RESEARCH ARTICLE

Environment and Growth Sustainability: An Empirical Analysis of Extended Solow Growth Model

Idongesit Udoh[1*], Idongesit Ukere[2], Ame Ekpenyong[3]

[1]Department of Economics, University of Ibadan, Nigeria, aidy4udoh@gmail.com
[2]Department of Business Administration and Management, Akwa Ibom State Polytechnic, Nigeria, ukereidy@gmail.com
[3]Department of Business Administration and Management, Akwa Ibom State Polytechnic, Nigeria, ameekpenyong221@gmail.com

Corresponding Author: Idongesit Udoh, aidy4udoh@gmail.com
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Abstract

The concern about how sustainable growth in the economy can be achieved without a negative impact on the environment has become a major issue in the world today due to climate change. This study extended the Solow growth model (SGM) to include ecological resources, land, and population. The study also empirically assesses the impact of particulate emission damage (ped), natural resources (nar), growth in agricultural land (gal), and population growth (pgr) on output per worker in Nigeria. An ARDL technique was adopted to empirically analyse the data. The results from the study found that output per worker increased with an increase in the explained variables used in the study. The study concluded that sustainable growth can be achieved through the reduction of human activities that deplete the environment. The study also recommended the need to prevent depletion of land and natural resources and equip the population with productive skills and technology.

Keywords: Environment; Resources; Growth

Introduction

The Solow growth model, one of neoclassical model ignored the prognostication of the rising population and human activities against the environment. Solow predicted that growth in the economy will depend on population growth (g), saving (s), and knowledge (or effective labour) (A). He also made a case for rural – urban migration of effective and non-effective labour which will lead to increase cities population. The model, however, excluded the possible effect that human activities and increasing population – especially in the industrialized cities – will have on the land and natural resources (the environment) that are fixed and depreciates overtime. The origin of all resources used by man is the environment (oil and other natural resource and land), which Romer (2012) noted are fixed. Any bid to follow a sequence of reliably increasing output will exhaust those resources, which will result in failure. Additionally, the limited quantity of land may start to impose rigid restrictions on the capacity for production. Alternatively, ever-increasing output might result in an ever-increasing pollution stock, which will also discontinue growth (Romer, 2012). London (2017) observed that the environment is made up of interdependent ecological and artificial components, human bustles have the potential to alter it. This, then, sways society's way of life, which encompasses the ecological, societal, and racial values that are present at a particular time and place. According to an excerpt from the IPCC report, Tollefson (2021) reported that modern society's continued dependent on fossil fuels is thawing the world at an unprecedented tempo in the last 2,000 years. These effects are already being felt as record-breaking famine, wildfires, and deluges decimate communities worldwide.

In an effort to enhance productivity and maintain growth, human actions leading to climate change prompted the United Nations (UN), with 195 member States, to create the IPCC. The historic study from the UN committee on climate change, which was published on August 9, 2021 and declared "code red for humanity" by the UN Secretary, demonstrates how human activity 'unequivocally' affects climate change in many regions of the world. The analysis warned that the present global surface temperature of 1.1 degrees Celsius, which results in greenhouse gas (GhG) emissions, might rise by more than the 1.5 degrees Celsius objective set by the Paris Agreement in the next 20 years. With a 2 degree Celsius rise in global warming, excessive heat will pass the thresholds for agricultural and human health, resulting in more scorchers, lengthier balmy seasons, and dumpier icy seasons. Wetness and dryness, strong winds, snow and ice, coastal regions, and oceans are among the regions that are likely to be impacted by human activities that contribute to climate change. Heavy rainfall resulting in flooding, prolonged rising seas, particularly in metropolitan areas, amplified melting of permafrost, and alterations in the ocean, such as ocean acidification and a decline in oxygen saturation, are already evident in some parts of the world. For instance, human activities geared towards productivity have contributed to recent disastrous floods in Nigeria, India, China, and northern Europe as well as heatwaves that have melted asphalt in North America and southern Europe compared to the pre-industrial era.

In the IPCC report, weather and climate extremes were noted, along with rises in thoroughly combined GhG levels since roughly 1750 that were brought about by human actions. These spikes were recognized through new climate change models exercises, evaluations, and techniques integrating multiple lines of evidence. To stop the unsustainable human activity that causes GhG emissions and other unfavourable environmental activities, quick action is required.

Despite expanding production to accommodate the growing world population considering the fixed natural resources and land, human actions have continued to destroy the environment, causing climate change. Consequently, the goal of this study is to expand the Solow Growth model to take into account environmental pollutants, natural resources, and land. This study will also assess empirically the impact of particulate emission damage (proxy for environmental pollutants), natural resources, land, and population growth on Output per worker in Nigeria.

Literature Review

Assumptions of Solow Growth Model

The expected growth in population (g) at a steady rate is one of the main assumptions of the Solow Growth Model (SGM). This can be expressed as $N' = N(1+g)$ in the population growth equation, in which N is the current population and N' is the population in the future. The model also presupposed that each consumer in the economy would save money at a fixed rate (or rates) (s). This is shown by the consumer equation, which reads $C = (1-s)Y$, in which C stands for consumption and Y for output.

The SGM also concocts a presumption that all businesses in the economy utilise identical technology to produce output (Y), with labour (L) and capital (K) serving as inputs. This is written as $Y = AF(K, L)$ in the production function equation, with the variables already defined. The Cobb Douglas production function of constant returns to scale (CRS) is supposed to be present in the production function. In this case, $Y = AK^{\alpha}L^{1-\alpha}$; where 0>1. This implies that SGM focused more on capital per worker and output per worker than on total output and total capital stock.

Finally, the SGM made the assumption that the capital accrual equation, which is given as $\dot{k} = k(1-\delta)+1$, was constructed by the contemporary accrual stock (k), impending accrual stock ($\dot{k}$), capital reduction rate (δ), and amount of investment in capital (I).

The dynamics of k are formed by combining the aforementioned hypotheses in the Solow Growth Model, which led to:

$$\dot{k}(t) = sf(k(t)) - (n+g+\delta)k(t)$$

Extension of the SGM

Follow the emergence of Solow Growth Model, scholars have recently development more interest on extending the Solow Growth Model to include the environment such as land and other natural resources. Romer (2012) observed the absent of ecological resources, smog, and other environmental reflexions from the Solow model. Malthus (1798) as put by Romer (2012) made his archetypal claim that people have deemed that these reflexions are vitally doable for lasting economic growth, which Solow model, however, argued against, while believing in countries convergence if they are on steady state based on alike rate of population growth (g), savings (s), and capital decline (δ).

Brock and Taylor (2005, 2010), were able to prove that the sustenance of cyst with non-renewable resources and non-abating air trait for a longer term will require fast and sufficient technological progress. Similarly, Romer (2012) noted that the use of resource and limitation of land downgrade growth by instigating resource utilization of each worker and land utilization of each worker to plummet because the land hoard is static, hence, an eventual plummet in resource. Therefore, even with growing pace of technology upfront of resource and land kerbs over the bygone few centuries, will still act as binding kerbs on productivity. Pollution is another environmental problem that can limit growth. This can be seen in recent global warming that shrinkage output by affecting rising seas and atmospheric conditions.

According to Guilló and Magalhaes (2018), rendering economic cyst attuned with the preservation of the environment is a major problem for industrialized societies as well as a requirement for maintaining the lives of the masses in emerging economies today. They expanded the Green Solow model by including land deterioration as an inevitable result of commerce and an investment input for land.

$$\frac{1}{T} In\frac{e^{C}_{it}}{e^{C}_{it-T}} = P_0 + P_1 Ine^{c}_{it-T} + P_2 InZ^{c}_{it-T} + P_3 InS_{ki} + P_4 InS_{zi}(1-\theta_i) - \psi_1) + ... + P_5 In(1-\theta_i) + P_6 In(\delta + g_B + g_L) + V_i$$

Where the median variation of emissions per person above a retro of distance $\frac{1}{T} In \frac{e_{it}^{C}}{e_{it-T}^{C}}$ is a function of preliminary worth of emissions per person, e_{it-T}^{C}, the preliminary worth of land-capital per person, Z_{it-T}^{C}, and some factors that reflects the long-lasting impact of per person income. These factors include made-capital expense rate, S_k, the rate of land-investment, S_z, the lessening exertion, θ, the human inferred mar, ψ, and the devaluing term, $(\delta + g_B + g_L)$, that depends on rate of deflation of capital $(\delta = \delta_k = \delta_z)$, the labour-improving mechanics progress rate, g_B, and the rate of study of human population, g_L.

The environmental Kuznets Curve hypothesis, according to Halkos and Psarianos (2015), - while attempting add environment in the growth model of neoclassical - predicts an inverse U-shape relationship between per capita income and environmental harm. Halkos and Psarianos (2015) specified the following model to determine this effect.

$$\left[\frac{C0_2}{c}\right]_{it} = \beta_0 + \alpha_i + \lambda_t + \beta_1\left[\frac{GDP}{c}\right]_{it} + \beta_2\left[\frac{GDP}{c}\right]_{it}^2 + \beta_3\left[\frac{GDP}{c}\right]_{it}^3 + \beta_4\frac{REN}{c} + \beta_5\left[\frac{C0_2}{c}\right]_{it-1} + \mu_{it}$$

Where $\left[\frac{C0_2}{c}\right]$ is per person emission of carbon dioxide, $\left[\frac{GDP}{c}\right]$ is GDP per person and $\left[\frac{REN}{c}\right]$ represent the per person electricity produce from renewable cradles.

London (2017) studies the existence of the substitution amid resources that are reusable and non-reusable that relieves on the extent of hi-tech stage (reusable dynamisms and stowage faculty), variations in utilization, and output routines, etc. presented an equation that recap the rapports as shown below.

$Y_t = f(Y_{t-1}, Y_{t-2}, distA_{t-1})$

Here, $distA_{t-1}$ depicts the disconnect among the needs of sustainability and available technology in this context. Since this equation is non-stationary and non-homogeneous, it cannot be resolved analytically. He stated that the best outcomes are cutting down on utilization, allocating resources to green technologies, and using ecological resources less than is defensible.

Romer (2012) addresses the issue of how constraints from nature impact longer growth. He made a distinction between environmental elements for which there are clearly defined property rights—such as land and ecological resources—and others outside —such as pure water and air.

He noted that output production that affect the environment has externalities. These externalities can be regulated through implementation of quotas and tax by government, fostering bargaining over externalities through the enforcement of the property rights, and the missing market of externality. Romer (2012) noted the existence of externalities on environmental goods without the property rights. That is, the possibility of firms causing pollution exclusive of offsetting the society they impair, hence, making stronger rationale for government intrusion. This is so because the producers of pollutions don't wear the outlays of their pollution, and an unfettered market emits undue pollution with effortless prevention of ecological cataclysm in an unfettered market.

In considering the eco-friendly possessions trade in the markets, Romer, scrutinised the duet of unadorned baseline situation and an imperative snag to the baseline plus the ecological possessions without an active market as shown below.

$$g_{Y/L}^{bgp} = \frac{(1-\alpha-\beta-\gamma)(n+g)-\beta b}{1-\alpha} - n = \frac{(1-\alpha-\beta-\gamma)g-\beta b-(\beta+\gamma)n}{1-\alpha}$$

Where the equation proves that cyst in earning per person on the balanced growth path (bgp), $g_{Y/L}^{bgp}$, meaning that reserve and terrestrial curbs can cause per person's yield to eventually be falling due to growth drag, but spur from technological progress can act as a spur to growth.

Methodology

This data from World Development Indicators (WDI) from 1990 to 2021 is adopted for this study. The test of hypotheses was done at a 5% level of significance. The econometric procedure that was adopted to assess how environmental pollution, natural resources, land, and population impact output per worker in Nigeria is Autoregressive Distributive Lags (ARDL). One multiple regression model was adopted to capture the impact of the objective variables on the reliant variable.

Theoretical Framework: The Sustainable Growth Model

This model derivation is based on Romer (2012) and Guilló and Magalhaes (2018) models. This new model is derived below.

$$Y_t = K_t^{\alpha} R_t^{\beta} T_t^{\gamma} + P_t^{\psi} + (A_t L_t)^{1-\alpha-\beta-\gamma-\psi}$$

($\alpha > 0$, $\beta > 0$, γ,>0, φ> 0, α+ β+γ+ φ < 1). (1)

Here, R is the means of production; T is land quantity; P is the Environmental Pollution rate; while K, A, and L are as defined earlier by Solow including the dynamics of K, L, and the effectiveness of labour

$$K_t = sY_t - \delta K_t, \dot{L}_t = nL_t; \dot{A}_t = gA_t$$

For more clarity, environmental pollution (P) in this context is express as P = (S_T(1-Θ_i) – φ), where S_T is the rate of terrestrial investment; Θ is the lessening exertion; and φ is the humanoid tempted impairment.

Equation (1) deals with resources, land, and pollution with the assumption that land quantity is immobile and in the overtime the extent used in production remains static. Thus,

$$\dot{T}_t = 0 \qquad (2)$$

Resource are assumed fixed and decline due to increase in production, we have,

$$\dot{R}_t = -bR_t, b > 0 \qquad (3)$$

Equation (3) assume rising resource overtime.

Furthermore, since firms used resource endowments and land on earth for production, increasing production by using these fixed assets in a long-run will lead to increase in pollution.

$$\dot{P}_t = eP_t, e > 0 \qquad (4)$$

Resources and earthbound featuring in the equation (1) implies that K/AL (capital per effective labour) no longer congregates to same value, which nullified the focusing on prior slant of K/AL to dissect the miens of economy.

To confirm the existence of bgp including the economy level of growth variables on that path, the model assume that A, L, R, T, and P are all emergent constantly, while K and Y are requisite for bgp.

Taking logs of equation (1) gives us

$$\ln Y_t = \alpha \ln K_t + \beta \ln R_t + \gamma \ln T_t + \psi \ln P_t + (1-\alpha-\beta-\gamma-\psi)[\ln A_t + \ln L_t] \quad (5)$$

Differentiating equation (5) with veneration to time (t) vintages

$$gY_t = \alpha gK_t + \beta gR_t + \gamma gT_t + \psi gP_t + (1-\alpha-\beta-\gamma-\psi)[gA_t + gL_t] \quad (6)$$

Equation (6) following the rule of the time offshoot of the variable's log equalling the it growth rate. Recall that the gR, gT, gA, gP, and gL are −b, 0, g, e, and n, correspondingly. Thus, (6) streamlines to

$$gY_t = \alpha gK_t - \beta b + \psi e + (1-\alpha-\beta-\gamma-\psi)[n+g] \quad (7)$$

Recall also that g(Y, K) require identical for the economy on a $g^{bgp}_{Y/L}$ g(K = Y). Unravelling (7) for gY produces

$$g^{bgp}_{Y/L} = \frac{(1-\alpha-\beta-\gamma)(n+g)-\beta b+\varphi e}{1-\alpha} \quad (8)$$

The implication of (8) is that the output per person rate of growth on the bgp is $g^{bgp}_{Y/L} = g^{bgp}_{Y} - g^{bgp}_{L}$

Using equation (8) and the fact that L grows at rate n, we can write

$$g^{bgp}_{Y/L} = \frac{(1-\alpha-\beta-\gamma)(n+g)-\beta b+\varphi e}{1-\alpha} - n$$

$$= \frac{(1-\alpha-\beta-\gamma)g-\beta b+\varphi e-(\beta+\gamma)n}{1-\alpha} \quad (9)$$

The equation (9) shows that crypt in earning per person on the balanced growth path, $g^{bgp}_{Y/L}$, can take a positive(+) or negative (–) attribute. Implying resource and land limitations including pollution lead to decrease in output per worker. The quantities of resources and land per person shortfall and increasing pollution due to increase in output production constitute slogs on sustainable growth. Technological progress is seen as a spur to growth, however. It will be required that the spur surpass the drags for sustained growth in output per person to be achieve. This equation also supports the Environmental Kuznets Curve Hypothesis, which shows the relationship between environmental depletion and per person income.

Model Specification

Based on the extended Solow model as derived in equation (9) above. The model is thus specified below.

$$ygl = f(ped, nar, gal, pgr) \quad (10)$$

With the econometrics version of equation (10) becoming

$$\log(ygl) = \delta_0 + \delta_1 ped + \delta_2 nar + \delta_3 gal + \delta_4 pgr + \psi_i \quad (11)$$

The apriori expectation from the variables in the model is $\delta_1 < 0; \delta_{2,3} > 0; \delta_4 < 0$

Where ygl is the output per worker, defined as a ratio of GDP and labour force participation rate; ped is particulate emission damage (% of GNI); nar is total natural resource rents as a percentage of GDP; gal is the growth rate of agricultural land; while ψ is the stochastic term in the model, and $\delta's$ are the coefficients of the independent variables.

This study adopted the ADF – unit root test to test for level of stationarity before proceeding to use the Autoregressive Distributive Lag (ARDL) to test variables' relationships.

Results and Discussion

Unit Root Result

The unit-root result in Table 1 above indicates the stationarity test. The model, which captures the environmental pollution, natural resources, land, and population impact on output per worker in Nigeria, shows that output per worker (ygl) and population growth rate (pgr) are stationary at second difference [i.e. I(2)]; particulate emission damage (ped) and natural resources rants are stationary at I(1)]; while natural resource rent (nar) stationary at [I(0)].

Table 1. Unit Root Result

Variables	**ADF Test Statistic**	**5% Mackinnon Critical Level**	**Order of Co-integration**
(LOG(ygl)	-6.928390	-2.967767	I(2)
Ped	-3.498706	-2.963972	I(1)
Nar	-7.451358	-2.967767	I(1)
Gal	-5.282992	-2.960411	I(0)
Pgr	-4.065254	-2.981038	I(2)

Source: Author's Computation from WDI data

F-Bounds Test

It is observed that the F-stat of (28.08569) exceeded the 1%, 5%, and 10% critical values at both the lower and upper bounds. Thus, the F-statistic is significant. The significance of the F-statistic signifies a long-run relationship in the model. Therefore, co-integration exists. Hence, need for long and short runs relationships appraisal. Table 2.

Table 2. F-Bounds Test Result

			H_0: No degree relationship	
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
		Finite Sample: n=35		
Actual Sample Size	28	(%)		
F-statistic	28.08569	10	2.2	3.09
K	4	5	2.56	3.49
		1	3.29	4.37

Source: Author's Computation from WDI data

Long-run Form ARDL and Bounds Test Result

According to the ARDL estimates of long-run coefficients, the relationship between ygl, nar, gal, and pgr is statistically significant, while that of ped is insignificant. Therefore, for the period under estimation, the natural resource rent, agricultural land growth, and population growth have been associated with the output per worker in Nigeria. The negative relationship of nar with ygl implies that when natural resource rent increases, output per worker in Nigeria will reduce. This might be associated with the non-exploitation of the resources for productive ventures. The relationship between gal and ygl is also negative, meaning that an increase in agricultural land reduces output per worker in Nigeria. This result shows the possibility of a reduction in output due to the idleness of the agricultural land. In the case of pgr, the positive relationship of pgr with ygl implies that when the population grows, output per worker in Nigeria will also increase. Particulate emissions are insignificant in explaining Nigeria's long-run output per worker, as evidenced by the result. Table 3.

Table 3: Long-run ARDL Form and Bounds Test

Dependent Variable: DLOG(ygl)				
Selected Model: ARDL(4, 4, 3, 3)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Ped	0.004845	0.011070	0.437684	0.6769
Nar	-0.018499	0.003712	-4.983684	0.0025
Gal	-31.05462	1.977746	-15.70203	0.0000
Pgr	2.047322	0.185567	11.03278	0.0000
C	16.12516	0.832088	19.37915	0.0000
LOG(ygl) - (0.0048*ped -0.0185*nar -31.0546*gal + 2.0473*pgr + 16.1252)				

Source: Author’s Computation from WDI data

ARDL Error Correction Regressed Result

The difference between the long and short runs equation measures the speed of adjustment of gowth resulting from the variations in the environmental variables. Table 4 shows the absolute error correction model’s value of 1.143935 (114.3935%), indicating a discrepancy between the short-run and long-run. The 114.3935% reveal that there are very fast rates of adjustment in each period. The coefficients of the residuals indicate that the disequilibrium between long-run and short-run output per worker in the economy is corrected within a year. The parsimonious results for the error correction term CointEq(-1) are negative and significant, which shows co-integration of the variables.

Also from the table, the coefficients of ygl when lagging for four (-3) periods are 0.778307 (77.8307%), showing the approximate speed of adjustment. This signposts that if deviancy exist from equilibrium, 77.8307% is tweaked in one quarter during the movement of the variable to equilibrium restoration. This is an indication of a fast adjustment speed of output per person, which may exhibit average hassle on the variable in reinstating equilibrium in the long run resulting from any disturbance. Further results acquired suggest that the overall R^2 is 0.995125, representing 99.5125% of income per worker, is explained by the variables in the model, while 0.4875% is accounted for by the error term in the model. This led to the overall rejection of the hypothesis that disturbances of the environment do not impact output per worker in Nigeria.

The estimated result in Table 4 using the ARDL model selection shows that the coefficient of particulate emission damage (ped) has a positive relationship with output per worker (ygl). Therefore, a 1% increase in the ped in the second period is expected to bring about a 0.015358% increase in output per worker. This finding confirms the environmental Kuznets curves, which hypnotise an increase in per capita income as environmental degradation increases. The result further shows that natural resource rent (nar) has a positive relationship with output per worker (ygl). This implies that an increase in nar of 1% will increase ygl by 0.001805%. This finding is in consonance with the study by Hamdi and Sbia (2013) conducted in Algeria. It also agrees with the Solow growth model that drag limitations in resources will limit growth due to their fixed nature. Growth in agricultural land (gal) also has a positive relationship with ygl, meaning that an increase in gal will emit 0.099755 upsurge in ygl. This is because more availability of agricultural land for cultivation will lead to an increase in farm output and income. When agricultural lands are destroyed due to human activities, it will reduce the output from the land, reducing income. In the case of population growth rate (pgr), the coefficient is also positive, implying that if population growth is one percent, output per worker will grow by 0.637110. This finding conforms with Solow's prediction of a possible increase in population leading to increasing aggregate output without a permanent effect on per capita output. However, it disagrees with the prediction of a lower steady-state rate level of per capita output due to an increase in population.

Table 4. ARDL Parsimonious Result

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
DLOG(YGL(-1))	-0.998763	0.090378	-11.05100	0.0000
DLOG(YGL(-2))	-1.111408	0.092697	-11.98972	0.0000
DLOG(YGL(-3))	-0.778307	0.061742	-12.60586	0.0000
D(PED)	-0.042389	0.007439	-5.698271	0.0013
D(PED(-1))	0.015358	0.007499	2.048106	0.0865
D(NAR)	-0.003733	0.000419	-8.916795	0.0001
D(NAR(-1))	0.010330	0.000679	15.21575	0.0000
D(NAR(-2))	0.005171	0.000353	14.65617	0.0000
D(NAR(-3))	0.001805	0.000296	6.093768	0.0009
D(GAL)	-36.34339	2.098708	-17.31703	0.0000
D(GAL(-1))	-0.119675	0.013736	-8.712254	0.0001
D(GAL(-2))	0.099755	0.016472	6.056136	0.0009
D(PGR)	-1.126909	0.074540	-15.11810	0.0000
D(PGR(-1))	-1.688099	0.148552	-11.36371	0.0000
D(PGR(-2))	-1.604029	0.106813	-15.01711	0.0000
D(PGR(-3))	0.637110	0.072882	8.741601	0.0001
CointEq(-1)*	-1.143935	0.065082	-17.57676	0.0000
R^2	0.995125			
Adjusted R^2	0.988035			
Standard Error	0.004452			

Source: Author’s Computation from WDI data.

Conclusion

This study extended the Solow Growth Model by including land, natural resources, and environmental pollution. The remodelling of the Solow growth model is as a result of the recent global concerns about climate change, which is believe to be a function of human activities. Climate change affects urban areas more than the rural areas. This is due to high present of industries and development in the urban than the rural areas, which pollutes the environment. This is seen in the high industrial and development regions of India, China and Northern Europe, North America, and Southern Europe compared with less-industrial and undeveloped African countries. The extended Solow Growth Model otherwise called Sustained Growth Model shows the relationship between resources, land, and pollution on growth rate in per capita income as argued by the Environmental Kuznets curve (EKC). Since natural resources and land that are fixed depletes overtime and pollution increase overtime as countries increase their output, African countries which depend mostly on natural resources with uncontrolled pollution growth should employ more technology in production to sustain the environment and growth.

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Empirical findings from the study revealed that particulate emission, natural resource rents, and the growth rate of agricultural land have a negative relationship with output per worker, while population growth possessed positive sway in the long run, with particulate emission damage being insignificant in explaining Nigeria's long-run output per worker. In the short run, the result shows that all the explained variables have positive relationships with output per worker in Nigeria. The study therefore recommends the need to prevent the depletion of land and natural resources and equip the population with productive skills and technology to enable them to increase output in the economy.

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