ECONOMIC GROWTH AND A QUALITATIVE SHIFT IN THE COMPOSITION OF ENERGY USE: WHICH OF THE ENERGY LADDER OR ENERGY STACKING MODELS IS THE MOST SUITABLE IN THE LONG RUN?

*Prisca Koncy Fosso**

1. Introduction

Different countries rely on a diverse mix of energy sources, including coal, oil, gas, hydroelectricity, nuclear power, biofuels, solar, wind, and geothermal energy. With continued global population growth, overall energy demand is rising irrespective of fuel type. Currently, fossil fuels—oil, gas, and coal—account for approximately 66 percent of total global energy use, and electricity consumption is projected to increase by 50 percent between 2021 and 2040 (IEA, *World Energy Outlook*, 2022). Against this backdrop, our analysis focuses on the four dominant energy sources worldwide—coal, oil, gas, and electricity—and their relationship to economic development.

Economic development is a universal aspiration, typically characterized by economic growth accompanied by structural transformation. Such growth depends

*Prisca Koncy Fosso is an Assistant Professor (Senior Lecturer) at the Faculty of Economics and Applied Management, University of Douala in Cameroon. She is also an Affiliate Researcher at the Laboratory of Theoretical and Applied Economics at the University of Douala. Previously, Dr. Fosso was a lecturer at the same university. She holds a Bachelor's, Master's, and Ph.D. in Economic Sciences from the University of Yaoundé II. Her main research interests include development economics, agricultural economics, and environmental economics.

The Journal of Energy and Development, Vol. 50, Nos. 1-2

on several key inputs, including capital, labor, and energy (Stern 2004, 2011; Ucan et al., 2014). Yet, the environmental consequences of energy use vary significantly depending on fuel choice. As Doğanalp et al. (2021) argue, energy lies at the center of macroeconomic growth, poverty reduction, and inequality, while simultaneously shaping global challenges such as climate change, food security, health, and education. For this reason, sustainable development requires shifting toward cleaner energy sources that can support growth without undermining environmental quality. Since environmentally harmful growth cannot be considered sustainable (Ogwumike and Ozughalu, 2015), the debate over energy transitions is framed largely around two competing hypotheses: the energy ladder model and the energy stacking model (Masera et al., 2000; Campbell et al., 2003; Heltberg, 2004; Hiemstra-van der Horst and Hovorka, 2008; Van der Kroon et al., 2013).

The energy ladder hypothesis posits that low-income households or those in transition rely primarily on "dirty" fuels such as biomass, charcoal, and kerosene, while higher-income households adopt more expensive but cleaner fuels such as electricity and gas (Schlag and Zuzarte, 2008; Gisore, 2017; Waweru et al., 2022). In this model, rising incomes drive substitution away from traditional fuels toward cleaner, modern energy sources (Heltberg, 2005).

However, numerous micro-level studies have found that the income–fuel choice relationship is weaker and more complex than the ladder model suggests (Campbell et al., 2003; Brouwer and Falcao, 2004; Gupta and Köhlin, 2006; Arnold et al., 2006; Farsi et al., 2007; Hiemstra-van der Horst and Hovorka, 2008; Mirza and Kemp, 2009; Van der Kroon et al., 2013). As an alternative, the energy stacking hypothesis argues that households often consume a mix of traditional and modern fuels regardless of income. This pattern, observed widely in Sub-Saharan Africa, reflects considerations such as affordability, availability, reliability of supply, and cultural preferences (Masera et al., 2000; Karekezi and Majoro, 2002; Elias and Victor, 2005; Maconachie et al., 2009; Waweru et al., 2022). Stacking behavior may also arise due to irregular income flows, fluctuating fuel prices, or the inconsistent supply of modern fuels (Davis, 1998; Hosier and Kipondya, 1993; Murphy, 2001; Van der Kroon et al., 2013).

Because individual household behavior aggregates into national and global energy patterns, it is essential to investigate which model—ladder or stacking—better characterizes long-run energy use at the macroeconomic level across developed and developing economies. This study aims to address that question and identify which framework provides more robust guidance for policies that can foster transitions to cleaner and more efficient energy systems.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 outlines the data and methodology. Section 4 presents the empirical results, and Section 5 concludes with policy implications.

2. Literature Review

Kraft and Kraft's (1978) seminal study first established the existence of a causal relationship between energy consumption and economic growth, noting that the direction of causality can run both from energy to growth and from growth to energy. Since then, a vast body of empirical research has examined this nexus, yet the results remain mixed. Such divergence is not surprising, as countries differ in their energy resource endowments, political and institutional arrangements, cultural contexts, and energy policies (Chen et al., 2007). Consequently, studies applied across diverse economic environments naturally yield heterogeneous findings.

Much of the existing literature focuses on *aggregate* energy use, assessing the relationship between total energy consumption and growth (see Wolde-Rufael, 2009; Ucan et al., 2014; Castro-Cárdenas and Ibarra-Yunez, 2023 for reviews). In contrast, fewer studies have undertaken *disaggregated* analyses, distinguishing between renewable and non-renewable energy sources. For instance, Apergis and Payne (2011, 2012), Tugcu et al. (2012), Al-Mulali et al. (2013), Pao et al. (2014), Shafiei and Salim (2014), Salim et al. (2014), Bloch et al. (2015), Fotourehchi (2017), and Kahia et al. (2017) find evidence of a bidirectional long-run causal relationship between renewable and non-renewable energy consumption and economic growth. By contrast, Wolde-Rufael (2004), Hamit-Haggar (2016), and Sasana and Ghozali (2017) report a one-way causal link running from clean (or non-clean) energy consumption to economic growth, while Sadorsky (2009) and Narayan and Smyth (2005) identify causality in the opposite direction—from economic growth to renewable energy consumption. Other studies, such as Menegaki (2011), Ben Jebli and Ben Youssef (2015), Bélaïd and Youssef (2017), and Burakov and Freidin (2017), conclude that no significant relationship exists between renewable energy use and growth.

Despite these contributions, very few studies have explicitly examined the causal impact of *specific types* of energy—such as coal, oil, gas, and electricity—on economic growth, or sought to assess whether these effects are positive, negative, or neutral. Yet this distinction is crucial for policy design. Identifying the links between clean and dirty energy consumption and economic growth in both developed and developing contexts is vital for formulating policies that promote sustainable economic growth while advancing global development objectives.

3. Data and Models

Research on the relationship between energy consumption and economic growth generally follows two main approaches. The first is a multivariate production-side approach, which incorporates energy consumption, GDP, capital, and labor as variables (Stern, 1993; Oh and Lee, 2004). The second is a demand-side approach, which models energy consumption in relation to GDP and energy prices (Asafu-Adjaye, 2000; Rafiq and Salim, 2009). Demand-side studies typically emphasize the effect of economic growth on energy consumption (Bloch et al., 2015).

In the present study, however, the absence of reliable energy price data necessitates a modification to the demand-side framework. Specifically, in the energy demand equation x, rather than including the price of an alternative energy source Y, we substitute the actual consumption of energy Y. This adjustment allows us to capture substitution and complementarity effects across energy types within the following framework in equations (1) through (4):

$$C_t = Y_t^{\theta} O_t^{\beta} G_t^{\alpha} E_t^{\gamma} \tag{1}$$

$$O_t = Y_t^{\theta} C_t^{\delta} G_t^{\alpha} E_t^{\gamma} \tag{2}$$

$$G_t = Y_t^{\theta} O_t^{\beta} C_t^{\delta} E_t^{\gamma} \tag{3}$$

$$E_t = Y_t^{\theta} O_t^{\beta} G_t^{\alpha} C_t^{\delta} \tag{4}$$

where C_t is coal consumption, O_t is oil consumption, G_t is gas consumption, E_t is electricity consumption, and Y_t is gross domestic product (constant 2015 US$) (GDP is used as a proxy of economic growth), and Θ, δ, β, α and γ are estimated parameters that measure the elasticity of aggregate output, coal consumption, oil consumption, gas consumption and electricity consumption, respectively. The logarithmic form of the above functions provides a log-linear form and yields equations (5) through (8):

$$lnC_t = \theta lnY_t + \beta lnO_t + \alpha lnG_t + \gamma lnE_t + \varepsilon_t \tag{5}$$

$$lnO_t = \theta lnY_t + \delta lnC_t + \alpha lnG_t + \gamma lnE_t + \varepsilon_t \tag{6}$$

$$lnG_t = \theta lnY_t + \beta lnO_t + \delta lnC_t + \gamma lnE_t + \varepsilon_t \tag{7}$$

$$lnE_t = \theta lnY_t + \beta lnO_t + \alpha lnG_t + \delta lnC_t + \varepsilon_t \tag{8}$$

We draw on data from the *World Development Indicators* (2022) and the *World Energy and Climate Statistics Yearbook* (2022). Real output is measured by GDP at constant 2015 US dollars, sourced from the *World Development Indicators*. Data on coal, oil, gas, and electricity consumption are taken from the *World Energy and Climate Statistics Yearbook*. Annual observations were compiled for a panel of 11 countries (see Table 1 for summary statistics). The sample includes the G7 economies—United States, Canada, Japan, Germany, France, United Kingdom, and Italy—and four African countries—Algeria, Egypt, Nigeria, and South Africa—chosen to allow for comparative analysis between developed and developing contexts. This selection is motivated by the fact that the G7 accounts for roughly 40 percent of global GDP and possesses abundant energy resources, whereas African economies, though endowed with substantial untapped energy potential, remain energy-poor and face structural constraints such as weak institutions, inadequate financing mechanisms, and insufficient regulatory frameworks to support sustainable energy development (Ogwumike and Ozughalu, 2015; UNDP, 2004; Wolde-Rufael, 2005).

The empirical estimation seeks to identify the long-run relationship between energy consumption and economic growth. To this end, we employ the autoregressive distributed lag (ARDL) model, following Pesaran, Shin, and Smith (2001). Prior to estimation, unit root tests are applied to confirm that the variables are non-stationary in levels but stationary in first differences (see Table 2). We then implement ARDL bounds testing to examine cointegration among the variables and to estimate long-run coefficients. The ARDL framework offers several advantages over alternative approaches (Engle and Granger, 1987; Pesaran and Shin, 1999; Haug, 2002; Saboori and Sulaiman, 2013; Bloch et al., 2015). It can be applied irrespective of whether variables are integrated of order zero or one, is suitable for small sample sizes, and can be specified flexibly to address issues of residual serial correlation and endogeneity.

4. Results and Discussion

Table 1 indicates that the United States records the highest mean values across all variables used in the estimations: real GDP (1.51×10^{13} US$), coal consumption (848.13 million tons), oil consumption (782.96 million tons), gas consumption (678.15 billion cubic meters), and electricity consumption (3,593.84 terawatt-hours).

The results of unit root tests (see Table 2) reveal that apart from the electricity consumption in France and in the USA, which are stationary at level, all the other variables in all the 11 selected countries are stationary in first differences (or integrated at order one).

The next step after unit root test results is to undertake an empirical investigation to explore the long-run impact of economic growth on all types of energy consumption (see equations 5 to 8) and deduce which of the energy ladder or energy stacking hypotheses is validated in each country (Table 3).

The results in Table 3 show that apart from Canada[1], in all other G7 countries energy ladder hypothesis is validated. In the selected African countries energy

[1] In Canada, despite oil being a dirty energy source, a percent increase in economic growth increases the consumption of oil energy. This can be explained by the fact that Canada has the third-largest proven oil reserves in the world after Venezuela and Saudi Arabia (Energy Institute Statistical Review of World Energy, 2023).

Table 1
SUMMARY STATISTICS ON THE SELECTED VARIABLES: MEAN AND (STD. DEV)

	G7 Countries (N=32)						
	Canada	**France**	**Germany**	**Italy**	**Japan**	**United Kingdom**	**USA**
Y: Gross domestic product (constant 2015 US$)							
	1.39e + 12 (2.00e + 11)	2.16e + 12 (3.03e + 11)	2.99e + 12 (3.68e + 11)	1.81e + 12 (1.25e + 11)	4.12e + 12 (3.04e + 11)	2.49e + 12 (4.29e + 11)	1.51e + 13 (3.23e + 12)
C: Coal consumption in million tons							
	49.79871 (11.77459)	20.0791 (6.000195)	252.5351 (55.40055)	19.25087 (4.637824)	163.4042 (26.08074)	56.63349 (26.69488)	848.1335 (160.0443)
O: Oil consumption in million							
	93.74962 (11.45529)	79.02975 (8.170487)	110.6361 (14.12621)	73.28685 (16.32694)	203.374 (30.31562)	64.45725 (7.602647)	782.9687 (65.96681)
G: Gas consumption in billion cubic meters							
	98.21013 (19.01861)	40.51341 (5.144418)	87.16211 (7.095765)	69.13091 (11.76166)	93.27268 (19.48069)	84.62196 (13.26293)	678.157 (96.41121)
E: Electricity consumption in terawatt hour							
	517.3176 (37.23486)	413.6798 (35.91466)	511.848 (26.84209)	282.3513 (31.19726)	953.0921 (77.23241)	320.7607 (22.17118)	3593.847 (383.3493)

	African Countries (N=32)			
	Algeria	**Egypt**	**Nigeria**	**South Africa**
Y: Gross domestic product (constant 2015 US$)				
	1.24e + 11 (3.54e + 10)	2.41e + 11 (9.57e + 10)	3.09e + 11 (1.40e + 11)	2.71e + 11 (6.54e + 10)
C: Coal consumption in million tons				
	0.7385741 (0.353339)	1.521346 (0.9682927)	0.0331601 (0.0210684)	170.2247 (22.26594)
O: Oil consumption in million				
	12.13533 (4.280467)	28.23468 (6.942369)	12.62585 (4.326604)	20.55212 (4.45488)
G: Gas consumption in billion cubic meters				
	27.26528 (10.6137)	34.23947 (19.11525)	11.20916 (5.220922)	3.372183 (1.441338)
E: Electricity consumption in terawatt hour				
	35.06985 (19.60518)	94.6378 (42.65135)	17.04297 (7.644397)	191.2646 (24.53039)

Note: Summary statistics were calculated with non-log data.
Source: The author's calculations are based on *World Development Indicators* (2022) and *World Energy and Climate Statistics Yearbook* (2022) data.

Table 2
UNIT ROOT TEST: ADF TEST

	G7 Countries						
	Canada I(n)	**France I(n)**	**Germany I(n)**	**Italy I(n)**	**Japan I(n)**	**United Kingdom I(n)**	**USA I(n)**
Y: Gross domestic product							
	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
C: Coal consumption							
	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
O: Oil consumption in million							
	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
G: Gas consumption							
	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
E: Electricity consumption							
	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(0)

	African Countries			
	Algeria I(n)	**Egypt I(n)**	**Nigeria I(n)**	**South Africa I(n)**
Y: Gross domestic product				
	I(1)	I(1)	I(1)	I(1)
C: Coal consumption				
	I(1)	I(1)	I(1)	I(1)
O: Oil consumption				
	I(1)	I(1)	I(1)	I(1)
G: Gas consumption				
	I(1)	I(1)	I(1)	I(1)
E: Electricity consumption				
	I(1)	I(1)	I(1)	I(1)

Note: I(n) means integrated at order n.

Source: The author's calculations are based on *World Development Indicators* (2022) and *World Energy and Climate Statistics Yearbook* (2022) data.

stacking hypothesis is validated. This confirms the conclusions of authors such as Heltberg (2005), Ouedraogo (2006), Van der Kroon et al. (2013), Hanna and Oliva (2015), and Adamu et al. (2020) who have found that in developing countries, the energy ladder remains a myth, not observed empirically. In fact, according to Van der Kroon et al. (2013) this energy stacking behavior "can be seen as a livelihood

Table 3
LONG-RUN IMPACT OF ECONOMIC GROWTH ON ALL TYPE OF ENERGY CONSUMPTION USING ARDL MODEL[a] IN ESTIMATING OF EQUATIONS 5 TO 8

Countries	Effect (estimated coefficient) of economic growth on energy consumption type i (i can be C, O, G or E) (5)	(6)	(7)	(8)	Validated Hypothesis:		
G7 Countries	C	O	G	E	Energy ladder	Energy stacking	None
United States	−3.171278***		−1.870917**	0.4268146***	✓		
United Kingdom	−7.228117***		−0.8556825***	0.2918583***	✓		
Japan	−2.292862***	−1.417768***	−4.49524**	1.028668**	✓		
Italy	−24.62317***		−2.275527**	0.8373502***	✓		
Germany	−0.874275***	−0.5811469***	0.5917736	4.926957	✓		
France	−2.903843***		0.7018887**	−0.6463768	✓		
Canada		0.8133332***	0.4941135***	−0.0266818		✓	
African countries							
Algeria		6.335351***	0.8395726***	0.9389875		✓	
Egypt	3.503198*	−0.253962	−3.982084***	0.9655978***		✓	
Nigeria	3.435792***	−27.30578	0.4937334***	−0.7210459		✓	
South Africa	1.169188***	0.7708931***	0.65702	1.088449**		✓	

Note: *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively. [a]see diagnostic tests in Appendix Table A. An empty cell means there is no long-run relationship.

Source: The author's calculations are based on *World Development Indicators* (2022) and *World Energy and Climate Statistics Yearbook* (2022) data.

strategy through which households cope with irregular income flows, protect themselves from unstable markets and hold on to their cultural practices."

In Japan, a 1 percent increase in economic growth reduces the consumption of coal, oil, and gas by 2.29 percent, 1.42 percent, and 4.49 percent, respectively, while increasing electricity consumption by 1.03 percent. Similar patterns are observed in the United States, the United Kingdom, and Italy, where economic growth reduces coal use (by 3.17, 7.23, and 24.62 percent, respectively) and gas consumption (by 1.87, 0.85, and 2.27 percent, respectively), but raises electricity use (by 0.43, 0.29, and 0.84 percent, respectively). In Germany, growth reduces coal and oil consumption by 0.87 and 0.58 percent, while in France, it lowers coal consumption by 2.90 percent but increases gas use by 0.70 percent.

By contrast, in Canada and Algeria, a 1 percent rise in GDP leads to higher oil consumption (0.81 and 6.33 percent, respectively) and gas consumption (0.49 and 0.84 percent, respectively). A similar dual pattern is observed in South Africa, where growth raises coal (1.17 percent), oil (0.77 percent), and electricity (1.09 percent) consumption, and in Nigeria, where it increases coal and gas consumption by 3.43 and 0.49 percent, respectively. In Egypt, economic growth reduces gas consumption by 3.98 percent but increases coal and electricity consumption by 3.50 and 0.96 percent, respectively.

5. Conclusion and Policy Implications

This study examines whether the energy ladder or energy stacking model provides a more suitable framework for understanding long-run energy use across developed and developing economies. Using data from the *World Development Indicators* (2022) and the *World Energy and Climate Statistics Yearbook* (2022), and applying an autoregressive distributed lag (ARDL) model, we analyze a sample of G7 countries as representatives of developed economies and selected African countries as representatives of developing economies. Our results show that, with the exception of Canada, the energy ladder hypothesis holds in developed countries, where rising income levels are associated with greater reliance on cleaner energy sources. By contrast, in the African countries examined—and in Canada—the empirical evidence supports the energy stacking model.

The policy implications of these findings are twofold. First, with the exception of Canada, G7 countries demonstrate the potential to achieve environmental sustainability alongside economic growth, consistent with the energy ladder framework. Second, for African economies and for Canada, where energy stacking prevails, economic growth alone is insufficient to ensure environmental sustainability. In these contexts, the adoption and enforcement of stronger environmental regulatory standards in energy use are essential. Such measures might include the introduction of environmental taxes on dirty fuels, with revenues earmarked for investment in research, the development of cleaner technologies, and the mitigation or sanitation of polluting energy sources. These steps would help align economic development with environmental sustainability in the long run.

REFERENCES

Adamu, M. B., H. Adamu, S. M. Ade, and G. I. Akeh. 2020. "Household Energy Consumption in Nigeria: A Review on the Applicability of the Energy Ladder Model." *Journal of Applied Science & Environmental Management* 24 (2): 237–44. https://doi.org/10.4314/jasem.v24i2.7.

Al-Mulali, U., H. G. Fereidouni, J. Y. Lee, and C. N. B. C. Sab. 2013. "Examining the Bidirectional Long Run Relationship between Renewable Energy Consumption and GDP Growth." *Renewable and Sustainable Energy Reviews* 22: 209–22.

Apergis, N., and J. E. Payne. 2011. "The Renewable Energy Consumption–Growth Nexus in Central America." *Applied Energy* 88: 343–47. https://doi.org/10.1016/j.apenergy.2010.07.013.

Apergis, N., and J. E. Payne. 2012. "Renewable and Non-Renewable Energy Consumption–Growth Nexus: Evidence from a Panel Error Correction Model." *Energy Economics* 34: 733–38. https://doi.org/10.1016/j.eneco.2011.04.007.

Arnold, J. E. M., G. Köhlin, and R. Persson. 2006. "Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives." *World Development* 34 (3): 596–611. https://doi.org/10.1016/j.worlddev.2005.08.008.

Asafu-Adjaye, J. 2000. "The Relationship between Energy Consumption, Energy Prices and Economic Growth: Time Series Evidence from Asian Developing Countries." *Energy Economics* 22 (6): 615–25. https://doi.org/10.1016/S0140-9883(00)00050-5.

Bélaïd, F., and M. Youssef. 2017. "Environmental Degradation, Renewable and Non-Renewable Electricity Consumption, and Economic Growth: Assessing the Evidence from Algeria." *Energy Policy* 102 (C): 277–87. DOI: https://doi.org/10.1016/j.enpol.2016.12.012.

Ben Jebli, M., and S. Ben Youssef. 2015. "Output, Renewable and Non-Renewable Energy Consumption and International Trade: Evidence from a Panel of 69 Countries." *Renewable Energy* 83 (C): 799–808. DOI: https://doi.org/10.1016/j.renene.2015.04.061.

Bloch, H., S. Rafiq, and R. Salim. 2015. "Economic Growth with Coal, Oil and Renewable Energy Consumption in China: Prospects for Fuel Substitution." *Economic Modelling* 44: 104–15. https://doi.org/10.1016/j.econmod.2014.09.017.

Brouwer, R., and M. P. Falcão. 2004. "Wood Fuel Consumption in Maputo, Mozambique." *Biomass and Bioenergy* 27: 233–45. https://doi.org/10.1016/j.biombioe.2004.01.005.

Burakov, D., and M. Freidin. 2017. "Financial Development, Economic Growth and Renewable Energy Consumption in Russia: A Vector Error Correction Approach." *International Journal of Energy Economics and Policy* 7 (6): 39–47.

Campbell, B. M., S. J. Vermeulen, J. J. Mangono, and R. Mabugu. 2003. "The Energy Transition in Action: Urban Domestic Fuel Choices in a Changing Zimbabwe." *Energy Policy* 31: 553–62. https://doi.org/10.1016/S0301-4215(02)00098-8.

Castro-Cárdenas, C., and A. Ibarra-Yúnez. 2023. "Understanding the Link between Energy Poverty and Economic Growth in Latin America." *Contaduría y Administración* 68 (2): 175–98. https://doi.org/10.22201/fca.24488410e.2023.4629.

Chen, S., H. Kuo, and C. Chen. 2007. "The Relationship between GDP and Electricity Consumption in 10 Asian Countries." *Energy Policy* 35 (4): 2611–21. https://doi.org/10.1016/j.enpol.2006.10.001.

Davis, M. 1998. "Rural Household Energy Consumption: The Effects of Access to Electricity: Evidence from South Africa." *Energy Policy* 26: 207–17. https://doi.org/10.1016/S0301-4215(97)00100-6.

Doğanalp, N., B. Ozsolak, and A. Aslan. 2021. “The Effects of Energy Poverty on Economic Growth: A Panel Data Analysis for BRICS Countries.” *Environmental Science and Pollution Research* 28: 50167–78. https://doi.org/10.1007/s11356-021-14185-x.

Elias, R. J., and D. G. Victor. 2005. *Energy Transitions in Developing Countries: A Review of Concepts and Literature.* Program on Energy and Sustainable Development, Stanford University.

Energy Institute. 2023. *Statistical Review of World Energy*. https://www.energyinst.org/statistical-review.

Engle, R. F., and C. W. J. Granger. 1987. “Co-Integration and Error Correction: Representation, Estimation, and Testing.” *Econometrica* 55: 251–76.

Farsi, M., M. Filippini, and S. Pachauri. 2007. “Fuel Choices in Urban Indian Households.” *Environment and Development Economics* 12: 757–74. https://doi.org/10.1017/S1355770X07003932.

Fotourehchi, Z. 2017. “Renewable Energy Consumption and Economic Growth: A Case Study for Developing Countries.” *International Journal of Energy Economics and Policy* 7 (2): 61–64.

Gisore, N. 2017. “Renewable Energy and Non-Renewable Energy Consumption, CO_2 Emissions and Economic Expansion Nexus: Further Evidence from Kenya.” *Energy Economics Letters* 4 (4): 36–48. https://doi.org/10.18488/journal.82.2017.44.36.48.

Gupta, G., and G. Köhlin. 2006. “Preferences for Domestic Fuel: Analysis with Socioeconomic Factors and Rankings in Kolkata, India.” *Ecological Economics* 57: 107–21.

Hamit-Haggar, M. 2016. “Clean Energy-Growth Nexus in Sub-Saharan Africa: Evidence from Cross-Sectionally Dependent Heterogeneous Panel with Structural Breaks.” *Renewable and Sustainable Energy Reviews* 57: 1237–44. https://doi.org/10.1016/j.rser.2015.12.161.

Hanna, R., and P. Oliva. 2015. “Moving up the Energy Ladder: The Effect of an Increase in Economic Well-Being on the Fuel Consumption Choices of the Poor in India.” *American Economic Review: Papers & Proceedings* 105 (5): 242–46. https://doi.org/10.1257/aer.p20151097.

Haug, A. A. 2002. “Temporal Aggregation and the Power of Cointegration Tests: A Monte Carlo Study.” *Oxford Bulletin of Economics and Statistics* 64: 399–412. https://doi.org/10.1111/1468-0084.00025.

Heltberg, R. 2004. “Fuel Switching: Evidence from Eight Developing Countries.” *Energy Economics* 26: 869–87. https://doi.org/10.1016/j.eneco.2004.04.018.

Heltberg, R. 2005. “Factors Determining Household Fuel Choice in Guatemala.” *Environment and Development Economics* 10: 337–61. https://doi.org/10.1017/S1355770X04001858.

Hiemstra-van der Horst, G., and A. J. Hovorka. 2008. “Reassessing the ‘Energy Ladder’: Household Energy Use in Maun, Botswana.” *Energy Policy* 36: 3333–44.

Hosier, R. H., and W. Kipondya. 1993. “Urban Household Energy Use in Tanzania: Prices, Substitutes and Poverty.” *Energy Policy* 21: 454–73.

International Energy Agency. 2022. *World Energy Outlook*. https://www.iea.org/weo.

Kahia, M., M. S. B. Aïssa, and C. Lanouar. 2017. “Renewable and Non-Renewable Energy Use–Economic Growth Nexus: The Case of MENA Net Oil Importing Countries.” *Renewable and Sustainable Energy Reviews* 71: 127–40. https://doi.org/10.1016/j.rser.2017.01.010.

Karekezi, S., and L. Majoro. 2002. “Improving Modern Energy Services for Africa’s Urban Poor.” *Energy Policy* 30: 1015–28. https://doi.org/10.1016/S0301-4215(02)00055-1.

Kraft, J., and A. Kraft. 1978. “On the Relationship between Energy and GNP.” *Journal of Energy and Development* 3 (2): 401–3.

Maconachie, R., A. Tanko, and M. Zakariya. 2009. “Descending the Energy Ladder? Oil Price Shocks and Domestic Fuel Choices in Kano, Nigeria.” *Land Use Policy* 26: 1090–99. https://doi.org/10.1016/j.landusepol.2009.01.008.

Masera, O. R., B. D. Saatkamp, and D. M. Kammen. 2000. “From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model.” *World Development* 28: 2083–103. https://doi.org/10.1016/S0305-750X(00)00076-0.

Menegaki, A. N. 2011. "Growth and Renewable Energy in Europe: A Random Effect Model with Evidence for Neutrality Hypothesis." *Energy Economics* 33 (2): 257–63.

Mirza, B., and R. Kemp. 2009. "Why Rural Rich Remain Energy Poor." UNU-MERIT Working Papers.

Murphy, J. T. 2001. "Making the Energy Transition in Rural East Africa: Is Leapfrogging an Alternative?" *Technological Forecasting and Social Change* 68: 173–93. https://doi.org/10.1016/S0040-1625(99)00091-8.

Narayan, P. K., and R. Smyth. 2005. "Electricity Consumption, Employment and Real Income in Australia: Evidence from Multivariate Granger Causality Tests." *Energy Policy* 33 (9): 1109–16.

Ogwumike, F. O., and U. M. Ozughalu. 2015. "Analysis of Energy Poverty and Its Implications for Sustainable Development in Nigeria." *Environment and Development Economics* 21: 273–90. https://doi.org/10.1017/S1355770X15000236.

Oh, W., and K. Lee. 2004. "Energy Consumption and Economic Growth in Korea: Testing the Causality Relation." *Journal of Policy Modeling* 26 (8–9): 973–81.

Ouedraogo, B. 2006. "Household Energy Preferences for Cooking in Urban Ouagadougou, Burkina Faso." *Energy Policy* 34: 3787–95.

Pao, H.-T., Y.-Y. Li, and H.-C. Fu. 2014. "Clean Energy, Non-Clean Energy, and Economic Growth in the MIST Countries." *Energy Policy* 67: 932–42. https://doi.org/10.1016/j.enpol.2013.12.039.

Pesaran, M. H., and Y. Shin. 1999. "An Autoregressive Distributed Lag Modeling Approach to Cointegration Analysis." In *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*, edited by S. Strøm, ch. 11. Cambridge: Cambridge University Press.

Pesaran, M. H., Y. Shin, and R. J. Smith. 2001. "Bounds Testing Approaches to the Analysis of Level Relationships." *Journal of Applied Econometrics* 16: 289–326.

Rafiq, S., and R. A. Salim. 2009. "Temporal Causality between Energy Consumption and Income in Six Asian Emerging Countries." *Applied Economics Quarterly* 55 (4): 1–16.

Saboori, B., and J. Sulaiman. 2013. "CO_2 Emissions, Energy Consumption and Economic Growth in Association of Southeast Asian Nations (ASEAN) Countries: A Cointegration Approach. " *Energy* 55: 813–22.

Sadorsky, P. 2009. "Renewable Energy Consumption and Income in Emerging Economies." *Energy Policy* 37: 4021–28. https://doi.org/10.1016/j.enpol.2009.05.003.

Salim, R. A., K. Hassan, and S. Shafiei. 2014. "Renewable and Non-Renewable Energy Consumption and Economic Activities: Further Evidence from OECD Countries." *Energy Economics* 44: 350–60. DOI: https://doi.org/10.1016/j.eneco.2014.05.001.

Sasana, H., and I. Ghozali. 2017. "The Impact of Fossil and Renewable Energy Consumption on the Economic Growth in Brazil, Russia, India, China and South Africa." *International Journal of Energy Economics and Policy* 7 (3): 194–200.

Schlag, N., and F. Zuzarte. 2008. "Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature." Stockholm Environment Institute.

Shafiei, S., and R. A. Salim. 2014. "Non-Renewable and Renewable Energy Consumption and CO_2 Emissions in OECD Countries: A Comparative Analysis." *Energy Policy* 66: 547–56. https://doi.org/10.1016/j.enpol.2013.10.064.

Stern, D. I. 1993. "Energy and Economic Growth in the USA: A Multivariate Approach." *Energy Economics* 15 (2): 137–50. https://doi.org/10.1016/0140-9883(93)90033-N.

Stern, D. I. 2004. "Economic Growth and Energy." In *Encyclopedia of Energy*, 2 (00147): 35–51.

Stern, D. I. 2011. "The Role of Energy in Economic Growth." In *Ecological Economics Reviews*, edited by Robert Costanza, Karin Limburg, and Ida Kubiszewski, 26–51. *Annals of the New York Academy of Sciences* 1219. https://doi.org/10.1111/j.1749-6632.2010.05921.x.

Tugcu, C. T., I. Ozturk, and A. Aslan. 2012. "Renewable and Non-Renewable Energy Consumption and Economic Growth Relationship Revisited: Evidence from G7 Countries." *Energy Economics* 34: 1942–50. DOI: https://doi.org/10.1016/j.eneco.2012.08.021.

Ucan, O., E. Aricioglu, and F. Yucel. 2014. "Energy Consumption and Economic Growth Nexus: Evidence from Developed Countries in Europe." *International Journal of Energy Economics and Policy* 4 (3): 411–19.

UNDP. 2004. *World Energy Assessment: Overview 2004 Update*. UNDP.

Van der Kroon, B., R. Brouwer, and P. J. H. van Beukering. 2013. "The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis." *Renewable and Sustainable Energy Reviews* 20: 504–13. DOI: https://doi.org/10.1016/j.rser.2012.11.045.

Waweru, D., N. Mose, and S. Otieno. 2022. "Household Energy Choice in Kenya: An Empirical Analysis of the Energy Ladder Hypothesis." *Journal of Energy Research and Reviews* 10 (4): 12–19. https://doi.org/10.9734/JENRR/2022/v10i430261.

Wolde-Rufael, Y. 2004. "Disaggregated Industrial Energy Consumption and GDP: The Case of Shanghai, 1952–1999." *Energy Economics* 26 (1): 69–75. https://doi.org/10.1016/S0140-9883(03)00032-X.

Wolde-Rufael, Y. 2005. "Energy Demand and Economic Growth: The African Experience." *Journal of Policy Modeling* 27: 891–903. https://doi.org/10.1016/j.jpolmod.2005.06.003.

World Bank. 2022. *World Development Indicators*. https://databank.worldbank.org/source/world-development-indicators.

World Energy and Climate Statistics. 2022. *Yearbook 2021*. Accessed October 2023.

APPENDIX

Appendix Table A

DIAGNOSTIC TESTS FOR ARDL MODELS IN TABLE 3

Test-statistics (p-Value, but critical value for the stability of model)

	Equation 5: Coal Consumption			
Countries	**Normality**	**Heteros**	**Correlation**	**Stability**
G7 countries				
Unites States	0.9868 (0.6105)	0.89 (0.3467)	0.671 (0.4126)	0.4127 (0.9479)
Unites Kingdom	0.0787 (0.9614)	2.45 (0.1177)	1.388 (0.2388)	0.6975 (0.9479)
Japan	0.0697 (0.9657)	1.17 (0.2803)	0.410 (0.5218)	0.5724 (0.9479)
Italy	0.896 (0.6540)	0.05 (0.8236)	0.140 (0.7081)	0.5966 (0.9479)
Germany	1.186 (0.5526)	0.46 (0.4954)	0.001 (0.9815)	0.4698 (0.9479)
France	0.648 (0.7804)	0.60 (0.4402)	0.000 (0.9846)	0.3534 (0.9479
Canada				
African countries				
Algeria				
Egypt	0.8534 (0.6527)	1.02 (0.3123)	2.345 (0.1257)	0.3759 (0.9479)
Nigeria	0.2732 (0.8723)	0.01 (0.9390)	0.291 (0.5897)	0.3593 (0.9479)
South Africa	0.695 (0.7064)	0.26 (0.6134)	2.004 (0.1569)	0.5590 (0.9479)

(continued)

Appendix Table A (continued)
DIAGNOSTIC TESTS FOR ARDL MODELS IN TABLE 3

	Equation 6: Oil Consumption			
Countries	**Normality**	**Heteros**	**Correlation**	**Stability**
G7 countries				
Unites States				
Unites Kingdom				
Japan	1.828 (0.4008)	0.03 (0.8645)	1.288 (0.2564)	0.2840 (0.9479)
Italy				
Germany	1.917 (0.3835)	1.26 (0.2608)	0.061 (0.8048)	0.4585 (0.9479)
France				
Canada	0.9353 (0.6265)	0.45 (0.5023)	0.454 (0.5004)	0.9015 (0.9479)
African countries				
Algeria	1.667 (0.4345)	0.15 (0.7002)	1.291 (0.2559)	0.2624 (0.9479)
Egypt	0.8104 (0.6669)	1.75 (0.1864)	1.080 (0.2987)	0.3011 (0.9479)
Nigeria	1.012 (0.603)	0.07 (0.7911)	0.018 (0.8921)	0.4021 (0.9479)
South Africa	0.1067 (0.948)	0.83 (0.3635)	1.481 (0.2236)	0.5039 (0.9479)

	Equation 7: Gas Consumption			
Countries	**Normality**	**Heteros**	**Correlation**	**Stability**
G7 countries				
Unites States	0.5559 (0.7573)	1.49 (0.2215)	0.388 (0.5336)	0.8244 (0.9479)
Unites Kingdom	2.083 (0.3529)	1.74 (0.1873)	1.062 (0.3027)	0.5279 (0.9479)
Japan	3.623 (0.1634)	0.13 (0.7201)	0.153 (0.6960)	0.3704 (0.9479)
Italy	1.812 (0.4265)	0.01 (0.9303)	0.175 (0.6755)	0.5218 (0.9479)
Germany	1.207 (0.5468)	0.86 (0.3532)	2.200 (0.1380)	0.4086 (0.9479)
France	1.93 (0.3809)	0.62 (0.4301)	0.049 (0.8252)	0.2565 (0.9479)
Canada	1.735 (0.4201)	0.22 (0.6380)	0.751 (0.3860)	0.2782 (0.9479)
African countries				
Algeria	1.595 (0.4505)	1.34 (0.2478)	2.59 (0.1078)	0.4661 (0.9479)
Egypt	2.557 (0.2785)	0.10 (0.7572)	2.028 (0.1545)	0.4605 (0.9479)
Nigeria	0.5564 (0.7571)	0.34 (0.5621)	0.085 (0.7712)	0.3730 (0.9479)
South Africa	1.754 (0.416)	0.06 (0.8015)	0.01 (0.9360)	0.3980 (0.9479)

(continued)

Appendix Table A (continued)
DIAGNOSTIC TESTS FOR ARDL MODELS IN TABLE 3

	Equation 8: Electricity Consumption			
Countries	**Normality**	**Heteros**	**Correlation**	**Stability**
G7 countries				
Unites States	0.425 (0.8086)	0.01 (0.9167)	1.162 (0.2811)	0.5417 (0.9479)
Unites Kingdom	1.49 (0.4747)	0.06 (0.8129)	0.928 (0.3354)	0.5064 (0.9479)
Japan	1.676 (0.4325)	2.35 (0.1252)	0.383 (0.4957)	0.4672 (0.9479)
Italy	1.017 (0.6014)	0.04 (0.8362)	2.045 (0.1573)	0.3417 (0.9479)
Germany	0.5479 (0.7604)	2.24 (0.1348)	0.552 (0.4576)	0.6766 (0.9479)
France	1.019 (0.6008)	0.38 (0.5394)	0.173 (0.6776)	0.2104 (0.9479)
Canada	2.125 (0.3456)	2.09 (0.1485)	0.715 (0.3978)	0.6812 (0.9479)
African countries				
Algeria	1.96 (0.3754)	0.32 (0.5698)	0.504 (0.4776)	0.4255 (0.9479)
Egypt	0.6442 (0.7246)	1.38 (0.2408)	0.000 (0.9939)	0.4480 (0.9479)
Nigeria	0.7408 (0.6905)	1.17 (0.2799)	0.302 (0.5829)	0.3869 (0.9479)
South Africa	2.141 (0.3429)	1.35 (0.2455)	0.023 (0.8803)	0.7650 (0.9479)

Note: An empty cell means there is no long-run relationship.