PERFORMANCE ANALYSIS OF ENVIRONMENTAL SUSTAINABILITY USING RENEWABLE ENERGY SOURCES TO DECREASE GREENHOUSE GAS EMISSION

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Highlight

This article presents the environmental sustainability performance analysis used to reduce greenhouse gas emissions through renewable energy resources.

Abstract

Given the finite nature of fossil energy supplies and the issues associated with Greenhouse Gas (GHG) emissions, it is imperative to prioritize Renewable Energy Sources (RES) to attain Sustainable Development (SD) objectives. The significance of RES in SD, mitigating GHG emissions, and enhancing energy security, coupled with the necessity for financial backing and substantial investments in RES projects, amplifies the role and significance of SD in advancing RES. This research investigates the effects of contemporary facility expansion and RES. This study examines changing relationships in the Sustainable Energies Development Pattern of carbon dioxide utilizing the Bayesian Vector Auto Regression (BVAR) approach. One of the critical metrics for assessing SD is the altered pure arrangement. This indicator was used as an environmentally friendly index for this aim. The findings demonstrate that the influence of positive impetus on RES usage contributes positively to SD in Uganda. The favorable impact of RES usage elevates carbon dioxide outputs to varying degrees. The effect of the increase in the sustainability index on RES usage is negatively correlated with GHG emissions. The research findings indicate that, according to the RMSE criteria, the previous SSVS-Full function was employed to examine the influence of RES usage on SD, whereas the standalone Normal-Wishart function was utilized. The study examines the dynamic links among SD, energy consumption (distinctly considering RES and non-RES energy), and carbon footprints.

Keywords

environment, sustainability, renewable energy sources, greenhouse gas.

Introduction

Solar and wind energies are indigenous and cost-free energy sources, representing optimal local options for addressing the rising electricity demand [1]. The Fraunhofer Institute for Solar Power Technologies' photovoltaics research indicates that the global installed Photovoltaic (PV) capacity surpassed 520 gigawatts, fulfilling around two percent of worldwide power demand. 61.7 gigawatts of wind energy production were added worldwide in 2020, reflecting a 20 percent increase.

Renewable Energy Sources (RES) are considered renewable power sources [2]. It is not sustainable because green power system elements are frequently manufactured in companies and facilities that utilize non-RES energy. Delivering these systems' elements and parts typically relies on traditional fuels. Greenhouse Gas (GHG) emissions are detrimental, contributing to atmospheric pollution [21]. The principal GHGs include water vapor (H2O), carbon dioxides (CO2), methane (CH4), nitrous oxides (N2O), and ozone (O3). Traditional energy sources, including coal and other fossil fuels, significantly contribute to GHG emissions. The combustion of fossil fuels adds to the widely recognized phenomenon of global warming, wherein the Earth's atmosphere increases in temperature by taking in and retaining sunlight [3].

RES is the optimal solution for delivering clean, dependable, and secure electricity [4]. Electricity produced from RES elevates living standards and stimulates economic development. Substituting traditional energy sources such as fossil fuels with alternative sources of energy aids in alleviating global warming caused by emissions of GHG [8]. Although RES is a domestic resource, it has constraints owing to elevated initial costs, intermittency, and geographical limits.

The annual energy consumption growth rate is 2% in wealthy nations and 6% in developing countries [5]. In Jordan, electricity demand rises annually, with the primary sources of energy for 2019 (the latest information available from the Ministry of Energies and Minerals Assets) identified as brought in petroleum and natural gas, accounting for 83% of the total usage of energy (9800 kt), then RES at 9%. The transport industry accounts for 44% of overall national energy use, with household consumption representing the second-highest proportion at 24.2%. Research has a critical energy dilemma as rising energy costs hinder economic development, given that most of its power is exported. In affluent nations, buildings typically account for roughly 25-45% of overall energy use, with traditional energy sources remaining predominant. Photovoltaic systems are extensively researched among active solar systems because of recent aesthetic and technological advancements and the dissemination of explicit design standards and suggestions.

Electrical networks for RES systems must exhibit greater flexibility and dynamism than traditional grids to enhance their energy-generating capacity and address the difficulties of intermittency and location-specific variability [31]. Implementing distributed power-generation models, including microgrids, smart grids, and autonomous (off-grid) electrical networks, can enhance the proportion of RES. Sustainable buildings utilizing RES like solar and wind may benefit the ecology and consumers by substituting conventional forms of energy with affordable, domestic, and eco-friendly alternatives [22].

Empirical research indicates that energy consumption and economic expansion primarily contribute to GHG emissions. Ecological economists assert that energy is the sole and paramount growth component in the environmental model. They claim that labor and capital require energy. Confident economists assert that energy influences sustainable development via labor force and capital rather than directly [7]. They contend that energy serves as an intermediate input, with labor, assets, and land being the fundamental components of production. The overutilization of energy, particularly fossil fuels, to attain economic expansion has resulted in heightened environmental harm.

The environmental repercussions of climate change and GHG emissions have heightened apprehensions regarding non-RES usage. In contrast, public interest in RES has surged due to its capacity to mitigate GHG emissions, lower carbon dioxide output, and safeguard the planet's health. RES mitigates emissions of GHG, elevated costs, energy volatility, and reliance on foreign energy sources [23]. Recent years have witnessed continuous advancements in technology concerning the environment.

The natural expansion literature demonstrates that technological innovation can positively impact the environment over the long run. Innovative technology enhances investment both directly and indirectly by decreasing data and exchange costs, augmenting the productivity of manufacturing elements, boosting savings, and optimizing resource allocation; it is environmentally sustainable.

This study aims to address the shortcomings of prior research. The most novel features of this research are as follows: An effective indicator is utilized to articulate Sustainable Development (SD) [9]. The distinction between RES and non-RES energy examines the correlation among environmentally friendly development, air quality, and energy consumption across various energy sources. The Bayesian Vector Auto Regression (BVAR) approach analyzes the dynamic connections between energy consumption and SD [32]. This study used the efficiency index as a metric for SD. The influence of favorable subsidies on RES utilization and SD in Uganda is examined. The favorable impact of using clean energy variably elevates carbon dioxide emissions. The effect of environmentally friendly development index development on RES usage has been assessed [10].

Background

Global apprehensions over the adverse effects of environmental change and escalating oil costs have prompted governments worldwide to implement new laws to facilitate broader use of RES. The primary foundations for a nation's long-term success are a robust and dependable energy infrastructure and a plentiful supply of fossil fuels to guarantee ongoing SD, social advancement, enhanced quality of life, and security [24]. In response to the continuing depletion of fossil fuel reserves and increased carbon emissions, emerging nations are transitioning towards extensive energy use from RES [11]. The energy production, development, and consumption methods are continually evolving, as seen by the proliferation and implementation of innovative RES in emerging nations [12]. Energy scientists and policymakers contend that with appropriate investments in green energy for power generation, most countries reliant on fossil fuels will progressively achieve independence from fossil fuels over time.

Numerous areas in Iran possess significant potential for energy from RES due to the plentiful wind and sun irradiation levels [25]. The considerable potential for wind in the Persian Gulf islands suggests that an increase in windmills might enhance the nation's power generation. Based on theoretical and empirical study, the study proposed a novel predictive model utilizing a lead-acid battery inside a hybrid power system. The research developed an integrated system for application in the coastal regions of Bangladesh, demonstrating a notable enhancement in the environmental sustainability of electricity using a sustainable hybrid system. Their findings suggest hybrid systems could address 61.4% and 69.2% of the load requirement and decrease CO_2 emissions by 63% and 69%, respectively. The research proposed an energy management method utilizing a type-1 fuzzy logic method for a hybrid system, including solar panels, wind turbines, and two battery packs to power a residence in Morocco—a comprehensive economic and environmental assessment of two hybrid power networks for distant regions [13]. The research examined several hybrid systems for energy provision in Indian communities [18].

In contrast, the research developed an energy-efficient microgrid that integrates a combination of solar-wind systems, framed as a matter of optimization. This research demonstrated that RES utilizing pumped hydro battery storage may finally supply electricity in remote regions. The study examined the home use of hybrid power plants and showed that a PV-wind system generates more power than other integrated methods, with a production rate of 16.2 kWh/year.

The research demonstrated that the cost of wind energy generation was $0.213 per kWh, whereas solar energy was $0.053 per kWh. The cost of energy generation from wind is higher than that of solar energy [33]. Thoroughly examined literature endorses the amalgamation of photovoltaic and wind systems, which has significant potential to provide the necessary power in the specified regions [26].

In light of escalating worries over global warming, reducing carbon footprints has emerged as a pivotal subject, prompting substantial study and extensive research to identify sustainable solutions since it is seen as a primary driver [15]. In this context, significant worldwide efforts are being made to address climate change by decreasing carbon dioxide emissions and minimizing the reliance on petroleum and coal as the primary energy sources [16].

Comparable international ecological agreements, such as the Paris and Tokyo Protocols, underscore the necessity of decreasing GHG emissions to achieve the objective of a net zero future for GHG. Collecting and dividing CO_2 from fossil fuel generators is an effective method for mitigating GHG emissions [27]. Reports indicate that 80% of fossil fuel burning results in GHG emissions, which might be mitigated via coordinated strategy and concerted efforts to attain a sustainable future [14]. A thorough analysis addressing worldwide prospects, advancements, and effective regulations related to the environment was provided. This research examines methods to mitigate threats to the environment [17]. The study conducted a realistic examination of the environmental impacts to assess and contrast the traditional extraction of fossil fuels and the possibility of carbon capture and storage in Norway and Japan [34]. Various life cycle assessment studies were analyzed, focusing on Carbon Capture and Storage (CCS) and carbon capture and use [28]. CCS has been shown to reduce the potential for global warming by 60%-80%, while it may increase some other life cycle impacts [19]. The study examined novel environmental outcomes of CO_2 capture generated by several sectors, including electricity and transportation [29]. They evaluated carbon capture and storage initiatives, underground gas storage, increased oil recovery, and GHG extraction. Established carbon reduction objectives examined critical elements of CO_2 capture, management, and storage alternatives.

Methods and Materials

Methods

This research encompasses electrical, ecological, and economic assessments to assess the suggested system's reliability and application. The study technique aimed to provide a framework for enhancing the power economy and diminishing the release of GHG from electricity produced by fossil fuels by implementing a Hybrid RES (HRES). An HRES comprises several forms, such as sun and wind, unlike traditional sources that depend on fossil fuels [30]. This modification converts an HRES-powered building into a green facility [6]. Information was gathered about consumption profiles, green energy resources, and GHG emissions [35].

The components of an HRES are adjusted to provide the necessary power production from available RES while minimizing the overall Net Present Cost (NPC) to meet technical, financial, and environmental criteria [20]. In alignment with the design parameters, the modeling program selects the most appropriate system for diverse inputs. This paper proposes a systematic approach to determine the most suitable HRES systems utilizing RES and environmentally friendly energy resources. The structure is predominantly comprised of the five steps illustrated in Figure 1.

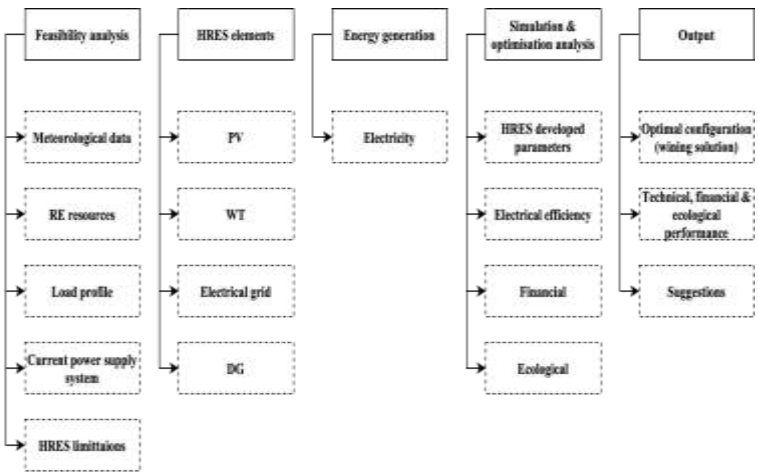

Figure 1. Optimal planning design of the proposed model

The initial phase involves a preliminary feasibility evaluation to identify possible HRES technology and establish an appropriate system to satisfy the load demand. The weather information provides insights into the particular study on ambient conditions, including wind velocity, temperature, and weather. The clean energy supplies at the site are assessed to determine an HRES, depending on their accessibility.

A load profile is necessary to ascertain the system's kilowatt requirements. The load report includes the load type (homes, advertisement, or industry) and regular and annual statistics indicating the energy requirements at specific times of day and the variations in load between summer and winter. The existing power supply serves as the energy source for the case study system before implementing the planned HRES. The HRES design constraints may restrict the implementation of some HRES technology and encompass geographical limitations (e.g., insufficient space for PV panels or obstructions to wind turbine structures).

The HRES elements include the subsystems within the suggested structure, possibly including solar, wind, mechanical power sources, and power grid infrastructure. Energy production refers to the electrical power supplied to the demands of several subsystems that constitute the HRES.

The modeling and optimization analysis phase encompasses parameters HRES establishes and assesses electrical effectiveness, economic viability, and ecological effects. The simulation gathers the HRES variables to ensure the optimization appropriately reflects the case study.

The system's effectiveness is enhanced by considering the kind of energy produced and its proximity to the load. A financial and ecological optimization throughout the simulation phase enhanced the total data generated. The concluding phase in the systematic framework is the results phase. The features and benefits of the suggested winning systems HRES are listed, and the contrast with the base-system arrangement is illustrated in Figure 2.

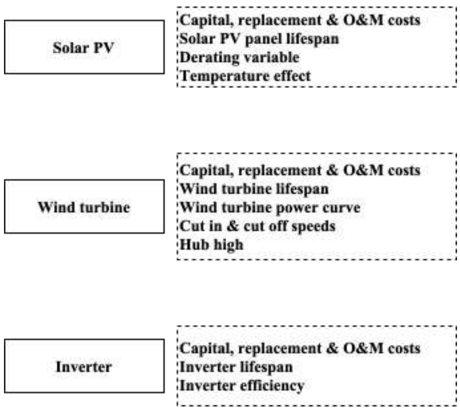

Figure 2. HRES input variables

The instrument employed to gather field measurement information for this investigation was the Power Masters electrical quality tester. This apparatus was linked to the primary distribution panels of the case-study resort, and the load usage profile and electrical usage were recorded at ten-minute intervals over thirty days to get a precise load history from the power distribution corporation. The property's intelligent meter provides the load profiles for an entire year with daily data. The comprehensive load profile information was generated by amalgamating the field information with the meter log profiles.

Results and Discussions

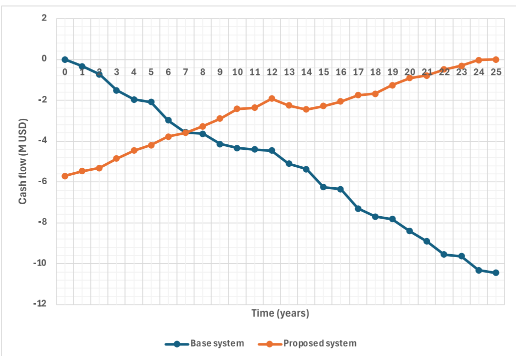

Figure 3. Optimal analysis of base and proposed system

Figure 3 illustrates the cumulative quantitative cash flow for the initial and optimum systems. As the project progresses, the financial flow of the starting system deteriorates, whereas the money flow of the chosen system progressively improves. The decline in cumulative nominal cash flow for the ideal system after around 25 years is attributable to the substantial maintenance cost of the wind turbines.

Based on the optimization results, the optimal HRES design was determined to have 580 kW photovoltaic arrays. Photovoltaic energy output during the summer exceeded that of winter owing to increased solar irradiation and extended daylight hours. The mean power output was approximately 450 kW from the photovoltaic systems, 320 kW from the converter, and 25 turbines. The power generation from windmills was relatively stable owing to the consistent wind available most of the year. The power source was a distributed generator (DG) gasoline engine already present in the baseline scenario.

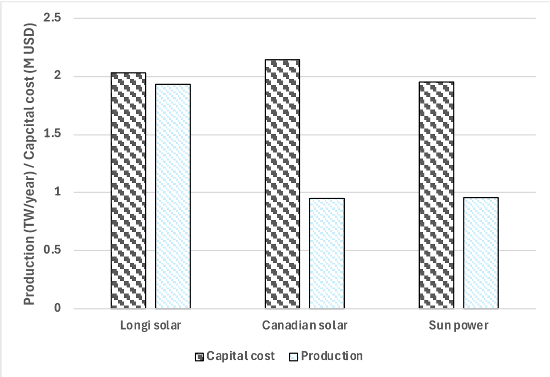

Figure 4. Production and capital cost analysis

This study utilized three photovoltaic structures: Canadian Solar, SunPower, and LONGi Solar Technologies. The most advantageous photovoltaic type was SunPower, with an initial price of USD 1.74M, succeeded by LONGi Solar at USD 2.142M and Canadian Solar at USD 2.312M, as seen in Figure 4. The annual power output for SunPower PV was 0.952M kW, while LONGi Solar and Canadian Solar produced 1.42M kW and 0.952M kW, respectively.

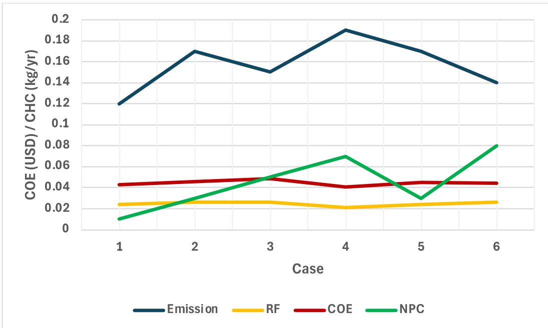

Figure 5. Economic and ecological performance analysis

The last column presents a comparison between each example and the primary case. This data encompasses the decrease in GHG emission levels and the NPC, COE, and O&M costs for each scenario relative to the baseline case. The decreased percentages indicate the interaction and alteration of the cross-bonding value by the various suggested setups. The optimal scenario had the most significant decrease in NPC at 54%, whereas the minimal drop in any situation was 14%. Furthermore, the O&M cost, primarily contingent on the grid usage bill, was diminished by 120% for the successful example owing to the surplus energy supplied. The changes in economic and ecological emissions across various scenarios are visually illustrated in Figure 5 for comparability.

The ecological evaluation of the best HRES design indicated a substantial reduction in GHG pollutants, decreasing from 0.942M kg/year in the base scenario (zero energy from RES) to 0.432M kg/year with a high green energy component of 71.3% in the overall system. The 76.3% decrease in emissions warrants removing diesel-powered generators, hence diminishing reliance on fossil fuels. The overall operational hours for the DG were substantially decreased from 24 to 7 hours per year. Consequently, the overall diesel fuel consumption diminished to around 39 L in the ideal scenario, in contrast to 1250 L in the baseline scenario. This enhances the reliance of the suggested ideal HRES on RES. Figure 6 presents a detailed analysis of the principal emission factors resulting from the best design.

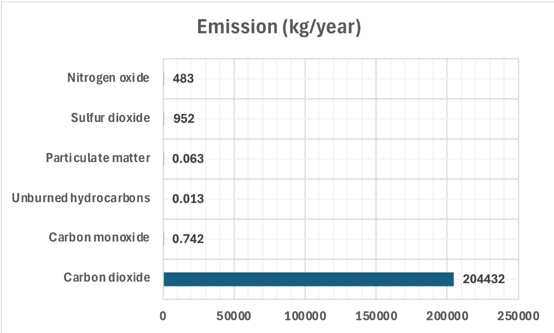

Figure 6. Major GHG emission analysis

The current study has established a novel HRES configuration that varies from previous studies regarding element dimensions, load specifications, and natural resources. Consequently, more than an accurate contrast with these systems is needed. Nonetheless, utilizing the systems' financial setup for comparability is permissible and acceptable. The outcome compares with the NPC and COE of this research on the Petra Marriott Resort in Jordan and the other referenced study. The COE values serve as the principal comparative metric for energy utilization from RES. Figure 7 depicts the NPC and COE values for the best HRES design across several global locations.

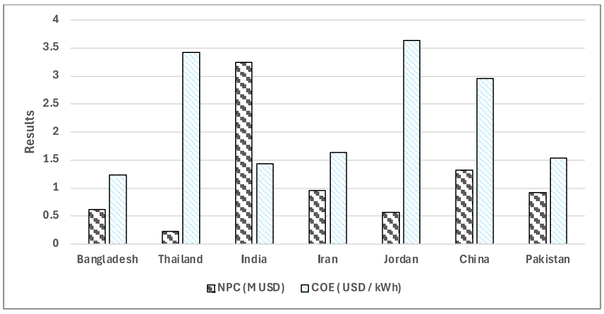

Figure 7. NPC and COE analysis

Figure 8 indicates that the favorable impact of SD enhances RES usage while detrimentally affecting non-RES usage. The response of RES and non-RES use to the effects of SD is transient and diminishes with time. Research findings on energy usage and job creation demonstrate that the positive impetus of economic expansion has favorably influenced the use of both RES and non-RES. The findings derived from the correlation between SD and energy use are varied. Economic development disregards the detrimental environmental effects of energy consumption, and a rise in revenue results in the expansion of material capital, thus leading to more significant expenditure on the extraction of energy sources, particularly fossil fuels. Nonetheless, the beneficial impact of SD and the attainment of advanced stages of sustainability in the nation will enhance the emphasis on environmental quality and social welfare, which are additional elements of SD. This will promote investment in energy from RES and diminish the reliance on fossil fuels.

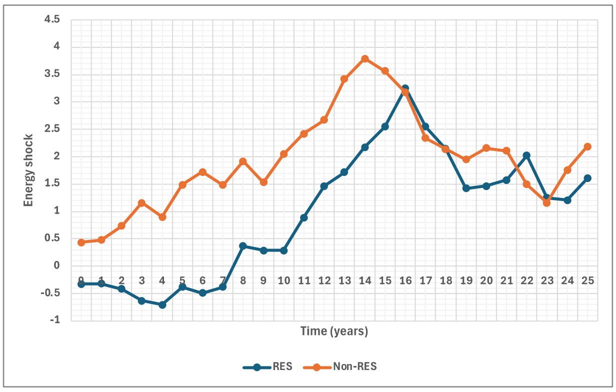

Figure 8. Energy shock analysis

Regulation Rule of Energy Storage

The primary regulatory constraint on energy storage that restricts the expansion of hybrid system capacity and reimbursements is outlined below: A 6% electricity loss is imposed on the customer due to the utilization of a transmission or distribution network, along with a charge of USD 0.2 per kWh. The generating power of the solar power plant to be integrated into the authorized dissemination or shipping and retail supply networks shall be established such that the annual energy output does not surpass the actual use recorded over the year prior from the time of the recipient's membership application, plus the energy estimated to account for expenses. Energy is generated by the conveyance of power via transportation and distribution systems. The candidate calculates the producing capacity in the request for new subscribers who have not been used in the past 12 months. The user will not receive compensation for yearly surplus amounts if the surplus energy is above 10% of the power the subscriber utilizes using the public conveyance procedure.

Conclusion

Environmental degradation and global warming necessitate SD. Utilizing the RMSE criterion, the previous Full function and the autonomous Normal-Wish artwork function are employed to examine the impact of green energy consumption on SD. This study examines the interrelated dynamics of environmentally friendly development, energy use (RES and non-RES), and CO2 outputs in Uganda from 1980 to 2020. Ani is employed to examine the impacts of shocks on variables in the model. BVAR surpasses other functions in analyzing non-RES usage and SD. The findings of the instantaneous response functions are as follows:

The findings indicate that RES and non-RES contribute positively to Uganda's SD. The reaction of SD to non-RES is inconsequential over the reviewed period. Still, its response to energy from RES is substantial and favorable from periods 1 to 25, becoming inconsequential afterward.

SD is becoming progressively attuned to the utilization of RES. RES and non-RES users respond differently to the beneficial impact of SD. SD in Uganda will enhance the utilization of RES while diminishing the reliance on non-RES. To attain SD, particularly in developing nations like Uganda, it is essential to utilize all forms of energy, including renewables and fossil sources. It attained SD notwithstanding environmental degradation.

The findings may be encapsulated as follows: While RES and non-RES contribute to SD in the country, promoting SD enhances the propensity to utilize energy that is not renewable. RES, such as wind and solar, are not always accessible, and large-scale storage remains unfeasible, resulting in diminished capacity and efficiency. These concerns underscore the necessity of sustaining non-RES capacity for production to ensure supply security. Clean energy enhances stability; nevertheless, if governments prioritize quick economic expansion and augmented gross national savings, non-RES is preferred owing to its cheaper cost.

Research findings indicate that a nation's transition from non-RES to RES must be executed gradually and with a gradual slope to achieve SD. An abrupt reduction in fossil resource consumption does not facilitate the nation's progress. The substantial expenses associated with installing and operating renewable methods and their minimal impact on the nation's energy portfolio hinder revenue growth and SD.

RES can enhance Uganda's SD but will also contribute to air pollution. Nonetheless, this pollution is inferior to non-RES and will dissipate more rapidly. RES generates less pollution than non-RES; nevertheless, they do not eliminate pollution. The findings indicate that RES is superior to non-renewable ones in mitigating air pollution.

Gross national savings determine the SD index. Expanding this aspect for growth in the first phases is crucial, as this objective necessitates all RES and non-RES forms. Following the enhancement of GNP and the progression towards SD, it is necessary to diminish the use of natural resources, particularly non-RES and air pollution. The increase of the SD index enhances investment in and usage of RES. GDP quantifies economic fluctuations but does not account for prospective obstacles, as the subjects above indicate. Macro choices must utilize the adjusted net savings indicator. Gross Savings (GS) as an economic metric might prompt policymakers to safeguard the environment, prioritize natural resources, and enhance societal well-being. "Green GDP" can facilitate the planning of growth in the economy. Economic advancement and a rise in gross national savings may result in policies that obstruct SD. Long-term SD necessitates that governments diversify energy sources, particularly RES. Establish a fund to provide financing for building RES plants and assist wealthy individuals in advancing RES initiatives. Fossil resources may serve as substitutes.

The significance of clean energy in achieving SD, mitigating GHG emissions, and enhancing energy security contrasts with the necessity for money and substantial investments in RES-related projects, amplifying the role and relevance of business growth. This study analyzes the effects of contemporary facility growth and technologies for RES on sustainable energy advancement, acknowledging the significance of this subject.

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