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Renewable Energy and Clean Environment: A Panel data Augmented Renewable Consumption Energy Solow Growth Model approach

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Abstract

As the global community need to transit from the fossil fuels era to a green economy with the use of renewable energy, this is an attempt to minimize the effect of global warming which occur due to war in the middle east, defunct USSR and as well as depletion of ozone layer which resulted from industrial revolution to this era of information revolution. Clean Renewable energy (CRE) proffers an essential panacea to the Structural Development Goal (SDP) problem. The motive of this study is to examine cohesively the growth rate renewable energy consumption to the (SDG) with respect to gross domestic product of west African countries. To achieve this laudable objective, the study employed a panel data Augmented Renewable Energy Solow growth model approach, obviously, the Solow growth model transforms Cobb Douglas production function.

The data used in the study were extracted from world bank database containing population, gross domestic products, gross fixed capital formation and renewable energy consumption for countries in west Africa. The period of study spanned between 2010 and 2022 across sixteen west Africa countries. A novel model named Augmented Solow growth model was proposed and adopted in the study. The findings of the study showed that renewable energy consumption and its allied variables contributed positively towards the SDG.

Keyword: renewable, sustainable, GDP, Solow, growth

1. Introduction

The potential of renewable energy sources to reduce environmental degradation and address energy security concerns has attracted a lot of attention in a recent year. The switch to renewable energy is now essential as conventional fossil fuels come under growing criticism for their role in climate change. It is critical in this context to comprehend how renewable energy contributes to economic progress. Using panel data Solow growth models is one method of examining the connection between renewable energy and economic growth. The Solow growth model offers a framework for comprehending the factors influencing long-term economic growth and is named after Nobel winner Robert Solow. Through the use of panel data which combines cross-sectional and time-series dimensions, researchers can take into consideration differences across time and between different nations.

Examining the relationship between renewable energy and economic growth while accounting for other pertinent variables like investment, human capital, and technical advancement is made possible by the use of a panel data Solow growth model technique. Researchers can evaluate the direct and indirect effects of adopting renewable energy on economic output and productivity with this approach. Numerous research works have utilized panel data Solow growth models to examine the connection

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between economic growth and renewable energy. Using a dynamic panel data model, Wang and Feng (2018) investigated how the use of renewable energy affected economic growth in fifteen Asia-Pacific nations. Their results indicated a strong and favorable correlation between the use of renewable energy and economic expansion. Zhang and Yang (2020) investigated the connection between the use of renewable energy sources and used panel data analysis to investigate the connection between the use of renewable energy and economic growth in 30 Chinese regions. Their findings showed that the use of renewable energy has a substantial and favorable influence on economic growth, however the amount of this benefit varies by location.

A panel data technique was utilized by Smith and Jones (2019) to investigate the correlation between GDP growth and investments in renewable energy in European nations. The positive impact of investments in renewable energy on economic growth was highlighted by their findings. A panel data analysis was carried out by Chen et al. (2021) to evaluate the impact of renewable energy on the economic growth of Latin American nations. Their research demonstrated the significance of context-specific factors by revealing large variability in the effects of renewable energy policy on economic performance. Zhang *et al*. (2018) investigated the connection between the use of renewable energy and economic growth in a sample of OECD nations using a panel data approach. Their conclusions emphasized how renewable energy improves economic performance. In order to evaluate the impact of renewable energy laws on economic growth in emerging economies, Li and Wang (2020) used a panel data study. The significance of policy frameworks in encouraging the adoption of renewable energy sources and promoting sustainable economic development was emphasized by their study.

It is possible to promote economic growth and reduce greenhouse gas emissions and environmental pollution at the same time by incorporating renewable energy into the energy mix(Stern, 2004) . Nevertheless, in order to fully comprehend the intricate connection between the uptake of renewable energy, economic growth, and environmental quality, advanced analytical techniques are needed. Among these approaches, the Solow growth model with panel data augmentation for renewable energy has become a potent analytical tool for these complex relationships (Acemoglu et al., 2012). This method integrates panel data analysis techniques with insights from the Solow growth model, a fundamental theory in economics that clarifies the factors influencing long-term economic growth (Solow, 1956). Researchers can capture both intertemporal and cross-sectional fluctuations in renewable energy use, economic growth, and environmental impacts by combining panel data, which offers information across many cross-sectional units and time periods (Wang and Zhou, 2018). Using a panel data enhanced Solow growth model for renewable energy, this study attempts to add to the body of knowledge by examining the connection between the use of renewable energy, economic growth, and environmental quality.

2. Augmented Renewable Energy Solow Model

Aggregate production function for the unique final goods is $Y_t = K_t^{\alpha} A_t L_t^{1-\alpha}$. Assume capital is the same as the final goods of the economy, but used in the production process of more goods. Y_t denotes level of output, in the study case, it is the GDP, A_t is a shifter of the production function. Technology is free; it is publicly available as a non-excludable, non-rival good and population is constant over time. Since the economy is closed (and there is no government spending), then Savings (S_t) can be given as

$$S_t = I_t = Y_t - C_t. \tag{1}$$

Individuals are assumed to save a constant fraction s of their income,

where

$$S_t = sY_t$$

$$C_t = (1-s)\,Y_t \;. \tag{2}$$

Imply that the supply of capital resulting from households. Behaviour can be expressed as

$$Ks_t = (1-\delta)K_t + S_t = (1-\delta)K_t + sY_t \ . \quad (3)$$

With the equation 3, the fundamental law of motion of the Solow growth model is:

$$K_{t+1} = sF\,[K_t \ , L_t \ , A_t] + (1-\delta)\,K_t. \quad (4)$$

Solow growth model is a mixture of an old-style Keynesian model and a modern dynamic macroeconomic model.

There are two factors: capital (K) and labor (L) which are paid by their marginal productivity and augmented by renewable energy consumption (RE). Following the works of Audienis *et al*. (2001) and Ding and Knight (2009), the effect of Renewable energy consumption on growth process can be augmented with Solow model in cross country evidence. Here, the Cobb-Douglas production function is formulated as:

$$Y_t = K_t^{\alpha} RE_t^{\beta} A_t L_t^{1-\alpha-\beta} \qquad 0 < \alpha + \beta < 1. \quad (5)$$

where A is denoted as the level of technology. L is assumed to be growing at exogenous population growth rate n and A refers to the level of technology which is assumed to grow at advancement of knowledge g. RE is defined as renewable energy consumption, β is the share of renewable energy in total output and all other variables are mentioned as before. The assumption of $\alpha + \beta < 1$ indicates decreasing returns to scale.

The share of income invested in physical capital (s_k) and share of income invested in renewable energy (s_{re}) depreciate at a common rate. Thus, the natural progress of the economy is determined by

$$k_t = s_k y_t - (n+g+\delta)k_t = s_k^{1-\beta} k_t^{\alpha} s_{re}^{\beta} k_t^{\beta} - (n+g+\delta)k_t. \quad (6)$$

for equilibrium we have

$$0 = s_k^{1-\beta} k_t^{\alpha} s_{re}^{\beta} k_t^{\beta} - (n+g+\delta)k_t. \quad (7)$$

$$(n+g+\delta)k_t = s_k k_t^{\alpha} s_{re} k_t^{\beta}. \quad (8)$$

$$\frac{(n+g+\delta)k_t}{k_t^{\alpha} k_t^{\beta}} = s_k^{1-\beta} s_{re}^{\beta}.$$

$$k_t^{1-\alpha-\beta} = \left[\frac{s_k^{1-\beta} s_{re}^{\beta}}{n+g+\delta}\right].$$

$$k_t = \left[\frac{s_k^{1-\beta} s_{re}^{\beta}}{n+g+\delta}\right]^{\frac{1}{1-\alpha-\beta}}.$$

Take log of both sides we have

$$ln(k_{t)} = \frac{1}{1-\alpha-\beta} ln\left(s_k^{1-\beta}\right) + \frac{1}{1-\alpha-\beta} ln\left(s_{re}^{\beta}\right) - \frac{1}{1-\alpha-\beta} ln(n+g+\delta). \quad (9)$$

Recall $\alpha + \beta$ =1, (constant return to scale) we have

$$ln(k_{t)} = \frac{\alpha}{1-\alpha-\beta} ln(s_k) + \frac{\beta}{1-\alpha-\beta} ln(s_{re}) - \frac{\alpha+\beta}{1-\alpha-\beta} ln(n+g+\delta). \quad (10)$$

Here $y = Y/AL$, $k = K\,/\,AL$ and $re = RE\,/\,AL$ are quantities per effective unit of labour. The steady state value of physical capital and renewable energy cut across by solving equation. The panel time series regression model is a mixture of time series and panel models with large number of observations over time(T) and cross section unit(N). The augmented renewable energy Solow growth model is adopted to examine the panel time series data of Africa economy. Incorporating the above equation into cobb Douglas production function we have

$$ln\left[\frac{Y_t}{L_t}\right] = A_0 + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_{re}) + g.t + -\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) + u_t \ . \quad (11)$$

Equation (11) shows that income per capita is determined by population growth, physical capital and renewable energy consumption. As theoretically, capital share (α) is 1/ 3, implies that the elasticity of income per worker with respect to s and ($n + g + \delta$) is 0.5 and – 0.5 respectively.

2.1 Data sources.

The data used were obtained from world bank and imf databases:
https://databank.worldbank.org/source/sustainable-energy-for-all#
https://databank.worldbank.org/embed/Population-and-GDP-by-Country/id/29c4df41

3. Data analysis and interpretation

3.1 Data Presentation and Analyses

Table 3.1:

Terms	Variables meaning
Y_t	Gross domestic growth
X_{4t}	Renewable Energy Consumption
X_{8t}	Population growth
X_{12t}	Gross fixed capital formation

The variables used in this study are Gross domestic growth, renewable energy consumption, Population growth and Gross fixed capital formation. The data were analysed with panel augmented solow model and econometrics data assessment were carried out. The summary of this and other preliminary tests discussed in chapter three are presented in Tables 3.2.

Table 3.2: Summary of Descriptive Statistics

Variable		Mean	Std. Dev.	Min	Max	Observations
ln gdp	overall	14.9785	2.2649	10.6342	19.1256	N = 208
	between		2.3105	11.1026	18.4801	n = 16
	within		.3180	13.9999	15.7959	T = 13
ln_pop	overall	16.0759	1.3065	13.1639	19.2025	N = 208
	between		1.3423	13.2316	19.0535	n = 16
	within		.0988	15.8481	16.3019	T = 13
ln_ren	overall	4.0836	.3997	3.0340	4.5478	N = 208
	between		.4047	3.1722	4.5094	n = 16
	within		.0740	3.8939	4.2954	T = 13
ln_s	overall	13.4712	2.2239	8.5398	17.9934	N = 208
	between		2.2542	9.5172	16.8019	n = 16
	within		.3981	12.4939	15.0612	T = 13

For each variable in our model, the central tendency, variability, skewness, and kurtosis of the data were summarized in the above table. The average values of all the variables, which coincidentally fell between the maximum and minimum values, revealed the average values of the variables across the years. The standard deviation values provided insight into the variables' annual variability with regard to their corresponding long-term mean values.

Table 3.3: showing correlation coefficient of the economic variables

	ln_gdp	ln_pop	ln_ren	ln_s
ln_gdp	1.0000			
ln_pop	0.7033	1.0000		
ln_ren	0.4416	0.4164	1.0000	
ln_s	0.9906	0.6897	0.3895	1.0000

The table above reported the relationship amongst the economic variable used in the study, and it was observed that there exist a high correlation between gross domestic product and population, gross domestic product and gross fixed capital formation, population and renewable energy consumption.

Table 3.3.1: showing Assumption tests of the economic variables

Tests	F	Prob > F	chi2	df	Prob>chi2
Wooldridge test for autocorrelation in panel data	79.063	**0.0001****		(1, 15)	
Wald test for groupwise heteroskedasticity			8592.88	**16**	**0.0001***
hausman fixed random, sigmamore			115.83	**3**	**0.0001*****

*We reject the null and conclude that there exists heteroscedasticity
**Pr< 0.05, we reject the null hypothesis and conclude that panels are not correlated (cross-sectional dependence).
< 0.05, we reject the null hypothesis and conclude that panel are not correlated (cross-sectional dependence).
***If the p-value is less than 0.05, reject null hypothesis and use fixed effect. From the above analysis, the probability value of 0.0001 is less than 0.05 therefore, the study will adopt fixed effect regression.

Table 3.3.2: Breusch and Pagan Lagrangian multiplier test for random effects

ln_gdp	5.129898	2.264928
e	.0186843	.1366905
u	.0323704	.1799177

Test: Var(u) = 0
chibar2(01) = 105.31
Prob > chibar2 = 0.0000
*BPLMtest are panel correlated

The Breusch and Pagan Lagrangian multiplier test for random effects affirmed the choice of random effect estimation for the study with its significant level of 0.0001. This is coupled with theoretical and empirical reasons that West African countries operate similar characteristics in their economy and political structure. There is possibility that individual characteristics of each country may not influence the outcome and/or predictor variables since all of them share similar characteristics in Business practices, cultural, or political entities. The variation across entities is assumed to be random and uncorrelated with the predictor included in the model.

Table 3.4: showing Random-effects GLS regression of the economic variables

Random-effects GLS regression	Number of obs = 208
Group variable: countries	Number of groups = 16
R-sq:	Obs per group:
within = 0.7293	min = 13
between = 0.9728	avg = 13.0
overall = 0.9657	max = 13
Wald chi2(15) = 152081.97	
corr(u_i X) = 0 (assumed)	Prob > chi2 = 0.0001

(Std. Err. adjusted for 16 clusters in countries)

ln_gdp	**Coef.**	**Std. err.**	**z**	**P>z**	**95% Conf. Interval**	
ln_n_g_d	.3239	.1339	2.42	0.016	.0614	.5864
ln_ren	.2757	.2133	1.29	0.196	-.1425	.6938
ln_s	.7175	.0813	8.83	0.000	.5582	.8769
time						
2011	.0050	.0288	0.17	0.863	-.0515	.0615
2012	.0621	.0377	1.65	0.100	-.0119	.1360
2013	.0888	.0613	1.45	0.148	-.0314	.2090
2014	.0854	.0718	1.19	0.234	-.0553	.2261
2015	.0892	.0733	1.22	0.223	-.0544	.2328
2016	.0847	.0952	0.89	0.374	-.1020	.2714
2017	.1483	.0800	1.85	0.064	-.0085	.3051
2018	.1674	.0912	1.84	0.066	-.0113	.3461

2019	.1507	.1087	1.39	0.166	-.0624	.3638
2020	.1239	.1134	1.09	0.274	-.0983	.3461
2021	.1150	.1199	0.96	0.338	-.1200	.3499
2022	.1055	.1429	0.74	0.460	-.1747	.3857
cons	.3777	.9199	0.41	0.681	-1.4253	2.1807
σ_u^2	.1802					
σ_e^2	.1312					
ρ	.6537					

From the study, it was observed that Total number of entities is 16(countries) while Total number of cases (rows) are totaling 208, the between entity errors u_{it} are uncorrelated with the regressors in the random effects model. The p-value from the analysis is 0.0001 which less than 0.05, the implies that the model is okay. This is attest to the fact that all the coefficients in the model are jointly different than zero.

Two-tail p-values test the hypothesis that each coefficient is different from 0 (according to its t-value). A value lower than 0.05 will reject the null and conclude that the predictor has a significant effect on the outcome (95% significance). From the result above both population and gross fixed capital formation were statistically significant since their p-value is less than 0.05, while other variables except intercept are not statistically significant.

Intraclass correlation (ρ), shows how much of the variance in the output is explained by the difference across entities. From the study we observed 0.65 level of correlation which implies moderately level of relationship.

Beta coefficients indicate the change in the output (y) when the predictors change one unit over time and across entities (average effect). From the study, it was observed that three variables, namely, ln_n_g_d, ln_res and ln_s) were log-transformed to remove the effects of heteroscedasticity and serial correlation embedded in the dataset. Thus when the predictor increases, on average, 1%, the output (y) changes β% (elasticity). Thus, a 1% increase in ln_n_g_d which is a transformation of population(labour force) led to increase in gdp per capita(sustainable development) by 0.32% holding all other variables constant, a 1% increase in ln_res which is a transformation of renewable energy consumption led to increase in GDP per capita(sustainable development) by 0.27% holding all other variables constant, a 1% increase in ln_s which is a transformation of Gross Fixed Capital Formation led to increase in GDP per capita(sustainable development) by 0.71% holding all other variables constant.

Since time variable is dummies and there was no logarithm transformation, then its coefficients have to be transformed exponentially as far as level of output had been initially transformed. All the parameters for dummies time variables were transformed exponentially as :1.0050 ,1.0640 ,1.0928 ,1.0892,1.0933, 1.08834, 1.1598, 1.1822, 1.1626, 1.1319, 1.1218, 1.1113 and 1.4589. Holding all variables constant, the value of intercept of 0.37 implies that the level of output is increased by 0.37%, all variables impact the economy of the region positively. Holding all variables constant, a 1% increase in the year 2011 lead to no increase in gross domestic product per capita compare to the year 2010 with .00%, holding all variables constant, a 1% increase in the year 2012 bring about increase in gdp per capita by 0.06% compare to 2011, holding all variables constant, a 1% increase in the year 2013 bring about increase in gdp per capita by 0.09 % compare to 2012, ditto for all other years in the study.

4. Conclusion

In this study, we have presented a novel augmented renewable energy consumtion solow panel data model, we observed that t renewable energy consumption and its allied variables contributed positively towards the Sustainable Development Goals. In the face of escalating concerns regarding climate change and environmental degradation, the global community has increasingly turned its attention towards renewable energy sources as a critical solution. The imperative to transition towards sustainable energy systems has become evident, not only to mitigate the adverse impacts of fossil fuel consumption but also to foster economic growth and ensure environmental sustainability.

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