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Energy consumption and economic growth in Zambia: A disaggregated approach

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Abstract

In this paper, the dynamic causal relationship between energy consumption – total and disaggregated – and economic growth in Zambia during the period 1990 to 2013 is investigated within a multivariate framework in an effort to address the omitted-variable-bias. The study was motivated by inadequate empirical research on the energy and economic growth nexus in the country under study, which could guide policymakers in an informed manner on policies related to energy consumption and economic growth. The study is aimed at unravelling whether or not economic growth in Zambia is dependent on energy consumption, and if found to be dependent, it further attempts to establish the elements of energy demand that propel economic growth in Zambia. To this end, three models were specified in the study, namely one model that considers total energy consumption in the country under study, with the other two models each consisting of an element of disaggregated energy consumption – fossil energy in the second model and renewable energy in the third model. Using the ARDL-bounds testing method within the multivariate Granger-causality framework, the results of the study revealed that the causality between economic growth and energy consumption in Zambia is sensitive to the measure of energy consumption employed and the timeframe of analysis considered. However, in the main, bidirectional causality, both in the long and short run, was found to be predominant. This finding has important policy implications for Zambia as it shows that the buoyant economic growth Zambia has enjoyed over the years is not only just energy-dependent, but that it has been dependent on specific energy types, while energy consumption has also been feeding on economic growth, making these two macroeconomic variables mutually dependent.

1. Introduction

Although the debate on the direction of causality between energy consumption and economic growth has been ongoing for some time, renewed focus on economic growth, on the one hand, and sustainable cleaner sources of energy, on the other hand, has necessitated a revisit of the energy-growth nexus, bringing together development economists, environmental economists and policymakers worldwide.

Extensive empirical work has undeniably been done on the subject in a number of countries, whether as individual countries or as groups of countries. However, the outcome of these studies has been conflicting; hence, inconclusive at best. An analysis of the existing literature on the energy-growth nexus has given rise to four views. The first view is the energy-dependent growth hypothesis, which postulates that unidirectional causality from energy consumption to economic growth exists (see, among others, Rahman, 2017; Rahman *et al*., 2020; Saidi *et al*., 2017; Tang *et al*., 2016; Wolde-Rufael, 2004), while the second view supports the growth-led energy consumption hypothesis, which posits that economic growth Granger-causes energy consumption (see Odhiambo, 2010; Onuonga, 2012; Ocal and Aslan, 2013; Odhiambo, 2014; Rahmad and Velayutharn, 2020).

The third view supports bidirectional causality between energy consumption and economic growth (see, among others, Belke *et al*., 2011; Chiou-Wei *et al*., 2008; Eren *et al*., 2019; Fuinhas and Marques, 2012; Glasure, 2002; Kahouli, 2019; Lin and Benjamin, 2018; Mirza and Kanwal, 2017). Then, there is the fourth, though unpopular, view – the neutrality view – that argues that energy consumption and economic growth are mutually independent and that there is no causality between them (see, among others, Akinlo, 2008; Altinay and Karagol, 2004; Cetin, 2016; Jebli and Youssef, 2015; Ozcan and Ozturk, 2019). The inconclusivity of the available evidence, on the one hand, and the need for certainty when drafting relevant energy and economic growth policies, call for this study to be conducted.

It can also be observed that a number of studies on the energy-growth causality have largely been on Asian, European an American countries (see Belke *et al*., 2011; Chiou-Wei *et al*., 2008; Saidi *et al*., 2017; among others), with most of these studies having been based on groups of countries, even though it is now well known that country-specific effects are important and tend to be eliminated once group analysis has been carried out (Casselli *et al*., 1996; Ghirmay, 2004; Nyasha and Odhiambo, 2021). Even though studies on individual countries have been conducted on the subject, most of them are on countries such as South Africa, Kenya, Tanzania, among other African countries (see Odhiambo, 2010; Onuonga, 2012; Odhiambo, 2014) and do not provide coverage for Zambia, which leaves Zambia with not empirical evidence to guide energy and growth policies in an informed manner.

Moreover, most of the studies have used a bivariate framework to examine the causal relationship between energy consumption and economic growth, despite the undisputed knowledge of the possibility of having invalid results emanating from bivariate causality tests as these tests suffer from the omission of important variables affecting both energy consumption and economic growth in the causality model (Nyasha and Odhiambo, 2020; Odhiambo, 2009). Besides altering the direction of causality, the introduction of additional variables into the causality model may also affect the magnitude of the estimates (Loizides and Vamvoukas, 2005; Odhiambo, 2009).

Against this backdrop, in this study, an empirical examination is conducted into the causal relationship between energy consumption – total and disaggregated – and economic growth in Zambia, during the period 1990 to 2013 using the ARDL-bounds testing approach within a multivariate Granger-causality setting. The study aims to unravel whether or not economic growth in Zambia is dependent on energy consumption, and if dependent, it further attempts to establish the elements of energy demand that propels economic growth in Zambia.

The rest of this paper is organised as follows: In Section 2, an overview is given of the energy sector in Zambia. Section 3 is aimed at reviewing the literature on the causality between energy consumption and economic growth. In Section 4, the empirical model specifications and estimation techniques are presented, while the empirical analysis and interpretation of the regression results are discussed in Section 5. The study is concluded in Section 6.

2. The energy consumption and economic growth dynamics in Zambia

According to the Sustainable Energy for All (SEA) (2022), Zambia has abundant energy resources, which encompass hydropower, biomass and coal. It also has renewable wind and solar energy sources. In Zambia, access to electricity is about 31%, with the rural population having a coverage of approximately 4.4%-11% (SEA, 2022).

While wood fuel remains the dominant source of energy accounting for more than 70% of the total energy supplies in the country, petroleum is the only energy source that is wholly imported. Since the early 2010s, almost 40% of Zambia's commercial energy has been sourced from petroleum imports, with the balance coming from hydropower, wood and coal (SEA, 2022).

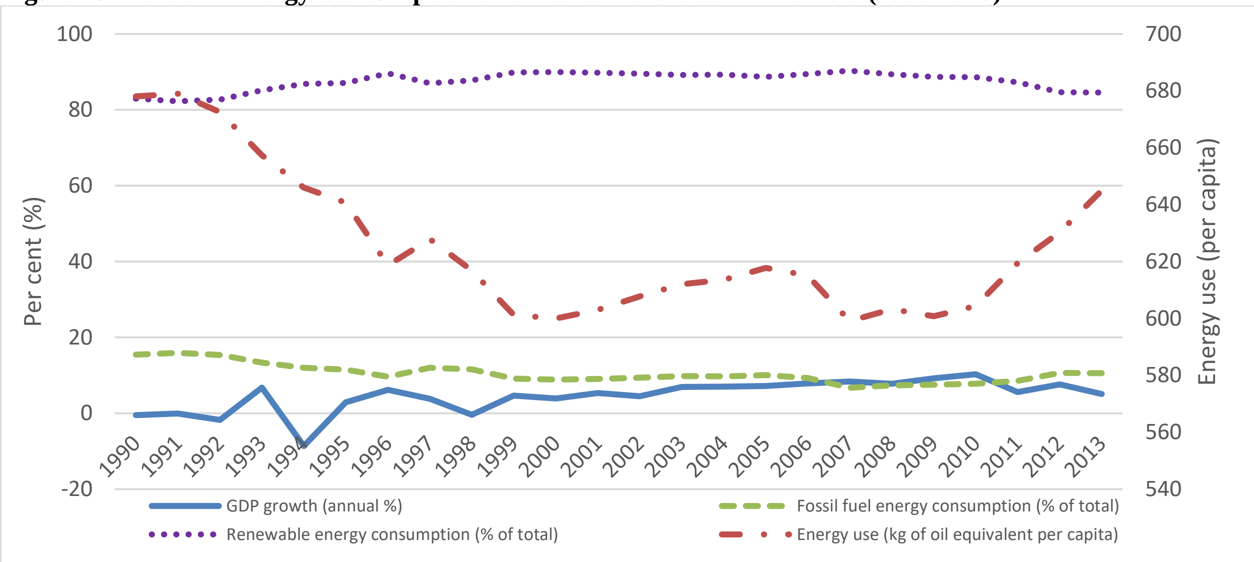
In recent years, the Government of Zambia has implemented several interventions, including the promulgation of policies to improve the energy situation in the country. The focus has increasingly been on the country's large indigenous resources to generate power, particularly, hydropower. The limelight has also been on the sustainable use of biomass and biofuels, and geothermal and coal. Similar to South Africa, the Zambian Government has also opened up its energy markets to several power generators in the form of Independent Power Producers (IPPs) who sell electricity to the national utility (SEA, 2022; International Trade Administration, 2022).

According to Sooka (2022), the consumption of coal in Zambia is mainly confined to the mining industry (54%), commerce and industry (37%), and the government and service sectors (9%). The contribution of coal to the total energy balance has been declining over the years due to operational constraints at some of the country's collieries (Sooka, 2022).

On the economic growth front, over the period, Zambia has enjoyed buoyant economic growth, averaging 5% over the period 1990-2013, with some years enjoying firm growth rates as high as over 7% (World Bank 2022a). However, the recent Covid-19 pandemic did not spare the country. The economy of Zambia fell into a deep recession due the adverse impact of the pandemic, which saw real GDP contracting by 4.9% in 2020, after having grown by 4.0% in 2018 and 1.9% in 2019 (African Development Bank Group, 2021). However, the Zambian economy recovered by 3.6% in 2021 following a historic contraction of 2.8% in 2020 (World Bank, 2022a). The recovery was driven by high copper prices, improved post-election market confidence, and continued recovery in agriculture (World Bank, 2022b).

Economic activity is expected to gradually pick up, averaging 3.8% over the period 2022-2025. Figure 1 summarises the economic and energy trends in Zambia over the review period.

Figure 1: Trends in Energy Consumption and Economic Growth in Zambia (1990-2013)



Source: Author computations; Data (World Bank, 2022a)

As shown in Figure 1, until 2010, economic growth has notably been increasing, while renewable energy consumption has been increasing, though marginally. On the other hand, fossil fuel and total energy consumption has been decreasing, only to recover after 2010 (World Bank 2022a).

3. Literature review

Although the causal relationship between energy consumption and economic growth has received growing attention over the years and has been examined expansively across a number of countries in the recent past, the outcome has largely been inconclusive, marred with conflicting results, broadly giving rise to four views.

The first view is the energy-dependent growth hypothesis. This hypothesis postulates that unidirectional causality from energy consumption to economic growth exists, and has found support in various studies such as those conducted by Akinlo (2009) in the case of Nigeria; Bekun *et al*. (2019) in the case of South Africa; Cai *et al*. (2018) in the cases of Canada, Germany and the US; Dergiades *et al*. (2013) in the case of Greece; Iyke (2015) in the case of Nigeria; Le and Quah (2018) in the cases of 14 selected countries in the Asia and the Pacific region; Lee (2005) in the case of developing countries; Odhiambo (2009) in the case of Tanzania; Odhiambo (2010) in the cases of South Africa and Kenya; Rahman (2017) in the cases of the Asian populous countries; Rahman *et al*. (2020) in the case of China; Saidi *et al*. (2017) in the cases of the European countries; Tang *et al*. (2016) in the case of Vietnam; and Wolde-Rufael (2004) in the case of Shanghai.

The second view supports the growth-led energy consumption hypothesis and posits that economic growth Granger-causes energy consumption. There is also significant empirical evidence in support of this hypothesis, including studies conducted by Abosedra and Baghestani (1989) in the case of the United States; Cheng (1999) in the case of India; Yang (2000) in the case of Taiwan; Gosh (2002) in the case of India; Shiu and Lam (2004) in the case of China; Narayan and Smyth (2005) in the case of Australia; Al-Iriani (2006) in the case of the Gulf Cooperation Council economies; Chen *et al*. (2007) in the cases of India, Malaysia, the Philippines and Singapore; Mehrara (2007) in the cases of 11 oil-exporting countries; Hu and Lin (2008) in the case of Taiwan; Odhiambo (2010) in the case of the Democratic Republic of Congo; Onuonga (2012) in the case of Kenya; Ocal and Aslan (2013) in the case of Turkey; Odhiambo (2014) in the cases of Ghana and Cote d'Ivoire; Rahmad and Velayutharn (2020) in the case of South Asia; and more recently, Rahman *et al*. (2020) in the case of China in which energy consumption is measured by gas consumption.

The third view is anchored on the mutual causal hypothesis; a hypothesis that supports bidirectional causality between energy consumption and economic growth. This view emphasises that energy consumption and economic growth are good for each other as they propel each other. Interestingly, this view has also found extensive support from empirical literature, based on the following studies: Apergis and Payne (2010) in 20 OECD countries; Belke *et al*. (2011) in 25 OECD countries; Chiou-Wei *et al*. (2008) in Malaysia and Indonesia; Eren *et al*. (2019) in India, and only in the long run, Fuinhas and Marques (2012) in Portugal, Italy, Greece, Spain and Turkey; Glasure (2002) in Korea; Kahouli (2019) in OECD countries; Lin and Benjamin (2018) in Mexico, Indonesia, Nigeria and Turkey countries; Mirza and

Kanwal (2017) in Pakistan; Saidi *et al*. (2017) in the cases of a global panel of 53 countries; Solarin and Shahbaz (2013) in Angola; Adams *et al*. (2016) in sub-Saharan African countries; Tugcu *et al*. (2012) in G7 countries; Wang *et al*. (2016) in China; Yidirim and Aslan (2012) in 17 OECD countries; and Zhang (2011) in Russia.

Then, there is the fourth and unpopular view, namely the neutrality view. It is this view that argues that energy consumption and economic growth are mutually independent and that there is no causality between them. The proponents of this view argue that there is no strong association between energy consumption and economic growth, and that any perceived relationship could be purely mechanical. Though unpopular, the neutrality view also has empirical evidence to lean on, through studies such as those conducted by Akinlo (2008) in Cameroon, Cote D'Ivoire, Nigeria, Kenya and Togo; Altinay and Karagol (2004) in Turkey; Cetin (2016) in seven countries; Chu (2012) in 24 out of 49 countries; Jebli and Youssef (2015) in 69 countries; Ozcan and Ozturk (2019) in 16 emerging economies; Ozturk and Acaravci (2011) in 11 Middle East and North Africa countries; and Tugcu and Tiwari (2016) in the BRICS countries.

Although each causality hypothesis has some studies in its support, the most common view, with the most studies in its support, is the bidirectional causality view, where the development of the energy sector and the real sector is mutually beneficial.

4. Estimation Technique

A multivariate Granger-causality model within an autoregressive distributed lag (ARDL)-bounds-testing framework by Pesaran and Shin (1999; 2001) is used in this study to examine the integration between various proxies of energy consumption, economic growth and the other two intermittent variables – inflation and trade openness – in an effort to address the gaps of bivariate Granger-causality. The choice of this approach was based on the well-documented advantages of the ARDL-bounds testing approach in the literature (see also Odhiambo, 2009; Nyasha and Odhiambo 2016). The approach does not impose the restrictive assumption that all model variables must be of the same order of integration. It is found suitable even when the sample size is small, which is a characteristic that was of essence given energy data constraints in this study. The ARDL approach was also found to automatically resolve endogeneity issues as it provides unbiased estimates of the long-run model and valid t-statistics, even when some of the regressors are endogenous (see also Harris and Sollis, 2003; Nyasha *et al.*, 2022; Odhiambo, 2022). Following Pesaran *et al* (2001), the ARDL model used in this study is specified as follows:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{n} \alpha_{2i} \Delta EC_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta IN_{t-i} + \sum_{i=0}^{n} \alpha_{4i} \Delta TR_{t-i} + \alpha_5 GDP_{t-1} + \alpha_6 EC_{t-1} + \alpha_7 IN_{t-1} + \alpha_8 TR_{t-1} + \mu_{1t} \quad \ldots\ldots\ldots\ldots (1)$$

$$\Delta EC_t = \beta_0 + \sum_{i=0}^{n} \beta_{1i} \Delta GDP_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta EC_{t-i} + \sum_{i=0}^{n} \beta_{3i} \Delta IN_{t-i} + \sum_{i=0}^{n} \beta_{4i} \Delta TR_{t-i} + \beta_5 GDP_{t-1} + \beta_6 EC_{t-1} + \beta_7 IN_{t-1} + \beta_8 TR_{t-1} + \mu_{2t} \quad \ldots\ldots\ldots\ldots (2)$$

$$\Delta IN_t = \gamma_0 + \sum_{i=0}^{n} \gamma_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{n} \gamma_{2i} \Delta EC_{t-i} + \sum_{i=1}^{n} \gamma_{3i} \Delta IN_{t-i} + \sum_{i=0}^{n} \gamma_{4i} \Delta TR_{t-i} + \gamma_5 GDP_{t-1} + \gamma_6 EC_{t-1} + \gamma_7 IN_{t-1} + \gamma_8 TR_{t-1} + \mu_{3t} \quad \ldots\ldots\ldots\ldots (3)$$

$$\Delta TR_t = \Omega_0 + \sum_{i=0}^{n} \Omega_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{n} \Omega_{2i} \Delta EC_{t-i} + \sum_{i=0}^{n} \Omega_{3i} \Delta IN_{t-i} + \sum_{i=1}^{n} \Omega_{4i} \Delta TR_{t-i} + \Omega_5 GDP_{t-1} + \Omega_6 EC_{t-1} + \Omega_7 IN_{t-1} + \Omega_8 TR_{t-1} + \mu_{4t} \quad \ldots\ldots\ldots\ldots (4)$$

Where:
GDP = Economic growth= real GDP growth rate
EC = Energy Consumption
Model 1: EC = EU = Energy use, total

Model 2: EC = FE = Fossil fuel energy consumption (% of total)
Model 3: EC = RE = Renewable energy consumption (% of total)
IN = Inflation, consumer prices (annual %)
TR = trade openness = sum of imports and exports as % of GDP

$a_{0,}$ β_0, γ_0 and Ω_0 = respective constants;
$a_1 - a_4$, $\beta_1 - \beta_4$, $\gamma_1 - \gamma_4$, and $\Omega_1 - \Omega_4$ = respective short-run coefficients;
$a_5 - a_8$, $\beta_5 - \beta_8$, $\gamma_5 - \gamma_8$, and $\Omega_5 - \Omega_8$ = respective long-run coefficients
Δ = difference operator;
n = lag length;
t = time period; and
μ_{it} = white-noise error terms.

A long-run relationship between the variables suggests that there must be Granger-causality in at least one direction. However, it does not indicate the direction of causality between these variables (Odhiambo, 2009; 2022). The generic ECM-based multivariate Granger-causality model specification is given as follows:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i}\Delta GDP_{t-i} + \sum_{i=1}^{n} \alpha_{2i}\Delta EC_{t-i} + \sum_{i=1}^{n} \alpha_{3i}\Delta IN_{t-i} + \sum_{i=1}^{n} \alpha_{4i}\Delta TR_{t-i} + \alpha_9 ECM_{t-1} + \mu_{1t} \quad \dots\dots\dots\dots (5)$$

$$\Delta EC_t = \beta_0 + \sum_{i=1}^{n} \beta_{1i}\Delta GDP_{t-i} + \sum_{i=1}^{n} \beta_{2i}\Delta EC_{t-i} + \sum_{i=1}^{n} \beta_{3i}\Delta IN_{t-i} + \sum_{i=1}^{n} \beta_{4i}\Delta TR_{t-i} + \beta_9 ECM_{t-1} + \mu_{2t} \quad \dots\dots\dots\dots (6)$$

$$\Delta IN_t = \gamma_0 + \sum_{i=1}^{n} \gamma_{1i}\Delta GDP_{t-i} + \sum_{i=1}^{n} \gamma_{2i}\Delta EC_{t-i} + \sum_{i=1}^{n} \gamma_{3i}\Delta IN_{t-i} + \sum_{i=1}^{n} \gamma_{4i}\Delta TR_{t-i} + \gamma_9 ECM_{t-1} + \mu_{3t} \quad \dots\dots\dots\dots (7)$$

$$\Delta TR_t = \Omega_0 + \sum_{i=1}^{n} \Omega_{1i}\Delta GDP_{t-i} + \sum_{i=1}^{n} \Omega_{2i}\Delta EC_{t-i} + \sum_{i=1}^{n} \Omega_{3i}\Delta IN_{t-i} + \sum_{i=1}^{n} \Omega_{4i}\Delta TR_{t-i} + \Omega_9 ECM_{t-1} + \mu_{4t} \quad \dots\dots\dots\dots (8)$$

Where:
ECM = Error-correction term;
$a_{9,}$ β_9, π_9 and Ω_9 = respective coefficients for the error-correction terms;
μ_{it} = mutually uncorrelated white-noise residuals; and all other variables and characters are as described in equations 1-4.

While the short-run causal impact is measured through the F-statistics on the explanatory variables, the long-run causal impact is determined by the error-correction term. Even though an error-correction term is incorporated in all the equations of the model (equations [5] to [8]), only equations where cointegration is confirmed are estimated with an error-correction term (Narayan and Smyth, 2004; Odhiambo, 2009).

Four causality outcomes are possible, namely (i) energy consumption causes economic growth; (ii) economic growth drives energy consumption; (iii) energy consumption and economic growth are mutually causal; and (iv) both variables are not causally related.

Data sources
Data used in this study were sourced from the World Bank (2022a) and the World Development Indicators Database. It covers the period 1990 to 2013. The study period was determined by the availability of total energy consumption and fossil energy that was available from 1990 until 2013.

5. Empirical Analysis

5.1 Stationarity Tests
The chosen methodology – the ARDL-bounds testing approach – does not require all variables to be integrated of the same order. However, the results are considered void should any one variable be integrated of order two or higher. This constraint necessitates that the variables be tested for stationarity before any analysis is carried out. In this study, two stationarity tests were carried out – the Dickey-Fuller generalised least square (DF-GLS) and the Phillips–Perron (PP)

tests – where the latter caters for structural breaks in data. Table 1 presents the results of the cointegration tests for all variables.

Table 1: Stationarity Tests of all Variables in Levels

Dickey-Fuller generalised least square (DF_GLS)					**Phillips–Perron (PP)**			
	Variables in levels		**Variables in 1st difference**		**Variables in levels**		**Variables in 1st difference**	
Variable	**Intercept**	**Intercept & Trend**	**Intercept**	**Intercept & Trend**	**Intercept**	**Intercept & Trend**	**Intercept**	**Intercept & Trend**
GDP	-3.240***	-6.158***	-	-	-3.393**	-6.089***	-	-
EU	-1.372	-0.621	-3.048***	-4.789***	-2.061	0.065	-2.960*	-4.749***
FE	-1.490	-1.620	-4.235***	-4.900***	-2.200	-0.962	-4.207***	-5.861***
RE	-1.365	-1.054	-4.177***	-4.528***	-1.768	-0.469	-4.187***	-8.904***
IN	-2.667**	-3.765**	-	-	-1.544	-2.194	-6.765***	-7.704***
TR	-1.362	-2.993*	-4.658***	-	-1.439	-1.898	-4.615***	-5.335***

Notes: *, ** and *** denote stationarity at the 10%, 5% and 1% significant levels, respectively; S = stationary; N = non-stationary.

As reported in Table 1, the variables were stationary in either levels or after first differencing, depending on the unit root test employed and whether an intercept or both intercepts and trends were included. In the main, the results of the stationarity tests carried out confirmed the applicability of the approach chosen for the data analysis – the ARDL-bound testing approach.

5.2 Cointegration Analysis

Before the direction of causality between the variables could be established, a bounds F-test for cointegration was performed to determine whether a stable long-run equilibrium relationship exists among the variables of interest, as determined by the specified model. The test was performed using the ARDL-bounds F-test for cointegration and the results are summarised in Table 2.

Table 2: Bounds F-test for Cointegration

Dependent Variable	**F-statistic**	**Cointegration Status**	**F-statistic**	**Cointegration Status**	**F-statistic**	**Cointegration Status**
	Model 1 (Total energy/EU)		**Model 2 (Fossil energy/FE)**		**Model 3 (Renewable energy/RE)**	
GDP	4.40**	Cointegrated	6.00***	Cointegrated	4.70**	Cointegrated
ENE	4.01*	Cointegrated	2.08	Not cointegrated	4.01*	Cointegrated
IN	13.43***	Cointegrated	4.87**	Cointegrated	5.83***	Cointegrated
TR	0.99	Not cointegrated	1.00	Not cointegrated	1.40	Not cointegrated
Asymptotic Critical Values						
Pesaran *et al.* (2001), p. 300 Table CI(iii) Case III	1%		5%		10%	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
	4.29	5.61	3.23	4.35	2.72	3.77

Notes: * and ** denote statistical significance at the 10% and 5% levels, respectively

The results reported in Table 2 show that where the calculated F-statistic is higher than the critical value, the cointegration relationship among the variables is sensitive to the choice of the dependent variable used, as well as the energy proxy used. In Models 1 and 3, where energy proxy was total energy (EU) and renewable energy (RE), respectively, cointegration was confirmed in all equations except the last one where trade openness (TR) is the independent variable. However, when energy consumption was proxied by fossil energy (FE), cointegration was only confirmed in two functions, namely the economic growth (GDP) and inflation (IN) functions. Overall, the results, therefore, reveal the presence of a long-run equilibrium relationship among the variables in all the three models, though with varying significance levels.

5.3 Causality test analysis

Following the confirmation of cointegration across all models, the study proceeded with testing for short-run and long-run causality between variables. A lagged error-correction term was included in the estimations of all the functions that had cointegration vectors. While long-run causality was confirmed through the significance of the coefficient of the lagged error-correction term, short-run causality was established by the significance of the F-statistics of the explanatory variables. The results of the causality test, within the Error-Correction Mechanism, are reported in Table 3.

Table 3: Results of the Granger-Causality Tests

Model 1: EC = EU = Energy Use, total					
Dependent Variable	**F-statistic [probability]**				ECT_{t-1} **[t-statistics]**
	ΔGDP_t	ΔEU_t	ΔIN_t	ΔTR_t	
ΔGDP_t	-	3.747* [0.075]	2.456 [0.141]	0.051 [0.825]	-0.960*** [-4.482]
ΔEU_t	5.130** [0.023]	-	0.038 [0.848]	0.402 [0.537]	-0.609*** [-4.183]
ΔIN_t	8.130*** [0.001]	3.189* [0.094]	-	7.444*** [0.003]	-0.810*** [-3.290]
ΔTR_t	0.502 [0.465]	0.310 [0.585]	3.369* [0.076]	-	-
Model 2: EC = FE = fossil fuel energy consumption (% of total)					
	ΔGDP_t	ΔFE_t	ΔIN_t	ΔTR_t	ECT_{t-1} **[t-statistics]**
ΔGDP_t	-	0.420 [0.528]	3.573* [0.080]	5.207** [0.039]	-1.425*** [-7.221]
ΔFE_t	9.089*** [0.001]	-	2.918 [0.110]	7.440*** [0.006]	-
ΔIN_t	10.215*** [0.000]	0.997 [0.333]	-	8.675*** [0.001]	-0.628*** [-5.169]
ΔTR_t	0.366 [0.553]	0.193 [0.666]	3.878* [0.076]	-	-
Model 3: EC = RE = Renewable energy consumption (% of total)					
	ΔGDP_t	ΔRE_t	ΔIN_t	ΔTR_t	ECT_{t-1} **[t-statistics]**
ΔGDP_t	-	3.150* [0.094]	10.851*** [0.004]	0.428 [0.522]	-0.862*** [-3.495]
ΔRE_t	-4.382** [0.014]	-	0.798 [0.386]	0.052 [0.822]	-0.467* [-1.808]
ΔIN_t	11.004*** [0.004]	1.518 [0.236]	-	3.821* [0.068]	-0.652*** [-5.477]

$\Delta \boldsymbol{TR_t}$	0.819 [0.379]	0.015 [0.903]	3.827* [0.068]	-	-

Notes: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively

The results reported in Table 3 reveal that there is a distinct bidirectional causal relationship between economic growth and energy consumption in Zambia when energy consumption is proxied by total energy consumption (ΔEU) (Model 1) and renewable energy consumption (ΔRE) (Model 3). These results were found holding, irrespective of the time horizon of the analysis. The long-run results were confirmed by the significant lagged error-correction terms in the economic growth (GDP) and energy (EU and RE) functions in the first and third models, which have been found to be negative and statistically significant. Meanwhile, the short-run causality was confirmed by the F-statistics in the corresponding economic growth and energy function that have also been found to be negative and statistically significant. When fossil energy consumption (FE) was considered, a unidirectional causality from economic growth to energy consumption was found, only in the short run, as confirmed by the F-statistic of economic growth ($\Delta \boldsymbol{GDP}$) in the energy function ($\Delta \boldsymbol{FE}$) in Model 2. In the main, although the causality between energy consumption and economic growth was found to be sensitive to the energy proxy used and time horizon considered, bidirectional causality, both in the long and short term, was found to be predominant.

Other results show that when total energy consumption was used as a proxy for energy (Model 1), there was: (i) long-run and short-run unidirectional causality from economic growth and energy consumption to inflation; (ii) long-run unidirectional causality from trade openness to inflation; and (iii) short-run bidirectional causality between trade openness and inflation. When energy consumption was proxied by fossil energy (Model 2), (i) economic growth and inflation were mutually causal, both in the long and short run; (ii) trade openness and inflation Granger-caused each other in the short run; but in the long run, trade openness Granger-caused inflation; and (iii) trade openness Granger-caused energy consumption only in the short run. When energy consumption was proxied by renewable energy (Model 3), (i) economic growth and inflation were mutually causal in both the long and short run; (ii) trade openness and inflation were mutually causal only in the short run, while in the long run, trade openness Granger-caused inflation.

The causality test results for Zambia are consistent with findings of other previous studies done on the same subject (see, among others, Akinlo, 2008; Altinay and Karagol, 2004; Cetin, 2016; Jebli and Youssef, 2015; Ozcan and Ozturk, 2019), emphasising the dominance of bidirectional causality between energy consumption and economic growth. The regression of the underlying causality models passes all the diagnostic tests against serial correlation, functional form, normality and heteroscedasticity.

6. Conclusion

In this study, the causal relationship between energy consumption – total and disaggregated – and economic growth was examined in Zambia, during the period 1990 to 2013. The study was motivated by inadequate empirical research on the energy and economic growth nexus in the country under study, which could guide policymakers in an informed manner on policies related to energy consumption and economic growth. The study is aimed at unravelling whether or not economic growth in Zambia is dependent on energy consumption, and if dependent, the study further attempts to establish the elements of energy demand that propel economic growth in Zambia. To this end, the study specified three models, namely one model that considers total energy consumption in the country under study, with the other two models each consisting of an element of disaggregated energy consumption – fossil energy in the second model and renewable energy in the third model. To address the omitted-variable-bias, two intermittent variables were incorporated in each of the three models, namely, inflation and trade openness, thereby creating a system of multivariate causality equations. Using the ARDL-bound testing method within the multivariate Granger-causality framework, the results of the study revealed that the causality between economic growth and energy consumption in Zambia is sensitive to the measure of energy consumption employed and the timeframe of analysis considered. A distinct long- and short-run bidirectional causal relationship between economic growth and energy consumption in Zambia was found when energy consumption was proxied by total energy consumption and renewable energy consumption. When fossil energy consumption was considered, unidirectional causality from economic growth to energy consumption was found, only in the short run. In the main, although the causality between energy consumption and economic growth was found to be sensitive to the energy proxy used and time horizon considered, bidirectional causality, both in the long and short run, was found to be predominant.

This finding has important policy implications for Zambia as it shows that the buoyant economic growth Zambia has enjoyed over the years is not only just energy-dependent, but it has been dependent on specific energy types, while energy consumption has also been feeding on economic growth, making these two macroeconomic variables mutually dependent. It is time that Zambia starts renewing its focus on renewable energy as it has been found to also drive the real sector, unlike the fossil energy consumption, which only benefits from economic growth, but does not extend the same courtesy to economic growth. Zambia can also mitigate the associated negative environmental effects of fossil fuels without jeopardising its economic growth prospects.

All efforts have been made to ensure that this study is analytically defensible as far as possible. However, similar to many other scientific research studies, it may suffer from a few limitations. Only total energy consumption data were used in this study, which were disaggregated into two categories, namely fossil energy and renewable energy, with data ending in 2013. It is, therefore, recommended that future studies revisit the energy-growth nexus when recent data become available. Further, future studies may also increase the categories of energy consumption to include liquefied petroleum gas, motor gasoline, gas/diesel oil, and electricity, among other common energy categories, as the relevant data become available. It will be interesting to find out whether the findings from these future studies could differ fundamentally from those from this study.

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