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Examining the renewable energy consumption-economic growth nexus in sub-Saharan African countries

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EXAMINING THE RENEWABLE ENERGY CONSUMPTION – ECONOMIC GROWTH NEXUS IN SUB-SAHARAN AFRICAN COUNTRIES

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Abstract

Given the role renewable energy is likely to play in the context of sustainable development, it is important to understand the relationship between renewable energy and economic growth. Therefore, this paper examines the relationship between renewable energy consumption and economic growth in a panel of sub-Saharan Africa countries from 1990-2011. Using a production function framework, the dependent variable is real GDP while the independent variables include renewable energy consumption, capital, and labor. The panel cointegration and Fully-Modified Ordinary Least Squares (FMOLS) results indicate the existence of a long-run and statistically significant relationship between real GDP and the independent variables. The results from the Granger Causality tests indicate unidirectional causality running from GDP to renewable energy consumption in the long-run.

Introduction

The relationship between energy consumption, the environment, and the unrelenting pursuit of economic growth is important to understand in the context of a world with finite resources and infinite needs. The global demand for energy will continue to increase as a result of increasing populations and accelerating economic growth in developing countries as their lifestyles become more energy intensive and consumption oriented. As a result, the question of how to satisfy the world's increasing energy demands in a sustainable manner is a problem the international community has recognized for decades, but has thus far been unable to provide any meaningful solutions. Therefore, this paper looks to further examine the relationship between renewable energy consumption and economic growth using a panel of sub-Saharan African countries.

An important development in energy economics from 2014 to 2015 has been the decline in world energy prices (IEA, 2015b). While global oil prices, in particular, have reached previously unimaginable lows, this is a temporary equilibrium. Fossil fuels are finite resources and, while large supplies do still exist, accelerating demand will inevitably exhaust their limited supply. More realistically, the effects of economic growth and energy consuming activities on environmental degradation and climate change will galvanize both governments and the international community to act well before the supply of fossil fuels is exhausted.

In light of the increased focus on climate change and emission reduction, it is expected that renewable energy sources will play an increasing role in the generation of the world's energy needs. Renewable energy can be broadly defined as any energy generated from natural processes including hydropower, geothermal, solar, tides, wind, biomass, and biofuels. According to the United Nations Environment Program renewable energy, excluding large hydroelectric projects, made up 53.6% of the total gigawatt capacity of all energy technologies installed in 2015 (UNEP, 2015). Importantly, renewable energy technologies are becoming much more prevalent in both developed and developing economies as they become cheaper, more reliable, and readily available (IEA, 2015b). During 2015, and for the first time ever, developing economies invested more money into renewables than develop economies (UNEP, 2015).

Energy is an important enabler that affects many aspects of economic and human development. In this sense, economic development may be constrained without sufficient energy capacity and access to affordable modern energy services. Energy access is often a prevalent problem in developing countries, as evidenced by the fact that over two-thirds of Africans lack access to electricity (IEA, 2015a). Nearly all of those people are located in sub-Saharan Africa which indicates that energy access is arguably one of sub-Saharan Africa's largest economic and human development obstacles (IEA, 2015a). Renewable energy technologies have the capability to be affordable, decentralized sources of electricity to those who are not connected to the electrical grid. In this regard, renewable energy technologies may help provide a sustainable solution to sub-Saharan Africa's energy access problems and support its economic development.

Given the role renewable energy is likely to play in the sustainable development discussion, it is important to understand the relationship between economic growth and renewable energy. This paper will attempt to further the understanding of this relationship using a panel of sub-Saharan African countries[1]. To empirically examine the relationship between renewable energy consumption and economic growth, this paper will utilize cointegration testing and a Fully-Modified Ordinary Least Squares (FMOLS) regression approach to determine the relationship between renewable energy consumption and gross domestic product (GDP). Furthermore, Granger Causality tests will be used to

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[1]Burundi, Cameroon, Central African Republic, Cote d'Ivoire, Democratic Republic of the Congo, Gabon, Ghana, Kenya, Malawi, Mali, Mauritania, Mauritius, Mozambique, Republic of the Congo, Rwanda, Senegal, South Africa, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe

determine if a causal relationship exists between renewable energy consumption and GDP. Consistent with previous papers, this paper utilizes a production model framework, including proxies for capital and labor as the independent variables in addition to a renewable energy proxy. Importantly, past research has been inconclusive as to what type of relationship exists between renewable energy and economic growth and there has yet to be an independent analysis of the sub-Saharan Africa region.

The rest of the paper is organized as follows. The first section serves as a literature review of the economic growth, energy, and renewable energy trends in sub-Saharan Africa. The second section contains an extensive literature review of both the energy consumption-economic growth nexus and, more specifically, the renewable energy-economic growth nexus. The third section describes the data, variables and methodology used in the analysis and finally the last section discusses the test results and final conclusions.

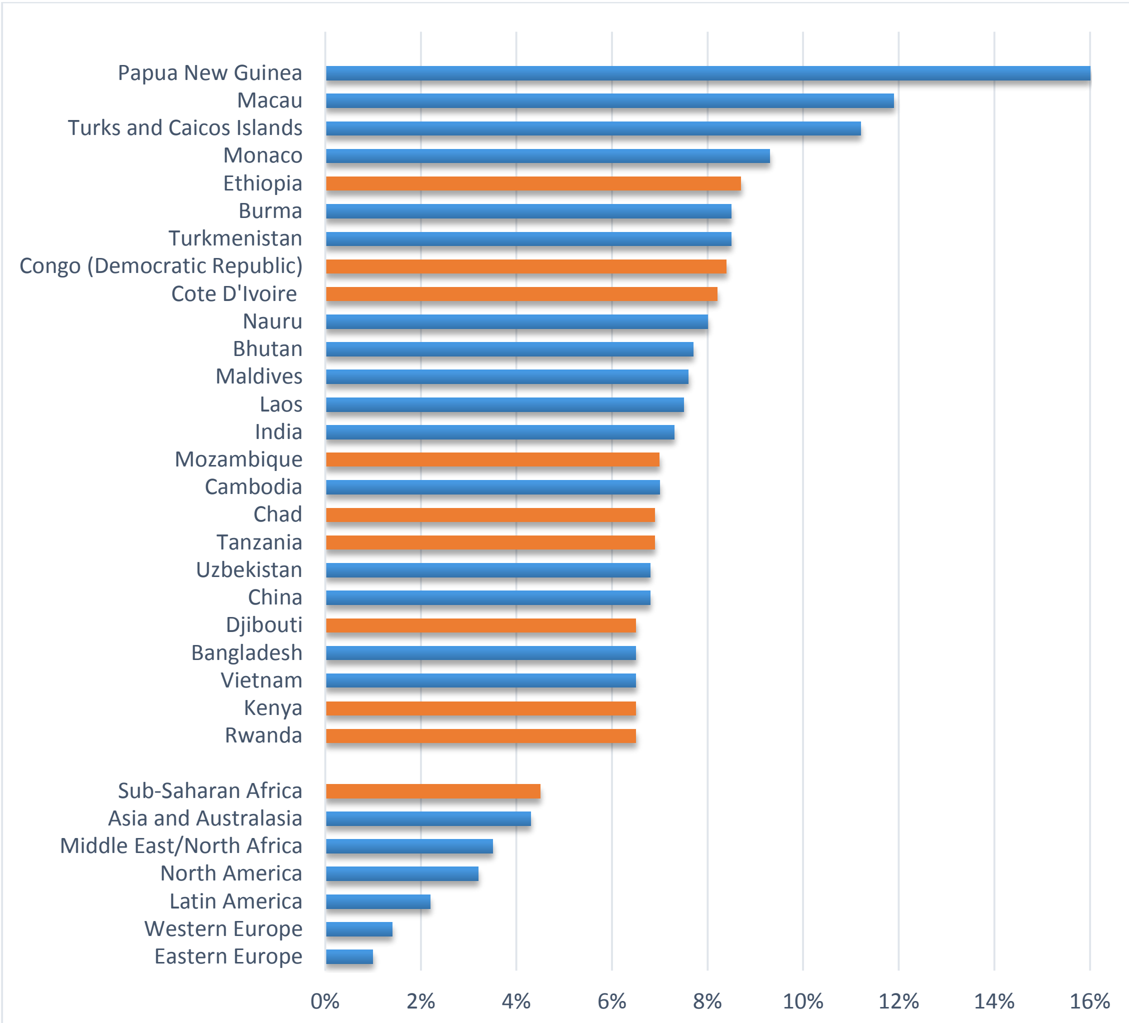
Literature Review

Sub-Saharan Africa: Economic and Energy Trends

Development trends

Much attention has been given to China in recent decades for its massive economic growth, but it is not the only country with impressive growth rates. In fact, of the 25 fastest growing economies in the world, nine of them are located in sub-Saharan Africa including Ethiopia, The Democratic Republic of Congo, Cote D'Ivoire, Mozambique, Tanzania, Chad, Rwanda, Kenya, and Djibouti (see Figure 1). Moreover, sub-Saharan Africa is projected to be the fastest growing economic region in the world with an aggregate growth rate of 4.5% in 2015 (Warren, 2015). While sub-Saharan Africa is one of the fastest growing regions in the world, it is also a region characterized by huge disparities in income, both on a per capita basis and between countries. For example, Nigeria and South Africa alone account for more than half of the total sub-Saharan economy (IEA, 2014).

Figure 1: GDP Growth: Top 25 Fastest Growing Countries and Regional Aggregates (2015 est.)



Source: (CIA, 2015)

The lost decades of the 1980s and 1990s, largely characterized by civil war and political strife, have given way to rising levels of human development, trade liberalization, and more diversified economies. Three keys to the accelerated growth during the post-2000 era in the region include greater political stability, high commodity demand and increasing commodity prices, and improved fiscal policies (AfDB, OECD, & UNDP, 2015). Since Africa is rich in natural resources, it is no surprise that commodity exports make up a majority of many country's revenue sources. In fact, more than 60% of sub-Saharan Africa's total exports in 2010-2014 resulted from fuels, ores, and metals compared to only 16% from manufactured goods (World Bank, 2016c).

This export pattern makes sub-Saharan Africa quite vulnerable to fluctuations in commodity prices. Two extreme examples are Nigeria and Angola, whose oil exports account for 60% of their fiscal revenues and more than 80% of their exports (World Bank, 2016c). This uneven distribution of revenue implies that Nigeria and Angola's fiscal policy and investment decisions will be heavily dependent on the price and demand of oil. This scenario is true for many of the commodity exporters who depend on volatile commodity prices and global demand as their primary revenue streams. This can lead to surpluses in good times that must be well managed, but often are not due to governance issues, or deficits which leads to a lack of investment in important development areas such as infrastructure or education.

Sub-Saharan Africa: An Energy Starved Region

While sub-Saharan Africa contains some of the fastest growing economies in the world, its energy sector is key to attaining its future development potential. As of now, it is hugely inefficient and inaccessible as evidenced by the fact that in 2013 sub-Saharan Africa was also home to nearly 634 million people, over two-thirds of the population, who had no access to electricity (IEA, 2015). This problem reflects the lack of infrastructure required to span such a large region and provide affordable and sufficient energy services to the rural population which makes up 63% of the sub-Saharan Africa population (IEA, 2014). As illustrated in Figure 2, only 15.27% of the rural population of sub-Saharan Africa had access to electricity compared to the worldwide average of 71.66% (World Bank, 2015). Moreover, approximately 25 countries in sub-Saharan Africa are experiencing a crisis of rolling blackouts (World Bank, 2016b). Not only are there access and capacity problems, but low incomes combined with expensive forms of energy supply, if any, make affordability of energy services also a major concern.

Figure 2: Electricity Access Rates

	2000	2013
Sub-Saharan Africa		
Access to electricity (% of population)	26.06%	35.31%
Access to electricity, rural (% of rural population)	9.73%	15.27%
Access to electricity, urban (% of urban population)	60.28%	71.61%
World		
Access to electricity (% of population)	79.31%	84.58%
Access to electricity, rural (% of rural population)	64.12%	71.66%
Access to electricity, urban (% of urban population)	95.27%	96.48%

Source: IEA, 2015a

Modern energy services have been a prerequisite to sustained development in every advanced economy. Encouragingly, sub-Saharan Africa has huge renewable resources which remain untapped including solar, hydroelectric in many countries, wind in coastal areas, and geothermal in the East African Rift Valley to help enable it to do just that (IEA, 2014). Hydropower is the most used renewable energy source in Africa (excluding bioenergy) and is attractive due to its large-scale potential development and low average electricity costs (IEA, 2014). To date, less than 10% of the hydroelectric potential in Africa has been tapped (IEA, 2014). Solar is becoming more and more popular as the average cost to generate electricity continues to decrease. For example, installed capacity increased from 40 megawatts in 2010 to around 280 megawatts in 2013 (IEA, 2014). Previously, most of that capacity was small-scale units, but now large projects are under construction in addition to an increase in mini-grid and off-grid systems in rural areas, which solar panels are ideal for (IEA, 2014). Mini-grid and off-grid systems powered by renewable energy sources are likely to play a much, much larger role in rural areas in the future.

Benefits of Renewable Energy

In the long term, it is not likely that fossil fuels can continue to be the energy source to fuel development in developing countries. Renewable energy technologies have more benefits to developing countries than merely being environmentally friendly. They also can provide protection against future price increases in conventional fuels by diversifying the energy portfolio, aid in the balancing of both budget and trade deficits, and create new local economic opportunities which help support poverty reduction and promote economic growth (Worldwatch, 2005; REN21, 2015).

One of the things renewable energy technologies can help developing countries with, besides a diversified energy portfolio and increased energy security, is poverty reduction by providing affordable and accessible electricity to poverty stricken communities. However, one of the main challenges facing rural development and poverty reduction brings us back to the issue of electricity access. To help increase access, mini-grids and other decentralized electricity generation strategies, such as personal solar or hydroelectric units, are beginning to become much less expensive and therefore more attractive methods of providing electricity access to rural areas (REN21, 2015). These units have the ability to provide a small amount of electricity for families or rural communities to use for personal and work related needs enabling them to become more productive citizens and provide a marginal increased standard of living.

REN21 (2015) has found that, a majority of developing countries have a natural advantage when it comes to renewable energy because of their abundant renewable energy resources. This makes a renewable solution to developing economies' energy problems even more competitive relative to the rising prices of more traditional energy sources (REN21, 2015). These are invaluable sources of energy within developing countries that have thus far been largely unexploited. For example, according to Adusei (2011), Ethiopia and the Democratic Republic of Congo possess about 61% of Africa's untapped hydroelectric power potentials. Moreover, in 2014, Kenya added 1.1 gigawatts of geothermal energy which was the largest share of newly added geothermal energy in the world (REN21, 2015).

Limitations of Renewable Energy

As renewable energy technology improves, its downsides will continue to decrease and it will become even more competitive with fossil fuels. However, there are still aspects of renewable energy technologies which have put countries off from implementing it earlier or in larger quantities. For instance, the initial investment cost is high, much larger than conventional energy sources, which does not favor developing countries (International Renewable Energy Agency, 2015). But while conventional energy sources have lower capital costs, they tend to have significant operating costs whereas the operating costs of renewable energy systems offset their high initial capital costs over time (Worldwatch Institute, 2005).

Electricity is required constantly in modern life today, so ideally there should be no breaks in service. This is one of the most common and pervasive critiques of renewable energy since it is often viewed as an intermittent energy source. This is because, as we all know, some days the sun doesn't shine, there may be no wind, or there may be a drought, each of which inhibit the production of solar, wind and hydro-electricity, respectively. Nevertheless, this ubiquitous concern about renewable energy is slowly being answered. In 2014, there were notable improvements in the usage and creation of energy storage units which can store excess electricity to be used in times when renewable energy technologies cannot generate electricity (REN21, 2015).

For renewable energies to become competitive worldwide there are a number of things that must happen. In some cases, government intervention may be necessary to start this process. Regulatory frameworks and the correct incentives must be put in place in order to properly motivate and mobilize the private sector to engage in the production and implementation of renewable energy technologies at an appropriate scale. Moreover, a level playing field between renewables and fossil fuels is critical for there to be any chance of direct competition, especially in developing countries. This implies the reduction or elimination of fossil fuel subsidies, or a shifting of the subsidies toward renewable energy, which would provide significant impetus toward additional renewable energy generation. In some regards, these actions are already being taken with feed-in tariffs and credits for investments in renewable energy technologies for example.

Energy Consumption and Economic Growth: Does a Relationship Exist?

In our increasingly energy-dependent world, the relationship between energy consumption and economic growth has become an increasingly popular research topic. As a result, literature on the energy consumption-economic growth nexus has expanded considerably in the past two decades. Studies have ranged from single country time series analyses to large panel analyses consisting of numerous countries. However, the results of these studies are often conflicting, especially in terms of the direction of causality. There are four causality scenarios which have led to the creation of the following hypotheses regarding the relationship between energy consumption and GDP.

First, if an increase in energy consumption causes an increase in GDP then this is evidence of the growth hypothesis. The growth hypothesis implies unidirectional causality running from energy consumption to GDP whereby energy acts as a complement to labor and capital in the production process (Payne, 2010). The growth hypothesis interprets energy as a driver of economic growth such that energy conservation policies, perhaps to reduce emissions for example, may result in a decrease in GDP. The second scenario is the antithesis of the growth hypothesis. As such, the conservation hypothesis states that there is unidirectional causality from GDP to energy consumption. The conservation hypothesis implies that energy conservation policies such as emission reductions or energy efficiency improvements will not adversely affect economic growth (Payne, 2010).

The third scenario suggests the existence of an interdependent relationship whereby energy consumption and GDP affect each other simultaneously (Payne, 2010). This scenario is described as the feedback hypothesis and is supported by evidence of bidirectional causality between energy consumption and GDP. Finally, the neutrality hypothesis sees energy consumption as a relatively small component of GDP and thus should not have a significant impact on economic growth (Payne, 2010). Consequently, the neutrality hypothesis is supported by the nonexistence of a causal relationship between energy consumption and GDP.

Appendix 1, obtained from Dobnik (2011), summarizes 30 panel data studies on the causal relationship between energy consumption and GDP. The studies include a variety of countries and regions of varying economic standings of varying economic development levels. The often conflicting results, particularly between studies consisting of similar countries and income levels, suggests that the relationship between energy consumption and GDP is still unclear. However, a look at the overall results provide some support for the feedback hypothesis as the most likely relationship between energy consumption and economic growth since 15 of the 30 studies reported results of bidirectional causality compared to five each for the growth and conservation hypotheses and one for the neutrality hypothesis.

The potential presence of a relationship between energy consumption and economic growth introduces a number of energy and environmental policy implications which could be significant for policy makers depending on the type of causal relationship that exists. Particularly in the renewable energy sector, the presence of unidirectional or bidirectional causality from renewable energy consumption to economic growth could provide an avenue to use government policies in order to both enhance the development of the renewable energy sector and boost economic growth (Apergis and Payne, 2014).

Renewable Energy Consumption and Economic Growth Literature

The literature studying the relationship between renewable energy and economic growth has expanded considerably in the last decade. The current research spans a wide variety of countries and regions and encompasses both developed to developing economies. Similar to the energy consumption-economic growth literature, the research findings also vary between countries and within regions.

Apergis and Payne (year) have authored a number of papers examining the relationship between renewable energy consumption and economic growth. By and large, their methodology remains relatively consistent between their earlier papers, utilizing cointegration tests, panel error correction models, and Granger-Causality tests to determine the long-run relationships and direction of causality between renewable energy consumption and economic growth. Furthermore, in each of their studies they utilize a production model including real GDP, renewable energy consumption (or renewable electricity consumption), gross fixed capital formation, and total labor force as their dependent and independent variables, respectively (Apergis & Payne, 2010a, 2010b, 2010c, 2011a, 2011b).

Apergis and Payne (2010a) observed 13 countries in Eurasia from 1992-2007, Apergis and Payne (2010b) used a panel of 20 Organization for Economic Cooperation and Development (OECD) countries from 1985-2005, and Apergis and Payne (2010c) examined six Central American countries from 1985-2005. In each of their studies they found similar results. Using a combination of panel error correction models and Granger causality testing, they were able find support for the feedback hypothesis which is indicative of an interdependent relationship, or bidirectional causality, between renewable energy consumption and economic growth in the long-run. Moreover, they also found that renewable energy consumption may affect real GDP through its positive effect on real gross fixed capital formation (Apergis & Payne, 2010a, 2010b, 2010c). Apergis and Danuletiu (2014) examined a much larger panel of

80 countries, and utilized slightly different econometric techniques to do so. Their findings are quite similar to those of Apergis and Payne mentioned above in that they find strong evidence of an interdependent relationship between renewable energy consumption and economic growth or the total sample as well as when the sample is broken down by regions (Apergis & Danuletiu, 2014).

Furthermore, Apergis and Payne (2011a) also studied the relationship between both renewable energy consumption and non-renewable energy consumption on economic growth for 80 countries over the period 1990-2007. Their findings revealed bidirectional causality between renewable and non-renewable energy consumption and economic growth in both the short and long-run (Apergis & Payne, 2011a). Apergis and Payne (2011b) examined a more specific relationship between renewable and non-renewable electricity consumption in 16 emerging market economies from 1990-2007. Their findings indicated that bidirectional causality existed in the long-run between both renewable and non-renewable electricity consumption on economic growth (Apergis and Payne, 2011b). These two studies utilized similar production models and methodologies as their previous works in 2010.

In addition to Apergis and Payne, there are a number of other authors who have examined this intriguing topic. Bobinaite, Juozapaviciene, and Konstantinaviciute (2011) sought to determine if renewable energy consumption in Lithuania might influence its real GDP. Specifically, they were wondering what the real GDP elasticity of renewable energy consumption would be. The results suggest that there is a unidirectional causality between renewable energy consumption and real GDP in the short run. Moreover, they were able to demonstrate that real GDP is elastic to renewable energy consumption and that consumption grows slower than real GDP (Bobinaite et al., 2011). Shahbaz, Loganathan, Zeshari, and Zaman (2015) also looked at the relationship between renewable energy consumption and economic growth within a single country, Pakistan. They also used a production function approach by incorporating capital and labor, but diverted from Apergis and Payne’s methodology by using an auto-regressive distributed lag model and a vector error correction model with

Granger causality testing to determine the long-run relationship and causality. Their results indicated that renewable energy, capital, and labor boost economic growth and the causality analysis showed the feedback effect between economic growth and renewable energy (Shahbaz et al., 2015).

Further panel studies include Bhattacharya, Paramati, Ozturk, and Bhattacharya (2015) which examined the relationship between renewable energy consumption and economic growth in the 38 top renewable energy consuming countries from 1991-2012. Interestingly, their findings illustrated that renewable energy consumption had a significant positive impact on economic output for 22 of the 38 included countries. Lin (2014) used a panel of nine OECD countries from 1982-2011 using a similar approach to Shahbaz et al. (2015). Lin's findings vary between countries, indicating the presence of both unidirectional and bidirectional causality. For Germany, Italy, and the United Kingdom, Lin found evidence of long-run unidirectional causality running from renewable energy consumption to economic growth which supports the growth hypothesis (Lin, 2014). However, for the United States and Japan Lin found a long-run unidirectional causality relationship running from economic growth to renewable energy consumption which is indicative of the conservation hypothesis (Lin, 2014). A summary of additional literature pertaining to the relationship between renewable energy consumption and economic growth may be found in Appendix 2. Given the context of these past studies, the following sections discuss the methodology used in this analysis to determine if a relationship between renewable energy consumption and economic growth exists within a panel of sub-Saharan African countries. Lastly, the results and their policy and development implications will be discussed.

Data, Methodology, and Results

Annual data from 1990-2011 were collected from the *World Bank Development Indicators*, *Penn World Tables*, and the *U.S. Energy Information Administration*. The multivariate panel data framework contains 23 countries and six independent variables. The variables used include the dependent variable, real GDP in constant 2005 USD (Y), and the independent variables which include renewable energy consumption defined in billions of kilowatt hours (RE), capital defined by gross fixed capital formation in millions of constant 2005 USD (K), and total labor force in millions of workers (L). All variables are transformed by the natural logarithm for interpretation purposes.

Since non-stationary variables lead to spurious regression results for ordinary least squares (OLS) regressions, it is important to determine the stationarity of the variables (Nielsen, 2005). However, Engle and Granger (1987) were able to illustrate that a combination of non-stationary variables may in fact be stationary. If this is the case, the variables are said to be cointegrated which implies that a long-run relationship exists between the dependent and independent variables. Therefore, Pedroni's panel cointegration test is used to determine if such a long-run relationship exists between the dependent variable, Y, and the independent variables, RE, K, and L. Table 1 reports the panel cointegration test statistics and p-values. The null hypothesis of no cointegration is strongly rejected by 6 of the 11 test statistics at the 1% significance level. This indicates that the variables are cointegrated and that a long-run relationship exists between the dependent variable (Y) and the independent variables (RE, K, and L).

Table 1: Pedroni (Engle-Granger based) Cointegration Estimates

Pedroni (Engle-Granger based) Cointegration Test				
Null hypothesis: No cointegration				
Trend assumption: Deterministic intercept and trend				
	Statistic	Probability	Weighted Statistic	Probability
Panel v-Statistic	-0.295	0.616	-1.390	0.918
Panel rho-Statistic	2.575	0.995	1.750	0.9600
Panel PP-Statistic	-2.947	0.002	-7.461	0.000***
Panel ADF-Statistic	-4.009	0.000***	-8.785	0.000***
Group rho-Statistic	3.965	1.000		
Group PP-Statistic	-8.684	0.000***		
Group ADF-Statistic	-6.547	0.000***		

*Notes: *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level*

After establishing that the variables are cointegrated, the long-run cointegrating equation is estimated using the FMOLS panel cointegration method.

$$\ln(Y_{it-}) = \alpha_i + \beta 1 * \ln(RE_{it}) + \beta 2 * \ln(K_{it}) + \beta 3 * \ln(L_{it})$$

The above equation is calculated for each country where i = 1, …, 23 for each country and t = 1, …, 22 for each year. To capture the different country-specific effects, a constant term is included. In the equation, this fixed effect term is represented by α. The parameter β represents the estimated coefficient of each variable, interpreted as the variable's effect on the dependent variable holding all else constant.

The results of the FMOLS regression can be seen in Table 2. Each of the coefficients is positive and statistically significant. However, the coefficient of RE is only moderately statistically significant at the 10% level whereas the coefficients of K and L are strongly significant at the 1% level. Since the variables are expressed in natural logarithms, the coefficients may be interpreted as elasticities. Thus, the FMOLS results indicate that over the long-run and holding all else equal, a 1% increase in renewable energy consumption increases real GDP by 0.03%; a 1% increase in gross fixed capital formation increases real GDP by 0.789%; and a 1% increase in the total labor force results in a 0.405% increase in real GDP. Capital seems to have the largest effect on GDP relative to renewable energy consumption and the labor force. Comparing these results to three similar analyses conducted by Apergis and Payne (2010a, 2010b, and 2010c), the effect of renewable energy consumption on GDP is much smaller in this analysis.

Table 2: Panel FMOLS Estimates

Panel Fully Modified Least Squares Model				
Dependent variable: Y				
Panel method: Pooled estimation				
Variable	Coefficient	Standard Error	t-Statistic	Probability
RE	0.030	0.016	1.911	0.056*
K	0.789	0.059	13.476	0.000***
L	0.405	0.066	6.172	0.000***
R-squared	0.992			
Adjusted R-squared	0.992			

*Notes: *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level*

Finally, in order to determine if a causal relationship exists between renewable energy consumption and real GDP, a pairwise Granger Causality test is performed. This test examines each variable and its causal effect on every other variable to determine the causal relationships. The results of the Granger Causality test may be seen in Table 3. Variable X is said to Granger Cause variable Z if the past values of X can help explain Z. The null hypothesis of the test is that variable X does not Granger Cause variable Z. Therefore, if the probability value is less than 10%, this is indicative of the existence of a causal relationship whereby variable X Granger Causes variable Z. These test results do not guarantee causation, rather they imply that variable X may be causing variable Z.

Table 3: Granger Causality Estimates

Pairwise Granger Causality Tests		
Lags: 4 (determined by AIC lag selection criteria)		
Null hypothesis	F-Statistic	Probability
RE does not Granger Cause Y	0.420	0.794
Y does not Granger Cause RE	2.079	0.083*
K does not Granger Cause Y	3.434	0.009***
Y does not Granger Cause K	1.657	0.159
L does not Granger Cause Y	8.330	0.000***
Y does not Granger Cause L	3.490	0.008***
K does not Granger Cause RE	1.954	0.101
RE does not Granger Cause K	0.332	0.857
L does not Granger Cause RE	1.530	0.193
RE does not Granger Cause L	1.668	0.157
L does not Granger Cause K	2.566	0.038**
K does not Granger Cause L	1.111	0.351

*Notes: *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level*

From the results in Table 3, the null hypothesis cannot be rejected that RE does not Granger Cause Y. Therefore, there is no evidence in support of the alternative hypothesis that an increase in renewable energy consumption will result in higher levels of GDP. However, the null hypothesis can be rejected regarding the relationship between GDP and renewable energy consumption. The p-value for this test is 0.083 which is significant at the 10% level, so we can say that there is evidence that real GDP Granger Causes renewable energy consumption. These findings conflict with many of those found among other studies, but which include a variety of different countries, regions, and levels of economic development (see Appendix 2). A majority of them found bidirectional causality. However, to my knowledge this is the first analysis that looks solely at countries located in sub-Saharan Africa, so this may be a reason for the differing results. Among the other results, there is evidence of bidirectional causality between L and Y in addition to unidirectional causality between K and Y and L and K. These findings are consistent with the economic literature and previous studies in that expect that increases in labor and capital would Granger Cause an increase real GDP.

Of the energy consumption hypotheses mentioned earlier, the relationship between renewable energy consumption and economic growth found using countries in sub-Saharan Africa supports the conservation hypothesis. Thus, the renewable energy policy implications suggest that increasing renewable energy consumption via the introduction of new renewable energy projects will not have an impact on GDP. Moreover, the cessation or reduction of renewable energy projects also will not have a negative impact. The results suggest that as real GDP increases throughout sub-Saharan Africa, there will be an associated increase in renewable energy consumption. This may be for a number of reasons including the current relatively high cost of renewable technologies compared to conventional energy sources, the uncertainty among energy providers regarding return on investment they are likely to see if they were to invest in renewable energy technologies, or a lack of government funds available to devote towards stimulating exploitation of renewable energy sources. The government typically plays a large role in stimulating investments in new areas through subsidies or production tax credits. However, they may be constrained fiscally to the point where they do not have the money to do so or lack the political capital to remove conventional energy subsidies or implement subsidies for renewable energy technologies to level the playing field.

Conclusion

This study has helped extend the research surrounding the relationship between renewable energy consumption and economic growth using a panel of 23 countries in sub-Saharan Africa, a region which previously has not been extensively researched. The findings of this study indicate that a long-run equilibrium relationship exists between GDP and the independent variables, renewable energy consumption, gross fixed capital formation, and labor. Moreover, from the results of the FMOLS regression, the long-run relationship indicates that a 1% increase in renewable energy consumption yields an increase of 0.030% in real GDP; a 1% increase in gross fixed capital formation yields an increase of 0.789% in real GDP; and a 1% increase in the labor force yields an increase of 0.405% in real GDP. Finally, the results of the Granger Causality tests support the conservation hypothesis. Specifically, the findings indicate that within this panel of sub-Saharan Africa countries renewable energy consumption does not cause GDP, but GDP does Granger Cause renewable energy consumption.

While renewable energy technologies could help expand energy access across sub-Saharan Africa, the findings of this study suggest that the effects of doing so may not have a significant impact on real GDP. For a number of reasons, expanding renewable energy technologies in sub-Saharan Africa may be a difficult policy objective including uncertainties surrounding the technology’s revenues and costs, accessibility of the technology, lack of private sector involvement, or government policy constraints including both fiscal legislative constraints. As renewable energy continues to expand its share within the world’s energy portfolio, further analysis in this area will be necessary to determine the positive or negative effects of using renewable energy development as an economic development tool.

Appendix 1

Energy Consumption-Economic Growth Literature Summary

Authors	Period	Countries	Causality
Lee (2005)	1975-2001	18 developing countries	Energy → Growth
Al-Iriani (2006)	1971-2002	GCC countries	Growth → Energy
Lee and Chang (2007)	1965-2002	22 developed countries	Energy ↔ Growth
	1971-2002	18 developing countries	Growth → Energy
Mahadevan and Asafu-Adjaye (2007)	1971-2002	10 net energy exporters	Growth → Energy
		10 net energy importers	Energy → Growth
Mehrara (2007)	1971-2002	11 oil exporting countries	Growth → Energy
Huang et al. (2008)	1971-2002	26 high income countries	Growth → Energy
		15 upper middle income countries	Growth → Energy
		22 lower middle income countries	Growth → Energy
		19 low income countries	Energy ~ Growth
Lee et al. (2008)	1960-2001	22 OECD countries	Energy ↔ Growth
Lee and Chang (2008)	1971-2002	16 Asian countries	Energy → Growth
Narayan and Smyth (2008)	1972-2002	G-7 countries	Energy → Growth
Apergis and Payne (2009a)	1991-2005	11 countries within the Commonwealth of Independent States	Energy ↔ Growth
Apergis and Payne (2009b)	1980-2004	6 Central American countries	Energy → Growth
Mishra et al. (2009)	1980-2005	9 Pacific Island countries	Energy ↔ Growth
Sinha (2009)	1975-2003	88 countries	Energy ↔ Growth
Apergis and Payne (2010c)	1980-2005	9 South American countries	Energy → Growth
Costantini and Martini (2010)	1960-2005	26 OECD countries	Energy ↔ Growth
	1970-2005	45 non-OECD countries	Energy ↔ Growth
Lee and Lee (2010)	1978-2004	25 OECD countries	Energy ↔ Growth
Ozturk et al. (2010)	1971-2005	13 upper middle income countries	Energy ↔ Growth
		24 lower middle income countries	Energy ↔ Growth
		14 low income countries	Growth → Energy
Apergis and Payne (2011b)	1990-2007	80 countries	Energy ↔ Growth
Belke et al. (2011)	1981-2007	25 OECD countries	Energy ↔ Growth
Kahsai et al. (2011)	1980-2007	40 Sub-Saharan African countries	Energy ↔ Growth
Niu et al. (2011)	1971-2005	4 developed Asia-Pacific countries	Energy ↔ Growth
		4 developing Asia-Pacific countries	Growth → Energy

Notes:

X → Y means variable X Granger-causes variable Y.

X ~ Y means that no Granger-causality exists

Source: Dobnik, 2011

Appendix 2

Renewable Energy Consumption – Economic Growth Literature Summary

Authors	Countries	Period	Causality	Hypothesis Supported
Apergis and Danuletiu (2014)	80 countries in Western Europe, Latin America, European Union, Asia, and Africa	1990-2012	RE $\leftrightarrow$ Y	Feedback hypothesis
Apergis and Payne (2010a)	Eurasia	1992-2007	RE $\leftrightarrow$ Y	Feedback hypothesis
Apergis and Payne (2010b)	OECD countries	1985 - 2005	RE $\leftrightarrow$ Y	Feedback hypothesis
Apergis and Payne (2010c)	Central America	1980-2006	RE $\leftrightarrow$ Y	Feedback hypothesis
Apergis and Payne (2011a)	80 countries	1990-2007	RE $\leftrightarrow$ Y NRE $\leftrightarrow$ Y	Feedback hypothesis
Apergis and Payne (2011b)	16 emerging makret economies	1990-2007	REE $\leftrightarrow$ Y NREE $\leftrightarrow$ Y	Feedback hypothesis Feedback hypothesis
Bhattacharya et al. (2015)	Top 38 renewable energy producing countries	1991-2012	23 countries: RE $\rightarrow$ Y 4 countries: Y $\rightarrow$ RE 11 countries: RE $\neq$ Y	Growth hypothesis Conservation hypothesis Neutrality hypothesis
Bobinaite et al. (2011)	Lithuania	1990-2009	RE $\rightarrow$ Y	Growth hypothesis (in the short run)
Bozkurt and Destek (2015)	U.S., Germany, Turkey, and Italy	1980-2012	U.S. & Germany: RE $\rightarrow$ Y Turkey & Italy: Y $\rightarrow$ RE	Growth hypothesis Conservation hypothesis
Ocal and Aslan (2013)	Turkey		Y $\rightarrow$ RE	Conservation hypothesis
Okyay et al. (2014)	Europe	1990-2011	NRE $\rightarrow$ Y	Growth hypothesis
Ozturk and Bilgili (2015)	Sub-Sahara Africa	1980-2009	Biomass $\rightarrow$ Y	Growth hypothesis
Sadorsky (2009)	Emerging market economies	1994-2003	RE $\leftrightarrow$ Y	Feedback hypothesis
Shafiei et al. (2013)	OECD countries	1980-2011	RE $\leftrightarrow$ Y NRE $\leftrightarrow$ Y	Feedback hypothesis Feedback hypothesis
Shahbaz et al. (2015)	Pakistan	1972-2011	RE $\leftrightarrow$ Y	Feedback hypothesis
Yildirim et al. (2012)	U.S.		RE $\neq$ Y	Neutrality hypothesis

Notes:
-All hypotheses refer to the long-run causality effects unless otherwise specified
-RE stands for renewable energy consumption and NRE stands for non-renewable energy consumption
-REE stands for renewable electricity consumption and NREE stands for non-renewable electricity consumption
-Y stands for real GDP
-Biomass stands for consumption of renewable biomass energy sources

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