

# Sustainability of renewable energy production: empirical evidence from developing and middle-income countries

Renewable  
energy  
production

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## Abstract

**Purpose** – This study aims to examine the appropriate measures needed toward achieving sustainability of renewable energy production among developing and middle-income countries.

**Design/methodology/approach** – This study uses semi-annual panel data covering the period 2000–2020 among 152 developing and middle-income countries and Cox proportional hazard model for the analysis.

**Findings** – Estimates indicate that effective operations of environmental institutions, investment in research and development, subsidizing the production of renewable energy, government investment in producing renewable energy and investment in renewable energy production made by the private sector will contribute immensely toward achieving sustainability of renewable energy production.

**Practical implications** – This study recommends that governments should rationalize their expenditures to mobilize enough resources for investment in renewable energy production. Again, operations of environmental institutions should be enhanced through giving their managers' performance contracts and licensing its employees. Enabling environment should be created for private sector to increase their investment in renewable energy production.

**Originality/value** – Empirical studies have been carried out exploring measures to deal with climate change. Nonetheless, the appropriate measures needed toward achieving sustainability of renewable energy production among developing and middle-income countries have not been explored in existing empirical studies. Hence, this study fills the gap in existing empirical studies.

**Keywords** Sustainability, Renewable energy production, Climate change, Environmental institutions, Investment in renewable energy production

**Paper type** Research paper

## Acronyms table

WHO	= World Health Organization;
BBC	= British Broadcasting Corporation;
EU	= European Union;

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*Data availability statement:* The data that support the findings of this study are openly available in [figshare] at [10.6084/m9.figshare.22632130].



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BEV	= battery electric vehicles;
UN	= United Nations;
NBAR	= National Bureau of Asian Research;
IRENA	= International Renewable Energy Agency;
RESC	= renewable energy supply chain;
PGEHT	= Pavement Geothermal Energy Harvesting Technologies;
WDI	= World Development Indicators;
VIF	= variance inflator factor;
WRI	= World Resources Institute;
IPCC	= Inter-governmental Panel on Climate Change;
AfDB	= Africa Development Bank; and
RESI	= Renewable Energy Sustainability Index.

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### Introduction

Currently, one of the pressing problems confronting the world which needs to be tackled is the issue of climate change. Extreme weather events in both developing and developed countries have led to frequent flooding, bushfires, drought, earthquakes and others in global economies (Franzitta *et al.*, 2016; Quek *et al.*, 2018; Wang and Yang, 2020). World Health Organization (WHO) indicated that climate change if not well dealt with will lead to 250,000 deaths per year pertaining to diseases like malnutrition, malaria, diarrhea and heat stress (WHO, 2021). This calls for an urgent need to aggressively deal with the problem of climate change in global economies. At the Conference of the Parties or also known as COP27 or the 2022 United Nations Climate Change Conference, countries agreed to set up a loss and damage fund which will provide funds for countries who are heavily affected by the adverse effects of climate change (UN, 2022a, 2022b). This indicates the need to intensify action toward increasing funds to deal with the issue of climate change.

Developed countries since the Paris Accord of 2015 have spearheaded numerous measures toward dealing with the problem. These countries are rapidly moving away from the use of vehicles that consumes fossil fuels and working toward the use of electric cars (BBC, 2022). Scientists are also working toward cleaner fuels for aircrafts (Fontes and Freires, 2018; González *et al.*, 2016; Ray, 2019). According to European Union (EU), the use of battery electric vehicles (BEV) in 2022 recorded 12.1% of the market share as against 9.1% in 2021 among European countries (EU, 2022). These countries are also working on emerging technologies that will help to absorb existing carbon dioxide emission from the atmosphere, which is popularly known as carbon sequestration (Al-Qadami *et al.*, 2022; Botelho *et al.*, 2016; Troldborg *et al.*, 2014).

Developing and middle-income countries have equally introduced important initiatives toward dealing with the problem, which include measures such as afforestation, increasing waste collection companies, recycling of wastes especially plastic wastes, implementing carbon farming, the production and consumption of renewable energy and others (Gottschamer and Zhang, 2016; Mardani *et al.*, 2015). According to United Nations (UN), from the period 2015 to 2020, renewable energy production has increased from 15.6% to 36.1% due to the measures implemented by these governments and other stakeholders (UN, 2022a, 2022b). Investment in renewable energy production among these countries made by governments from the period 2015 to 2020 has increased by 25% (UN, 2022a, 2022b).

In developing countries like Ecuador, reports from Reuters News Agency in 2021 indicated that the government has prepared grant concessions with private companies in the energy sector to increase renewable energy production with a total investment of \$1.9bn

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(Reuters News Agency, 2021). This development will increase the country's renewable energy production by 17.8% over the next three years (Reuters News Agency, 2021).

With respect to middle-income countries, according to World Bank, the production of renewable energy as of 2018 has reached a total amount of \$14bn, these investments are geared toward achieving Paris Agreement of 1.5°C (World Bank, 2021). National Bureau of Asian Research's (NBAR) statistics indicated that, from the period 2017 to 2022, renewable energy production in Bangladesh has increased by 40% to help mitigate climate change (NBAR, 2022). With respect to Argentina, International Renewable Energy Agency (IRENA) postulated that renewable energy production has increased by 33% over the period 2011–2019 (IRENA, 2022a, 2022b). These estimates on renewable energy production from developing and middle-income countries indicate, over the period, how these countries have increased renewable energy production and consumption toward mitigating climate change. These investments in renewable energy production among these countries will not only contribute toward mitigating climate change but more also help toward enhancing economic growth among these countries (Irfan *et al.*, 2023; Adebayo, 2023; Wu *et al.*, 2023).

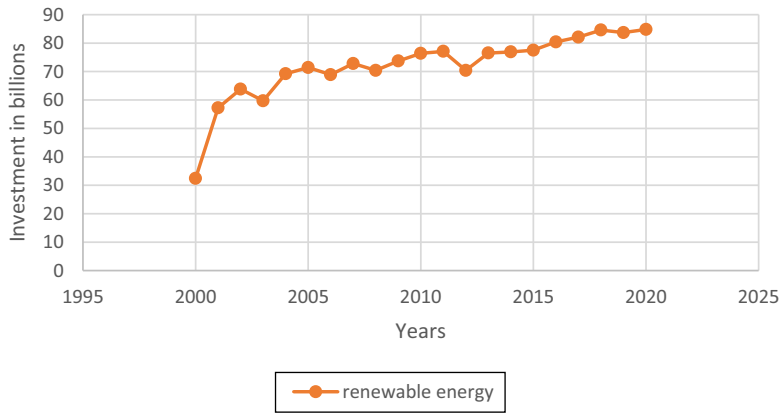
Despite these laudable developments, renewable energy production among these developing and middle-income countries faces a lot of challenges that question its sustainability and further expansion to help tackle climate change. In 2022, IRENA indicated the challenges confronting renewable energy production in these countries include a higher initial cost of acquisition, installation and operations, lack of frequent maintenance especially in the government sector, less funding for research institutions, importation of falsified and substandard renewable energy products and others (IRENA, 2022a, 2022b). For example, IRENA identified that investment in research facilities toward mass production of renewable energy in developing countries has increased by just 8.91% since 2015, which more needs to be done (IRENA, 2022a, 2022b).

According to World Bank, the average cost of generating energy from solar mini-grids is hovering around \$0.38/kWh among lower-middle-income countries (World Bank, 2023). This is very high which affects its expansion and sustainability among these countries. These challenges threaten its sustainability and further expansion to achieve climate change targets. Hence, the question remains what are the appropriate measures that need to be operationalized among developing and middle-income countries toward achieving sustainability of renewable energy production and its further expansion among these countries? As a matter of fact, the novelty of the study dwells on it contributes to existing empirical studies by examining the appropriate measures that need to be operationalized to achieve sustainability of renewable energy production among developing and middle-income countries. This study achieves its objective with the data sourced from 152 developing and middle-income countries and Cox proportional hazard model to examine the sustainability of renewable energy production among these countries.

### **Trend analysis on the investment in renewable energy production among developing and middle-income countries**

Figure 1 represents the investment in renewable energy production made by developing and middle-income countries covering the period 2000–2020. The estimates indicate that, from the period 2000 to 2004, there was an increase in the investment in renewable energy production among these countries; however, there was a drop in 2005. From the period 2006 to 2010, there was an increase in this investment. Between the period 2011 and 2012, there was a drop in the level of investment. While from the period 2014 to 2020, there was an increase in investment in renewable energy production among these developing and middle-income countries.

## Investment in renewable energy production

**Figure 1.**

Investment in renewable energy production among developing and middle-income countries

**Source:** Author's own conceptualization (data sourced from International Renewable Energy Agency, IRENA)

### Literature review

This section focuses on reviewing relevant theory on renewable energy production. Moreover, it also reviews empirical studies that focus on the sustainability of renewable energy production.

#### *Theoretical review*

[West et al. \(2010\)](#) developed the cultural theoretical approach that examines renewable energy policy and public perceptions of renewable energy. The theory stated that the public opposition to the establishment of renewable energy facilities and their unwillingness to invest in renewable energy is a stumbling block toward the expansion of renewable energy in a lot of countries especially developing and lower-middle-income countries. Hence, cultural theory's framework on renewable energy policy and public perceptions of renewable energy is geared toward deepen the understanding of the general public on the need to embrace the usage and investment in renewable energy.

Government policies both in developed and developing countries should be tailored toward expanding investment in renewable energy and broaden public participation. The theory advocated for the provision of strong economic incentives to strengthen energy consumption and production behavior toward mitigating climate change. The theory is relevant for the study because it highlights the need for the increase in governments' investment in renewable energy production and public participation in its consumption toward achieving climate change objectives. As a matter of fact, achieving sustainability of renewable energy production among developing and middle-income countries depends on these two dominant factors.

*Empirical review.* This section of the study reviews empirical studies that focus on sustainability of renewable energy production.

[Wang and Yang \(2020\)](#) contributed to the existing empirical studies by assessing the relevant approaches needed for sustainable renewable energy production for EU countries.

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The study used data from 27 European countries and fuzzy clustering model which depends on genetic algorithm for real coding for the analysis.

The study's result indicated that, energy productivity, electricity price and policy support, renewable energy emission intensity and continuous investment from both government and private sector is needed toward achieving this objective. The study concluded by urging countries to work toward sustainable development by intensifying renewable energy production and consumption.

[Al-Qadami et al. \(2022\)](#) examined Pavement Geothermal Energy Harvesting Technologies (PGEHT) needed for sustainable renewable energy production. The study used systematic review with emphasis on harvesting thermal energy production for the analysis. In total, 713 articles covering the period 2006–2021 were sourced for the analysis. The study's outcome identified that countries should work toward maximizing PGEHT toward achieving this objective of sustaining renewable energy production.

[Amjith and Bavanish \(2022\)](#) examined how intensifying biomass and wind production as a renewable energy will contribute toward achieving sustainable environment. As the global population is increasing over the period, there is the need to intensify renewable energy production in terms of biomass and wind production toward mitigating climate change. Hence, [Amjith and Bavanish \(2022\)](#) sought to investigate this subject matter. The result of the study indicated that intensifying biomass-based hybrid energy systems will help to achieve cost-effectiveness in the energy industry, provide immense contributions toward environmental sustainability and positively affects off-grid rural electrification.

[Adebayo et al. \(2023a, 2023b\)](#) assessed the role of hydroelectricity and natural gas consumption toward achieving environmental sustainability in USA. The study achieved its objective by analyzing time- and frequency-varying impacts of hydroelectricity energy consumption, natural gas energy consumption and economic growth on environmental sustainability. The study also examined the dynamic relationship short, medium and long effects of hydroelectricity energy consumption, natural gas energy consumption and economic growth. Findings of the study indicated robust positive relationship between natural gas energy consumption and carbon dioxide emissions. Moreover, a negative relationship was found between hydro energy consumption and CO<sub>2</sub> emissions in the long-term frequencies.

[Zang et al. \(2023\)](#) examined the asymmetric impact of renewable energy consumption and technology innovation on environmental degradation in Spain with emphasis on Sustainable Development Goals (SDGs) framework. The study achieved its objective with the use of data covering the period 1980–2018 and nonlinear ARDL (Autoregressive Distributed Lag) model for estimation. Results of the study indicated that intensifying the production of renewable energy in Spain will contribute immensely toward achieving environmental quality. The result of the study also identified that the development of technological innovation contributes immensely toward reducing carbon dioxide emission. The study concluded by stating that indeed Spain is on the right path of decarbonization.

These empirical studies and others ([González et al., 2016](#); [Gottschamer and Zhang, 2016](#); [Cirstea et al., 2018](#); [Fontes and Freires, 2018](#); [Quek et al., 2018](#); [Ray, 2019](#)) did not assessed appropriate measures needed among developing and middle-income countries toward ensuring that renewable energy production is sustainable to help mitigate climate change. In 2022, IRENA indicated that, challenges confronting renewable energy production in developing and middle-income countries include higher initial cost of acquisition, installation and operations, lack of frequent maintenance especially in the government sector, less funding for research institutions, importation of falsified and substandard renewable energy products and others ([IRENA, 2022a, 2022b](#)). These pressing challenges

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threaten the sustainability of renewable energy production among these countries. Hence, this study fills the yawning gap in existing empirical studies by examining the appropriate measures needed toward achieving sustainability of renewable energy production among these countries.

### **Methodology**

This section focuses on model specification, variables measurement, proxies used and scope of the study.

#### *Variables measurement, proxies and expected results*

This section explains variables and their proxies used for the analysis, definitions and their expected results. This includes dependent variable, independent variables and control variables, which are extracted from World Bank (World Development Indicators database).

#### *Dependent variable*

In survival analysis, dependent variable, which is the hazard rate, indicates the probability of sustaining a variable (e.g. industrialization policies). The estimation technique measures hazard rate which comprises of time and event. The time represents how long to sustain the variable (e.g. industrialization policy). Event according to the estimation technique is binary, that is 1 if sustainable and 0 otherwise.

With respect to this study, the dependent variable, which is the hazard rate, indicates the probability of sustaining renewable energy production to help deal with climate change. Time represents how long renewable energy production is expected to be sustainable. For this study, the time period is between 10 and 20 years. This time period is chosen based on the economic growth of these countries, which is 1.4% on average annually among these countries (World Bank, 2020). The growth of their economies will give governments the needed funds to sustain renewable energy production. The event is 1 if renewable energy production is sustainable, 0 if not sustainable.

#### *Independent variables*

Government investment in renewable energy production is proxied by electricity production that is generated from renewable energy. The variable measures electricity production that is generated from renewable energy with the help of government investment in the sector. The variable is measured in kilowatt hours (kWh) of total electricity produced from renewable energy. Governments among these countries ability to increase their renewable energy production investment, helps to inject more money into the sector toward achieving sustainability of renewable energy production. Hence, it is expected to have positive effect.

Private investment in the production of renewable energy is proxied by private investment in the energy sector (this includes renewable energy). The variable measures the amount of investment in the energy sector made by the private sector, this covers renewable energy production. The variable is measured in monetary value (US dollars). The private sector's ability to increase their renewable energy production investment augments governments' efforts and increase liquidity injection in the sector. This will help toward achieving the objective of sustainability of renewable energy production, it is therefore expected to have positive effect.

Investment in research and development is proxied by research and development expenditure as a percentage of GDP. The variable measures capital and current expenditures made by governments and private sector on research and development (which

includes renewable energy) as a proportion of GDP. The variable is measured in percentage. Continuous increase in investment in research and development will contribute positively toward discovering new forms of renewable energy production and improved approaches toward producing it at a minimize cost of production. This will contribute immensely toward achieving sustainable renewable energy production.

Subsidizing renewable energy production is proxied by government's subsidies and transfers granted for local production (this includes renewable energy production). The variable measures the amount of subsidies and other transfers governments grant for local production. The continuous subsidizing of renewable energy production will help toward making it affordable to domestic consumers, this will expand its consumption and production. Hence, it is expected to help achieve the objective of sustainability, it is measured in monetary values.

Management of renewable energy production is proxied by rating on the quality of public administration. The quality of public administration explains how managers of government institutions implement government policies to achieve the needed objective. Some of these government policies include policies implemented toward renewable energy production and consumption. The variable ranges on a scale from 1 to 6. The higher the score, the better the performance of these managers of these policies. Proper management of renewable energy production will ensure efficient usage of resources in the energy sector, this will contribute positively toward achieving sustainable production of renewable energy. Hence, the variable is expected to have positive effect.

Environmental institution is proxied by rating on policies implemented by environmental institutions geared toward achieving climate change targets. The variable measures performance of countries with respect to their policies implemented by their environmental institutions toward mitigating climate change. The variable ranges on a scale from 1 to 6. A higher score represents better performance of the country. These institutions' ability to formulate and implement policies will contribute positively toward sustaining and expanding the production of renewable energy. Hence, it is expected to have positive effect.

Population control is proxied by the usage of condoms among males. The variable measures the percentage of males in a country who use condoms during sexual intercourse. Governments and other stakeholders in Africa ability to implement effective measures toward controlling the population will reduce excessive demand for renewable energy production. This will contribute positively toward achieving sustainability of renewable energy production, it is measured in percentage.

#### *Control variables*

GDP growth variable is used for the analysis, this represents the expansion in economic activities in a country in a year. As the economy expands, it provides governments the needed resources toward sustaining and expanding the production of renewable energy. Hence, it is expected to have positive effect on renewable energy production sustainability, it is measured in percentage.

Inflation rate of the variable is used for the analysis. This indicates the persistent and general increase in the prices of goods and services over the period. Inflation rate increases the cost of operations and cost of maintenance of facilities for companies that produce renewable energy. The continuous prevalent of this situation adversely affects sustainability of renewable energy production. Hence, it is expected to have negative effect on sustainability of renewable energy production, it is measured in percentage.

Literacy rate of the variable is used for the analysis. The variable measures the percentage of the population from the age of 15 years and above who can read and write. As majority of the citizenry knowledge is enhanced, it helps them to appreciate the relevance of renewable energy production. This increases their consumption; this will contribute positively toward achieving its sustainability. Hence, the variable is expected to have positive effect, it is measured in percentage.

#### *Scope of the study*

The study uses panel data covering 152 developing and middle-income countries over the period 2000–2020 for the analysis. The Cox proportional hazard model for survival analysis requires large observations; hence, this time period is extrapolated into semi-annual data to increase the observations for robust results. This study period is relevant for the analysis because during these periods, governments and other stakeholders have made various investments toward increasing renewable energy production.

However, renewable energy production is confronting challenges which threaten its sustainability. Hence, the study is interested in finding out various approaches of achieving sustainability of renewable energy production among these countries.

#### *Model specification*

Cox proportional hazard model developed by Cox (1972) is used for the study's analysis. This estimation technique is widely used for survival analysis where the researcher is interested in finding out how policies, approaches or relevant measures can be sustainable for long period of time toward achieving long-term objectives. The estimation technique is deemed necessary for the study because the study is interested in finding out appropriate measures needed toward achieving sustainability of renewable energy production.

These measures include investment in the production of renewable energy made by governments, management of renewable energy production, operations of environmental institutions, investment in renewable energy production made by the private sector, investment in research and development, subsidizing the production of renewable energy and population control. This estimation technique produces four results: exponential, Weibull, Gompertz and Cox regression results. Exponential, Weibull and Gompertz's estimates represent parametric estimates, whereas that of Cox regression represents semi-parametric result. These four regression estimates are expected to be similar when large observations minimum of 6,000 is used for the estimation. In the midst of small observations, regression estimates from Weibull and Gompertz tend to be similar, hence the interpretation is based on these two estimates.

Cox proportional hazard model is generally specified as;

$$\lambda(t, X_j) = \lambda_0(t) \exp[X_j \beta] \quad (1)$$

where  $\lambda(t, X_j)$  gives the hazard rate for the entity  $j$ ,  $X_j$  is the set of  $p$  covariates for the entity  $j$ ,  $\beta$  is the constant coefficient vector and  $\lambda_0(t)$  is the baseline hazard. The use of Cox proportional hazard model is advantageous because it allows the  $\beta$  coefficients to be estimated even when the baseline hazard is not known. Baseline hazard measures how the risk of an event changes over time at a given baseline levels of covariates and parameters while the hazard rate represents the probability of an event happening.

For the purposes of this study, the hazard rate represents the probability of sustaining renewable energy production among these countries over the period 10–20 years.

The model's general likelihood or probability function is specified as;

$$L(\beta) = \prod_{j=t}^r \frac{\exp(X_j \beta)}{\sum_{t \in R_j} \exp(X_j \beta)} \quad (2)$$

where  $r$  is the number of time periods,  $X_j$  is the vector of covariates associated with the entity experiencing the event at time  $i$ ,  $i = 1, 2, \dots, r$  and  $R_j$  is the risk set at time  $i$ . That is, the risk that will be accrued to the entity if it fails to achieve the needed mandate. The equation measures the probability of achieving the needed objective. With respect to this study, the  $x_i$  represents measures that will help toward achieving sustainability of renewable energy production. Where  $r$  in this study explains the number of years this objective will be achieved and  $R_j$  is the risk these countries will face if this objective is not achieved. Event in the analysis represents: 1 sustainable renewable energy production and 0 otherwise. While time/spell represents how long renewable energy production can be sustainable. With respect to this analysis, the equation presented above represents probability of sustaining renewable energy production.

With respect to this study, (1) is rewritten as;

$$\lambda(t, X_{it}) = \lambda_0(t) \exp[X_{it} \beta_i] + \mu \quad (3)$$

where  $X_{it}$  are the covariates (measures) needed to help achieve this objective.  $\beta_i$  is the regression coefficient,  $\lambda_0(t)$  is the baseline hazard,  $\lambda(t, X_{it})$  gives the hazard rate and  $\mu$  is the error term.

Based on [equation \(3\)](#), the model used for this study is specified as;

$$SUS = \lambda_0(t) \exp[\beta_0 + \beta_1 GOVINVEST_{it} + \beta_2 MGT_{it} + \beta_3 PVINVEST_{it} + \beta_4 ENVINS_{it} + \beta_5 INVRD_{it} + \beta_6 SUBRES_{it} + \beta_7 POP_{it} + \beta_8 INFLAT_{it} + \beta_9 LITER_{it} + \beta_{10} GDP_{it} + \mu] \quad (4)$$

where

- SUS = sustainability of renewable energy production;
- GOVINVEST = government investment in renewable energy production;
- MGT = management of renewable energy production;
- PVINVEST = private investment in renewable energy production;
- INVRD = investment in research and development;
- SUBRES = subsidizing the production of renewable energy;
- POP = population control;
- ENVINS = environmental institutions;
- GDP = GDP growth;
- LITER = literacy rate; and
- INFLAT = inflation rate.

In [equation \(4\)](#), GDP growth, inflation rate and literacy rate are the control variables. The remaining part of the study that covers the results and discussion of the study deals with estimates from the descriptive statistics, correlation test, results for parametric coefficients

and hazard ratios. The last section of the study deals with conclusion of the study with its policy recommendations to help achieve the needed objective.

### Results and discussion

This section analyzes descriptive statistics, correlation test and parametric estimates obtained from the Cox proportional hazard model.

#### *Estimates for descriptive statistics*

Summary statistics have been presented in [Table 1](#). Values from government investment in renewable energy, private sector investment in renewable energy and subsidizing renewable energy production are logged to help simplify the analysis. Government investment in renewable energy indicates mean value of 19.11, minimum value of 13.82 and maximum value of 26.37. This means that, there is no wide difference in government investment in renewable energy production among these countries. Management of renewable energy production shows mean value of 3.18, minimum value of 1 and maximum value of 6. This means that, there is no wide difference in the management of renewable energy production among these countries. Private investment in renewable energy production shows mean value of 19.50, minimum value of 13.12 and maximum value of 24.26. This means that, there is no wide difference in private investment in renewable energy production among these countries. Investment in research and development shows mean value of 0.45, minimum value of 0.33 and maximum value of 0.67. This means that there is no wide difference in the investment in research and development (that helps to propel renewable energy production) among these countries.

Environmental institution shows mean value of 3.53, minimum value of 1 and maximum value of 6. This means that there is no wide difference in the operations of environmental institutions among these countries. Subsidizing renewable energy production shows mean value of 24.12, minimum value of 0.40 and maximum value of 34.75. This means that there is a wide difference when it comes to subsidizing cost of producing renewable energy. Population control shows mean value of 40.29, minimum value of 3.57 and maximum value of 87.9. This means a wide difference in these countries commitment toward controlling their population.

Variables	Observation	Mean	SD	Minimum	Maximum
Government investment in renewable energy	5,804	19.11	2.21	13.82	26.37
Management of renewable energy production	5,745	3.18	1.22	1	6
Private investment in renewable energy	5,889	19.50	1.80	13.12	24.26
Environmental institution	5,884	3.53	1.19	1	6
Investment in research and development	6,232	0.45	0.09	0.33	0.67
Subsidizing production of renewable energy	5,767	24.12	3.66	0.40	34.75
Population control	5,748	40.29	18.42	3.57	87.9
Inflation rate	6025	29.28	386.99	-17.64	23773.13
Literacy rate	6,232	75.95	10.42	50.50	96.26
GDP growth	6,106	3.44	6.61	-4.047	11.973

**Table 1.**

Descriptive statistics **Source:** Authors' own creation

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### *Correlation test*

Correlation test is carried out for the independent variables to check for multicollinearity using the variance inflator factor (VIF). The result is shown in [Table A1](#) in the [Appendix](#), the highest VIF is 1.06 for investment in research and development. The rule of thumb states that, for a variable to cause multicollinearity it should have a VIF greater than 5. Because none of these variables has a VIF higher than 5, there is no existence of multicollinearity among the independent variables.

### *Results for parametric coefficients and hazard ratios*

The results for Weibull and Gompertz models' coefficients and hazard ratios have been presented in [Table 2](#). With Cox proportional hazard model estimation, the model coefficients are interpreted in terms of their signs but not the magnitude of the coefficients. In this analysis, positive coefficient means the variable (measure) will help toward achieving sustainability of renewable energy production to mitigate climate change. While negative coefficient means that the variable (measure) will adversely affect the objective of achieving sustainability of renewable energy production.

Model hazard ratio is interpreted in terms of the magnitude of the value, all the values are positive. For example, if the value is less than 1 (e.g. 0.77), this value is subtracted from 1, which gives 0.23, this is interpreted as 23% reduction in hazard ratio. This implies that there is 23% less likely that the objective of sustainability of renewable energy production will be achieved. Put differently, the result means that the probability of achieving this objective is very low. The reverse is the interpretation, when the value of hazard ratio is greater than 1.

Estimates with respect to government investment in renewable energy production indicate positive coefficient with a value of 0.022 and hazard ratio of 1.022, when you control for inflation rate, GDP growth and literacy rate. The positive coefficient result implies that governments among developing and middle income countries' ability to continuously increase their investment in renewable energy production will contribute positively toward achieving sustainability of renewable energy production. The result is consistent with expectation and empirical studies' results of ([Al-Qadami et al., 2022](#); [Kartal et al., 2023](#); [Adebayo et al., 2023a, 2023b](#)). [Kartal et al. \(2023\)](#) stated that among the states in USA, there is the need for government authorities to work toward nuclear energy transition and ecological sustainability to help achieve the needed environmental quality.

Even though, government investment will contribute toward achieving sustainability of renewable energy production. The hazard ratio result indicates that the probability of government committing enough resources for its production in the next 10–20 years is only 2.2%, which is very low. Hence, governments among developing and middle-income countries should work toward increasing their investment in renewable energy production by ensuring expenditure rationalization to channel enough resources for massive investment in renewable energy production. Moreover, government agencies and departments should be enforced by law to comply with the usage of renewable energy. These will help to increase government investment in renewable energy production.

Estimates for private investment in renewable energy production indicate coefficients values of 0.0055 (Weibull) and 0.0049 (Gompertz) and hazard ratio of 1.0055, when you control for inflation rate, GDP growth and literacy rate. This means that private investment made by domestic and foreign individuals and institutions (e.g. Africa Development Bank, UN, World Bank, foundations, nongovernment organizations, educational institutes and others) contributes positively toward achieving sustainability of renewable energy production. This result is consistent with our expectation and empirical studies' results of [Cirstea et al. \(2018\)](#) and [Owusu and Asumadu-Sarkodie \(2016\)](#).

**Table 2.**  
Results from  
parametric  
coefficients and  
model hazard ratios

	Weibull regression coefficients	Gompertz regression coefficients	Weibull Hazard ratios	Gompertz hazard ratios
Sustainable renewable energy				
Government Investment	0.022*** (0.0092)	0.022*** (0.0092)	1.022*** (0.0094)	1.022*** (0.0094)
Management of renewable energy	-0.023 (0.053)	-0.025 (0.053)	0.98 (0.052)	0.98 (0.052)
Private investment	0.0055*** (0.012)	0.0049*** (0.012)	1.0055*** (0.012)	1.0055*** (0.012)
Environmental institutions	0.063*** (0.059)	0.063*** (0.059)	1.065*** (0.062)	1.065*** (0.062)
Investment in research and development	0.056*** (0.11)	0.056*** (0.11)	0.94*** (0.11)	0.95*** (0.11)
Subsidizing production	0.016*** (0.0059)	0.016*** (0.0059)	1.016*** (0.006)	1.016*** (0.006)
Population control	-0.040 (0.036)	-0.041 (0.036)	0.96 (0.035)	0.96 (0.035)
Inflation rate	0.032** (0.015)	0.031** (0.015)	1.032** (0.015)	1.032** (0.015)
GDP growth	0.0012 (0.0029)	0.0013 (0.0029)	1.0012 (0.0029)	1.0013 (0.0029)
Literacy rate	0.00052 (0.00204)	0.00045 (0.0020)	1.0005 (0.00204)	1.0005 (0.00203)
Constant	-19.37*** (0.50)	-8.76*** (0.42)	3.87e-09 *** (1.92e-09)	0.00016*** (0.000065)
<i>N</i>	6,233	6,233	6,233	6,233

**Notes:** Standard errors in parentheses; \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$

**Source:** Authors' own creation

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Even though it will contribute toward achieving this objective, the hazard ratio result indicates that the probability of private investment in renewable energy production increasing in the next 10–20 years is only 0.55%, which is very low. In 2022, World Resources Institute (WRI) reiterated the need to increase private investment in renewable energy production by 60.5% in the next 10 years among these countries to help mitigate climate change (WRI, 2022a, 2022b). The enabling environment that needs to be created among these countries to drive these private investments should be created. The enabling environment which borders on provision of infrastructure, efficient institutions, tax waivers, laws enforcing its usage in state enterprises and real estate buildings, political stability, renewable industrial parks and others, should be created to achieve this objective.

Environmental institutions results indicate positive coefficient value of 0.063 and hazard ratio of 1.065, when you control for inflation rate, GDP growth and literacy rate. This implies that environmental institutions carrying out their operations effectively with regards to policies implemented on renewable energy production, will positively contribute toward achieving this objective. This result is consistent with our expectation and empirical study result of Mardani *et al.* (2015). Even though it will contribute toward achieving this objective, its probability contribution toward achieving this objective is only 6.5% (as indicated by the hazard ratio), which is very low. Hence, more efforts should be channeled toward enhancing their operations. Inter-governmental Panel on Climate Change has advised governments among these countries to efficiently position its institutions toward achieving the climate change targets. This can be achieved by giving managers of these institutions performance contracts and licensing their employees to achieve this mandate.

Results for investment in research and development indicate positive coefficient value of 0.056 and hazard ratio of 0.95, when you control for inflation rate, GDP growth and literacy rate. This implies that, government and private sectors' ability to demonstrate increase commitment in the investment in research and development more specifically with respect to renewable energy production will contribute positively toward achieving sustainability of renewable energy production. This is because it will help toward introduction of new approaches in renewable energy production and advanced approaches toward minimizing its cost of production.

This is consistent with our expectation and empirical studies' results carried out by Quek *et al.* (2018), Ray (2019) and Wang and Yang (2020). However, the hazard ratio result indicates that the probability of these countries increasing their investments in research and development in the next 10–20 years is only 5%, which is very low. Hence, intense efforts should be channeled toward increasing their investments in research and development. Especially, among African countries, Africa Development Bank (AfDB) has urged member countries to work toward increasing investment in research and development to achieve the climate change targets. Hence, governments among developing and middle-income countries should ensure that reasonable budget allocation is set aside for such laudable development.

Subsidizing renewable energy production results indicate positive coefficient of 0.016 and hazard ratio of 1.016, when you control for inflation rate, GDP growth and literacy rate. This means that, governments among these countries ability to subsidize the cost of producing renewable energy will contribute toward achieving sustainable production of renewable energy. This is because it will make it affordable for consumers, helping producers to expand its production and moreover sustain its production. This is consistent with our expectation and empirical studies' results of González *et al.* (2016) and Fontes and Freires (2018). However, the probability of governments increasing their subsidies for renewable energy production in the next 10–20 years is 1.6%, which is very low. Hence,

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governments in developing and middle-income countries should channel the needed efforts toward providing enough funds for this by imposing marginal taxes on mining, banking, oil, manufacturing, insurance and telecommunications companies to make enough resources toward subsidizing its production. This will help toward increasing its production to achieve the climate change target.

Inflation rate estimates indicate positive coefficient of 0.032 and hazard ratio of 1.032. This result is not consistent with our expectation, the expectation was that inflation rate by increasing cost of production will adversely affect the objective of achieving sustainability of renewable energy production. However, the result indicates the opposite outcome. One possible reason identified for this result is that, as these countries experience increasing cost of producing renewable energy. This situation will force companies producing renewable energy to develop innovative approaches of minimizing their cost of production. These innovative approaches will contribute toward its sustainability.

### **Conclusion**

The devastating effect of climate change has mounted the necessary pressure on global leaders and agencies to marshal the needed efforts to deal with the situation. Numerous measures have been implemented toward achieving this ambition, some of these measures include carbon farming, development of rooftop garden, development of sponge cities, afforestation, increase in the recycling of waste, production of renewable energy and others to help tackle this pressing issue of climate change. This study contributes toward dealing with the problem by examining the appropriate measures that need to be operationalized by developing and middle-income countries to achieve sustainability of renewable energy production.

The objective of the study is achieved with the use of panel data on 152 countries from developing and middle-income countries covering the period 2000–2020 and Cox proportional hazard model estimation technique for survival analysis. Using this estimation technique requires a lot of observations. Hence, the time period 2000–2020 is extrapolated into semi-annual data to increase the number of observations for robust results. Result of the study indicated that investments made by governments in renewable energy production, private investment in renewable energy production, effective operations of environmental institutions, investment in research and development and subsidizing the production of renewable energy, these measures properly operationalized will contribute positively toward achieving the objective of sustainability of renewable energy production.

Based on these results the study recommends that, in order for governments among these countries to increase their investments in renewable energy production. These governments should work toward expenditure rationalization to save enough resources which will be channeled toward renewable energy production. Moreover, government agencies and departments should be enforced by law to comply with the usage of renewable energy. These will help to increase government investment in renewable energy production. Again, private sector investment in renewable energy production should be intensified by enabling environment for private investments in renewable energy production to strive. This enabling environment borders on provision of infrastructure, efficient institutions, tax waivers, laws enforcing its usage in real estate buildings, political stability, renewable industrial parks and others should be created to achieve this objective.

In addition, environmental institutions among these countries that help in effective implementation of policies on renewable energy production. Their operations should be enhanced by giving their managers performance contracts and licensing its employees.

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Variables	VIF	1/VIF
Investment in research and development	1.06	0.95
Literacy rate	1.05	0.95
GDP growth	1.03	0.97
Management of renewable	1.01	0.99
Population control	1.01	0.99
Private investment	1.01	0.99
Environmental institution	1.01	0.99
Inflation rate	1.01	0.99
Subsidizing cost of production	1.00	0.99
Mean VIF	1.02	

**Table A1.**Multicollinearity test **Source:** Authors' own creation**Corresponding author**Bismark Osei can be contacted at: [bismarkosei84@yahoo.com](mailto:bismarkosei84@yahoo.com)