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REVIEW PAPER

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Solar energy for sustainability in Africa: The challenges of socio-economic factors and technical complexities

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Summary

The world is faced with increased energy resources depletion, fluctuating costs, global warming, greenhouse gas emissions, air pollution, and poor health effects which characterise traditional energy sources. All of these difficulties would be considerably alleviated if renewable energy were not widely used. This study draws from existing literature to propose a conceptual model that underpinned the focus on the relationship between solar energy projects and sustainability dimensions (economic, social and environmental sustainability). Socio-economic factors and technical complexities were tested to ascertain the moderating effect on solar energy and sustainability. A mixed research approach comprising quantitative and qualitative methodologies was integrated to carry out this study. The qualitative study was based on a case study of an ITC centre powered by solar energy in an academic institution in Nigeria. While the quantitative study depended on a survey with 227 valid responses taken through snowball sampling from the professionals working in the energy industry. Hierarchical multiple regression using SPSS 26 was carried out for the moderation analysis of the socio-economic factors and technical complexities towards sustainability dimensions. Results showed that solar energy has a strong positive direct effect on sustainability in all aspects of economic, social and environmental dimensions. The socio-economic factors are seen to have a moderating effect on the positive relationship between solar energy and all the three dimensions of sustainability, whereas technical complexities determine inverse moderating effect only on the relationship between solar energy and economic sustainability. The findings predicted that the socio-factors are the major challenges in hindering the overall sustainability in Africa rather than technical complexities, hence lead to a major concern for

Abbreviations: CO2, Carbon Dioxide; ENV, Environmental Sustainability; ES, Economic Sustainability; GW, Gigawatts; H, Hypothesis; IEA, International Energy Agency; KMO, Kaiser-Meyer-Olkin; kwh, Kilowatt hours; MW, Megawatt; PV, Photovoltaic; SE, Solar Energy; SEF, Socio-economic Factors; SPSS, Statistical Package for the Social Sciences; SS, Social Sustainability; Std. Error, Standard Error; TC, Technical Complexities; TETFUND, Tertiary Education Trust Fund; UN, United Nations; USD, US Dollar; $, Dollar.

the economic, social and environmental dimensions. A similar outcome is also validated by the Case study of ITC centre powered project of solar energy. This study recommends a detailed model of solar energy development in terms of its potential and challenges in the developing parts of the world.

KEYWORDS

economic sustainability, environmental sustainability, social sustainability, socio-economic factors, solar energy, technical complexities

1 | INTRODUCTION

Global solar energy (SE) demand is quite volatile and varies greatly between countries. According to International Energy Agency (IEA),[1] by the end of 2019, a total of 629 GW of SE had been installed around the world. Honduras now has enough solar PV capacity to supply 12.5% of the country's electrical energy, while Australia is approaching 11%. Italy, Germany and Greece can supply between 7% and 8% of their annual domestic electricity demand, respectively.[1]

Due to the depletion and environmental devastation caused by fossil fuel and biomass usage, several scholars[2-5] advocate the hypothesis that renewable energy should be used to replace, not simply supplement, fossil fuel use. SE is especially preferred because it has a low carbon footprint.[6,7] The integration of SE as an essential renewable energy source[5] with circular economy is a pivotal component of sustainability. Solar photovoltaic (PV) capacity in the United States reached 88.9 GW by the end of 2020, enough to power 16.4 million American households.[8] However, if not built or managed effectively and holistically, solar power can still result in waste products and other consequences throughout its life cycle and the by-products of its processing.[9] IEA[1] reported the top 10 countries by SE capacity by 2019 shown in Figure 1.

Currently SE is gaining traction globally but not without accompanying challenges, as well as opportunities. Therefore, there is a need for management to apply socio-economic principles to ensure that its development potential and its attendant challenges are appropriately managed. Realising the SE potential necessitates using a planning lens that considers not only speed and immediate cost, but also the broader holistic sustainable advantages that can be realised along the value chain.

This study aims to investigate the impact of SE on the economic sustainability (EC) and environmental sustainability (ENV) under different socio-economic challenges and technical complexities (TCs). In order to meet the study aim, the following objectives were placed performed in this research.

i. To evaluate the opportunities for the development and implementation of sustainable management practices on SE.
ii. To understand the challenges of SE in achieving the sustainable development.

The challenges of socio-economic factors (SEF) in developing African countries for the SE sustainability entail major threats to the clean-energy services, energy waste reduction, energy conservation, energy efficiency,

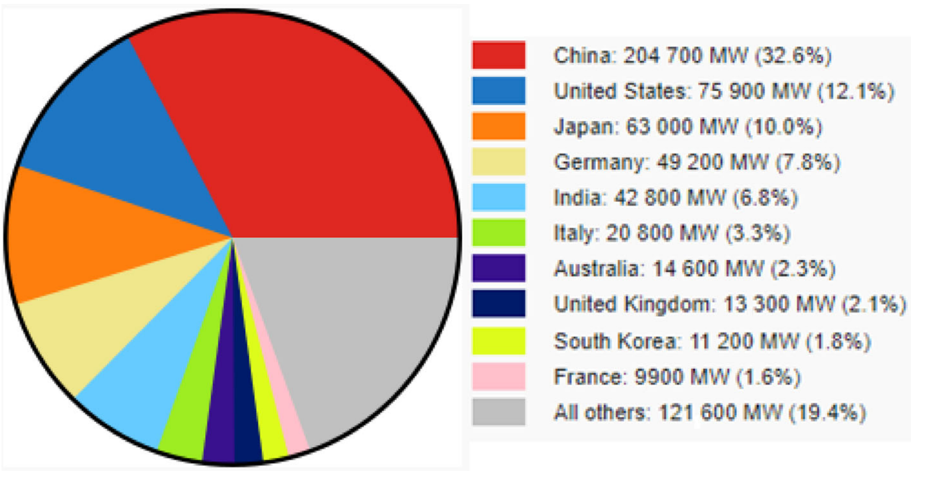

FIGURE 1 Ten top solar energy countries by capacity by 2019 (*Source*: Reference 1)

energy security and CO_2 emissions reduction. Moreover, these challenges are also the major threats on the global scale as well as at the local settlements. These threats cannot be fully equipped until and unless and unless the government and local scale circular policies for SE are not formulated. In addition to socio-economic challenges, the TCs are also the hardcore aspects of the solar technologies, which need to be addressed to make it easily accessible at the local scale. This relationship will allow the urban energy system to cope with their specific sustainability challenges, as well as harness their opportunities. However, there is not much research that focuses on the SEF and TCs, more especially on its influences on the SE sustainability in urban areas settlements. The rationale for this research is categorised into two, the practical rationale and theoretical rationale.

The issues of sustainable management of SE are elusive in most parts of the world in spite of the UN sustainable development goals[10] that seek to meet the targets and vis-a-vis clean energy generation and utilisation. The challenges and drawbacks of SE technologies are issues of great concern in sustainable management. In some cases, there is no adequate policy framework to enforce the sustainability of the SE system. On the other hand, the existing policies are not matched up with implementation and required enforcement that comply with sustainability standards. In other cases, the problem may be energy wastage and other poor energy sustainable practices, high carbon emissions, or a gross violation of quality control and quality assurance standards in the generation, distribution and maintenance of SE systems. Based on the foregoing, this research seeks to understand the challenges and opportunities of SE sustainability in urban areas.

In a nutshell, the theoretical rationale for this study stems from the fact that there are insufficient studies in the literature to assess the impacts of SE on sustainability under different socio-economic challenges and TCs. This study will, therefore, seek to make a significant contribution to the academic literature in this area.

2 | LITERATURE REVIEW

This part of the research reviews several studies from the existing literature that are relevant to the current investigation. By drawing on relevant books, articles, journals and conference papers, this part of the study advances a critical analysis of sustainable development and sustainability issues in the general context of the emerging global SE system with the instrumentality of sustainable management policies, sustainability concept, models and dimensions.

2.1 | Sustainability

Several scholars and researchers have tackled the term sustainability from various perspectives, based on the subject at hand and the viewpoint from which it is seen. Therefore, the term "sustainability" has a variety of definitions in the literature. According to Van Zon,[11] the terms "sustainability" and "sustainable" first appeared in the Oxford English Dictionary in the second part of the twentieth century. The core word for sustainability is "sustinere," which means "to keep going." It has a variety of synonyms, including keep, maintain, and preserve. "Sustinere-eco," according to Agyekum-Mensah et al,[12] is a phrase that has sparked a lot of controversy about what it means to hold or preserve the environment.

2.1.1 | Sustainability models

There are several theories and models of sustainability in the literature. Jenkins[13] proposed sustainability theories that are focused on and coordinate social reactions, financial matters, ecological concerns and social issues. An economic model support monetary capital and financial involvements; an environmental model looks to organic variety and natural respectability; a political model looks to social frameworks that acknowledge human dignity. This model prioritises key components which must be sustained – economic, ecological and political. In the model of sustainability by Todorov and Marinova,[14] they classified sustainability models into quantitative, physical, conceptual and standardising models. Thatcher,[15] as well as Irhoma,[16] proposed four models of sustainability (Figure 2): The three-pillar model (also referred to as the Triple Bottom Line or Three circle Model), the Prism Model (also referred to as the Four Pillars Model); Nested Circle of Sustainability Model (also referred to as the Concentric Circles Model or Egg of Wellbeing Model); and the Two-tiered sustainability equilibria Model. This research work shall focus on the three pillar model of sustainability as a theoretical framework upon which it is based.

2.1.2 | The three-pillar model of sustainability

The three-pillar model of sustainability is based on the mathematical concept of a Venn diagram embedded with the overlapping circles which depict the important sustainability types of social, economic and environmental goals, and the intersection of these three elements leads to overall sustainability. The overlap at the point of interception accurately depicts that all of the domains involved are satisfactory sustainability. However, this those not necessarily

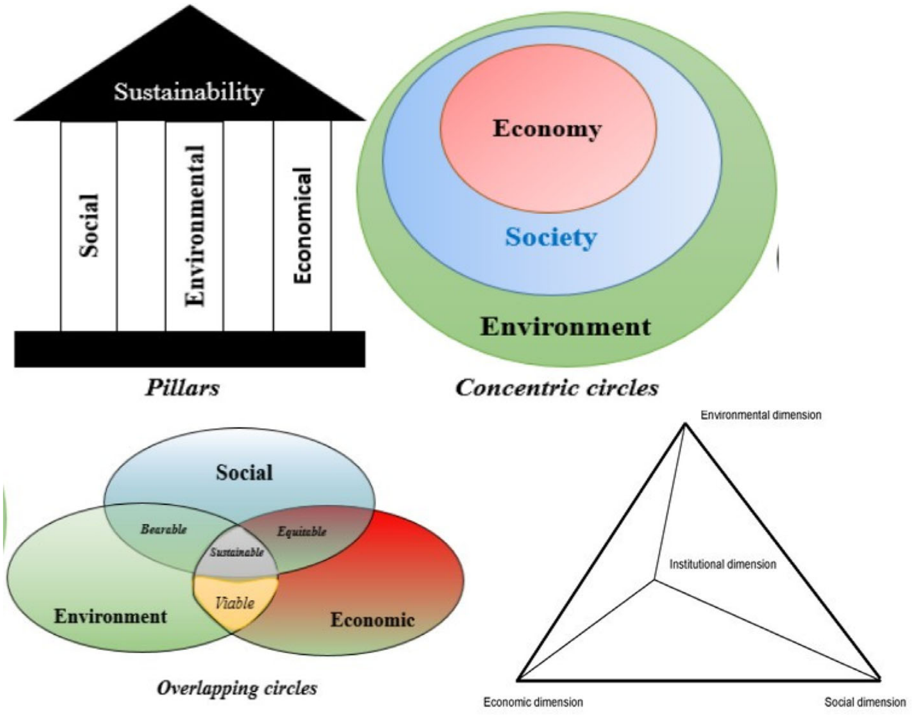

FIGURE 2 Models of sustainability (*Source*: Reference 16)

mean that sustainability must cover every one of these domains. The various aspects – economic, social and environment are not exclusively dependent upon one another, any of these areas could stand alone and pursue a target of attaining sustainability. There is a growing argument in the literature that of the three aspects of suitability in the three-pillar model – the economic, social and environmental aspects, the environmental concerns are more fundamental and should be given more consideration in the pursuit of sustainability.[17] This argument is in line with the view of Howes et al,[18] which state that the environment is critical in supporting the economy and the society. To put it another way, the environment can survive without human societies and economies, but economies and societies cannot survive without the resources of the environment, making the environment domain the most significant in this idea.[19] Economic advantage must be based on long-term activities that work within society's and nature's restrictions. Figure 3 shows the various components of the three pillar model of sustainability.

The essential feature of the environmental line of sustainable development is the preservation of environmental resources for future generations. In other words, it emphasises the need for environmental protection through the efficient use of energy resources. It also emphasises the importance of reducing greenhouse gas emissions and ecological imprint.[20,21] This is because environmental measures, like the social line, have an impact on the long-term viability of organisations.

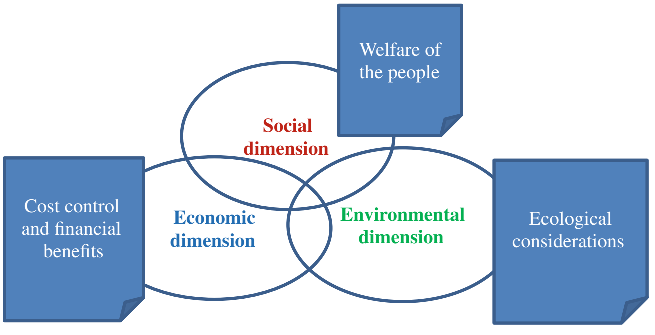

FIGURE 3 Three-pillar model of sustainability (Modified from the overlapping circle sustainability model after Reference 16)

2.1.3 | SE security for sustainability

There have been no studies in the SE field that have attempted to investigate sustainability in terms of the combined implications and influence of socio-economic issues, and technical challenges. These difficulties have not been thoroughly examined, and as a result, no comprehensive solution has been devised to solve them and enhance current SE sustainability issues in metropolitan settings. Sustainable energy generation, efficient use, industrial process efficiency, life cycle assessment, carbon footprint and overall sustainable development are all concerns. As a result, the goal of this research is to fill this gap in the sustainability literature.

2.2 | SE system in urban area

According to Grubler et al,[22] more than half of the world's population lives in cities, and these cities are expected to absorb almost all of the world's population expansion through 2050, totalling an additional 3 billion people. The growth of the rural population in many emerging countries will be dwarfed by population movements to cities in the next decades. The world is already primarily urban in terms of energy consumption. According to this study, cities account for 60% to 80% of global final energy use.[22]

Grubler et al[22] proposed two perspectives of urban energy systems, functional and spatial perspectives. The functional viewpoint considers urban sites and their urbanisation to encompass not only the physical locations of people and economic activity, but also the types of activities they engage in, and the infrastructure and functional framework services provided by urban agglomerations. Urban regions are increasingly defined by functional qualities, which are represented in the analysis of urban energy systems. Alternatively, the traditional spatial concept of cities as defined by political or geographical limits has shifted to urban agglomerations, which include greater metropolitan areas or urban populations.

Broadly speaking, energy systems are categorised into two types based on their sources as:

i. Nonrenewable energy and
ii. Renewable energy

2.2.1 | Energy translation

Fossil fuels (oil, gas, coal) are deemed nonrenewable because their use depletes scarce resources such as fuel, gas and coal. Maqbool[23] distinguishes between renewable and nonrenewable energy. Renewable energy, on the other hand, is free and naturally renewed, and it is frequently used to deliver energy in four critical service points: electricity, rural off-grid power generation, water and air heating and cooling. SE, wind energy, hydroelectric energy, geothermal energy, tidal energy, wave energy, nuclear energy and biomass are examples of alternative energy sources (renewable energy). SE is argued by some literature,[24,25] to stand out among other renewable energy sources since most of the others, whether directly or indirectly, rely on the sun upon. For example, wind energy indirectly comes from the sun since it is required to drive the wind; hydroelectric energy also comes from the sun because the sun produces evaporation, which vapourises and falls back as rain. Rain falls into rivers or is flooded downhill into rivers, and the force of the rain is captured in hydroelectric dams to generate electricity. Similarly, biomass comes from the remains of plants that are produced when the sun causes photosynthesis to occur.

2.2.2 | SE and sustainability

When the sun's rays strike the solar panel, electrical energy is generated. Several scholars[2,3,5] support the view that SE should be used to replace, not simply supplement, fossil fuel consumption, due to the depletion and environmental damage it produces. This is the viewpoint of Shahsavari and Akbari[26] and Rigo et al,[27] who believe that SE is eternal and attainable, and that it is necessary for future livelihood, particularly in developing nations for rural areas. Similarly, GNESD[28] asserts that solar PV energy is the most cost-effective means to promote health, claiming that health improvement is impossible without it.

One of the major problems of the SE system is the high initial installation cost; for example, in 2022, the average price per watt for SE in the United States is \$2.77,[29] though it is much better than the price of 2016, which was \$3.70, still not enough for easily acceptable on wider public level.[30] Furthermore, most household solar panels have efficiency of 10% to 20%, which is another flaw in solar technology.[31] SE, like other kinds of renewable energy, is influenced by weather conditions.[32] Although it is a free source of energy, there are only a few sites with ideal climatic conditions for the installation of solar panels, such as the sun's radiation angle and daytime. Electricity production will not be cost-effective in this manner if the climatic conditions are not suitable. Another issue with SE is the storage of electricity. SE is transported to batteries before entering the distribution network. Despite advancements in the technology of battery production, they remain expensive and not economical for use. Many firms are now presently pursuing research to develop cost-effective batteries. However, none of them has been able to considerably reduce the cost of batteries. SE technologies have also been chastised for requiring a big amount of land to be produced. Solar power generation on a large scale frequently necessitates enormous areas of land. A 1 MW solar power plant with crystalline panels (about 18% efficiency) would require approximately 4 acres (16 187 m^2) of land, while thin film technologies (12% efficiency) would require approximately 6 acres (24 281 m^2).[2,33,34]

Nonetheless, it is expected that the future cost of designing and manufacturing solar panels would decrease due to economies of scale in future solar system production such that SE will become a more accessible and cost-effective source of energy. Other components' performance constraints, like batteries and inverters, are also areas where there is an opportunity for improvement, further research and development.

From a holistic point of view, the gains of SE, overweigh the demerits.

From the review of the literature, this study has put forward the following hypotheses:

Hypothesis 1. *SE has a positive effect on ES.*

Hypothesis 2. *SE has a positive effect on social sustainability (SS).*

Hypothesis 3. *SE has a positive effect on ENV.*

2.3 | The role of socio-economy factors towards sustainability

Stakeholder involvement, uncertainty in communicating with stakeholders and investment matters are all SEF that affect sustainability. Because the development of transformational projects and radical technology is expected to have far-reaching socio-economic consequences. Sustainable development necessitates the recognition of a diverse set of stakeholders, including primary stakeholders (investors, managers, suppliers, employees, customers, government and policymakers) who are directly involved in the process, as well as secondary stakeholders (such as pressure groups) who are not directly involved in a market relationship but can have a significant impact on a company's business.[21,35] Sustainable development innovation is more complicated than traditional market-driven innovation because of the added interacting constraints from social and environmental issues. Past research on innovation dynamics has implicitly acknowledged the importance of key stakeholders, but has undervalued the role of secondary stakeholders, who are frequently highly influential in sustainable development innovation. The ambiguity of stakeholders is another key socio-economic aspect. This could be due to the fact that different stakeholders have different aims, demands and perspectives. Additionally, particular stakeholders may have irreconcilable views of one another over ethical, religious, cultural, societal or other problems.[35,36]

From the review of existing literature carried out in this part of the research, the following hypotheses are developed for this study:

Hypothesis 4. *SEF inversely moderate the positive relationship between SE and ES.*

Hypothesis 5. *SEF inversely moderate the positive relationship between SE and SS.*

Hypothesis 6. *SEF inversely moderate the positive relationship between SE and ENV.*

2.4 | The role of TCs towards sustainability

Jun, Qiuzhen, and Qingguo[37] discussed the organisational contingency theory, which is based on the moderating influence of uncertainty and risk management in the context of project use of new technology. Organisational complexity, uncertainty, dynamic complexity, intra-organisational complexity, marketing complexity, temporary complexity, development complexity, environmental complexity and structural complexity were all factors captured in a broader spectrum view of project complexities in the literature.[38,39] Molepo et al[39] went into much detail about the origins of these issues. Organisational complications develop when a project involves a big multidisciplinary team or when numerous organisations interact. The project's technical and design requirements, as well as the project's broad scope, can all contribute to technological complexity. Uncertainties in a project might arise from differences in project costs or in project goals and outcomes. Multiple and frequent changes in the project and management process might lead to dynamic difficulties. Collaboration with other organisations or communication failures between participating businesses can cause intra-organisational complications. Unpredictable market variables, a high level of rivalry, and demand and supply variations can all contribute to marketing difficulties. Unanticipated future limitations, such as changes in government or company ownership, can cause temporal complexity. Poor management of an endeavour or a development plan can lead to development complexity. Environmental concerns linked with the project's location may add to the project's environmental complexity. The project manager's level of control over restricted resources or a lack of top management support for the project may cause structural complexity.

From the review of existing literature carried out in this part of the research, the following hypotheses are developed for this study:

Hypothesis 7. *TCs inversely moderate the positive relationship between SE and ES.*

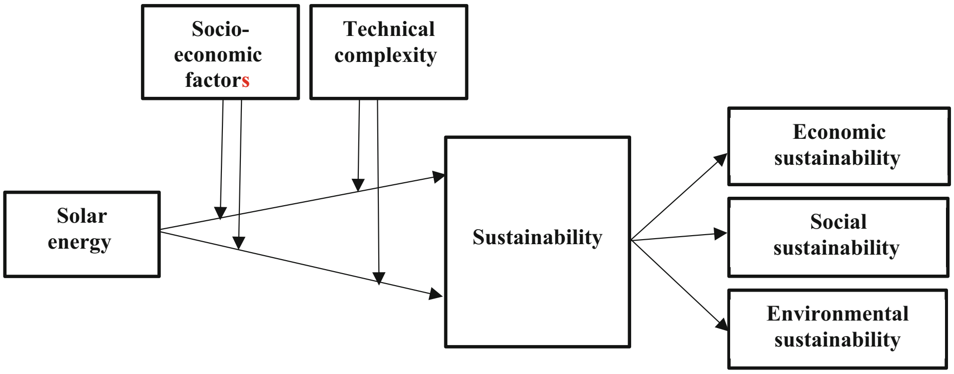

FIGURE 4 Research framework

Hypothesis 8. *TCs inversely moderate the positive relationship between SE and SS.*

Hypothesis 9. *TCs inversely moderate the positive relationship between SE and ENV.*

2.5 | Research framework

The literature review has attempted to do justice to the concept of sustainability. It has done an overview of notable definitions cut across time and a variety of researchers. It has outlined empirical theories of sustainability, discussed its models and dimensions, and has zoomed in on the triple bottom line theory. A critical review and synthesis of the literature on sustainability was carried out, upon which a literature gap was drawn for this study. The literature review on SE elucidates the imperativeness of a paradigm shift in the SE system of urban areas towards sustainability in the selection of energy sources, stating views on SE and its distinct characteristics among other energy sources.

After a review of the literature relevant to this study, in line with the research objectives, Figure 4 gives a conceptual model of the current study. This framework seeks to establish a direct relationship between SE and sustainability, as well as the moderating effect of SEF and TCs.

3 | METHODOLOGY

3.1 | Research design

This study used the mixed-method strategy to collect the data. The rationale for this strategy is that it provides a comprehensive and all-encompassing dataset to achieve the objectives of the research. Also, the use of these two research designs complements one another as well as validates the data collected and the research outcomes. It compensates for the constraints of the primary research method, supplements the core design, makes stronger inferences, and provides a diverse, elaborate, and comprehensive view of the study findings. In a nutshell, these rationales are summed up by the word "triangulation," in which the project study design approaches a design from many angles or perspectives but converges at a point, with various designs confirming one another.[40,41]

3.2 | Data collection

3.2.1 | Data collection for quantitative study

The quantitative research method used for this study enables the collection of numerical data based on a developed questionnaire. The research generates primary data from a structured outline survey through questionnaires that are digitally distributed. The use of surveys to collect raw data is very suitable for investigating quantifiable variables and can also be used to generate digital data from the respondents of this study.

Questionnaire design

The questionnaire design includes a brief description of the research goals and objectives, as well as certain aspects of ethical considerations such as confidentiality. The questionnaire was managed using Survey Monkey software. The link to the questionnaire was sent to the respondents using the respondents online. The questionnaire was divided into two parts – Part A covers demographic questions, while Part B covers topics related to the research question.

The questionnaire was created using a 5-point Likert Scale. The score of the first point is "strongly disagree," the second point score is "Disagree," the third point score is "Neutral," the fourth point score is "Agree," and the fifth point score is "Strongly agree."

The major reason to use the 5-point Likert scale instead of the 7-point or 9-point Likert scales is the response rate and response quality increase with it.[42-44] Moreover, it also helps reducing the respondents' "frustration level," which in turn results in a good response rate to accept.

Measurement of scales

The questionnaire for this study was developed in line with the research questions and based on six variables (independent, moderating and dependent variables). The independent variable is SE; the moderating variables are SEF and TCs, while the dependent variables are the economic dimension of sustainability, the social dimension of sustainability and environmental dimension of sustainability.

Measurement of SE. SE was measured using the scales of El-Khozondar and El-Batta[45] and Sindhu, Nehra and Luthra.[46] Ten dimensions used include alternative energy, uniqueness, alternative energy, clean energy, carbon footprint, installation cost, increased supply, constant supply, ENV, ES SS.

Measurement of SEF. This is based on the scale of Abrar et al,[47]; and Ul-Haq et al[48] with four dimensions. They are household income, educational level, household size and age.

Measurement of TCs. TCs are based on the scale of Barki et al[49] and Wallace et al[50] They comprise three dimensions: technology, TCs and new technology.

Measurement of ES. This is based on the scale of Maqbool,[23] O'Brien et al,[51] and Wu et al.[52] It has nine dimensions, including cost, affordability, billing, employment, business cost, initial installation rate, revenue generation, subvention and gross domestic product.

Measurement of SS. It is based on the studies of Hussain et al[53] Garnett et al[54] and Liu et al.[55] It has eight dimensions, namely, community involvement, employment, social engagements, urbanisation, risk assessment, awareness, social amenities and quality of life.

Measurement of ENV. It is based on scales from Levaggi et al[56] and Ahmadi et al,[57] with 12 dimensions. These are ENV, carbon footprint, health, noise pollution, air pollution, smell pollution, dust pollution, water pollution, emission reduction, clean energy, health impact and environmental friendliness.

3.2.2 | Sampling technique

Probability or nonprobability sampling methods are commonly used for research sampling.[58] In probability sampling techniques, all elements or members of the population have the same probability of being selected in the sample, while in non-probability sampling techniques, there is no equal opportunity. The sample was generated using purposeful snowball sampling techniques to get quality responses for this study.

The sample population was industry professionals and academic researchers. The sample size for this study is 227 respondents spread all over Africa.

3.2.3 | Data collection for qualitative study

Data Collection was through e-mail discussions, on-site measurements and local documents. The case study for this research is a solar powered ITC centre located in Kogi State Polytechnic, Lokoja, Nigeria.

3.3 | Method of data analysis

3.3.1 | Analysis of quantitative data

Reliability analysis was carried out using the Cronbach's alpha. Moreover, Correlation Analysis was also carried out to evaluate the strength of the relationships between the variables. Also, the moderation variables were analysed in SPSS using hierarchical regression analysis.[59]

3.3.2 | Qualitative study analysis

The generalisation technique is used in the analysis of this case study, which is more analytical and cognitive than statistical, founded on the principles of reasoning.[60] Based on evidence from the case, the study will adopt the naturalistic generalisation through which, the researcher can consider the investigated case as a microcosm of a larger system macrocosm.

4 | RESEARCH FINDINGS

The purpose of this section is to present the results of the online questionnaire as well as the results of the case study method used. Also, data analysis is a necessary and vital component of any research investigation in order for researchers to make sense of the data obtained. This section also presented the different analysis techniques carried out on the collected data and the findings are presented.

4.1 | Quantitative study data presentation and analysis

4.1.1 | Data compilation and screening

Before undertaking any statistical study, it is important to first ensure that the obtained data is clean by screening it to ensure that it is usable, reliable and valid.[61] Results collected from the online questionnaire using jotform.com were exported to Ms Excel and imported to SPSS 26. In the screening of data, four rows were removed from the dataset as a result of blank data of up to 30% of the row. Also, for two rows where data was missing, an average of data entry was taken to prevent blank entry. This was done using the "BLANKCOUNT" command in MS Excel.

Outliers such as unengaging respondents were removed from the dataset. The dataset was checked for any unengaged response by taking a SD of the various rows. Two cases of unengaged responses were removed as the respondent answered to "agree" on every item on the Likert scale.

4.1.2 | Demographic analysis

The demographic information is collected in the first section of the questionnaire utilised in the study. Researchers collect demographic data to describe the persons or organisations in their study on a regular basis. These data are presented in the form of a narrative, a table, charts, or graphs, with basic frequency statistics utilised in the analysis.[62]

In the current research, the respondents are asked four demographic questions such as age, gender, highest academic qualification and job designation. This is because the study requires a more tailored response. A frequency and descriptive statistics of the demographic variables are done using SPSS and the results presented in Table 1 and Figures 5 to 8.

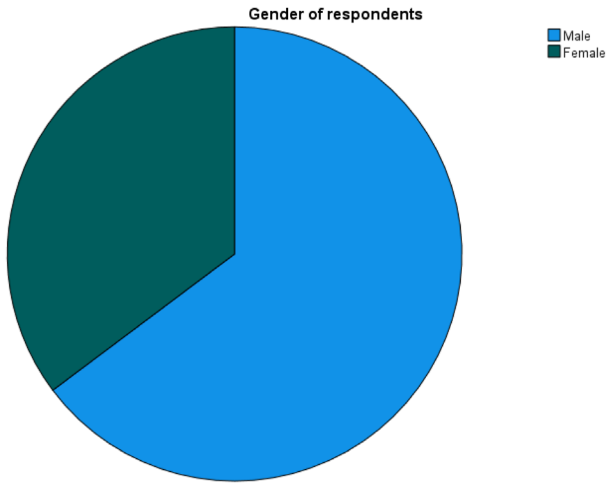

FIGURE 5 Gender of respondents

TABLE 1 Respondents demographic statistics

Item	Category	Frequency (227)	Percent
Gender	Male	147	64.76
	Female	80	35.24
Years of work experience	1-5 years	39	17.2
	6-10 years	103	45.4
	11-15 years	28	12.3
	16-20 years	21	9.3
	21-25 years	18	7.9
	25-Above years	18	7.9
Job designation	Director	17	7.5
	General manager	22	9.7
	Line manager	19	8.4
	Researcher	137	60.4
	Post graduate researcher	30	13.2
	Other	2	.9
Qualification of respondents	Degree	52	22.9
	Masters/PhD	175	77.1

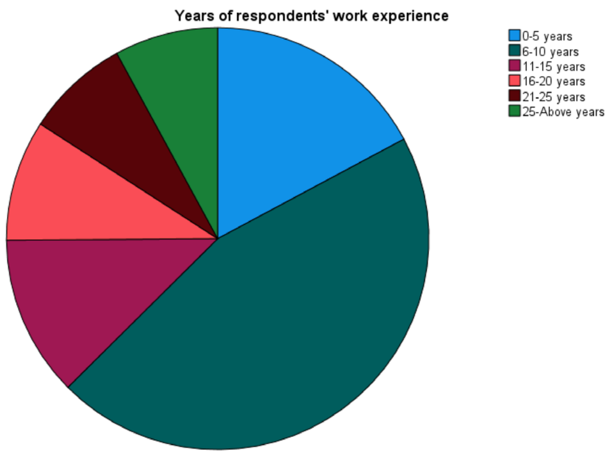

FIGURE 6 Years of respondents' work experience

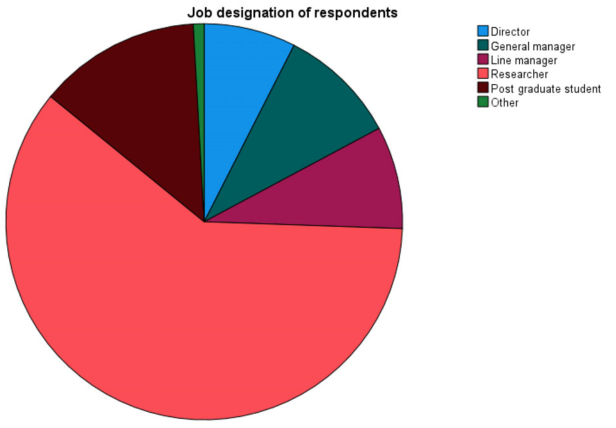

FIGURE 7 Job designation of respondents

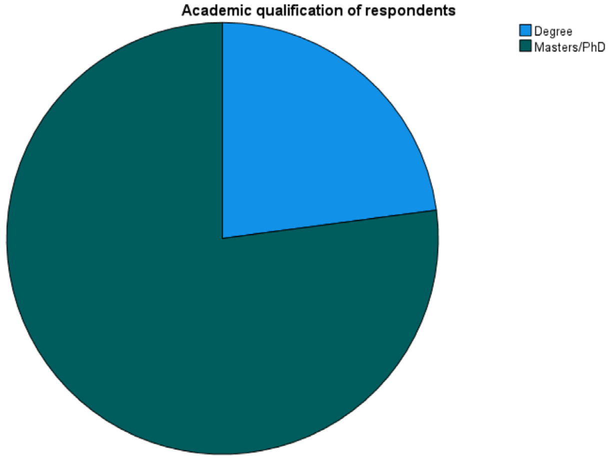

FIGURE 8 Academic qualification of respondents

4.1.3 | Reliability and validity analysis

Reliability analysis was carried out using Cronbach's Alpha in SPSS using measured variables. The result of the Cronbach's Alpha for this research is .94 which is excellent as per the acceptance range in the literature and threshold guidelines.[63,64]

Table 2 shows the descriptive statistics for demographic variables done using SPSS 26.

Factor Analysis is important for testing hypotheses, accounts for measurement error, and allows for testing complex multivariate models, Factor analysis for this study was done using varimax rotation with Kaiser normalisation to group all the independent, mediating, moderating and dependent variables. The commonality value was found to be over 0.5 for all the variables, so accordingly all were retained for performing the data analysis. The lowest commonality value was found for TC which had a value of 0.515, which is still within the acceptable range. All the retained values are shown in Table 4 and the scree plot in Figure 9. Similarly, the KMO and Bartlett's test was also performed which highlights the acceptable values, as shown in Table 3.

Table 4 highlights the communalities of factors involved in this research. Figure 9 highlights the scree plot of the factors involved in this research.

4.1.4 | Correlation analysis

Correlation analysis was carried out to determine the dependency or statistical relationship between the variables. Table 5 shows the results of the correlation carried out on the computed variable. If the *P*-value or significance value is <0.05 it is meaning that the chance of error is less than 5%, This means the nonsignificant chance of error, therefore, a strong relationship.

4.1.5 | Hierarchical regression analysis

In the hierarchical regression analysis, moderation occurs when the relationship between independent and dependent variables depends on another variable known as the moderating variable, which is used to determine the diminishing impact of moderating variable on the independent and dependent relationships. The dependency or interaction on the moderating variable may be categorical or quantitative.[65]

Moderation analysis is carried out in hierarchical regression analysis whereby, the moderator is a third variable that affects the zero-order correlation between the dependent and independent variables, or the value of the slope of the dependent variable on the independent variable. Hierarchical multiple regression analysis determines the moderating analysis to a representation of the interaction between the independent variable and its determinants.[65]

TABLE 2 Descriptive statistics

	Cronbach's alpha	Mean	SD	Variance	Skewness		Kurtosis	
Factor	Statistic	Statistic	Statistic	Statistic	Statistic	SE	Statistic	SE
CE	0.820	4.07	.556	.310	−.999	.162	4.233	.322
POL	0.867	4.17	.525	.275	−.902	.162	2.717	.322
SEF	0.846	2.3678	.45194	.204	.811	.162	2.153	.322
TC	0.116	3.9236	.75130	.564	−.732	.162	.774	.322
ES	0.713	4.0514	.51464	.265	−.281	.162	.406	.322
SS	0.783	4.2638	.60007	.360	−1.511	.162	4.593	.322
ENV	0.895	4.2287	.54146	.293	−.975	.162	2.968	.322

Abbreviations: ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.

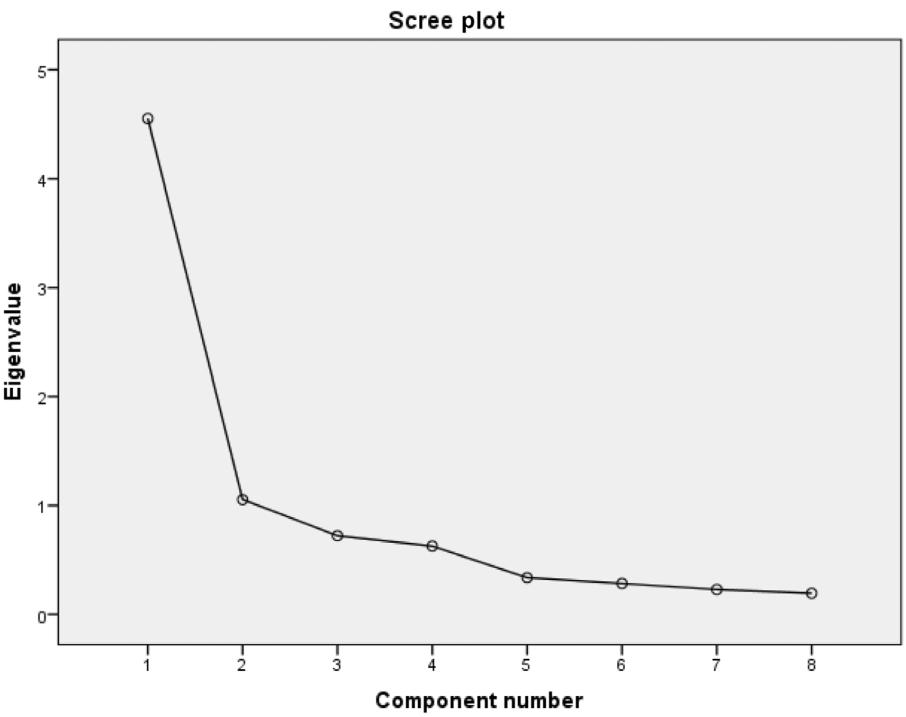

FIGURE 9 Scree plot

TABLE 3 Kaiser-Meyer-Olkin (KMO) and Bartlett's test

Kaiser-Meyer-Olkin measure of sampling adequacy		0.853
Bartlett's test of sphericity	Approximate Chi-Square	1042.425
	df	28
	Sig.	.000

TABLE 4 Communalities

Factor	Initial	Extraction
SE	1.000	.659
CE	1.000	.704
POL	1.000	.749
SEF	1.000	.824
TC	1.000	.515
ES	1.000	.767
SS	1.000	.686
ENV	1.000	.704

Note: Extraction method used is principal component analysis.
Abbreviations: ENV, environmental sustainability; ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.

Moderation analysis for ES

Moderation analysis using hierarchical regression analysis in SPSS 26 for the effect of SEF and TCs on ES was carried out. It was observed that the relationship between SE and ES is largely deviated by the moderating influence of SEF and TCs. The results predict that the SEF and TCs

TABLE 5 Correlation of variables

Correlations						
Factor	**SE**	**SEF**	**TC**	**ES**	**SS**	**ENV**
SE	1	−.053	.272[a]	.482[a]	.431[a]	.372[a]
SEF	−.053	1	.090	.124	−.076	−.016
TC	.272[a]	.090	1	.525[a]	.224[a]	.289[a]
ES	.482[a]	.124	.525[a]	1	.582[a]	.564[a]
SS	.431[a]	−.076	.224[a]	.582[a]	1	.682[a]
ENV	.372[a]	−.016	.289[a]	.564[a]	.682[a]	1

Abbreviations: ENV, environmental sustainability; ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.

[a]Correlation is significant at the .01 level (two-tailed).

TABLE 6 Moderation analysis on ES

Regression models	**ES**		
Attribute	***β*-value**	***t*-value**	**R^2**
Model 1			.339
SE	.582***	10.733	
Model 2			.532
SE	.422***	8.639	
SEF	.159***	3.361	
TC	.404***	8.093	
Model 3			.571
SE	.544***	3.213	
SEF	1.495***	4.745	
TC	−.832**	−2.531	
SESEF	−1.662***	−4.266	
SETC	1.607***	3.749	

Abbreviations: ENV, environmental sustainability; ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.

*$P < .10$, **$P < .05$, ***$P < .01$.

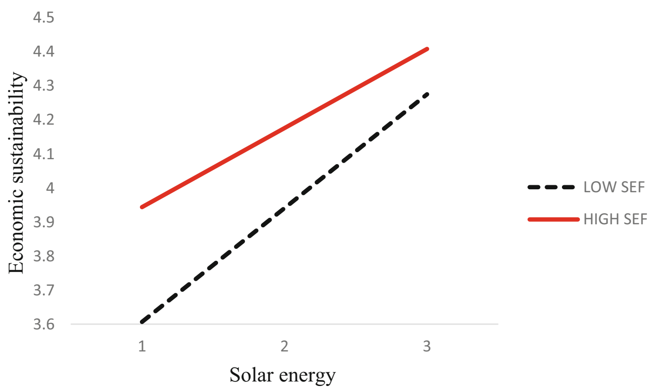

FIGURE 10 Moderation effect of socio-economic factors on economic sustainability

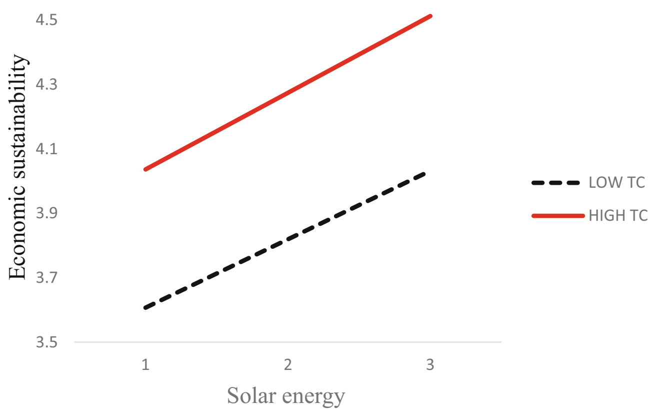

FIGURE 11 Moderation effect of technical complexities on economic sustainability

have strong influences on the SE choices while contributing to ES. Better socio-economic conditions technical expertise and availability can provide a guaranteed outcome of ES through innovative SE technologies. The summary of the results is shown in Table 6.

Figures 10 and 11 are the slopes, which show the effect of moderation analysis carried out when ES is the dependent factor. The slop analysis presented in Figure 10 and 11 show a clear deviation in the relationships between SE and ES after the involvement of the moderating factors of SEF and TCs.

Moderation analysis for SS

Moderation analysis using hierarchical regression modelling in SPSS 26 for the effect of SEF and TCs on SS was carried out and a summary of the results is shown in Table 7. The relationship between SE and SS is largely deviated by the moderating influence of the SEF, whereas no significant change was observed in the relationship with the involvement of the TCs. The results predict that the SEF have a strong influence on the SE choices while

TABLE 7 Moderation analysis on social sustainability (SS)

Regression models	SS		
Attribute	***β*-value**	***t*-value**	**R^2**
Model 1			.300
SE	.547***	9.810	
Model 2			.314
SE	.502***	8.498	
SEF	.027	.474	
TC	.120**	1.992	
Model 3			.359
SE	1.152***	5.571	
SEF	1.315***	3.415	
TC	−.214	−.533	
SESEF	−1.625***	−3.413	
SETC	.398	.760	

Abbreviations: ENV, environmental sustainability; ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.
**P* < .10, ***P* < .05, ****P* < .01.

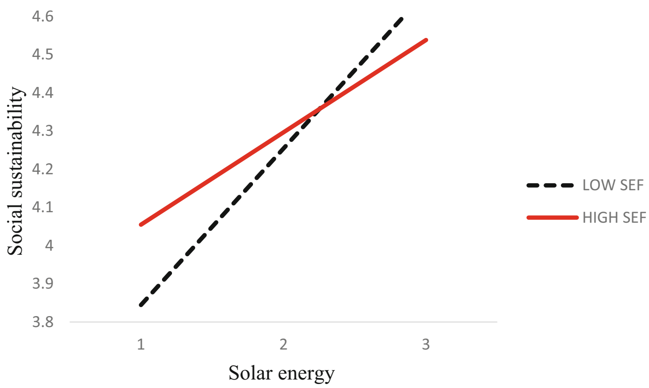

FIGURE 12 Moderation effect of socio-economic factors on social sustainability

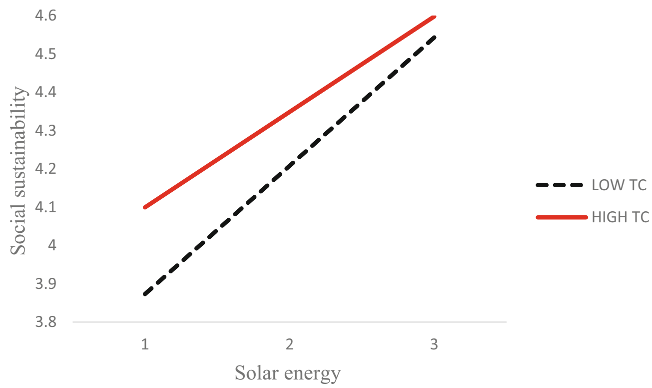

FIGURE 13 Moderation effect of technical complexities on social sustainability

TABLE 8 Moderation analysis on ENV

Regression models	ENV		
Attribute	***β*-value**	***t*-value**	**R^2**
Model 1			.292
SE	.540***	9.634	
Model 2			.335
SE	.464***	7.967	
SEF	.036	.646	
TC	.209***	3.510	
Model 3			.388
SE	1.183***	5.852	
SEF	1.425***	3.789	
TC	−.123	−.313	
SESEF	−1.753***	−3.769	
SETC	.390	.762	

Abbreviations: ENV, environmental sustainability; ES, economic sustainability; SEF, socio-economic factors; SS, social sustainability; TC, technical complexities.
**P* < .10, ***P* < .05, ****P* < .01.

contributing towards SS. However, the TCs do not seem to be interfering between the SE choices and the SS. Reasonable socio-economic conditions can enhance SS through innovative SE technologies, and when there is a socio-economic concern, the TCs are not considered to be any big issue.

Figures 12 and 13 are the slopes, which show the effect of the moderation analysis carried out when SS is the dependent factor.

The slop analysis presented in Figure 12 shows a clear deviation in the relationships between SE and SS after the involvement of the moderating factors of SEF. While the slop analysis presented in Figure 13 highlights that the TCs do not lead to any significant change between the independent factor of SE and the dependent factor of SS.

Moderation analysis for ENV

Moderation analysis using hierarchical regression in SPSS 26 for the effect of SEF and TCs on ENV was carried out. It was found that the relationship between SE and ENV is largely diverged by the moderating influence of the SEF; however, no significant change was observed in the relationship with the involvement of the TCs. The results predict that the SEF have a strong influence on the SE choices while contributing towards ENV. However, the TCs do not seem to be interfering between the SE choices and the ENV. Reasonable socio-economic

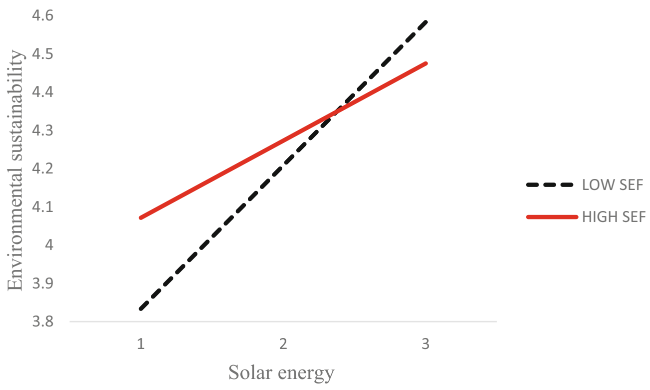

FIGURE 14 Moderation effect on environmental sustainability

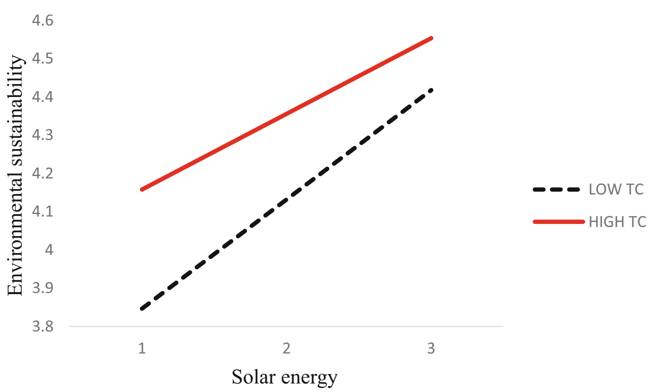

FIGURE 15 Moderation effect on environmental sustainability

TABLE 9 Cost of installing the photovoltaic system

No.	Component	Amount (USD)
1	120 W monocrystalline silicon module	$160
2	Deep acid lead battery 83.2 Ah	$16
3	Charge controller	$190
4	Inverter (1 kw)	$160
5	Total cost	

conditions can enhance ENV through innovative SE technologies, and when there is a socio-economic concern, the TCs are not considered to be any big issue.

The summary of the results is shown in Table 8.

Figures 14 and 15 are the slopes, which show the effect of the moderation analysis carried out with ENV as a dependent variable. The slop analysis presented in Figure 14 shows a clear deviation in the relationships between SE and ENV after the involvement of the moderating factors of SEF. While the slop analysis presented in Figure 15 highlights that the TCs do not lead to any significant change between the independent factor of SE and the dependent factor of ENV.

The Hierarchical Multiple Regression test on the moderating effect of socio-economic factor show significant P-values (<.05) for all the sustainability dimensions (ES, SS and ENV). However, the Hierarchical Multiple Regression test shows that the TCs only intervene in the relationship between SE and ES, whereas it does not show any moderating influence over SS and ENV.

4.2 | Qualitative study result presentation and analysis

The case for this study is the ICT centre of Kogi State Polytechnic, Lokoja Kogi State. A Tertiary Education Trust Fund (TETFUND) sponsored SE powered computer and internet centre open to academic staff and researchers of the polytechnic.

4.2.1 | PV design

A stand-alone PV system was designed with dual function as a car park and its roof was used to support the 12 PV panels. The entire system includes solar panels, batteries, converters and inverters,

4.2.2 | Economic analysis

The breakdown of the cost of installation for the PV system is shown in Table 9.

The average daily electricity usage for the ITC centre is estimated at a cost of 0.3 USD/kwh. The average National Grid cost of electricity in Nigeria is put at 0.1 USD/kwh.[66] The initial cost of installing and use of the PV system is more expensive than the national grid. However, with a lifespan of 25 to 30 years, the PV system will become less expensive.

4.2.3 | Environmental analysis

The life cycle assessment in terms of electricity generation is done to determine the amount of CO_2 emission that is reduced by the SE system in the Polytechnic. Data from the amount of CO_2 emitted through national grid electricity generation in Nigeria is 440 gCO_2eq/kwh.[66] The institution of the case study does not have the equipment to measure the average life cycle assessment based on Nordin et al[67] was used to ascertain the amount of

CO_2 emission from the PV system, which is estimated as 161.3 gCO_2eq/kwh.

To calculate the Emission saved through SE use in Kogi State Polytechnic Lokoja (KSPE), subtract the Estimated Emission of PV (EE PV) from the Nigerian Emission rate (NigE) (see Equation 1).

$$\text{KSPE} = \text{NigE} - \text{EEPV}. \tag{1}$$

$$\text{KSPE} = 440 - 161.3 = 278.7\,\text{gCO}_2\text{eq/kwh}.$$

Hence, by installing and use of SE, the institution has been able to reduce CO_2 emissions up to 278.7 gCO_2eq/Kwh, which highlights the significant benefits of the usage of SE from the ENV perspective.

5 | DISCUSSION

This study began with a model proposing that SE has a direct effect on the various facets of sustainability, it also proposes a moderation impact of SEF and TCs on SE and sustainability. From the demographic variables in this research, the finding on gender (Table 1) show that 64.5% of the respondents are male while 35.2% and female. This shows a fairly balanced gender representation in this study. Also, from the years of work experience (Table 1), most of the respondents representing 45.4% have between 6 and 10 years of experience. This shows that the respondents have a substantial experience in their respective jobs making the result of this study valid. From Table 3 on job description, 137 respondents representing 60.4% are researchers, 13.2% are postgraduate researchers, 9.7% are general managers, 8.4% are line managers, 7.5% are directors with 0.9% who have chosen not stated their job role as other. The level of academic qualification of respondents (Table 1) favours this study, as 77.1% have Master's degree or a PhD, while 22.9% who have a first degree. Similarly, the Cronbach's Alpha analysis shows a high value of 0.942 which indicates strong reliability of the result of this study. The Pearson Correlation (Table 5) indicates a strong correlation between most of the variable, which is also a positive reflection of the findings of this study.

5.1 | Role of SE on ES

Results from the direct relationship analysis (detailed result available in Section 4) have indicated a strong positive direct relationship between SE and ES as seen in the result presented in Section 4. Thus, these findings go in the favour of the Hypothesis 1.

The findings of this study are in line with the findings of Luckett and Needham,[68] who is of a similar view that SE can build strong and diverse economic benefits. They agree that SE is sustainable, emphasising the eminent energy transition to SE sources, which they described as feasible and achievable. SE consumption would help to meet the energy need as well as achieve the sustainable development goal of cheap, assessable and clean energy that results in the well-being of all. There is a concern in the study of Kabir et al[2] about the initial high cost of installation of PV systems. This view is in tandem with the result of the case study analysis carried out in this present study. However, with a life span of about 25 to 30 years, the overall long-term gains and long-run economic advantages make SE economically sustainable. In addition, there is the "ripple effect" gains of job creation and triggering economic activities in urban communities.

5.2 | Role of SE on SS

Results from the direct relationship analysis (detailed result available in Section 4) has indicated a strong positive direct relationship between SE and ES as seen in the regression analysis findings. Also, the P-value is <.05 which shows a significant impact of SE on SS. Moreover, positive and significant correlation was also observed between the SE and SS dimension. So, the Hypothesis 2 is accepted by the findings of the regression analysis.

The findings of this study are in line with Geall and Shen[69] who advanced the benefits of SE to communities such as rural electrification, social involvement and improvement of quality of life for urban dwellers.

These findings are also in line with the study of Abrar et al.[47] However, at the same time, it implies that the age of household members, sexual orientation, employment status and academic qualification are not determinants of SE sustainability in any of the three dimensions – economic, social and environmental.

5.3 | Role of SE on ENV

The regression findings also highlight that the relationship in between SE and ENV is significant at $P < .05$. These findings predict that SE also contributes to bringing ENV. The correlation analysis between SE and ENV was also found significant. Thus, the Hypothesis 3, which shows a direct relationship between the SE and ENV, is accepted.

Similar findings were also observed in the case study of the ITC centre powered by SE in an academic institution in Nigeria, which reveals a 278.7 gCO_2eq/kwh

reduction in carbon footage as a result of SE usage. The direct relationship in the regression analysis (detailed result available in Section 4) is also strong for the factor. SE is clean of air, water and land pollution.[3]

5.4 | Role of SEF and TCs on ES

From the hierarchical regression analysis (detailed result available in Section 4) carried out, Hypothesis 4 that proposes that SEF inversely moderate the positive relationship between SE and ES was accepted. Similarly, Hypothesis 7 that TCs inversely moderate the positive relationship between SE and SS was also accepted. Thus, Hypotheses 4 and 7 are accepted.

This is evidenced by significant *P*-values (see Table 6) in the hierarchical regression analysis. The inverse impacts of SEF and TCs in between SE and ES were also highlighted in the slope analysis in Figures 10 and 11. So, the socio-economic and technical challenges are the key hindrance factors to economic growth in developing African countries. This assertion is particularly important in Africa and other developing countries where rural electrification is challenging as most of the population does not have access to the national grid.[70]

5.5 | Role of SEF and TCs on SS

The hierarchical regression analysis (detailed result available in Table 7) carried out in this study, with the Hypothesis 5 that proposes that SEF inversely moderate the positive relationship between SE and SS was accepted.

The inverse impact of SEF between SE and SS is also highlighted in the slope analysis presented in Figure 12.

However, the Hypothesis 8 that TCs inversely moderate the positive relationship between SE and SS was not accepted. The slope analysis shown in Figure 13, also highlighted that there is not any significant inverse impact of TCs in between the impact of SE on SS. The work of Wallace et al[50] agrees with this finding. This means that TCs though impact SE but do not significant negative changes to the adoption of SE sustainability.

5.6 | Role of SEF and TCs on ENV

These findings of the hierarchical regression analysis depict that, SEF inversely moderate the relationship between SE and ENV. The inverse impact of SEF between SE and ENV was also highlighted in the slope analysis presented in Figure 14. Thus, Hypothesis 6 is accepted.

Hypothesis 9, which proposed that TCs inversely moderate the positive relationship between SE and ENV was not accepted. Similarly, there is no significant inverse moderating role of TCs was observed between the SE and ENV by the slope analysis shown in Figure 15. It predicts that in order to gain the ENV the influence of SEF is rather put more harmful impacts on the environmental dimension of sustainability compared to any sort of inverse impact of TCs. Thus, Hypothesis 6 is accepted, however, is not found to be accepted on the significant level of $P < .05$.

6 | CONCLUSION

This study concludes that there is a direct positive relationship between SE and all dimensions of sustainability. The study was drawn based on a thorough literature review to propose a conceptual model to test and validate in this research. The research was conducted using the mixed-method approach, consisting of quantitative and qualitative data. The quantitative data was based on survey data of 227 African professionals working in the energy industry, contacted through a snowball approach. While in order to validate and take the qualitative view, a review of a case study in African based was also done, the case study was of an ITC centre powered by SE in an academic institution in Nigeria. The quantitative data was analysed by the hierarchical regression analysis through SPSS 26, which also provides a direct linkage between SE and dimensions of sustainability. Moreover, the inversely moderating influence of SEF and TCs in between the SE and sustainability dimensions was also measured.

The findings highlight that SE has a direct and significant impact on economic, social and ENV. So, it means SE is a cheap and environmentally friendly source of energy which can meet the needs of developing countries while not compromising on any sort of environmental aspects. Through the hierarchical multiple regression analysis, it was also observed that SEF inversely moderate the positive relationship between SE and all the dimensions of sustainability (ES, SS and ENV). So, the findings predict the importance of socio-economic conditions in the communities of developing African and other developing countries. In order to gain a real sustainability in all aspects of economic, social and environmental dimensions, the socio-economic conditions need to be better placed for the general public living in these communities. It can rightly say that the sustainability of any community is well linked to its socio-economic conditions.

Finally, the study establishes that TCs inversely moderate only in between the relationship between SE and ES, and no significant impact of TCs was observed on SS and ENV. So, it can be seen that when there is an intention to gain sustainability in any developing community, TCs do not prevail over any serious sort of challenge. These findings were also validated by the case study analysis of ITC centre powered by SE in an academic institution in Nigeria. Where the centre has successfully reached its sustainability targets with no pressure of any sort of technical difficulties. So, it can be the rightly pose that in order to gain sustainability the socio-economic conditions are the major pre-requisites to meet rather than being worried about technical and innovative technologies.

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