Renewable Energy power plant	Investment cost
10MW SEPP	$15,000,000
10MW Hydropower plant	$40,000,000

Source: *Nigeria Sovereign Investment Authority, (2023).*

ii) Operations and maintenance cost (O&M): once commissioned, the proposed power plants will require an interval maintenance and operational cost throughout the economic life of the plants. According to IRENA (2012), O&M expenses are often expressed as a percentage of investment expenditures calculated per kW each year. The typical values lie between 1-4 %. The IEA (2019) assumes a 3 % O&M for small power plants. According to the office of energy efficiency & renewable energy press release (2005), a small power plant ranges from 100 kilowatts and 10 MW. Table 4 shows the estimated annual O&M cost by multiplying the cost of investment by 3%, where the cost of the investment for the solar plant and hydropower plant are estimated as $15million and $40milion respectively, the O&M will therefore be $450,000 and $1.2 million per year.

Table 4: Annual O&M cost of the proposed renewable energy power plant

Renewable Energy power plant	Estimation	O&M Cost
10MW SEPP	$^{3}/_{100} \times 15{,}000{,}000$	$450,000
10MW Hydropower plant	$^{3}/_{100} \times 40{,}000{,}000$	$1,200,000

Source: *International renewable energy agency (2012).*

6.1.2 Project benefits

i) Health Cost Saving: Air pollution is a major cause of respiratory and cardiovascular diseases, which can result in medical expenses and loss in productivity. By reducing air pollution, the number of people suffering from these diseases could decrease, resulting in lower healthcare costs and increased productivity. According to a study conducted by the world health organization (WHO) in 2016, air pollution in Kano state, Nigeria, resulted in an estimated 3,150 premature deaths and 1.2 million disability-adjusted life years (DALYs) lost. The economic cost of these health impacts was estimated to be approximately $1.3 billion with a population of 13 million the economic cost per individual is $1,000. According to the Energy Information Administration (2020) 10 MW power plant could potentially power 940 households annually and the average house hold size in rural areas is 5.9 persons (Nigeria National Bureau of Statistics, 2016). By transferring this benefit in Bauchi state, the estimated health cost saving is $5.55 million as shown in Table 5.

Table 5: Health cost saving of the proposed renewable energy power plant

Power plant	Health cost per individual	Total no. of household	Average household size	Expected annual benefit	Monetary Benefit
10 MW renewable energy	$1,000	940	5.9	$1000 \times 940 \times 5.9$	$5,546,000

Source: *Energy information administration (2020) and the Nigerian National bureau of statistics, (2016)*

ii) Greenhouse gas emission: Reduction in the use of fossil fuels for power generation will reduce CO_2 emissions by an estimated 13,500 tonnes annually while using a 10 MW solar plant. Unfortunately, Nigeria does not yet have a standardized price for greenhouse gas reductions. The hydropower plant is anticipated to reduce greenhouse gas emissions by 14,400 metric tonnes annually using the IPCC (2012) emission rate. However, some Nigerian organizations, including the Nigeria Carbon Pricing Mechanism and the Nigerian Emissions Trading Scheme, are currently working to establish a framework for carbon pricing and trading in the nation. South Africa is one of the few African countries with a functional carbon market. According to the international monetary fund, African department (2023) carbon tax rate for power sector in South Africa is $8.30 per tonne of CO_2 emitted and the average electricity tariff according to ESKOM (2022) is $0.17 per KWh, which represent 2.05 % of the carbon tax rate. In Nigeria the electricity tariff is $0.029, using the benefit transfer approach, $0.029 should represent 2.05 % of the desired carbon tax rate (x). Table 6 shows 2.05 % of carbon tax rate (x) equals $0.029, by change of subject, carbon rate (x) equals $1.42 per tonne of CO_2 emitted. Table 6 also shows that by multiplying the estimated carbon tax rate with the GHG annual metric tonne we arrive at a monetary benefit of $19,170 and $20,448 for the solar and hydro power plant respectively.

Table 6: Health cost saving of the proposed renewable energy power plant

Power plant	GHG annual metric ton	Household electricity tariff	Carbon tax rate per ton ($)	Annual benefit per ton	Monetary benefit
10 MW SEPP	13,500	$0.029	$x \times 2.05\% = 0.029$ $\therefore x = 1.42$	1.42×13,500	$19,170
10 MW Hydropower	14,400	$0.029	1.42	1.42×14,400	$20,448

Source: *Intergovernmental Panel on Climate Change (2012*).

6.2 Results and discussion

To access the environmental and health benefits viability of the solar and hydropower plant, a cost benefit analysis is conducted using the Monte Carlo simulation method. Two scenarios are considered for each project; a best case scenario utilizing a maximum possible input parameters and a worst case scenario using a minimum possible input parameters of the expected benefits to calculate a discounted cash flows over a 25 and 50 years' time period for the solar and hydro power plant respectively. Additionally 1000 combinations of stochastic input parameters are simulated using a simple random sampling method with the range defined by the best and worst case scenarios. The input parameters have uniform distributions. The choice of the distribution is as a result of the input parameters being modelled have a strict upper and lower bounds (i.e minimum and maximum values).

To have a better understanding of the quality of representation, table 7 outlines the summary statistic with eight moments of distribution, illustrating the location and dispersion of the mean, minimum, maximum and the standard deviation after a count of 1000 simulations.

Table 7: Summary of the estimated variables of the CBA

Power plant	Mean (million $)	Min (million $)	Max (million $)	Standard deviation (million $)	Total discounted benefit ($)	Total discounted cost ($)	NPV ($)	EANB ($)
10 MW SEPP	4.862138	-177	168	48.89884	87,013,344	22,029,935	64,983,409	4,159,715.56
10 MW Hydropower	-4.92607	-159	155	45.86605	119,687,733	65,778,621	53,909,112	2,509,479.97

Source: *Author's computation (2023)*

The results revealed that both project yields positive NPV of $65 million and $53 million, this implies that over the course of the project life span, both plant would be profitable. Attributing to the varying year span, an EANB was conducted revealing the solar power plant to be more viable as it yields $4 million as against the hydropower plant of $2 million. This suggests that despite its brief economic useful life, the solar power plant is a more feasible investment.

The location and dispersion of the NPV when the input parameter have a uniform distribution as interpreted above can be seen visually in figure 2 and 3, where the distribution of NPV's and density of outcomes are demonstrated in the histogram.

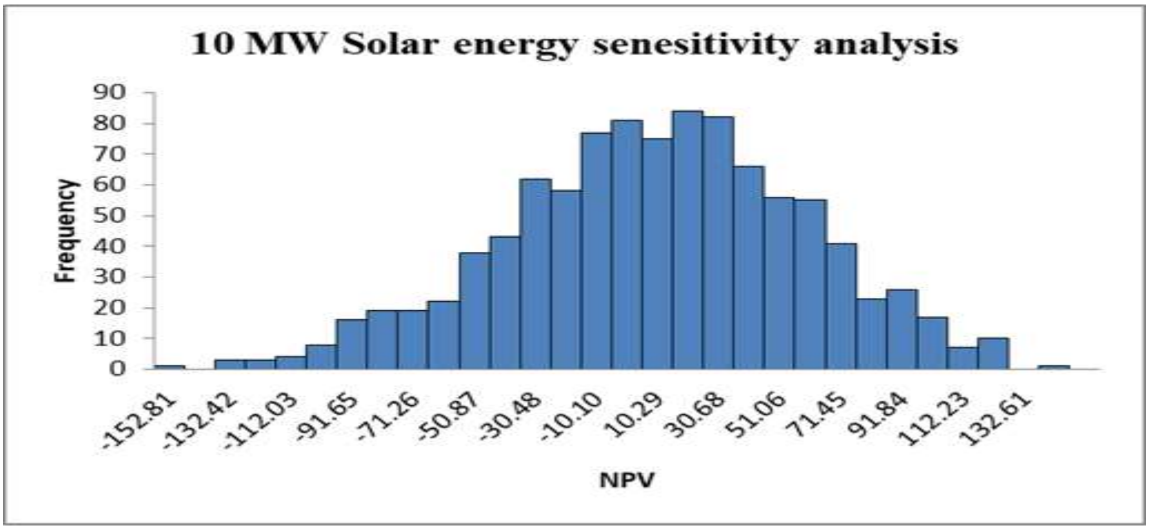

Figure 2 - Monte Carlo simulation of the 10 MW solar plant

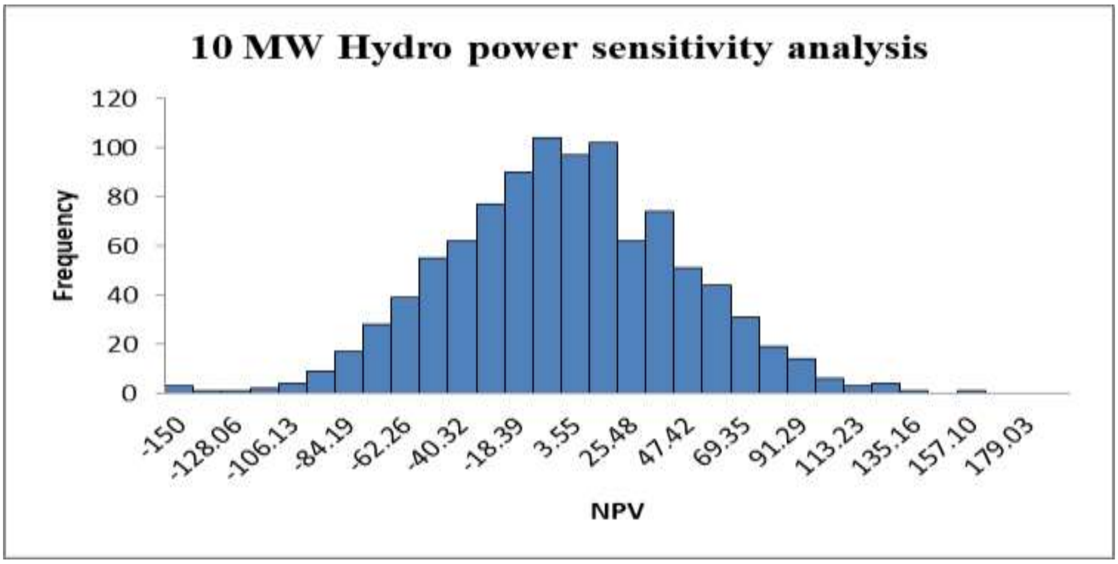

Figure 3 - Monte Carlo simulation of the 10 MW hydropower plant

The Monte Carlo simulation provides a more elaborated understanding of the possible outcome due to its alignment with the law of large numbers. In the simulation the expected average return is about $4 million and a negative return of about $4 million for the solar and hydro power plant respectively. This indicates that the simulated NPVs yielded more positive values for the solar plants and otherwise for the hydropower plant.

Although the histogram portrait the lowest NPV value as -152.81 and the highest NPV as 132.61, it is eminent to focus on the frequency occurrences of the NPV value which depicts that the positive NPV's (10.20 to 132.61) in the solar power plant had higher frequencies of up to 90. On the other hand the hydro power plant who's lowest and highest from the histogram NPV is -150 and 179.03 respectively. The positive NPV's (3.55 to 179.03) reveals a fall in frequency at an increasing rate.

Considering these results and distribution of the NPV, it can be argued that the solar power project is the more viable option, not only does it have a technological advantage as a result of the shorter life span, it also yielded a higher NPV, EANB and a more desirable Monte Carlo simulation.

Table 8 shows the list of steps according to Boardman et al. (2018) involved carrying out a CBA, its serves as a tool to check that all the require steps in conducting a CBA are identified and met.

Table 8: The ten basic steps of a CBA and the work done in the analysis in this report.

S/N	CBA Steps	Brief explanation
1	Explain the purpose of the CBA	The purpose of this paper is to conduct an environmental and health CBA on a 10 MW solar and hydro power plant. The implantation of this project will promote the Nigeria government's strategic plan to optimally utilize the available renewable energy resources for a cleaner and secure energy supply.
2	Specify the set of alternatives	This paper has two alternative, namely: i) 10 MW Solar energy power plant ii) 10 MW Hydropower plant
3	Define whose benefits and costs counts	The benefits and cost are from the society point of view.
4	Identify the impact category	This paper categorizes the impact into two parts, the environmental, and health impact.
5	Predict the impacts quantitatively over the life of the project	Quantitatively, the impacts category influences the solar plant for a period of 25 years and a period of 50 years for the hydropower plant.
6	Monetize all impact	The solar plant has the following monetary impact a. Investment cost : $15M b. O&M cost: $450,000 c. Health saving cost: $5.5M d. GHG: $23,895 And the hydropower plant has the following monetary impact a. Investment cost : $40M b. O&M cost: $1.2M c. Health saving cost: $5.5M d. GHG: $25,488
7	Discount benefits and cost to obtain the present value	The total discounted benefit are $87M and $119M for the SEPP and the Hydropower plant respectively and the total discounted cost are $22 M and $65 M
8	Compute the NPV of each alternative	The NPV of the power plant are $64M and $53M for the SEPP and the hydropower plant respectively.
9	Perform a sensitivity analysis	A Monte Carlos simulation was carried out on both power plant to determine if some assumptions in the parameter affects the positive results obtained
10	Make a recommendation	The 10 MW solar plant is the recommended renewable energy plant based on the NPV and EANB

Source: *Boardman et al. (2018) and author.*

7. Conclusions

The 10 MW solar power plant and hydropower power are crucial infrastructural projects in Nigeria, which will provide additional and clean energy in Bauchi state if established. The cost of constructing the solar plant and the hydro plant is estimated to be about $15 million and $40 million respectively, after estimating the costs and benefits using a discount rate of 4 % both power plants showed positive net benefits. Owing to different economic life span, an

EANB was conducted, and revealed that the 10 MW SEPP is more viable, despite having a shorter economic life span.

Based on the findings of this paper, both projects are viable, but in comparison, the 10 MW solar energy power plant is more desirable. Although the research indicates that both solar and hydropower facilities have a positive NPV, it is still vital to conduct a further analysis that takes into account all other form of social costs and benefits, while exploring other estimation approaches. A more thorough analysis will make sure that the decision to invest in renewable energy is not only financially sound based on transferring benefits, but also sustainable while using a different approach. To restate CBA is but one factor that aims to steer political decision-making toward more effective resource allocation. It is not always the case that CBA influences decision-making, a lot of progressive organizations and environmentalists prefer to base their arguments on moral and ethical considerations rather than CBAs, such groups will be more successful if they don't "give up on rationality" and carry out CBAs.

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Appendix

Table 9 - NPV of the projected 10 MW solar energy power plant

Monetary Valuation					Discount cost and benefits				
Year	*investment cost*	*O&M cost*	*Health cost saving*	*GHG*	*O&M Cost*	*Health Cost Saving*	*GHG*	*Net annual benefit*	*present value*
0	15,000,000								(15,000,000)
1		450,000	5,546,000	23,895	432,692.31	5,332,692.31	22,975.96	5,355,668.27	4,922,975.96
2		450,000	5,546,000	23,895	416,050.30	5,127,588.76	22,092.27	5,149,681.03	4,733,630.73
3		450,000	5,546,000	23,895	400,048.36	4,930,373.81	21,242.57	4,951,616.37	4,551,568.01
4		450,000	5,546,000	23,895	384,661.89	4,740,744.04	20,425.55	4,761,169.59	4,376,507.70
5		450,000	5,546,000	23,895	369,867.20	4,558,407.73	19,639.95	4,578,047.68	4,208,180.48
6		450,000	5,546,000	23,895	355,641.54	4,383,084.36	18,884.57	4,401,968.93	4,046,327.39
7		450,000	5,546,000	23,895	341,963.02	4,214,504.19	18,158.24	4,232,662.43	3,890,699.41
8		450,000	5,546,000	23,895	328,810.59	4,052,407.88	17,459.84	4,069,867.72	3,741,057.13
9		450,000	5,546,000	23,895	316,164.03	3,896,546.04	16,788.31	3,913,334.35	3,597,170.31
10		450,000	5,546,000	23,895	304,003.88	3,746,678.88	16,142.61	3,762,821.49	3,458,817.61
11		450,000	5,546,000	23,895	292,311.42	3,602,575.85	15,521.74	3,618,097.58	3,325,786.16
12		450,000	5,546,000	23,895	281,068.67	3,464,015.24	14,924.75	3,478,939.98	3,197,871.31
13		450,000	5,546,000	23,895	270,258.34	3,330,783.88	14,350.72	3,345,134.60	3,074,876.26
14		450,000	5,546,000	23,895	259,863.79	3,202,676.81	13,798.77	3,216,475.58	2,956,611.79
15		450,000	5,546,000	23,895	249,869.03	3,079,496.93	13,268.05	3,092,764.98	2,842,895.95
16		450,000	5,546,000	23,895	240,258.68	2,961,054.74	12,757.74	2,973,812.48	2,733,553.80
17		450,000	5,546,000	23,895	231,017.96	2,847,168.02	12,267.05	2,859,435.08	2,628,417.11
18		450,000	5,546,000	23,895	222,132.65	2,737,661.56	11,795.24	2,749,456.80	2,527,324.15
19		450,000	5,546,000	23,895	213,589.09	2,632,366.88	11,341.58	2,643,708.46	2,430,119.37
20		450,000	5,546,000	23,895	205,374.13	2,531,122.00	10,905.37	2,542,027.37	2,336,653.24
21		450,000	5,546,000	23,895	197,475.12	2,433,771.16	10,485.93	2,444,257.09	2,246,781.97
22		450,000	5,546,000	23,895	189,879.92	2,340,164.57	10,082.62	2,350,247.20	2,160,367.27
23		450,000	5,546,000	23,895	182,576.85	2,250,158.24	9,694.83	2,259,853.08	2,077,276.23
24		450,000	5,546,000	23,895	175,554.66	2,163,613.70	9,321.95	2,172,935.65	1,997,380.99
25		450,000	5,546,000	23,895	168,802.56	2,080,397.79	8,963.42	2,089,361.20	1,920,558.64
									64,983,409

Table 10-NPV of the projected 10MW hydropower plant

Monetary Valuation					Discount cost and benefits				
Year	*investment cost*	*O&M cost*	*Health cost saving*	*GHG*	*O&M Cost*	*Health Cost Saving*	*GHG*	*Net annual benefit*	*present value*
0	40,000,000								(40,000,000)
1		1,200,000	5,546,000	25,488	1,153,846.15	5,332,692.31	24,507.69	5,357,200.00	4,203,353.85
2		1,200,000	5,546,000	25,488	1,109,467.46	5,127,588.76	23,565.09	5,151,153.85	4,041,686.39
3		1,200,000	5,546,000	25,488	1,066,795.63	4,930,373.81	22,658.74	4,953,032.54	3,886,236.91
4		1,200,000	5,546,000	25,488	1,025,765.03	4,740,744.04	21,787.25	4,762,531.29	3,736,766.26
5		1,200,000	5,546,000	25,488	986,312.53	4,558,407.73	20,949.28	4,579,357.01	3,593,044.48
6		1,200,000	5,546,000	25,488	948,377.43	4,383,084.36	20,143.54	4,403,227.90	3,454,850.47
7		1,200,000	5,546,000	25,488	911,901.38	4,214,504.19	19,368.79	4,233,872.98	3,321,971.60
8		1,200,000	5,546,000	25,488	876,828.25	4,052,407.88	18,623.83	4,071,031.71	3,194,203.46
9		1,200,000	5,546,000	25,488	843,104.08	3,896,546.04	17,907.53	3,914,453.57	3,071,349.48
10		1,200,000	5,546,000	25,488	810,677.00	3,746,678.88	17,218.78	3,763,897.66	2,953,220.66
11		1,200,000	5,546,000	25,488	779,497.12	3,602,575.85	16,556.52	3,619,132.37	2,839,635.25
12		1,200,000	5,546,000	25,488	749,516.46	3,464,015.24	15,919.73	3,479,934.97	2,730,418.51
13		1,200,000	5,546,000	25,488	720,688.90	3,330,783.88	15,307.43	3,346,091.31	2,625,402.41
14		1,200,000	5,546,000	25,488	692,970.10	3,202,676.81	14,718.68	3,217,395.49	2,524,425.39
15		1,200,000	5,546,000	25,488	666,317.40	3,079,496.93	14,152.58	3,093,649.51	2,427,332.11
16		1,200,000	5,546,000	25,488	640,689.81	2,961,054.74	13,608.25	2,974,662.99	2,333,973.18
17		1,200,000	5,546,000	25,488	616,047.90	2,847,168.02	13,084.86	2,860,252.88	2,244,204.98
18		1,200,000	5,546,000	25,488	592,353.75	2,737,661.56	12,581.59	2,750,243.15	2,157,889.41
19		1,200,000	5,546,000	25,488	569,570.91	2,632,366.88	12,097.69	2,644,464.57	2,074,893.66
20		1,200,000	5,546,000	25,488	547,664.34	2,531,122.00	11,632.39	2,542,754.39	1,995,090.06
21		1,200,000	5,546,000	25,488	526,600.32	2,433,771.16	11,184.99	2,444,956.15	1,918,355.83
22		1,200,000	5,546,000	25,488	506,346.46	2,340,164.57	10,754.80	2,350,919.37	1,844,572.91
23		1,200,000	5,546,000	25,488	486,871.60	2,250,158.24	10,341.15	2,260,499.40	1,773,627.80
24		1,200,000	5,546,000	25,488	468,145.77	2,163,613.70	9,943.42	2,173,557.11	1,705,411.34
25		1,200,000	5,546,000	25,488	450,140.16	2,080,397.79	9,560.98	2,089,958.76	1,639,818.60
26		1,200,000	5,546,000	25,488	432,827.08	2,000,382.49	9,193.25	2,009,575.73	1,576,748.65
27		1,200,000	5,546,000	25,488	416,179.88	1,923,444.70	8,839.66	1,932,284.36	1,516,104.47
28		1,200,000	5,546,000	25,488	400,172.97	1,849,466.06	8,499.67	1,857,965.73	1,457,792.76
29		1,200,000	5,546,000	25,488	384,781.70	1,778,332.75	8,172.76	1,786,505.51	1,401,723.81
30		1,200,000	5,546,000	25,488	369,982.40	1,709,935.33	7,858.43	1,717,793.76	1,347,811.36
31		1,200,000	5,546,000	25,488	355,752.31	1,644,168.59	7,556.18	1,651,724.77	1,295,972.46
32		1,200,000	5,546,000	25,488	342,069.53	1,580,931.34	7,265.56	1,588,196.89	1,246,127.36
33		1,200,000	5,546,000	25,488	328,913.01	1,520,126.28	6,986.11	1,527,112.40	1,198,199.39
34		1,200,000	5,546,000	25,488	316,262.51	1,461,659.89	6,717.42	1,468,377.30	1,152,114.80
35		1,200,000	5,546,000	25,488	304,098.56	1,405,442.20	6,459.05	1,411,901.25	1,107,802.69
36		1,200,000	5,546,000	25,488	292,402.47	1,351,386.73	6,210.63	1,357,597.36	1,065,194.89
37		1,200,000	5,546,000	25,488	281,156.22	1,299,410.32	5,971.76	1,305,382.08	1,024,225.86
38		1,200,000	5,546,000	25,488	270,342.52	1,249,433.00	5,742.08	1,255,175.07	984,832.56
39		1,200,000	5,546,000	25,488	259,944.73	1,201,377.88	5,521.23	1,206,899.11	946,954.38
40		1,200,000	5,546,000	25,488	249,946.85	1,155,171.04	5,308.87	1,160,479.91	910,533.06
41		1,200,000	5,546,000	25,488	240,333.51	1,110,741.39	5,104.68	1,115,846.07	875,512.56
42		1,200,000	5,546,000	25,488	231,089.92	1,068,020.56	4,908.35	1,072,928.91	841,839.00
43		1,200,000	5,546,000	25,488	222,201.84	1,026,942.85	4,719.57	1,031,662.42	809,460.57
44		1,200,000	5,546,000	25,488	213,655.62	987,445.05	4,538.05	991,983.09	778,327.48
45		1,200,000	5,546,000	25,488	205,438.09	949,466.39	4,363.51	953,829.90	748,391.80
46		1,200,000	5,546,000	25,488	197,536.63	912,948.45	4,195.68	917,144.13	719,607.50
47		1,200,000	5,546,000	25,488	189,939.07	877,835.05	4,034.31	881,869.36	691,930.29
48		1,200,000	5,546,000	25,488	182,633.72	844,072.17	3,879.14	847,951.31	665,317.59
49		1,200,000	5,546,000	25,488	175,609.34	811,607.85	3,729.94	815,337.79	639,728.45
50		1,200,000	5,546,000	25,488	168,855.14	780,392.16	3,586.48	783,978.65	615,123.51
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