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The Impact of Wood Fuel Energy on Economic Growth in Sub-Saharan Africa: Dynamic Macro-Panel Approach

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Abstract: This study estimates the impact of wood fuel consumption on economic growth in 19 sub-Saharan African countries over the 1979-2017 period. The study employs dynamic macro-panel estimators, which comprises pooled mean group (PMG), mean group (MG), and dynamic fixed effects (DFE). The estimated result reveals that PMG is the most efficient estimator among the three estimators based on the Hausman *h*-test. The results from PMG model reveal that wood fuel consumption has significant negative impact on economic growth. Also, when an interaction term between labor and wood fuel consumption was included in the model and estimated, the coefficient of wood fuel consumption yields negative and significant coefficient. This suggests that the interaction term has a negative and significant effect on economic growth. These results unveil that wood fuel consumption negatively and significantly affect economic growth, both directly and indirectly. The policy recommendations from this study are as follows: (1) Governments of these countries should provide adequate and affordable modern fuels to the populace; especially rural dwellers to decrease the use of wood fuel for cooking and heating (2) policy makers should intensify awareness campaign on the risk and danger wood fuel poses to economic growth so as to discourage its use and (3) policy makers should provide adequate solar powered stoves and solar-powered room heaters as cheap substitutes to the use of wood fuel for cooking and heating. These recommendations will assist in negating the negative effects of wood fuel consumption on economic growth of the region.

Keywords: wood fuel consumption; economic growth; pooled mean group; mean group; dynamic fixed effect; panel dynamic ordinary least squares

1. Introduction

About 50% of the world's population is exposed to indoor air pollution with sub-Saharan Africa having the highest figure due to the consumption of traditional biomass fuels. IEA [1] reports that 94% and 73% of the rural and urban population in Africa rely on wood fuels as the main primary energy source for cooking, respectively. The rural settlements relying mostly on fuelwood (i.e., firewood), while the urban settlements depend mainly on charcoal. These wood fuels also provide energy source to most small- and medium-scale industries in both rural and urban centers such as bread making industries, brick-making industries, beer brewing industries, tobacco curing industries, etc. Despite the importance of wood fuel in providing energy to the households, small, and medium industries of the region, it is perceived to be detrimental to the region's economy. This is because; indoor air pollution from burning of wood fuel is linked to premature deaths from acute and chronic cardiovascular diseases, and other respiratory diseases [2].

The effect of indoor air pollution from wood fuels on health can lower the income level of the households, as a result of decrease in the population's productivity due to illnesses. Also, the adverse effect of wood fuel usage can be associated with the increase in the morbidity and mortality among the population [2]. Yeh [3] revealed that an increase in traditional biomass usage increases infant and child mortality rates in developing countries. It therefore reduces the availability of work force and also increases the social health cost of pollution. Thus, the economic growth rate being experienced by most sub-Saharan African countries can be potentially negated by the health cost sustained from the indoor air pollution. To strengthen this argument, Gangadharan and Valenzuela [4] demonstrated that most of the developing countries have their increased income wiped away by social health cost of pollution from traditional biomass consumption. In another study by Maji et al. [5], renewable energy, which is mainly dominated by wood fuel in sub-Saharan Africa, was found to have negative effect on economic growth in West Africa. Furthermore, the pollution from wood fuels result in loss of workdays by the able-bodied persons due to illness or taking care of sick ones suffering from wood fuel smoke related illnesses. Rehfuess [6] maintained that falling sick from indoor air pollution resulting from consumption of traditional biomass or caring for the sick children lessens earnings and can result in increased private health care expenditure and medication expenses. This, in turn, leads to what is called "poverty vicious circle for traditional biomass consumption".

Sub-Saharan is a leading region with the highest disease burden of indoor air pollution-related complications from traditional biomass use. The economic burden of it is put between 0.5% and 2.5% portions of world's GDP. This is equivalent to $150–$750 billion per annum [7]. In terms of mortality, it is estimated that about 600,000 lives are lost each year from exposure to biomass smoke in sub-Saharan Africa [8]; while the cost of too much dependence on biomass fuel mostly wood in the region is US$36.9 billion annually. Also, the productive time lost from gathering wood fuel is estimated to be US$29.6billion. Thus, there is a need for an empirical investigation and subsequent policy suggestions as the global burden of biomass consumption related diseases according to WHO [9] is very significant and on the rise, especially in the sub-Saharan Africa. It is therefore on this background that the study intends to investigate the impact of wood fuel consumption on the economic growth in sub-Saharan Africa.

This study has some practical significance. At the present, the consumption of wood fuel in this region is high and on the rise. The demand for it is projected to increase further in the coming decades, if alternative modern fuels are not made available and affordable to the people of the region. While the production and consumption of wood fuels in other regions (North America, Latin America, Europe, and Asia) are declining, the reverse is the case in sub-Saharan Africa. Therefore, it is paramount to ascertain how the continuous reliance on wood fuel by countries within the region affects their economies. Though there some benefits that are seen in terms of income generation for the wood fuel operators and rural poor, who rely on the wood fuel extraction as the means of livelihood, there are costs associated with its consumption through the adverse health effects, which may potentially affect the economy. Thus, researching its real impact on the economy will assist in providing details to the policy makers about the level and magnitude of the impact, for them to provide appropriate policy action. This study will contribute to the body of knowledge and literature in forest economics and biomass-related literature.

Most of the existing literature lay more emphasis on investigating the relationship between aggregate biomass and economic growth in different parts of the world. These studies include Shahbaz et al. [10], Bildirici [11], Bildirici [12], Bildirici and Ozaksoy [13], Bilgili and Ozturk [14], Aslan [15], Ozturk and Bilgili [16], Bildirici and Ozaksoy [17]. For instance, Shahbaz et al. [10] investigated the relationship between biomass energy consumption and economic growth in BRICS countries for the 1991Q1-2015Q4 period and revealed that biomass energy consumption stimulates economic growth. Bildirici [11] found a long-run relationship between biomass and economic growth in seven developing and emerging countries and further revealed that biomass energy consumption facilitates economic growth in Chile, Brazil, and Bolivia for sample period of 1980 to 2009. In a similar vein, Bildirici [12] assessed the relationship between biomass energy and economic growth in transition countries covering 1990 to 2011 period and reported that biomass energy has a long-run relationship with economic growth and that its impact positively on it. A literature survey reveals that biomass energy–economic growth nexus was equally investigated in Europe by Bildirici and Ozaksoy [13]. Bildirici and Ozaksoy [13] examined the relationship between biomass energy consumption and economic growth in selected European countries covering 1960 to 2010 period and revealed long-run relationship between the two variables. The study further shows a strong causality from biomass energy consumption to economic growth. Also, a study conducted on G-7 countries by Bilgili and Ozturk [14] found biomass energy to be facilitating economic growth as labor and capital using dynamic panel estimator. In the case of United States of America, Aslan [15] indicates that biomass energy consumption causes economic growth.

In the case of Africa, the following literature are available. Ozturk and Bilgili [16] investigated the long-run relationship between biomass energy and economic growth in Sub-saharan African countries using dynamic ordinary least squares. The study included population and trade openness variables alongside biomass energy in economic growth model. The result of the study revealed that biomass energy consumption has significant positive impact on economic growth. Equally, Bildirici and Ozaksoy [17] examined the relationship between biomass energy consumption and economic growth in sub-Saharan African countries over the 1980–2013 period using ARDL method. The study reported that biomass energy consumption causes economic growth in the sampled countries.

Having discovered that most existing literature studied the aggregate impact of biomass consumption on economic growth, this study specifically focuses on one major component of biomass, which is wood fuel, on the economic growth using different methodological framework. The study investigates the impact of wood fuel consumption on economic growth through its impact on the productivity of labor. This is another contribution to the literature.

The remainder of the paper is structured as follows. Section 2 provides methodology and model specification. Results and discussions are presented in the Section 3. Section 4 contains conclusion and policy recommendation.

2. Methodology and Model Specification

2.1. Empirical Model

The empirical model for investigating the impact of wood fuel consumption on economic growth is based on the Cobb–Douglas production function. The original model from the theory is as follows:

$$Y = AK^{\alpha}L^{\beta} \tag{1}$$

where Y, A, K, and L are defined as output, technology, capital, and labor, respectively. While α and β are the respective share of capital and labor in the output. By theory, in the short-run, capital is assumed to be fixed and as such output (Y) depends solely on labor to vary. At first, the total output increases at an increasing rate and later increase at a decreasing rate until it reaches a maximum point, after which it would begin to decline continuously. Whereas in the long-run, output is assumed to depend on both labor and capital as they are variable.

Other than these theoretical variables, Mulegeta et al. [18] argued that energy consumption complements labor and capital in determining economic growth and as such, it should be considered as an independent factor input alongside labou and capital in economic growth model. Some other studies such as Omri et al. [19], Ang [20], Sharma [21], and Shahbaz et al. [22] also argued that the Cobb–Douglas production function can be augmented by inclusion of energy variable as thus:

$$Y = AK^{\alpha}E^{\pi}L^{\beta}e^{\sigma} \tag{2}$$

where Y is the output, K is capital, E is energy, L is labor, A is technology, and e is the residual term, which is assumed to have zero mean and constant variance. The exponents, α, π, and β are the elasticity of output with respect to capital, energy, and labor. Assuming the technological component of the model is restricted as in Equation (3), constant return to scale can is established.

$$\alpha + \pi + \beta = 1 \tag{3}$$

It is important to emphasize that the component A in the model is technology, which stands for productivity factors. It captures the factors that have influence on output through the introduction and application of new technology. These factors are normally observed through technological transfer [23].

Since the objective of this study is to investigate the impact of wood fuel consumption on economic growth, the study extends Equation (2) by introducing wood fuel consumption as complimentary variable to energy consumption in a linearized Cobb–Douglas production function and presented in a panel setting (see Equation (4)). Some existing biomass–economic growth nexus' studies have included biomass energy consumption, which wood fuel is part of, in economic growth models. These studies include Shahbaz et al. [10], Aslan [15], Bilgili and Ozturk [14], Ozturk and Bilgili [16], Bildirici [11], and Bildirici [12]. For instance, Shahbaz et al. [10] used production function growth model to examine the linkage between biomass energy consumption and economic growth by incorporating capital and trade openness as economic growth's determinants. The authors used log-linear specification by specifying the model in logarithm form, as log-linear specification produces reliable results [24]. Following these studies, Equation (4) is specified. The inclusion of wood fuel in economic growth model in the case of Sub-Saharan Africa can equally be substantiated by Ozturk and Bilgili [16], who used similar approach in linear panel model.

To capture the wood fuel consumption's impact on economic growth through its impact on the productivity of labor, the current study incorporates an interaction term between labor force and wood fuel consumption in the same Equation (4) as follows:

$$\ln Y_{it} = \alpha_0 + \phi \ln TO_{it} + \varphi \ln K_{it} + \delta \ln WC_{it} + \eta \ln L_{it} + \psi \ln E_{it} + \rho(\ln L \times \ln WC)_{it} + e_{it} \tag{4}$$

and the interaction is defined as: $\frac{\partial \ln Y_{it}}{\partial \ln L_{it}} = \beta_1 + \beta_2 \ln WC_{it}$, where Y, TO, K, WC, L, E, and *(WC×L)* are the real income or GDP per capita, capital, trade openness, wood fuel consumption, labor, energy, and the interaction between labor and wood fuel consumption, respectively. Moreover, α_0 is constant, ϕ is coefficient of trade openness, φ is the coefficient of capital, δ is the coefficient of wood fuel consumption, η is the coefficient of labor, ψ is the coefficient of energy consumption, and ρ is the coefficient of the interaction term between labor and wood fuel consumption. β_1 and β_2 are coefficients in the interaction, and ∂ represents the partial derivative. The subscripts, i and t are the individual country and time periods, respectively.

By definition, $e_{it} = \mu_i + \eta_t + v_{it}$, where v_{it} are, by assumption, independently and identically distributed with zero mean and constant variance.

2.2. Description of the Variables in the Model

Economic growth was measured using real GDP per capita in PPP terms as observed in many literature (see, [24,25]). Labor was theoretically assumed to be one of the major factors that influence growth. In a Cobb–Douglas production theory, it assumed that labor is the main determinant of output in the short-run as capital is assumed to be fixed within the production period. Practically, in sub-Saharan Africa, labor is one of key determinants of growth as most of the productive activities are labor intensive. Thus, it was expected to have a positive signed coefficient. The measurement for labor in this study was the active population between the ages of 15 and 64.

Trade openness was measured using export and import as a percentage of GDP. This is in accordance with the existing literature (see, [26,27]). Since trade allows the movement of goods, services, and capital among countries, it is expected that export and import will trigger growth performance of a country. As such, the expected sign of the coefficient of trade openness was positive.

Capital is another theoretically established stimulant of growth performance. Consistent with the existing study by Bilgili and Ozturk [14], it is proxied by gross fixed capital formation. The expected sign of the coefficient of capital was positive. This can be backed up by theory, which suggests that an increase in capital results in increasing economic growth.

Energy is considered an important factor of production, which complements both labor and capital in stimulating economic growth, as argued by Mulegeta et al. [18]. The expected sign of the coefficient of energy in this study was positive, as more energy is believed to increase growth in sub-Saharan Africa. Energy was proxied by energy use (kg of oil equivalent per capita).

Wood fuel consumption was measured using the total wood fuels consumed in cubic meters (solid volume units). Though some existing literature on biomass energy consumption and economic growth revealed a positive signed coefficient, wood fuel consumption coefficient in this study was expected have a negative sign as a priori. This is because the wood fuel consumed in sub-Saharan Africa is majorly traditional, which is unclean and hazardous, so many diseases are linked to wood fuel burning smoke. Therefore, too much reliance on such traditional energy source can slow down economic growth in the region.

All the data on the variables are obtained from African development indicators (WDI) of World Bank and FAOSTAT of food and agricultural organization (FAO). The data cover 19 sub-Saharan African countries for the 1979–2017 period. The choice of the countries and the period were determined by data availability. The data used can be found under the supplementary materials.

2.3. Estimation Method

2.3.1. PMG, MG and DFE Estimators

Following Bildirici [12] who applied panel autoregressive and distributed lag (ARDL) estimators in the analysis of biomass energy–economic growth relationship in an economic growth model, this study applied similar dynamic panel estimators to test for the long-run relationship and obtain the long-run estimates of wood fuel consumption and economic growth. The estimation technique was macro panel data analysis, which deals with large number of time period (T) relative to number of cross-sections (N) or large number of both the periods and cross-sections. In the case of large T and small N, Roodman [28] asserted that GMM estimators would produce spurious results due to the following reasons: (1) As T becomes larger, the instruments increase too, which subsequently affect the validity of Sargan test of over-identifying restriction. As such, the null hypothesis of exogeneity of instruments may be unnecessarily rejected. This can lead to doubt about the validity of the estimates. (2) Having small N can lead to a doubtful or unreliable autocorrelation test. In general, the application of GMM estimators in such s situation may result in inconsistent and unreliable results. The suitable estimators for such panel setting are panel ARDL estimators, which include mean group (MG), pooled mean group (PMG), and dynamic fixed effect (DFE).

To specify our model, it is pertinent to note that Pesaran et al. [29], Loayza and Ranciere [30], and Samargandi et al. [31] asserted that dynamic heterogeneous panel could be incorporated into an error correction model based ARDL (p,q) approach, with p as the dependent variable's lag and q as regressors' lag. Therefore, the general model for wood fuel consumption and economic growth is specified accordingly as follows:

$$\Delta \ln Y_{i,t} = \sum_{j=1}^{p-1} \beta_j^i \Delta \ln Y_{i,t-j} + \sum_{j=0}^{q-1} \rho_j^i \ln \Delta X_{i,t-j} + \delta^i [\ln Y_{i,t-1} - \{\theta_0^i + \theta_1^i X_{i,t-1}\}] + \mu_{it} \tag{5}$$

where Y is the real GDP per capita, X is the vector set of all independent variables included in the model including wood fuel consumption and the interaction term, β and ρ are the respective short-run dynamic coefficients of lagged dependent and independent variables, θ represents the coefficients of the long-run, δ represents the coefficient of the speed of adjustment to the equilibrium in the long-run, i represents the countries, t represents the years, and μ is the error term. The whole term in the square bracket represents the long-run regression derived from:

$$\ln Y_{i,t} = \theta_0^i + \theta_1^i X_{i,t} + \varepsilon_{i,t} \tag{6}$$

where $\varepsilon_{i,t} \sim I(0)$.

The model would be estimated using MG estimator by Pesaran and Smith [32], PMG estimator by Pesaran et al. [29], and DFE estimator. This form of error correction model for cointegration test in ARDL set up was presented by Pesaran and Smith [32] and Pesaran [33]. One of the major advantages of this methodology is that unlike Philipps and Hansen [34] and Johansen [35] who asserted that long-run relationship could only occur among the variables of the same order of integration, Pesaran and Shin [36] noted that panel ARDL approach could be used even if the variables are of different order of integration, i.e., I(0), I(1) or mixed. As such, testing for unit in panel ARDL is not necessary. More so, with panel ARDL, both the short-run and long-run estimates could be obtained simultaneously. Most importantly, particularly PMG and MG, Pesaran et al. [29] noted that the estimators produce consistent estimates in spite of the possibility of endogeneity presence as it includes the lags of dependent and independent variables.

Finally, there is a need to make comparison and choice between PMG, MG, and DFE estimators in terms of efficiency and consistency. To do so, we need to conduct a test called Hausman *h*-test. Hausman *h*-test is a test based on panel ARDL approach that measures the efficiency and consistency of the estimates of MG, PMG, or DFE. As such, the test would be conducted in this regard.

2.3.2. Unit Root and Cointegration Tests

Before going into the main estimation of the panel ARDL estimators, unit root and cointegration would be conducted to ascertain the order of integration of the variables and the probable existence of long-run relationship among the variables respectively. Levin, Lin, and Chu [37], Fisher ADF, and Fisher PP unit root tests will be used to identify the order of integration of the variables. These tests were chosen owing to their power in detecting the order of integration of variables in a balanced panel setting, as in the case of this study, whilst the long-run relationship among the variables would be tested using Pedroni [38] cointegration test. This test is based on the Engle–Granger [39] two-stage cointegration framework, which allows for heterogeneity across cross-sections in intercepts and trends.

2.3.3. Robustness Test

As a test for robustness, panel dynamic ordinary least squares (DOLS) would be conducted to affirm the findings of PMG, MG, and DFE against the suspected endogeneity and serial correlation problems in the model. Panel DOLS is popularly known for its power to deal with the problems of endogeneity and serial correlation in a model. Therefore, this technique will only serve as a validation test for the panel ARDL estimators discussed earlier. The following model will be estimated:

$$Y_{it} = \partial_i + \theta_i X_{it} + e_{it} \tag{7}$$

where X_{it} refers to the $m \times n$ matrix of trade openness, energy, wood fuel consumption, labor, capital, and the interaction term. While θ_i is the $m \times 1$ vector of all the coefficients of the regressors.

DOLS regression corrects endogeneity and serial correlation that is common with ordinary least square (OLS) estimator through differenced leads and lags. This could be represented in the following equation:

$$Y_{it} = \partial_i + X_{it}' \theta_i + \sum_{k=-q}^{q} \lambda_{ip} \Delta X_{it+p} + e_{it} \tag{8}$$

If Y_{it} and X_{it} are $I(1)$ and cointegrated, Kao and Chiang [40] and Pedroni [41] can be used to estimate the long-run coefficients of OLS and DOLS as follows:

$$\tilde{\theta}_{OLS} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}(X_{it} - \overline{X}_i)(X_{it} - \overline{X})'\right)^{-1}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}(X_{it} - \overline{X}_i)(Y_{it} - \overline{X})'\right) \tag{9}$$

$$\tilde{\theta}_{DOLS} = N^{-1}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\beta_{it}\beta_{it}'\right)^{-1}\left(\sum_{t=1}^{T}\beta_{it}(Y_{it} - \overline{Y}_i)\right) \tag{10}$$

where Y_{it} and β_{it} are the dependent variable and the vector of independent variables.

3. Results and Discussion

The estimation process begins with the preliminary tests to check the normality of the series and also to ensure that there is no multicollinearity among the explanatory variables. Table 1 contains the summary of the descriptive statistics of each of the variables. The results show that all the series employed are normally distributed, while the results of the correlation test among the explanatory variables are presented in form of correlation matrix in Table 2. Considering the range of the absolute values (0.076–0.562) in the table, it is safe to conclude that there is no multicollinearity problem among the explanatory variables. This is because the values are below the benchmark of 0.80 [42].

Table 1. Descriptive statistics.

Variable	Observations	Mean	Std. Deviation	Min.	Max.
GDP per capita	722	7.516	0.970	5.512	9.766
Labour	722	15.598	1.287	12.831	18.285
Capital	722	3.311	1.805	0.741	11.806
Trade Openness	722	4.177	0.468	1.843	5.187
Energy	722	6.244	0.574	5.376	8.015
Wood fuel	722	15.779	1.468	12.876	18.446

Table 2. Correlation matrix.

	Labour	Capital	Trade Openness	Energy	Wood Fuel
Labour	1.000				
Capital	0.350	1.000			
Trade openness	−0.470	0.078	1.000		
Energy	−0.076	0.178	0.166	1.000	
Wood fuel	0.432	0.246	−0.562	−0.268	1.000

Considering the longer period covered by the study, it is imperative to conduct unit root and cointegration tests to assess the order of integration of the variables and the existence of long-run relationship among the variables, respectively. The results for the unit root tests are reported in Table 3. Based on the result, Levin Lin and Chu, ADF Fisher, and PP Fisher tests suggest that labor, capital, and wood fuel consumption are stationary at level; whereas, GDP per capita, trade openness, and energy consumption stationary at first difference. The order of integration of the variables is therefore a mixture of I(0) and I(1), which suitably fits the application of panel ARDL estimators.

Table 3. Results for the unit root tests.

Series	Levin Lin & Chu		ADF Fisher		PP-Fisher	
	No Trend	Trend	No Trend	Trend	No Trend	Trend
Level						
GDP per capita	−0.698 (0.242)	−7.357 (0.859)	32.523 (0.720)	44.744 (0.209)	38.498 (0.446)	34.347 (0.639)
Labour	−9.166 (0.000) ***	8.411 (0.902)	60.586 (0.011) **	14.149 (0.999)	104.439 (0.000) ***	3.030 (0.981)
Capital	−2.922 (0.001) ***	−2.601 (0.004) ***	62.800 (0.006) ***	47.681 (0.135)	77.971 (0.000) ***	61.761 (0.008)***
Trade Openness	−0.553 (0.360)	−1.219 (0.111)	44.338 (0.221)	41.491 (0.292)	47.351 (0.142)	34.582 (0.628)
Energy	−0.977 (0.124)	−0.772 (0.219)	40.282 (0.369)	24.847 (0.950)	36.134 (0.556)	21.818 (0.983)
Wood fuel	−7.438 (0.000) ***	−0.797 (0.212)	74.712 (0.000) ***	23.605 (0.967)	133.578 (0.000) ***	21.187 (0.987)
First Difference						
GDP per capita	−6.562 (0.000) ***	−5.767 (0.000) ***	−8.860 (0.000) ***	145.254 (0.000) ***	244.373 (0.000) ***	250.117 (0.000) ***
Labour	10.868 (0.000) ***	78.403 (0.000) ***	10.876 (0.000) ***	61.961 (0.000) ***	74.016 (0.000) ***	92.921 (0.000) ***
Capital	−11.066 (0.000) ***	−9.074 (0.000) ***	241.787 (0.000) ***	191.591 (0.000) ***	479.330 (0.000) ***	142.555 (0.000) ***
Trade Openness	−10.940 (0.000) ***	−9.063 (0.000) ***	251.821 (0.000) ***	193.863 (0.000) ***	448.072 (0.000) ***	501.598 (0.000) ***
Energy	−9.205 (0.000) ***	−7.666 (0.000) ***	203.622 (0.000) ***	172.789 (0.000) ***	363.400 (0.000) ***	337.771 (0.000) ***
Wood fuel	−5.562 (0.000) ***	−6.616 (0.000) ***	141.239 (0.000) ***	172.502 (0.000) ***	222.826 (0.000) ***	494.149 (0.000) ***

Notes: * (**) *** indicate significant at 10%, 5% and 1% respectively.

To test for long-run relationship among the variables, this study employs the Pedroni cointegration test and the results of the test are presented in Table 4. Two types of residual tests as suggested by Pedroni [38] are reported in the table. The first panel in the table contains the first type, which consist of four sub-tests, i.e., panel-v, panel-rho, panel PP, and panel ADF statistics. These tests are based on pooling the residuals of the regression along the within dimension of the panel. The second panel in the table contains the second type, which comprises three sub-tests, i.e., group rho, group PP, and group ADF statistics. These tests on the other hand, are based on pooling the residuals of the regression along the between dimension of the panel. All the seven sub-tests from both the two types have the same null hypothesis of no cointegration. The results reveal that about five out the seven statistics are significant. Narayan, Smyth, and Prasad [43] and Lee and Chang [44] maintained that if at least four statistics are significant, the null hypothesis of no cointegration could be rejected and hence cointegration exists. Also, Pedroni [38] suggests that to conclude about the existence of cointegration, panel ADF and group ADF have to be considered as they have better small sample properties and as such their statistics provide reliable estimates. Following these authors, it can be concluded that long-run relationship exists among the variables as five out of the seven statistics including panel ADF and group ADF are significant.

Table 4. Results for Pedroni cointegration test.

	Dependent Variable: GDP per Capita	
	Without Trend	**With Trend**
Within Dimension		
Panel v-Statistic	8.422 ***	−10.161 ***
Panel rho-Statistic	2.195	6.382 ***
Panel PP-Statistic	−2.432 **	−0.275
Panel ADF-Statistic	−2.211 **	−2.370 ***
Between Dimension		
Group rho-Statistic	3.554	4.622 **
Group PP-Statistic	−1.466 *	−0.250
Group ADF-Statistic	−3.281 ***	−3.786 ***

Notes: * (**) *** indicate significant at 10%, 5% and 1% respectively.

Table 5 presents the results of PMG, MG, and DFE estimation as well as the result of Hausman *h*-test. The results reveal that wood fuel consumption has a significant negative impact on economic growth in the long-run according to both PMG and MG estimators, while the long-run coefficient of wood fuel consumption yielded by DFE estimator suggests a negative but insignificant impact on economic growth. In the short-run, while the coefficient of wood fuel consumption is negative but insignificant from PMG estimator, the results yielded by MG and DFE estimators indicate that the coefficient of wood fuel consumption has a negative and significant impact on economic growth. To ascertain the validity and efficiency of long-run homogeneity restriction across the cross sections, Hausman *h*-test has been tested and reported in Table 5. The result of the test accepts the null hypothesis of homogeneity restriction on the long-run coefficients, as the respective Hausman *h*-test *p*-values of 0.610 and 0.501 for MG and DFE are both insignificant. This suggests that PMG is a more efficient estimator than MG/DFE.

Having detected PMG as the most efficient estimator among the three estimators, the analysis of this study would center on its result. The result of the PMG estimator as earlier stated shows that wood fuel consumption has a negative and significant impact on economic growth in the long-run. In the short-run, the coefficient of wood fuel consumption is negatively signed but insignificant. Specifically, it suggests that an increase in wood fuel consumption lowers economic growth in the long-run and that economic growth is insensitive to the rise in wood fuel consumption in the short-run.

To further estimate the impact of wood fuel consumption on economic growth through its impact on labor, the study explored the interaction between labor and wood fuel consumption and re-estimated the PMG model. The results are presented in the first part of Table 6. The results indicate that wood fuel consumption still yielded a negative and significant coefficient with respect to economic growth after the inclusion of the interaction term. The coefficient of the interaction between labor and wood fuel consumption was negative and significant in the long run, which reveals that an increase in wood fuel consumption results in a decrease in economic growth by lowering the productivity of labor. This finding is in conformity to the earlier expectation that wood fuel consumption could lower both productivity and income of labor, which in turn would harm economic growth. However, in the short run, the interaction term yielded a negative but insignificant coefficient.

Table 5. Results for pooled mean group, mean group, and dynamic fixed effect estimation.

Variable	Pooled Mean group		Mean Group		Dynamic Fixed Effects	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Long-run coefficients						
Labour	1.214 ***	0.360	1.187 ***	0.408	0.668 **	0.298
Capital	0.005	0.862	−0.022	0.053	0.520 **	0.210
Energy	2.387 ***	0.471	1.124 **	0.470	0.396	0.463
Wood fuel	−1.558 ***	0.797	−1.828 **	0.732	−0.121	0.403
Trade Openness	0.012	0.863	0.083	0.078	0.665 **	0.278
Error-correction coeff.	−0.299 ***	0.110	−0.326 ***	0.056	−0.366 ***	0.094
Short-run coefficients						
Δ Labour	1.171 ***	0.302	0.938 ***	0.342	0.265	0.183
Δ Capital	0.033 ***	0.012	0.019	0.014	−0.001	0.008
Δ Energy	0.119 **	0.052	−0.006	0.043	0.178 ***	0.042
Δ Wood fuel	−2.016	0.384	−1.488 ***	0.379	−0.172 ***	0.045
Δ Trade Openness	0.035 *	0.019	0.010	0.012	0.033 ***	0.012
Intercept	−0.948 ***	0.360	3.902	1.924	−0.292	0.184
Country	19		19		19	
Observation	722		646		646	
Hausman test			0.382 [c]		0.408 [d]	
p-value			0.610		0.501	

Notes: * (**) *** indicate significant at 10%, 5%, and 1%, respectively. Δ is first difference operator. The estimation of pooled mean group, mean, and dynamic fixed effects are carried out using xtpmg command in stata, while controlling for time and country specific effects. While the first panel of the table presents the long-run estimation and speed of adjustment, the second panel reports the short-run estimated coefficients and Hausman test results. The Hausman test result reveal that PMG is consistent and efficient estimator than MG and DFE. The exponent c and d in the Hausman test results indicate that PMG is more efficient estimator than MG and DFE under the null hypothesis, respectively.

Table 6. Comparison of the results obtained from pooled mean group with results obtained from panel dynamic ordinary least square (OLS) after inclusion of an interaction term.

Variable	Pooled Mean Group		Panel Dynamic OLS	
	Coefficient	Std. Error	Coefficient	Std. Error
Long-run coefficients				
Labour	5.729 ***	0.486	5.001 ***	0.477
Capital	0.052	0.033	0.052 ***	0.012
Energy	0.103 *	0.060	0.542 ***	0.054
Wood fuel	−0.468 ***	0.039	−0.705 ***	0.461
Trade Openness	0.173 ***	0.037	0.057 ***	0.019
Labour*Wood fuel	−0.572 ***	0.048	−0.956 ***	0.434
Error-correction coefficient	−0.341 ***	0.038		
Short-run coefficients				
Δ Labour	0.261	1.715		
Δ Capital	0.030 **	0.012		
Δ Energy	0.201 ***	0.065		
Δ Wood fuel	−0.215	1.403		
Δ Trade Openness	0.038 **	0.017		
Δ(Labour*Wood fuel)	−0.261	1.715		
Intercept	−5.263	4.632		
Country	19			
Observation	722			

Notes: * (**) *** indicate significant at 10%, 5% and 1% respectively. Δ is first difference operator. While the first panel of the table presents the long-run estimation and speed of adjustment, the second panel reports the short-run estimated coefficients.

The long-run finding suggests that wood fuel consumption in sub-Saharan Africa generates a negative effect on the marginal growth rate of the region's economy directly and through its effect on labor. This finding substantiates the result obtained by Maji et al. [5] in the case of West Africa, where renewable energy was found to have a negative effect on economic growth. The authors argued that the main renewable energy consumed in West Africa is wood biomass, which is usually unclean and highly polluting when burnt. As such, they can cause different diseases that are life threatening and subsequently results in lowering economic growth; because when individuals are sick, they tend to be absent from work and that lowers both their productivity and income, and economic growth of the region heavily relies on labor productivity. This is because sub-Saharan African economies (with the exception of South Africa) are majorly labor intensive based. Also, respiratory and pulmonary infections associated with wood fuel smoke add to the disease burden in the region, which requires higher budgetary expenditure on the part of governments and individuals to tackle. This reduces government expenditure on other productive activities that can facilitate economic growth of the region. It equally reduces disposable income of individuals in the region as a significant part of it goes for treatment of wood smoke-related infections at the private level, which could have been invested in productive ventures.

Similarly, in the sub-Saharan African region, men, women, and children depending on their location are saddled with the responsibility of gathering of wood fuel. They tend to travel longer distance to fetch wood for cooking and heating. This sole act keeps them away from productive activities, which will have had a greater positive impact on the economy. It also keeps children away from school, which invariably affects the development of human capital. Altogether, these effects slow down economic growth of the region.

Some of the control variables included in the model (PMG) such as labor and energy yielded positive and significant coefficients in both the long and short run. The other control variables such as capital and trade openness were positive but insignificant in the long run. On the other hand, they were positive and significant in the short run. The error correction term, which measures the speed of adjustment, was −0.299 (29.9%). This means that the long-run convergence among the variables would be sped at 29.9%. It further affirms the long-run relationship among the variables as established earlier.

The coefficients of all the control variables (i.e., labor, energy, trade openness) included in the model with the exception of capital, were rightly signed and significant in the long run in accordance with the theory. While in the short-run, capital, energy, and trade openness were positive and significant. Only labor was positive but insignificant in influencing growth in the short run. The speed of adjustment of variables' convergence to long-run equilibrium was −0.341 (34.1%), which was faster than in the previous model.

To clear the doubt of perceived endogeneity problem associated with the long-run estimates of PMG model, this study estimated the same model using panel DOLS with one leading and one lagging as a robustness check. Panel DOLS is famous for its ability and power to deal with endogeneity and serial correlation problems. As such, the results of panel DOLS would not only serve as robustness check, but also a diagnostic check for long-run PMG model against endogeneity bias and serial correlation. The results of the panel DOLS are presented in the second part of Table 6. The results indicate that all the variables included in the model were rightly signed and significant as expected. Most importantly, the coefficients of wood fuel consumption and the interaction between labor and wood fuel consumption were negative and significant. This finding substantiates and validates the result obtained from PMG's long-run estimates.

4. Conclusions and Policy Recommendation

This study investigated the impact of wood fuel consumption on economic growth in 19 sub-Saharan African countries over the 1979–2017 period. Panel ARDL method comprised of PMG, MG, and DFE estimators were employed to achieve the objective of the study. The results of the Hausman h-test suggested that the PMG estimator is the most efficient estimator over MG and DFE estimators. Focusing on the results from PMG, it indicated that wood fuel consumption has a significant negative impact on economic growth. When labor interacted with wood fuel consumption, the coefficient of the interaction term appeared negative and significant. This reveals that wood fuel consumption affects economic growth negatively, both directly and indirectly. To ensure robustness and reliability of the PMG estimates, panel DOLS was used to estimate the same model. The results obtained for the interest variables were similar to the PMG's, and as such, substantiates and validates the estimates of PMG model.

Based on the findings, this study makes the following policy recommendations. First, since the majority of the populace in the region use wood fuel for cooking and heating, governments should provide adequate and affordable modern fuels to decrease the use of wood fuel. This is because modern fuels are currently not adequately available to many people in the region, especially in the rural areas where majority of the population reside. Also, even where the modern fuels are available, they not affordable by many. Therefore, providing adequate and subsidized modern fuels can help to significantly reduce the use of wood fuel. Second, policy makers should intensify awareness campaigns on the risk and danger that wood fuel use poses to economic growth of the region. This would equally assist in discouraging its consumption as many people in the region are ignorant of its potential negative effects. Last, policy makers should consider providing adequate solar-powered stoves and solar-powered room heaters as cheap substitutes for the use of wood fuel for cooking and heating activities since the region is endowed with abundant solar energy.

Supplementary Materials: The data for this study are available online at http://www.mdpi.com/2071-1050/12/8/3280/s1.

Author Contributions: C.S. collected the data, developed the methodology, analysed the data, and discussed the results; A.S.A.-R. reviewed the literature, conducted validation tests, reviewed the whole manuscript and edited it. All authors have read and agreed to the published version of the manuscript.

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