The Role of Renewable and Non-Renewable Energy on Economic Growth and the Environment

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ABSTRACT

The consequences of human activities on the ecosystem and the environment have its inherent implications. This has been a topical discourse among energy economist /environmental practitioners and government officials saddled with the mandate to formulate energy blueprint and action plans. Thus, the need to carefully underpin the root cause and propose possible ways to mitigate against the protection of the environment is pertinent in a time of global consciousness towards green energy sources. This thesis is based upon this motivation. The thesis is structured into four parts. First, the investigation of energy use and economic growth nexus from 1960 to 2016 in South Africa while accounting for capital, labor, and carbon dioxide emissions. We applied Bayer and Hanck (2013) combined co-integration approach, Pesaran, et al. (2001) bounds test and Kripfganz and Schneider (2018) critical values and approximate p-values. The empirical evidence finds support for a long-run equilibrium relationship among investigated variables. The Granger causality test indicates one-way causality from energy use to economic growth, validating the energy-led growth hypothesis. Our study found an inverted U-shaped pattern between energy use and economic growth in the long run. This finding suggests that at a higher level of economic development there is less intensification of energy consumption, hence, signifying a decline in energy intensity while validating energy efficiency in South Africa.

The second strands of this thesis proceed to examine the long-run and causal interaction between, renewable energy consumption, non-renewable energy consumption, and economic growth in a carbon function. The current study

incorporates natural resources rent to the model as an additional variable. Empirical evidence is based on a balanced panel data between annual periods of 1996-2014 for selected EU-16 countries. The Kao test reveals a cointegration between carbon dioxide emissions, economic growth, natural resources rent, renewable, and nonrenewable energy consumption. The Panel Pooled Mean Group-Autoregressive Auto regressive distributive lag model (PMG-ARDL) suggests a positive significant relationship between the countries' natural resource rent and CO_2 emissions in the long-run. Implying that the overdependence on natural resource rent affects environmental sustainability of the panel countries if conservation and management options are ignored. Our study affirms that nonrenewable energy consumption and economic growth increase carbon emission flaring while renewable consumption declines CO_2 emissions. The panel causality analysis reveals a feedback mechanism between economic growth, renewable, and nonrenewable energy consumption. We further observed a feedback causality between natural resources rent and economic growth. Effective policy implications could be drawn toward cleaner and environmentally friendly energy sources, especially in attaining the Sustainable Development Goals.

The third strand of this dissertation offers a new perspective to the electricity-led growth hypothesis for the case of Pakistan. The dissertation revisits the interaction between electricity consumption, real gross domestic product and carbon dioxide emissions in Pakistan. To this end, our study relies on annual data from 1971-2014 for the econometric analysis while accounting for the structural break(s). According to the Maki cointegration test, a cointegration equilibrium relationship exists among electricity consumption, economic growth and carbon dioxide emissions. The empirical findings from Toda-Yamamoto causality test provided the following insights: (i) A unidirectional causality was found running from economic growth to electricity consumption. Thus, this study validates the conservative hypothesis, meaning that in Pakistan, conservative energy strategies cannot harm economic progress. (ii) Causality was also found running from electricity consumption to carbon dioxide emissions. This implies that industrial activities trigger an increase in carbon emissions flaring which in return translates into environmental degradation. This outcome has inherent policy implications which are further discussed in the conclusion section.

Finally, the last section of this dissertation dwells on electricity consumption, carbon dioxide emissions and economic growth for the case of Zimbabwe. To achieve this, the study set off by examining the stationarity properties of the variables under review with the Zivot-Andrews (1992) unit root test that accounts for a single structural break. Subsequently, Maki (2012) cointegration test, which accounts for multiple structural breaks, is applied for equilibrium relationship between the variables under review while the long run regression of dynamic ordinary least square (DOLS) is employed for long-run coefficients as estimation procedures. In order to account for the direction of causality flow the Toda-Yamamoto (1995) causality test is used for annual frequency data set spanning from 1971-2014. Empirical evidence from the Maki cointegration test shows that there exists a long-run equilibrium relationship between electricity consumption, carbon dioxide emissions and real gross domestic product per capita over the sampled period. The long-run regression suggests that there exists a positive statistically significant relationship between real income and electricity consumption. Thus, corroborating the electricity-led growth hypothesis. This result is supported by the causality test, as one-way causality is observed running from electricity consumption to real gross domestic product. Thus, this is suggestive to government administrators and policymakers that the Zimbabwean economy is

electricity dependent. However, there is a tradeoff for environmental quality. As increase in electricity consumption increases carbon dioxide emissions. The need for diversification of Zimbabwe energy portfolio to cleaner and environmentally friendly energy sources is recommended given the world global consciousness for cleaner energy consumption.

Keywords: Energy conservation hypothesis, energy consumption, combined cointegration, Dynamic causality, Renewable energy consumption, non-renewable, Electricity Consumption, Economic Growth, Maki Cointegration, South Africa, and Pakistan.

ÖZ

İnsan faaliyetlerinin ekosistem ve çevre üzerindeki sonuçlarının kendine has etkileri vardır. Bu, enerji planını ve eylem planlarını formüle etme zorunluluğuyla ilgilenen enerji ekonomisti / çevre pratisyenleri ve hükümet yetkilileri arasında güncel bir konu olmuştur. Bu nedenle, çevresel problemlerin kök nedenini dikkatlice araştırmak ve çevrenin korunmasına karşı önlem almanın olası yollarını önerme ihtiyacı, yeşil enerji kaynaklarına karşı küresel bilinçlenme döneminde geçerlidir. Bu tez, bu motivasyona dayanmaktadır. Tez dört bölüme ayrılmıştır. İlk olarak, Güney Afrika'da 1960'tan 2016'ya enerji kullanımı ve ekonomik büyüme ilişkisi, sermaye, emek ve karbondioksit emisyonları dikkate alınarak araştırılmıştır. Bu ilişkiyi araştırmak için Bayer ve Hanck (2013) eşbütünleşme yaklaşımı, Pesaran ve ark. (2001) sınır testi ve Kripfganz ve Schneider (2018) kritik değerleri ve yaklaşık p değerleri uygulanmıştır. Ampirik kanıt, incelenen değişkenler arasında uzun dönemli bir ilişki olduğunu desteklemektedir. Granger nedensellik testi, enerji kaynaklı büyüme hipotezini doğrulayarak, enerji kullanımından ekonomik büyümeye tek yönlü bir nedensellik ilişkisi olduğunu göstermektedir. Çalışmamızda, uzun vadede enerji kullanımı ile ekonomik büyüme arasında ters U şeklinde bir ilişki bulunmuştur. Bu bulgu, daha yüksek bir ekonomik gelişme düzeyinde, enerji tüketiminde daha az yoğunlaşma olduğunu, dolayısıyla Güney Afrika'da enerji verimliliğini doğrularken enerji yoğunluğunda bir düşüş olduğunu göstermektedir.

Tezin ikinci kısmında, bir karbon fonksiyonunda yenilenebilir enerji tüketimi, yenilenemeyen enerji tüketimi ve ekonomik büyüme arasındaki uzun dönem ve nedensellik ilişkisi incelenmektedir. Bu çalışma, kiralanan doğal kaynaklar modele ek

bir değişken olarak dahil edilmiştir. Ampirik sonuçlar, seçilen AB-16 ülkeleri için yıllık 1996-2014 dönemleri arasındaki dengeli bir panel verilerine dayanmaktadır. Kao testi, karbondioksit emisyonları, ekonomik büyüme, doğal kaynaklar kirası, yenilenebilir ve yenilenemeyen enerji tüketimi arasında bir uzun dönemli bir ilişki olduğunu ortaya koymaktadır. Panel Havuzlanmış Ortalama Grup-Gecikmesi dağıtılmış otoregresif model (PMG-ARDL) sonuçları, uzun vadede ülkelerin doğal kaynak kirası ve CO2 emisyonları arasında pozitif bir ilişki olduğunu göstermektedir. Koruma ve yönetim seçeneklerinin göz ardı edilmesi durumunda, doğal kaynak kirasına aşırı bağımlılığın panel ülkelerinin çevresel sürdürülebilirliğini etkilediği ortaya konmuştur. Çalışmamız, yenilenemeyen enerji tüketiminin ve ekonomik büyümenin karbon salınımını artırdığını, yenilenebilir tüketimin CO2 emisyonlarını azalttığını doğrulamaktadır. Panel nedensellik analizi, ekonomik büyüme, yenilenebilir ve yenilenemeyen enerji tüketimi arasında bir geri bildirim mekanizması ortaya koymaktadır. Ayrıca, doğal kaynak kirası ile ekonomik büyüme arasında bir geri beslemeli nedensellik ilişkisi bulunmuştur. Özellikle sürdürülebilir kalkınma hedeflerine ulaşmak için daha temiz ve çevre dostu enerji kaynaklarına yönelik etkili politika sonuçları çizilebilir.

Bu tezin üçüncü kısmı, Pakistan için elektrik kaynaklı büyüme hipotezi üzerine yeni bir bakış açısı sunmaktadır. Tez, Pakistan'da elektrik tüketimi, reel gayri safi yurtiçi hasıla ve karbondioksit emisyonları arasındaki ilişkiyi incelemektedir. Bu amaçla, çalışmamız, yapısal kırılmayı dikkate alan ekonometrik analizler için 1971-2014 yılları arasındaki yıllık verilere dayanmaktadır. Maki eşbütünleşme testine göre, elektrik tüketimi, ekonomik büyüme ve karbondioksit emisyonları arasında uzun dönemli ilişki vardır. Toda-Yamamoto nedensellik testinden elde edilen ampirik bulgular: (i) Ekonomik büyümeden elektrik tüketimine tek yönlü bir nedensellik ilişkisi bulunmuştur. Bu nedenle, bu çalışma muhafazakâr hipotezini doğrular, yani Pakistan'da muhafazakâr enerji stratejileri ekonomik ilerlemeye zarar veremez. (ii) elektrik tüketiminden karbondioksit emisyonlarına da tek yönlü nedensellik ilişkisi bulunmuştur. Bu sonuca göre, endüstriyel faaliyetler, karbon salınımında bir artışa neden olur ve bunun karşılığında çevresel bozulmaya neden olduğu bulunmuştur.

Son olarak, bu tezin son bölümünde, Zimbabwe için elektrik tüketimi, karbondioksit emisyonları ve ekonomik büyüme ilişkisi ele alınmıştır. Bu amaçla çalışmada öncelikle, incelenen değişkenlerin durağanlık özelliklerini incelemek için tek bir yapısal kırılmayı dikkate alan Zivot-Andrews (1992) birim kök testi uygulanmıştır. Daha sonra, birden fazla yapısal kırılmayı hesaba katan Maki (2012) eşbütünleşme testi incelenen değişkenler arasındaki denge ilişkisine uygulanırken, dinamik en küçük kareler yöntemi (DOLS) uzun dönem regresyonu tahmin prosedürleri olarak uzun dönem katsayıları için kullanılır. Nedensellik ilişkisinin yönünü belirleyebilmek için, Toda-Yamamoto (1995) nedensellik testi, 1971-2014 arasında değişen yıllık frekans verileri için kullanılmıştır. Maki eşbütünleşme testinden elde edilen ampirik sonuçlara göre, incelenen dönemde elektrik tüketimi, karbondioksit emisyonları ve kişi başına düşen reel gayri safi yurtiçi hasıla arasında uzun dönemli bir ilişki bulunmuştur. Uzun dönem regresyon sonuçları ise reel gelir ile elektrik tüketimi arasında istatistiksel olarak anlamlı bir ilişki olduğunu göstermektedir. Böylece, elektrik kaynaklı büyüme hipotezini desteklemektedir. Bu sonuç nedensellik testi ile de desteklenmektedir, çünkü elektrik tüketiminden reel gayri safi yurtiçi hasılaya doğru tek yönlü nedensellik ilişkisi gözlemlenmiştir. Bu nedenle, devlet yöneticileri ve politika yapıcılar için Zimbabwe ekonomisinin elektriğe bağlı olduğu öne sürülmektedir. Ancak, çevresel kalite için bir dezavantaj var. Elektrik tüketimindeki artış, karbondioksit emisyonunu artırdıkça. Zimbabwe enerji portföyünün daha temiz ve çevre dostu enerji kaynaklarına çeşitlendirilmesi ihtiyacı, daha temiz enerji tüketimi konusunda dünyaya duyduğu dünya bilinci göz önünde bulundurulması önerilir.

Anahtar Kelimeler: Enerji tasarrufu hipotezi, enerji tüketimi, kombine eşbütünleşme, Dinamik nedensellik, Yenilenebilir enerji tüketimi, Yenilenemeyen enerji tüketimi, Ekonomik Büyüme, Maki Eşbütünleşme, Güney Afrika ve Pakistan.

DEDICATION

I dedicate this work to God Almighty my maker.

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ARDL	Autoregressive Distributed Lag
BP	British Petroleum
BRICS	Brazil Russia Indian China and South Africa
DEM	Department of Energy and Minerals
GCC	Gulf Cooperation Countries
HP	Hodrick Prescott
PMG-ARDL	Pool Mean Group Autoregressive Distributed Lag
TY	Toda-Yamamoto
VECM	Vector Error Correction Model
ZA	Zivot Andrews

Chapter 1

INTRODUCTION

The pioneering study on the linkage between energy consumption and economic growth by Kraft and Kraft (1978) conducted for the United States was an invitation for several other studies to take place in different countries and blocs of countries (Emir and Bekun, 2019; Sarkodie and Owusu 2017; Tang *et al*. 2013; Sadorsky 2011; Apergis and Payne 2010; Balcilar *et al*.2010). The discussion of this topic is still heated in the energy economics literature, as much attention has been placed on the outcomes by energy practitioners and government administrators, particularly since it has been observed that economies with higher energy production and consumption have higher per capita incomes (Owusu and Asumadu, 2016).

This dissertation is built on the theoretical foundation proposed by Simon Kuznets (1955) on the conceptualization of the relationship between economic growth and inequality. This phenomenon has since been adopted in the energy literature to conceptualize the Environmental Kuznets Curve hypothesis (EKC hereafter). This EKC concept explains the tradeoff between environmental degradation popularly measured by carbon dioxide emission (CO_2) and economic growth. The idea was popularized by Grossman and Krueger (1995) since then several other studies have been documented in the literature that validated the hypothesis (Katircioğlu & Katircioğlu, 2018; Katircioğlu & Taşpinar,2017; Katircioğlu,2014). This dissertation adds to the existing literature by querying further determinant of Greenhouse gas emission (GHG), given intense energy consumption. This thesis augments the conventional EKC setting by incorporating resources rent which has receive little or no attention in the literature given the environmental cost implication of extraction of the total natural resources from the primary stage to its final rent stage. This dissertation seeks to fill this gap. Thus, it is pertinent for government administrators and all stakeholders to understand the dynamic interaction between the variables under investigation for them to engage in effective and robust energy and environmental policy construction forms the first section of this dissertation with the search light on South Africa. The South Africa economy has an interesting energy mix worthy of investigation.

The second strands of this dissertation focus on a pertinent issue on the environment. One of the most pertinent environmental turmoil of the past decades is global warming, thus it has continued to characterize the global climate change. Through the contribution of labor, capital resources and other production inputs, increased human activities are largely responsible for the growth in the world’s economy (Owusu and Asumadu, 2016). However, competition for natural resources and sustainability among organism, especially human, have been linked to environmental degradation. So far, carbon emissions remain the largest contributor to declining environmental sustainability. The concentration of carbon dioxide (CO_2) emission has reportedly increased by about 45% in the last 130 years (Carbon Footprint, 2018). Thus, the need *to* the underpinning of the dynamic nexus of resource rent, renewable energy and non-renewable energy with carbon dioxide emissions of the 16 EU countries (Austria, Belgium, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Portugal, Spain, Sweden, and United Kingdom) over the period

1996-2014 with panel econometrics procedure to address the hypothesis nexus between the highlighted variables.

The third section of this dissertation focus on the electricity consumption and economic growth nexus in Zimbabwe in a multivariate framework by the inclusion of carbon dioxide emissions to control for the impact of environmental quality in regards to energy consumption and economic growth over the investigated time frame. Studies of this sort is pertinent for the case of Zimbabwe given the huge deficit in energy demand in the last decades. The direction of causality flow is also investigated in the course of the study to properly inform stakeholders and policymakers alike to more insightful judgement in terms of causality outcomes.

The Last section of this thesis attempt to render new argument to the electricity-economic growth nexus. Most recently economies around the globe have recently experienced energy shortage due to the swift increase in energy demand (Balcilar et al. 2010; Dlamini et al. 2015; Sekantsi and Okot 2016; Tamba et al. 2017). This is so, given the integral role energy (electricity) plays in socio-economic growth and development, both in developing and developed nations. The debate on whether economic development precedes energy consumption or vice versa is still heated in the energy economics literature and has led energy scholars to explore the dynamic relationship and causality between electricity consumption and macroeconomic variables like income, gross national product, employment, and energy price among others. Thus, this current study focuses on Pakistan, a country faced with a huge electrification deficit and an underdeveloped energy infrastructure which has crippled its economic productivity.

Finally, the last sections harmonize the key findings and concludes the sequence of studies and in a stylized manner with inherent policy implications accordingly.

Chapter 2

ANOTHER LOOK AT THE RELATIONSHIP BETWEEN ENERGY CONSUMPTION, CARBON DIOXIDE EMISSIONS, AND ECONOMIC GROWTH IN SOUTH AFRICA

The pioneering study on the linkage between energy consumption and economic growth by Kraft and Kraft (1978) conducted for the United States was an invitation for several other studies to take place in different countries and blocs of countries (Emir and Bekun, 2019; Akadiri et al. 2018; Sarkodie and Owusu 2017; Tang et al. 2013; Sadorsky 2011; Apergis and Payne 2010). The discussion of this topic is still heated in the energy economics literature, as much attention has been placed on the outcomes by energy practitioners and government administrators, particularly since it has been observed that economies with higher energy production and consumption have higher per capita incomes (Owusu and Asumadu, 2016). Thus, it is pertinent for government administrators and all stakeholders to understand the dynamic interaction between the variables under investigation for them to engage in effective and robust energy and environmental policy construction.

Thus far, the energy literature has produced four well-established strands based on causality flows (Inglesi-Lotz and Pouris, 2016; Sarkodie and Adom, 2018; Sarkodie et al., 2019). The first strand involves the energy led-growth hypothesis. This divide in the literature asserts that economic growth is premised on increased energy consumption (*inter alia* Damette and Seghir 2013; Ghali and El-Sakka 2004). The second strand or group consists of the conservative hypotheses (Baranzini et al. 2013; Jamil and Ahmad 2010), in which economic activities are said to drive higher energy consumption. The third strand is represented by what is known as feedback causality, in which causality is observed to be running from both sides (Lee et al. 2008; Tang and Tan 2013). Finally, the fourth strand centres on the neutrality hypothesis (Halicioglu 2009; Soytas and Sari 2006), in which there is no causality in either direction from economic growth and energy consumption.[1]

There exist well-documented studies in the energy economics literature, which have been done mostly on developed economies in the past decades. However, little or no studies regarding the theme for the case Sub-Saharan Africa (SSA). Thus, this current study seeks to fill this identified gap by focusing on South Africa. This attention has become necessary given the central role the country plays on the continent. To the best of our knowledge, only Balcilar (2010), Menyah and Wolde-Rufael (2010) have investigated this relationship in South Africa. The statistics from the South Africa Department of Energy and Minerals (DEM, 2008) provides ample evidence that the South African economy is energy driven. Its energy sector accounts for fifteen percent of the nation's economic output, with coal ranking top contributor to her energy source. Further statistics from the World Bank (2016) shows that approximately 70 percent of the nation's aggregate energy supply is extracted from coal, while its coal-fired power plant stations account for 93 percent of its electricity production. Over-

[1] For brevity of space, the interested reader can consult the studies of Ozturk, I. for a detail survey on the energy-growth literature.

dependence on coal by the South African economy has translated into intense levels of carbon emissions (Winkler 2007). South Africa is reputed to be the 7^{th} largest greenhouse gas emitter in the world.

Following the studies of Odhiambo (2009) and Ziramba (2009) for the case of South Africa, the current study extends the extant literature by investigating the long run and causality interaction between the considered variables while accounting for capital, labor, and the dynamics of carbon dioxide emissions in a multivariate framework in order to avoid omitted variable bias. We also intend to extend the frontier of knowledge by examining the long-run and causality linkage between energy consumption-growth nexus for the South Africa economy. Our study's novelty/contribution also relies on the adoption of recent time series econometrics methodologies that account for a possible structural break, something previous studies fail to address. Our study uses the unit root test reputed to account for a single structural break advanced by Zivot-Andrews (ZA), (1992) to investigate the stationarity traits of the series under review. An ADRL bound testing was employed for cointegration analysis while modelling for possible break years. The newly advanced combined cointegration by Bayer and Hanck (BH), (2013) was also applied to affirm cointegration results over the investigated period. Subsequently, causality analysis was conducted via Granger causality methodology.

The rest of this study is structured as: Section 2 renders brief insights into the South African energy sector and CO_2 emissions. Section 3 focuses on sources of data and methodological procedure applied. Section 4 presents the study findings and discussion. Concluding remarks and policy implication(s) are presented in Section 5.

2.1 An Overview of Energy Sector Dynamics in South Africa

South Africa has dynamic geographical features, with a coastline that stretches more than 2,500 kilometres (1,600 miles). South Africa is bordered by Namibia on its western coast, while southwards around the tip of Africa and to the north, it is bordered by Mozambique. South Africa is reputed to have a rapidly emerging economy with strengths in natural resources, energy, and the financial sector.

The South African economy is said to depend on its abundant coal resources. The recent statistics show that electricity mostly generated by using coal sources (almost 90% of the country's power), followed by nuclear (5.2%) and natural gas (3.2%). Furthermore, electricity needs for South Africa were expected to be more than 56000MW by 2030 (DOE, 2016). According to statistics from the Energy Council (WEC, 2016), South Africa is the 6th largest producer of coal in the world, and its energy production is primarily driven by coal. South Africa has a well-organized energy production and supply system. Regardless of its endowment in coal energy production and importation, the nation has limited crude oil and natural gas. The country also possesses some degree of renewable energy sources. A report from the DEM (2016) affirms that the nation's rich sunshine is currently being exploited for possible electricity power generation for both industrial and residential consumption. The contribution of South Africa's energy sector to the national output (i.e., GDP) is placed at 15%, which account for approximately 250,000 employment opportunities for South Africa's citizenry (Beg et al. 2002).[2]

[2] For brevity, interested readers can consult the following website for details on the South African energy dynamic: https://www.indexmundi.com/south_africa/#Energy

2.2 An Overview of CO_2 Emissions in South Africa

South Africa has a very interesting dynamic energy sector with a huge reliance on coal production for her energy needs. There has been a rise in her energy demand that has triggered carbon dioxide emissions directly and indirectly. This is substantiated as CO_2 emissions grow at the same pace if not more than her energy consumption and economic growth in recent times (See Figure 1).

Statistics from U.S energy information administration reveals that South Africa is reputed as most intensive carbon emission non-oil producing developing country (EIA, 2010). South Africa accounts for 42% of Africa emissions, alone which stretch more than entire sub-Saharan Africa together as well as greenhouse gas emitter, on the world sale 1% of world emissions. This is derived from her huge coal operation in the economy that drives CO_2 emissions (Nasr et al., 2015; Shahbaz et al., 2013; EIA, 2010). Figure 1 provides the dynamics of economic growth, energy use and CO_2 emissions level of South Africa. Figure 1 shows a strong evidence of economic progress and a rise in energy use and CO_2 level as their trend increases. Meaning that the higher the economic growth and energy use, the higher environmental degradation in South Africa. Thus, there were some giant strides to mitigate the menace that threatens environmental sustainability. Among such strides is seen in South Africa's membership as a signatory to the Kyoto protocol and the Paris agreement. Since fossil fuel-based energy sources still dominate South Africa's energy sector portfolio, hence, increases energy intensity, South Africa faces higher challenges of environmental degradation. DOE (2016) report suggests that about 18,000 MW of renewable energy in South Africa's energy mix would reduce CO_2 emissions by 34% by 2020 as a part of its commitment to the Paris agreement.

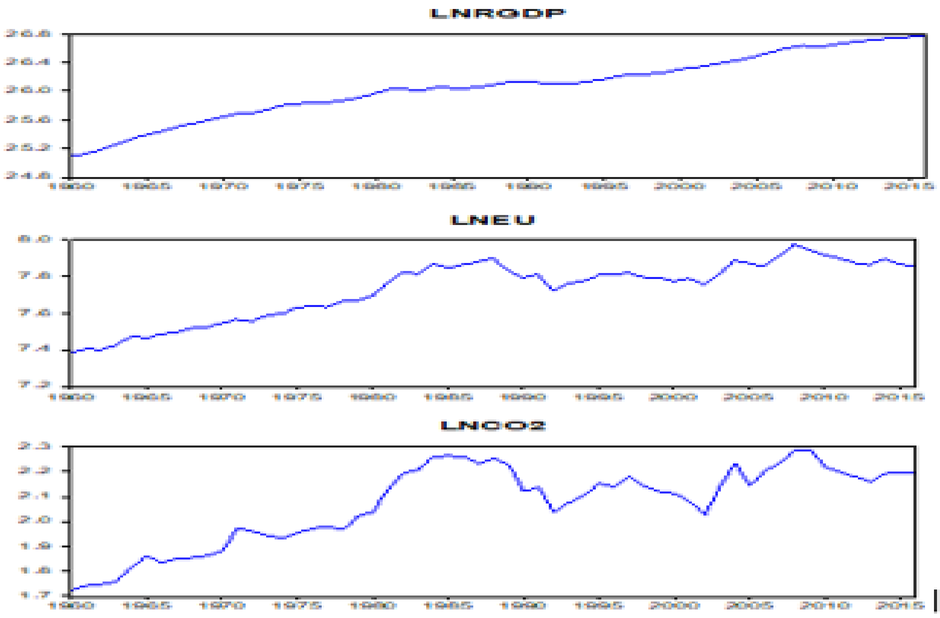

Figure 1: Dynamics of Economic Growth, Energy Use and CO2 Emission in South Africa.

2.3 Materials and Methods

To examine long- and short- run interactions between economic growth (RGDP), use of energy (EU), gross capital formation (K), labor (L), and carbon dioxide emissions (CO_2) in South Africa, data for the above-mentioned variables were collated from the World Bank Indicators (www.databank.worldbank.org), with the exception of labor. The labour data was obtained from the Conference Board of Canada (2018). The selection of the variables is based on the Sustainable Development Goals (SDGs) 7,8,9 and 13 (United Nations, 2015). Energy use — Access to energy and its related services plays a critical role in economic development, thus, sustainable development (SDG 7). Economic growth — A sustained economic development relies on improved labour productivity and access to financial services (SDG 8). Labour/Gross capital formation — Improvements in employment, labour productivity, and manufacturing output depend on renewed investments needed to build strong infrastructures, thus, improving industrial share economic development (SDG 9). Carbon dioxide emissions —

Climate change mitigation depends on responsible consumption and production option of energy and its related services (SDG 13). Annual frequency data from 1960 to 2016 was used to examine the interactions among the interested variables. The investigated variables were used in their logarithmic form to minimize problems with heteroscedasticity. RGDP and CO_2 are used as proxies for economic growth and environmental degradation, respectively. RGDP and gross capital formation (K) are measured in constant 2010 USD, CO_2 is measured in metric tons per capita, and EU is measured in kg of oil equivalent per capita. The functional relationship for this study is expressed as (Soytas and Sari, 2009):

$$EU = f\,(RGDP, RGDP^2, K, L, CO_2) \quad (1)$$

$$CO_2 = f\,(RGDP, EU, K) \quad (2)$$

$$lnEU_t = \alpha + \beta_1 lnRGDP_t + \beta_2 lnRGDP_t{}^2 + \beta_3 lnL_t + \beta_4 lnK_t + \beta_5 lnC02_t + \varepsilon_t \quad (3)$$

$$ln\mathrm{CO}_{2_t} = \alpha + \beta_1 lnRGDP_t + \beta_2 ln\mathrm{EU} + \beta_3 lnK_t + \varepsilon_t \quad (4)$$

where α is a constant term, and the β's is slope parameters which need to be estimated. To examine for possible long-run interactions amongst these variables, BH (2013) combined cointegration technique was employed, and the results were confirmed using Pesaran et al. (2001) Bounds testing technique. Furthermore, short-run interactions among the variables under consideration were also investigated.

The stationarity properties of the series were examined prior to the cointegration test. Therefore, we employed the conventional ADF and PP unit root tests. However, these tests do not consider structural breaks. Thus, to account for a possible structural break, ZA (1992) test was employed. Once we had the information on the order of integration of the series, an attempt is made to examine the presence of a cointegration among the variables by employing the more recent BH (2013) test and Bounds testing approach.

Bayer and Hanck's (2013) cointegration technique combine the tests of Engel and Granger (EG) (1987) and Johansen (JOH), the error correction F-test of Boswijk (BO) (1994), and the error correction t-test of Banerjee et al. (BDM) (1998). Bayer and Hanck's (2013) technique depend on the same order of integration of the series, i.e., all variables are integrated order one, and jointly determines test statistics for the listed techniques. The BH test has a null hypothesis of no cointegration against an alternative of cointegration among variables. The Fisher's equation is provided below.

$$EG - JOH = -2[\ln(P_{EG}) + (P_{JOH})] \tag{5}$$

$$EG - JOH - BO - BDM = -2[\ln((P_{EG}) + (P_{JOH}) + (P_{BO}) + (P_{BDM}) \tag{6}$$

where pEG, pJOH, pBO, and pBDM represent the significance levels for the Engel and Granger (1987), Johansen (1991), Boswijk (1994), and Banerjee et al. (1998) cointegration tests, respectively. Thus, if the computed Fisher (1932) statistic is greater than the critical values provided by the BH (2013) combined cointegration statistics, the hypothesis of non-convergence is rejected.

To confirm the consistency and robustness of the results, the bounds testing approach was employed in the presence of structural breaks. This approach describes a dynamic unrestricted error model by using a linear transformation that joins together the long run and short-run dynamics without losing any information for the long run (Pesaran et al. 2001). A dynamic unrestricted error model presented below:

$$\Delta\, ln\, E\, U_t = \theta_1 + \theta_2 EU_t + \theta_3\, ln\, R\, GDP + \theta_4\, ln\, R\, GDP_{t-1}^2 + \theta_5\, ln\, K_{t-1} + \theta_6\, ln\, L_{t-1} + \sum_{j=1}^{p} \theta_j \Delta\, ln\, E\, U_{t-j} + \sum_{k=0}^{q} \theta_k \Delta\, ln\, R\, GDP_{t-k} + \sum_{l=0}^{r} \theta_l \Delta\, ln\, R\, GDP_{t-l}^2 + \sum_{m=0}^{s} \theta_m \Delta\, ln\, K_{t-m} + \sum_{n=0}^{t} \theta_n \Delta\, ln\, L_{t-n} + \mu t \tag{7}$$

$$\Delta ln\mathrm{CO}_{2_t} = \theta_1 + \theta_1 lnCO_{2t} + \theta_2\, ln\, R\, GDP + \theta_3\, ln\, EU_{t-1} + \theta_4\, ln\, K_{t-1} + \sum_{j=1}^{p} \theta_j \Delta\, ln\, \mathrm{CO}_{2_{t-j}} + \sum_{k=0}^{q} \theta_k \Delta\, ln\, R\, GDP_{t-k} + \sum_{l=0}^{r} \theta_l \Delta lnEU_{t-1} + \sum_{m=0}^{s} \theta_m \Delta\, ln\, K_{t-m} + \mu t \qquad (8)$$

"where" Δ and μ represent the first difference operator and the normally distributed residual term, respectively. After that, to examine the cointegration relationship between investigated variables, the Wald test was employed by imposing limitations on the estimated coefficients. If the calculated F-statistic exceeds the upper level, then the hypothesis of no cointegration among variables is rejected. Furthermore, our study's fitted model was subjected to diagnostic and robustness checks, including normality, heteroscedasticity, and autocorrelation tests. Also, model stability was confirmed using the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMsq) tests. Finally, we applied the causality test to examine the directions of flow of the dynamic causal link among the investigated variables.

2.4 Results and Empirical Findings

To scrutinize the stationarity of the data series (Appendix A) as a precondition of the cointegration method, the study employs ADF and PP unit root tests to check the stationary properties. Table 1 reports the outcomes of these tests and their order of integration while accounting for a possible structural break[3]. However, in the presence of a structural break in the series, ADF and PP unit root tests are weak; the result is biased and gives spurious results in terms of the non-rejection of the unit root hypothesis (Shahbaz et al. 2013). Therefore, the ZA (1992) unit root test was employed to define the breakpoint. All test statistics support the claim that all variables have unit root in their level form and integrated order one.

[3] For brevity, visual plots of the series show possible structural breaks. The graphs can be made available on request.

Table 1: Unit Root Results

Panel A: Level				
Variables	ADF	PP	ZA Unit Root Test	
	t-statistics	T-statistics	T-statistics	Time break
LnRGDP	-3.2826	-2.8756	-3.6053(1)	2005
$LnRGDP^2$	-3.1836	-2.7683	-3.5365(1)	2005
LnEU	-1.5659	-1.5548	-4.1484(0)	1989
LnK	-2.5164	-2.1299	-4.5058(1)	1985
LnL	-1.9412	-2.1027	-4.0524(0)	1987
$LnCO_2$	-1.9311	-1.9822	-4.0419(0)	1990
Panel B: Δ				
Variables	ADF	PP	ZA Unit root test	
	t-statistics	T-statistics	T-statistics	Time break
LnRGDP	-4.5868*	-4.6307*	-6.2114(0)*	1994
$LnRGDP^2$	-4.6072*	-4.6523*	-6.1903(0)*	1994
LnEU	-7.6523*	-7.6548*	-8.3256(0)*	2003
LnK	-5.7784*	-5.9456*	-7.1826(1)*	1994
LnL	-6.8072*	-6.8968*	-7.8831(0)*	1992
$LnCO_2$	-7.3071*	-7.3070*	-7.9337(0)*	2003

Source: Authors' computations
Note: *, ** denote the 1% and 5% significance levels, respectively. The Mackinnon (1996) one-sided p-value is reported. Models with intercept and trend were reported for ADF and PP test statistics. () indicate the lag lengths of the variables. Δ represents first difference.

Since all the variables are stationary at their first differenced, the BH (2013) combined cointegration test was employed to test the cointegration among the variables. Table 2 presents the results and demonstrates that the calculated Fisher statistics for EG-JOH, as well as for EG-JOH-BO-BDM, for EU, RGDP, $RGDP^2$, K, L, and CO_2 are consistently greater than the critical value at a one percent significance level. Therefore, we can infer that the series EU, RGDP, $RGDP^2$, K, L, and CO_2 are cointegrated and a long run interaction exists among the variables over the investigated period. Furthermore, the ARDL bounds testing result validates BH (2013) conclusion and discovers long-run relationships between the variables at the 1% level of significance. The right-hand column of Table 2 presents the residual diagnostic check for the model. The fitted model is free from both serial correlation and heteroscedasticity and it's properly specified. The CUSUM and CUSUMsq plots were found between the 95% confidence interval, thus, our model meets the stability conditions[4].

Table 2: Bayer and Hanck (2013) Test Results

Models	EG-JOH	EG-JOH-BO-BDM	Cointegration remark	
RGDP=f (RGDP2,EU,K,L,CO_2)	55.3491*	165.8732*	Yes	
$RGDP^2$=f (RGDP,EU,K,L,CO_2)	55.3652*	165.8893*	Yes	
EU=f (RGDP,$RGDP^2$,K,L,CO_2)	69.0775*	92.1235*	Yes	
K=f (RGDP,$RGDP^2$,EU,L,CO_2)	61.4866*	76.4725*	Yes	
L=f (RGDP,$RGDP^2$,EU,K,CO_2)	56.0609*	68.1507*	Yes	
CO_2=f(RGDP,$RGDP^2$,EU,K,L)	66.6300*	89.6963*	Yes	
Bounds testing Results		Diagnostic test		
Estimated models	F-statistics	χ^2 white	χ^2 LM test	χ^2 RESET
EU =f(RGDP,$RGDP^2$,K,L,CO_2)	4.9941*	0.5260	0.2707	0.9776
	Critical values			
	Lower bounds 1(0)	Upper bounds 1(1)		
1%	3.41	4.68		
5%	2.62	3.79		
10%	2.26	3.35		

Source: Authors' computations
Note: *,** represent the 0.01 and 0.05 level of significance, respectively.
Critical values for EG-JOH at 0.01 and 0.05 are 15.701 and 10.419, respectively, while, for EG-JOH-BO-BDM, they are 29.850 and 19.888, respectively.

Tables 3 reports the Pesaran, Shin, and Smith (2001) bounds test and Kripfganz and Schneider (2018) critical values and approximate p-values test results. The test further validates the existence of a level long-run relationship among the study variables. The was attain with both F-statistic and T- statistical greater than the upper bounds for all statistical significance level as well as the P-value with K=4 as the number of parameters in the fitted model. The choice of the Kripfganz and Schneider (2018) critical values rest on its uniqueness to provide more robust and reliable outcomes in the presence of small finite sample size.

[4] CUSUM and CUSUMsq tests are available upon request.

Table 3: Pesaran, Shin, and Smith Bounds Test and Kripfganz and Schneider.

$lnCO_2$	K	10%		5%		1%		p-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	10.9260	2.8200	3.9400	3.3990	4.6410	4.7250	6.2170	0.0000	0.0000
t	-6.2080	-2.5510	-3.4350	-2.8790	-3.8000	-3.5330	-4.5140	0.0000	0.0000

Source: Authors Computation.

The long- and short- run dynamic impacts of RGDP, $RGDP^2$, K, L, and CO_2 on EU are presented in Table 4. The cointegration coefficient is also statistically significant at the one percent significance level, which verifies the established long-run equilibrium among the variables. Our fitted model is robust with an error correction term of approximately 16% of the speed of adjustment to its cointegration path with the contribution of all the explanatory variables. Interestingly, our analysis found an inverted U-shaped relationship between EU and RGDP in the long run, thus, corroborates Sarkodie and Strezov (2018). That is, a one percent increase in economic activities and the square term of RGDP give rise to magnitudes of 15.2% and -0.28%, respectively. However, this hypothesis is not significant in the short-run. Energy use plays a critical role in economic growth; however, the energy-intensive economy is tantamount to pollution-intensification, which contributes negatively to environmental sustainability. The inverted U-shaped relationship between EU and RGDP implies that at a higher threshold level of economic growth, there is less intensification of energy use. The decline in energy intensity at higher development may be attributed to improvements in energy sector efficiency, structural changes in the economy and change in energy consumption patterns. Sarkodie and Strezov (2018) argued that a structural change in the economy, by moving from energy-intensive production patterns to less energy and pollution-intensive production reduces energy intensity while improving energy efficiency. Even though fossil fuel energy technologies dominate the energy portfolio in South Africa, however, a recent study (Sarkodie and Adams, 2018) reveals that the incorporation of renewable energy and clean energy technologies like nuclear energy into South Africa's energy mix have contributed immensely to energy efficiency and the decline of environmental pollution. Change in consumption patterns due to behavioural and lifestyle changes may account for the reduction in energy demand in higher economic development. It is argued that higher economic development translating into higher household income levels motivates the acquisition and the replacement of outmoded energy consuming appliances with less and energy efficient appliances — energy conservation options, hence, improving energy efficiency (Sarkodie and Adom, 2018).

Contrary to Apergis and Payne (2009) who found a positive impact of capital and labour on energy usage in Central America, our empirical results demonstrate that labour and capital have a negative effect on energy use in the long run, while labour has a positive effect on energy use in the short run. We find that a one percent increase in labour demand will cause a 0.33% decrease in energy consumption in the long-run. Along with this, a 1% rise in capital formation will cause a 0.09% reduction in energy consumption in the long run, while it will cause a 0.04% increase in the short run. The initial positive shocks in energy consumption are expected in the initial or short-term effects of gross capital formation and labour. A shift from unemployment state to an employed state is often characterized by the 'wobbling effect'. As usual, people tend to utilize all the lost opportunities during the unemployed condition, as such, reflects in energy consumption behaviour and lifestyle. However, in the long-run, as labour effect stabilizes, and income level grows, the willingness to pay for cleaner and modern energy appliances due to self-actualization leads to a reduction in energy consumption, reflecting in energy efficiency. The long-run negative effect of gross capital formation implies the acquisition of less pollution, less disposal, and energy conservative assets such as machineries, equipment, infrastructures, agricultural-related cultivated assets, among others. As investments in clean, modern and energy efficient tangible and intangible assets increases, economic productivity per energy consumption decreases, thus, reducing energy intensity while improving energy efficiency.

In the case of CO_2, a positive-significant relationship occurs between CO_2 and energy consumption both in the long run and short run. Our results are in line with Sarkodie (2018); Sarkodie and Adom (2018); Wang et al. (2018), who argues that a positive effect of carbon dioxide emission on energy use. This implies that "climate change induces by higher atmospheric greenhouse gas accumulation will cause a backfire in energy use, since more energy may be needed for heating and cooling purposes" as posited by Sarkodie and Adom (2018). This finding is of significance for government administrators and environmental specialists.

Table 4: ARDL Results

Dependent variable = lnEU			
Long-run results			
Variable	Coefficient	Std.error	T.stat.
Constant	-194.086	52.5030	-3.6967
lnRGDP	15.2060*	3.9747	3.8257
$lnRGDP^2$	-0.2879*	0.0770	-3.7408
lnK	-0.0868	0.0781	-1.1110
lnL	-0.3335**	0.1306	-2.5539
$lnCO_2$	0.9528*	0.0939	10.1520
Short-run results			
Variable	Coefficient	Std.error	T.stat.
ECT(-1)	-0.15946*	0.2578	-6.1853
ΔlnEU(-1)	0.3630***	0.1894	1.9170
ΔlnRGDP	12.3393	15.7410	0.7839
$\Delta lnRGDP^2$	-0.2231	0.2998	-0.7442
ΔlnK	0.0428	0.0389	1.0978
ΔlnL	-0.8160*	0.2097	-3.8922
$\Delta lnCO_2$	0.9324*	0.0965	9.6596

Source: Authors' computations. Note: *, **, *** represent the 0.01, 0.05, and 0.10 significance levels, respectively.

Table 5 below render the short and long run dynamics for the current study with a fast pace of adjustment of 90%, which is statistically significant at 1% level to equilibrium path with the contribution of other regressors. This is an indication of a workable mechanism. The fitted carbon function model reveals that economic growth (GDP) and carbon dioxide emission exhibits an inverse relationship. This suggests that a 1% increase in economic activities in South Africa decreases CO_2 emission by 0.25% in the long run while statistically insignificant in the short-run. This is insightful, as it indicates that South Africa's economic growth does not increase CO_2 emissions, given the country's antecedent in greenhouse gas emissions flaring over the years. The outcome further implies that South Africa has initiated compliance with global partnership and international practices in its economic dealings. Contrary to the inverse association observed between GDP and CO_2, energy use and CO_2 exhibit a positive correlation in both long- and short- run. Our results are corroborated by Kais and Sami (2016) with evidence from 58 countries, Alam et al. (2016) with evidence from Brazil, India, China, and Indonesia. This implies that an increase in energy consumption triggers carbon dioxide emissions in South Africa. Thus, government and energy stakeholders are encouraged to promote cleaner energy sources like solar, wind, hydro, bioenergy, and nuclear energy consumption. Renewable and green energy technologies have been proven to be more environmentally friendly and support ecosystem rejuvenation compared to conventional energy sources (Owusu and Asumadu, 2016). To account for the role of capital in carbon function modeling, the study examined the nexus between CO_2 emissions and capital formation. The results reveal a significant positive relationship between CO_2 emissions and capital formation in the long-run relative to the insignificant short-term effect.

Table 5: Long- and Short-run Analysis for CO_2 Emission

	ΔlnCO2	Coef.	Std. Err.	t	P>t
ADJ					
	ECT(-1)	-0.9011	0.1452	-6.2100	0.0000
LR					
	lnGDP	-0.2445	0.0469	-5.2100	0.0000
	lnEUSE	1.3200	0.0691	19.0900	0.0000
	lnK	0.0882	0.0273	3.2300	0.0020
SR					
	ΔlnGDP	-0.3792	0.2337	-1.6200	0.1110
	ΔlnEUSE	1.0832	0.1085	9.9800	0.0000
	ΔlnK	0.0673	0.0499	1.3500	0.1840
	_cons	-3.5098	0.7004	-5.0100	0.0000

Source: Authors' computations.

The Granger causality test is applied to test the directional flow of the causal relationships among variables. Table 6 provides the empirical findings of this analysis. The results affirm that there is a one-way causality running from energy use, labour, and CO_2 emissions to economic growth. The results are in line with Sepatan (2016), Bhattacharya et al. (2016), Fotourehchi (2017), and Khobai and Le Roux (2017).

Energy consumption and labour remain the building blocks of economic development. In accordance with SDG 7 and 8, improving energy production and consumption patterns and increasing labour productivity are critical to a sustainable economic development (United Nations, 2015). The one-way causality running from energy use to CO_2 emissions is supported by Shahbaz et al. (2012) and Balsalobre et al. (2018). This validates the energy-induced growth hypothesis for the case of South Africa. Sarkodie and Adams (2018) revealed that South Africa's energy portfolio is dominated by fossil fuel energy technologies especially coal power plants, as such, increases atmospheric CO_2 emissions during combustion processes. Furthermore**,** unidirectional causality is also seen from energy use to labour and CO_2 emissions as well as from CO_2 emissions to labour. Feedback causality is found between capital formation and CO_2 emissions.

Table 6: Causality Analysis

Null Hypothesis:	Causality	F-Statistic	Prob.
LNRGDP ⇏ LNEU	EU → RGDP	1.81597	0.1835
LNEU ⇏ LNRGDP		8.79044*	0.0045
$LNRGDP^2$ ⇏ LNEU	EU→$RGDP^2$	1.72000	0.1953
LNEU ⇏ $LNRGDP^2$		8.83279*	0.0044
LNK ⇏ LNEU	K≠EU	2.28493	0.1366
LNEU ⇏ LNK		0.77138	0.3838
LNL ⇏ LNEU	EU→L	0.00382	0.9510
LNEU ⇏ LNL		9.56867*	0.0032
$LNCO_2$ ⇏ LNEU	EU→CO_2	0.06587	0.7984
LNEU ⇏ $LNCO_2$		4.71200**	0.0345
$LNRGDP^2$ ⇏ LNRGDP	RGDP↔$RGDP^2$	4.79262**	0.0330
LNRGDP ⇏ $LNRGDP^2$		4.57682**	0.0370
LNK ⇏ LNRGDP	RGDP ≠ K	0.26207	0.6108
LNRGDP ⇏ LNK		1.41572	0.2394
LNL ⇏ LNRGDP	L→RGDP	2.86355***	0.0965
LNRGDP ⇏ LNL		2.42588	0.1253
$LNCO_2$ ⇏ LNRGDP	CO2→RGDP	9.79703*	0.0028
LNRGDP ⇏ $LNCO_2$		2.06006	0.1571
LNK ⇏ $LNRGDP^2$	K≠$RGDP^2$	0.21032	0.6484
$LNRGDP^2$ ⇏ LNK		1.50390	0.2255
LNL ⇏ $LNRGDP^2$	L≠$RGDP^2$	2.64300	0.1099
$LNRGDP^2$ ⇏ LNL		2.39874	0.1274
$LNCO_2$ ⇏ $LNRGDP^2$	CO_2→$RGDP^2$	9.75773*	0.0029
$LNRGDP^2$ ⇏ $LNCO_2$		1.99460	0.1637
LNL ⇏ LNK	L≠K	2.14337	0.1491
LNK ⇏ LNL		0.02119	0.8848
$LNCO_2$ ⇏ LNK	K↔CO_2	3.19973***	0.0794
LNK ⇏ $LNCO_2$		3.03314***	0.0874
$LNCO_2$ ⇏ LNL	CO2→L	7.17081*	0.0098
LNL ⇏ $LNCO_2$		0.14473	0.7051

Note: ≠ represents no Granger causality, → symbolized unidirectional causality, and ↔ represents feedback causality. ⇏ symbolized 'does not granger cause'
*, **, *** represent 0.01, 0.05 and 0.10 level of significance, respectively.

2.5 Conclusion

This study investigated the causal link between energy use and economic growth, a topical topic in energy and economics literature. Due to the lack of consensus on causality direction of the scope of the study, we draw attention to the theme by accounting for the contribution of capital, labour, and CO_2 emissions to energy use in the case of South Africa. The empirical analyses for this study span from 1960 to 2016 on an annual basis. Empirical findings reveal a long-run equilibrium relationship among the investigated variables using BH (2013) combined cointegration test and confirmed by Pesaran et al.'s (2001) bounds testing approach. This implies that the joint contributions of CO_2 emissions, economic growth, capital formation, and labour spur an increase in South Africa's energy consumption.

The causal analysis between energy use and economic growth reveals a unidirectional causality. Thus, the results validate the energy-induced growth hypothesis. This means that energy conservative policy/strategies will harm the initial economic development in South Africa, which is instructive for government administrators. Interestingly, our analysis investigated an inverted U-shaped relationship between energy consumption and economic growth in the long run. This relationship implies that at a higher threshold level of economic activities, there is less intensification of energy use. The unidirectional causality observed from energy use to CO_2 emissions is of concern to environmental specialists giving the global awareness of the need for renewable and cleaner energy sources. This is a warning sign for South Africa to strengthen its commitment to the Kyoto Protocol and the Paris Agreement.

Chapter 3

TOWARDS A SUSTAINABLE ENVIRONMENT : NEXUS BETWEEN CO_2 EMISSIONS, RESOURCE RENT, RENEWABLE AND NON-RENEWABLE ENERGY IN 16-EU COUNTRIES

3.1 Introduction

One of the most pertinent environmental turmoil of the past decades is global warming, thus it has continued to characterize the global climate change. Through the contribution of labor, capital resources and other production inputs, increased human activities are largely responsible for the growth in the world's economy (Owusu and Asumadu, 2016). However, competition for natural resources and sustainability among organism, especially human, have been linked to environmental degradation. So far, carbon emissions remain the largest contributor to declining environmental sustainability. The concentration of carbon dioxide (CO_2) emission has reportedly increased by about 45% in the last 130 years (Carbon Footprint, 2018). In addition to the emission of carbon dioxide from plants, animals and other sources, the common by-product of energy source usage has largely been attributed to carbon emissions. Unfortunately, CO_2 emissions remain unfriendly to environmental sustainability and constitute a focal factor in the global debate on climate change. Hence, the concept of mitigating carbon dioxide emissions which largely constitute the anthropogenic greenhouse gas (GHG) (about 81% of greenhouse gases), has consistently become a priority of the world's advanced economies (Owusu and Asumadu-Sarkodie, 2016). This is because CO_2 emissions have persistently remained the world's most threatening issue facing the natural ecosystem and human development. Anthropogenic CO_2 emissions trap heat in the atmosphere, thereby increasing the global temperature. According to the Intergovernmental Panel on Climate Change (IPCC, 2014) 5th assessment report, the gaseous emission has undesirably increased from 9,434.4 million tons in 1961 to 34,649.4 million tons in 2011.

In this context, the British Petroleum (BP) Statistical Review of World Energy (British Petroleum, 2018) noted that carbon dioxide emissions increased from 29,714.2 million tons in 2009 to 33,444.0 million tons in 2017. Despite the Paris Agreement of 2015[5] and the strong drive toward reducing carbon emission by member countries, the BP report indicates that the global carbon dioxide emissions have increased by 1.6% between 2006 and 2017. Importantly, between the said periods, the growth rate of carbon dioxide emissions in the European region which is only second to the Middle East countries is about 2.5% (British Petroleum, 2018). Hence, the continent has consistently been at the forefront of the push against climate change. Even after witnessing the attainment of its commitment within the first period (2008-2012) of the Kyoto Protocol, subsequent targets were set to accommodate a shift in the decomposition factors of CO_2 emission in the region. The dynamics that have impacted the changes associated with the level of energy-related carbon dioxide emissions have been identified in the extant literature. Some of these driving forces previously mentioned includes: economic growth (Apergis et al., 2010; Sarkodie and Owusu,

[5] More details relating to the Paris Agreement of 2015 is contained is available at: https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement.

2016a); fossil fuel or non-renewable energy component (Khoshnevis Yazdi and Shakouri, 2017; Nguyen and Kakinaka, 2019); renewable energy component (Inglesi-Lotz and Dogan, 2018; Khoshnevis Yazdi and Ghorchi Beygi, 2018), and other notable factors (Al-mulali, 2012; Sarkodie and Owusu, 2016b). And, specifically in the EU-28, resource rent (of the natural *resource) which* is the total revenue earned from the extraction of the natural resource, is expected to determine both the economic growth and carbon abatement policy of the region.

However, the diversity in economies and its dynamics, extant literature continues to establish the link between natural resources and the economic indicators (Ahmed et al., 2016; Badeeb et al., 2017; Balsalobre-Lorente et al., 2018; Ben-Salha et al., 2018; Satti et al., 2014; Shahbaz et al., 2018). Specifically, in panel investigation of five European (EU-5) countries, Balsalobre-Lorente et al. (2018) found that natural resources, economic growth, and renewable electricity are significant determinants of CO_2. As such, the study examined the environmental Kuznets curve (EKC) hypothesis in the observed countries for the period 1985-2016. In specifics, the relationship between economic growth and CO_2 is found to exhibit N-shape. The empirical results indicate that natural resources abundance, renewable electricity consumption, and energy innovation inhibit environmental degradation. On the other hand, the interaction between renewable electricity consumption and economic growth is found to worsen the current state of the environment. For the case of the United States (US), Shahbaz et al. (2018) applied Bayer and Hank cointegration test and vector error correction model (VECM) to detect the direction of causality for financial development, education and resource rent. The empirical evidence of the investigation which spans for the period 1960-2016 suggests a positive and statistical relationship between resource rent and financial development. A similar trend is observed between education and financial development, education is found to exert a positive impact.

The current study hypothesized the underpinning of the dynamic nexus of resource rent, renewable energy and non-renewable energy with carbon dioxide emissions of the 16 EU countries (Austria, Belgium, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Portugal, Spain, Sweden, and United Kingdom) over the period 1996-2014. Although previous literature reveals a similar scope of the study, however, this study contributes to existing literature in a few notable areas. First, contrary to previous attempts, the study further incorporates resource rent to the existing and pre-determined CO_2 emissions model. The addition of the variable would help investigate the contribution of the earnings from natural resources of the selected regions to their CO_2 abatement drive and policies. Second, the uniqueness of this study is reflected in the adopted estimation approach to investigate the concept among EU countries. As observed, the investigation considered sixteen selected EU countries which comprise accordingly to the availability of the main examined variables, especially renewable energy consumption. *Last, the study* jointly examined the short run-long run by utilizing the Pooled Mean Group/Autoregressive Distributed Lag (PMG-ARDL) and Granger causality relationships associated with the estimated model.

The remainder of the study is organized as follows: section 2 outlines the methodology employed in the study. Results and Discussion are presented in section 3 and Section 4 offers concluding remarks that include policy implication of the study.

3.2 Materials and Methods

The rising prices of fossil energy resources and the efficient use of energy account for the high convergence speed of energy transition among the European countries. Also, the energy transition policy is being advocated among these countries because of higher emission levels associated with the inefficient use of energy. In the European Union (EU), the adoption of 2001/77/EC (European Union 2001) and 2003/30/EC (European Union 2003) directives[6] has further paved way for the development of renewable energy sources. To further enhance the economic, social and environmental sustainability of the regional countries, a mandatory target and regulative framework are aimed to pave way for the adoption of renewable energy by the member states in 2020 (the EU Directive 2009/406/EC). In the region, it is reported that renewable energy is now cost-competitive and efficient even as fossil fuels imports is reduced by 16 billion Euros by early 2017. The dynamics of the natural resource rent, renewables and nonrenewable relative to carbon dioxide emissions of the European Union is further represented in Figure 2.

[6] The directives of the European Union of renewable energy is contained in https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028.

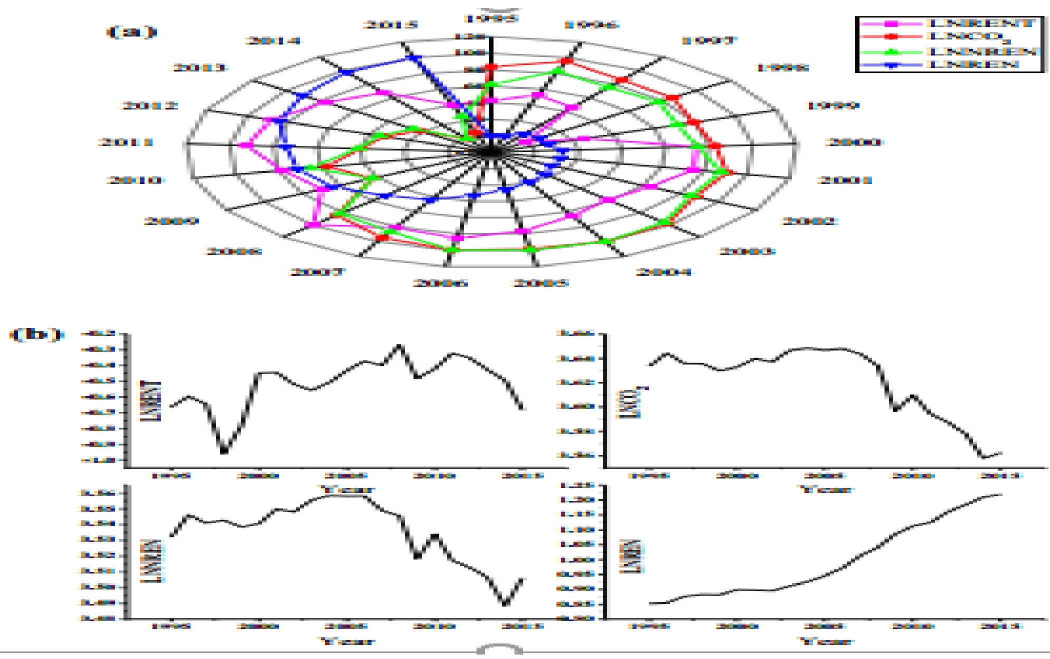

Figure 2: Dynamics of the Natural Resource Rent, Renewables and Nonrenewable Relative to Carbon Dioxide Emissions of the European Union.

3.2.1 Data

Our study employs balanced and periodically annual data 1996-2014 for the estimated series. The estimation model uses carbon dioxide emissions (CO_2) (the kilotons of the burning of solid, liquid and gas fossil fuels, gas flaring, and the manufacture of cement) as the dependent variable. The explanatory variables employed are: Real Gross Domestic Product (*GDP*) per capita (measured in constant 2010 USD), the renewable energy consumption (*REN*) as the share of renewables in the total final energy consumption, energy use (non-renewables denoted as *NREN*) is the kilogram of oil equivalent per capita which is measured in the form of primary energy source before transformation into other end-use, and the resource rent (*RENT*) is the total natural resources rents. In the estimation model, the unobserved factors are controlled for by real *GDP* per capita. The World Bank (2017) Development Indicator is the source of the aforementioned data series. Data availability (especially for renewable energy) is largely responsible for both the restricted period of the data series and the selection of the estimated countries. See Table 7 for a summary of data description.

Table 7: Data Description

Variable Name	Code	Source
Carbon dioxide emissions	C02	World development indicator
Real Gross domestic product	GDP	World development indicator
Total natural rent	RENT	World development indicator
Renewable energy consumption	REN	World development indicator
Nonrenewable energy consumption	NREN	World development indicator

Source: Authors compilation.

3.2.2 Model Estimation

While a good number of studies have explored the nexus between energy consumption and economic growth in a carbon-income model framework, with CO_2 emissions as endogenous variable see (Inglesi-Lotz and Dogan, 2018; Khoshnevis Yazdi and Shakouri, 2017; Nguyen and Kakinaka, 2019). Sadorsky (2009) posited that renewable energy consumption makes up a relatively small fraction of the overall energy mix in most countries. Thus, on the above premise the current study disaggregates energy consumption into renewable and non-renewable energy consumption. This present study add to the existing literature on carbon-income modelling by incorporating total natural resources rent[7] as a control variable following the study Satti et al., (2014), Ahmed et al., (2016), Badeeb et al., (2017) Balsalobre-Lorente et al., (2018), Ben-Salha et al., (2018) and Shahbaz et al., (2018) In this current study, we incorporate the total natural resource rent as an additional variable to capture for natural resource

[77] Total natural resource rent is the sum of oil rent, natural gas rent, coal rents (hard and soft), mineral rent and forest rent. Natural resource rent is computed by the difference between the price of a commodity and the average cost of producing it. That is, total revenue that can be generated from the extraction of the natural resources less the cost of extracting the resources (including a normal return on investment to the extractive enterprise) as outlined by (WDI,2019).

extraction cost and its implication on GHG emissions in EU, given that most natural resources are in their primary form that requires exploration i.e., (transformation from crude to finished goods for final consumption) which come with its environmental consequences. In addition, the model construction would also help us to avoid omitted variables bias problem. such that:

$$CO_2 = f(GDP, RENT, REN, NREN) \quad (9)$$

$$lnCO_{2_{i,t}} = \alpha + \beta_1 lnGDP_{i,t} + \beta_2 lnRENT_{i,t} + \beta_3 lnREN_{i,t} + \beta_4 lnNREN_{i,t} + \varepsilon_{i,t}$$

(10)

For the data series to have a constant variance, the study applies a logarithmic transformation. Here, $lnCO_{2_{i,t}}$ against $lnGDP_{i,t}$, $lnRENT_{i,t}$, $lnREN_{i,t}$, and $lnNREN_{i,t}$ denote the logarithmic transformed dependent variable versus the independent variables, α represents the intercept term, $\beta's$ are the partial slope coefficients, and $\varepsilon_{i,t}$ is the stochastic term.

Due to bias triggered by the correlation between the mean-differenced independent variables and the white noise term, standard ARDL estimation models are incapable of controlling for bias especially in panel data models with individual effects. As such, a combination of PMG estimator by Pesaran et al. (1999) and ARDL model provide a solution to the challenge contrary to the inappropriate dynamic panel generalized method of moments (GMM) estimators (Sarkodie and Strezov, 2018b).

Contrary to existing panel data models available in Destek and Sarkodie (2019), Sarkodie (2018), and Sarkodie and Strezov (2019b), this study follows the PMG-ARDL pathway utilized in Sarkodie and Strezov (2018b), expressed as:

$$\Delta lny_{i,t} = \phi_i ECT_{i,t} + \sum_{j=0}^{q-1} \Delta lnX_{i,t-j}\, \beta_{i,j} + \sum_{j=1}^{p-1} \psi_{i,j^*}\, \Delta lny_{i,t-j} + \varepsilon_{i,t} \quad (11)$$

$$ECT_{i,t} = y_{i,t-1} - X_{i,t}\theta \quad (12)$$

Where, y is the dependent variable (CO_2), X represents the regressors ($GDP, RENT, REN, NREN$) with same number of lags q across individual cross-sectional units i in time t, Δ denotes the difference operator, ϕ represents the adjustment coefficient, θ denotes the long-run coefficient that produces β and ψ estimates after reaching convergence, and ε represents the error term.

This study follows 3 paths for its empirical route. (i) Stationarity test by fisher ADF and Pesaran et al. (2003) unit root test (ii) cointegration analysis and long-run regression advanced by Pesaran et al. (1999) and (iii) Causality analysis through Dumitrescu and Hurlin (2012). However, preliminary estimation of descriptive statistics and correlation analysis were conducted.

3.3 Results and Discussion

The summary statistics are reported in Table 8. This is necessary to ascertain the basic measure of central tendency and dispersion of the variables how they fare over the investigated period (1996-2014). Table 2 shows that carbon dioxide has a minimum value of 86,759 kt tones from the start-up years with a maximum of 13,6985 kt tons over the period under consideration while real income has highest (maximum) of over \$11,000 and a minimum of 8,000 plus. All interest variables under consideration are negatively skewed except for total natural resource rent and non-renewable energy consumption. The current study is conducted for sample size panel of 304 observations with all series not normally distributed with the exemption of carbon dioxide that is normally distributed given the failure to reject the null hypothesis of normality.

Table 8: Descriptive Statistics for EU-16 Countries Under Review

	LNCO2	LNGDP	RRENT	LNREN	NREN
Mean	11.5586	10.4157	0.4113	2.1639	3732.953
Median	11.1885	10.5681	0.1546	2.1872	3587.883
Maximum	13.6985	11.0215	2.8391	3.9109	7134.854
Minimum	8.6759	8.2296	0.0006	-0.1592	1687.785
Std. Dev.	1.1898	0.5461	0.5478	1.0028	1260.710
Skewness	-0.1641	-2.3939	2.1155	-0.2943	0.6882
Kurtosis	2.7402	8.9928	7.6723	2.3155	2.6694
Jarque-Bera	2.2192	745.2860	503.2614	10.32476	25.3858
Probability	0.3297	0.0000	0.0000	0.0057	0.0003
Sum	3513.798	3166.360	125.0482	657.8451	113.4818.
Sum Sq. Dev.	428.9640	90.3566	90.9417	304.6833	4.82E+08
Observations	304	304	304	304	304

Source: Authors computation.

In addition to the summary statistics analysis, we conducted a correlation matrix analysis to explore the relationship between the variables under review as resented in Table 9, A significant positive relationship is observed between carbon dioxide emissions and real GDP for the sampled period. However, for the case of total resource rent, an inverse statistically significant synergy is seen with carbon dioxide emissions while for renewable energy consumption and carbon dioxide emissions a negative statistical association is observed which is desirable for the sampled countries. This implies that renewable energy sources mitigate against carbon dioxide emissions. Also, for non-renewable energy consumption as *apriori* expectation, the positive significant relationship is seen. It is noteworthy that correlation coefficients estimation analysis is not sufficient on its own to validate any outcome. It on the above premise that this study proceeds to conduct more econometrics analysis that is more reliable and consistent to either validate or refute the objectives of this study.

Table 9: Correlation Matrix Analysis

	LNCO2	LNGDP	RENT	LNREN	NREN
LNCO2	1.0000				
T-Statistic	-----				
Prob.Value	-----				
LNGDP	0.1813	1.0000			
T-Statistic	3.2040	-----			
Prob.Value	0.0015**	-----			
RENT	-0.1345	-0.3869	1.0000		
T-Statistic	-2.3590	-7.2934	-----		
Prob.Value	0.0190**	0.0000***	-----		
LNREN	-0.2502	0.0199	0.1026	1.0000	
T-Statistic	-4.4914	0.3468	1.7932	-----	
Prob.Value	0.0000***	0.7290	0.0739*	-----	
LNNREN	0.1516	0.5054	-0.0401	0.1218	1.0000
T-Statistic	2.6650	10.1791	-0.6979	2.1329	-----
Prob.Value	0.0081***	0.0000***	0.4857	0.0337**	-----

Source: Authors computation
Note: ***. **,* represents 0.01, 0.05 and 0.10 rejection level respectively

Table 10: Unit Root Results

	ADF-Fisher		Im Pesaran Shin	
	Level	Δ	Level	Δ
lnrgdp	23.613	73.311***	1.154	-4.175***
Lnren	24.350	69.770***	1.023	-3.848***
lnnren	17.475	82.909***	3.841	-5.296***
lnrent	73.012***	155.620***	-3.997***	-11.289***
lnC02	19.862	92.568***	2.550	-5.765***

Source: Authors computation
Note: ***. **, * represents 0.01, 0.05 and 0.10 rejection level respectively while Δ denotes first difference.

Stationarity test is pertinent in econometrics analysis to circumvent spurious regression trap. Tables 10 renders the unit root analysis, we observed that all variables of interest are first difference stationary except for natural resource rent that is stationary even at 1% significance level. Thus, the general conclusion is that all series are mixed order integrated as reported by both ADF-Fisher unit root test and Im Pesaran Shin unit root test.

Table 11: Pooled Mean Group with Dynamic Autoregressive Distributed Lag (PMG-ARDL (1,1,1,1,1)

Model: lnCO2 = f(lngdp, lnrent, lnren, lnnren)				
			Long run	
Variable	Coefficient	Std. Error	t-Statistic	Prob.
lngdp	1.1536***	0.2313	4.9877	0.0000
lnrent	0.0740***	0.0252	2.9410	0.0036
Lnren	-0.1805***	0.0427	-4.2388	0.0000
lnnrn	0.8819***	0.1589	5.5469	0.0000
		Short run		
ECT	-0.0700***	0.0241	-2.9041	0.0041
lngdp	0.0130	0.0542	0.2406	0.8101
lnrent	-0.0007	0.0069	-0.0980	0.9220
Lnren	-0.1284***	0.0467	-2.7513	0.0065
lnnren	1.1228***	0.0931	12.0575	0.0000
Constant	-0.4772***	0.1575	-3.0282	0.0028
	Kao Residual Cointegration test			
			t-Stat	Prob.
ADF			-2.4593	0.0070
Residual variance			0.000671	
HAC variance			0.000705	

Note number of observations 288, information criterion-Akaike information criterion (AIC), maximum lag 1 as suggested by AIC and most parsimonious

Note: ***. **, * denotes 0.01, 0.05 and 0.10 rejection level respectively.

Subsequently, our study examined the long run relationship between the variables. According to Kao residual cointegration test, there exist long-run (equilibrium relationship) between carbon dioxide emissions, economic growth, renewable energy consumption, non-renewable consumption and natural rent over the period considered. Thus, we proceed to investigate the magnitude of cointegration as reported in Table 11 via PMG-ARDL. The results show a robust estimation with a convergence speed of 7% by the contribution of other regressors towards their equilibrium path. The current study observes a positive significant relationship between carbon emissions and economic growth. As a 1% increase in economic activities birth a corresponding 1.15% increase in carbon dioxide emission (environmental degradation) in the long run. This is in line with the environmental Kuznets hypothesis thus our study affirms a positive linear relationship between economic growth and environmental degradation (Shahbaz et al., 2017). This finding is indicative to environmental administrator/policy makers in the region to curtail CO_2 emissions. Similarly, in the short run linear positive relationship exit between economic growth and CO_2 though not statistically significant. Regarding natural rent, in the short run, there is exist an inverse relationship with CO_2 emissions for the sampled region. Contrary in the long rum we observe a positive relationship between natural resource rent and CO_2 emissions. This is desirable as the exploration of natural resources triggers economic growth directly and subsequently spur increased CO_2 emissions. This is also true during the exploration of most natural resources increase in environmental quality. Regarding renewable energy consumption in both the long-short run there exist a statistical inverse relationship with CO_2. This result is interesting to energy and environmental economists as 1% increase in the consumption of renewable energy sources leads to 0.18% in the long run and 0.13% in the short run decrease in the state of the environment in the selected European Union countries investigated.

This result is laudable, the possible explanation could be that most EU countries are a signatory to the Kyoto protocol agreement to decrease CO_2 emission. This position is advocated in the recent studies of Alola and Alola (2018); Emir and Bekun (2019). While for the case of non-renewable energy consumption sources, we observed a positive and statistically significant relationship in both the short and long run. This is in line with previous studies as non-renewable energy sources like fossil fuel consumption triggers increased CO_2 emission and by extension depletion in environmental quality.

In Figure 3, the diagnostic test of confidence ellipse is captured with the stability points centralized within the ellipse. Hence, it implies that the estimation model presents a significant confidence level.

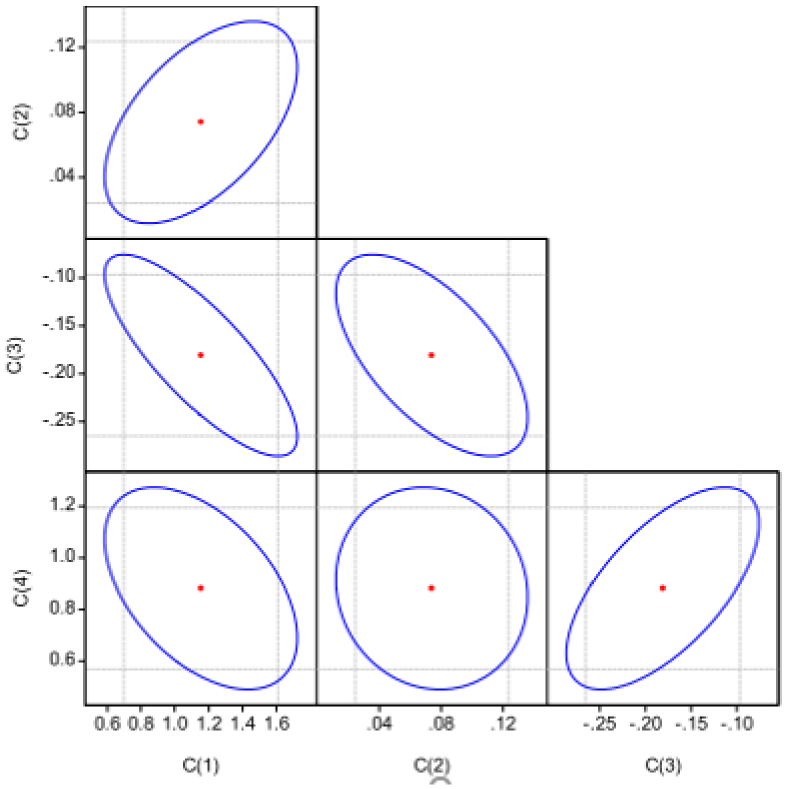

Figure 3: Coefficient Diagnostic with Confidence Interval.

The diagnostic test of confidence ellipse is captured with the stability points centralized within the ellipse. Hence, it implies that the estimation model presents a significant confidence level.

Table 12: Dumitrescu and Hurlin (2012) Panel

Null Hypothesis:	W-Stat.	Zbar-Stat.	Causality	Prob.
LNGDP does not homogeneously cause LNCO2	4.193***	6.604	CO2→RGDP	0.000
LNCO2 does not homogeneously cause LNGDP	3.023	4.062		0.000
LNREN does not homogeneously cause LNCO2	10.41***	20.131	REN→RGDP	0.000
LNCO2 does not homogeneously cause LNREN	4.179	6.574		0.000
LNNREN does not homogeneously cause LNCO2	5.497***	9.438	REN↔C02	0.000
LNCO2 does not homogeneously cause LNNREN	6.528***	11.678		0.000
LNRENT does not homogeneously cause LNCO2	4.551	7.382	RENT≠C02	0.000
LNCO2 does not homogeneously cause LNRENT	0.510	-1.397		0.162
LNREN does not homogeneously cause LNGDP	4.724	7.758	REN≠GDP	0.000
LNGDP does not homogeneously cause LNREN	4.009	6.203		0.000
LNNREN does not homogeneously cause LNGDP	3.180***	4.403	NREN→GDP	0.000
LNGDP does not homogeneously cause LNNREN	6.372	11.339		0.000
LNRRENT does not homogeneously cause LNGDP	5.013***	8.386	RENT↔GDP	0.000
LNGDP does not homogeneously cause LNRRENT	3.217	4.483		0.000
LNNREN does not homogeneously cause LNREN	3.410***	4.902	NREN↔REN	0.000
LNREN does not homogeneously cause LNNREN	10.432	20.160		0.000
LNRENT does not homogeneously cause LNREN	2.362*	2.625	RENT→REN	0.008
LNREN does not homogeneously cause LNRRENT	1.879	1.576		0.115
LNRENT does not homogeneously cause LNNREN	6.156***	10.869	RENT→NREN	0.000
LNNREN does not homogeneously cause LNRRENT	0.690	-1.006		0.314

Source: Authors computation. Note: ***. **, * depicts 0.01,0.05 and 0.10 rejection level respectively. Were ≠, → and ↔ represents No Granger causality, one-way causality and bi-directional causality respectively.

Table 12 finally reports the Dumitrescu and Hurlin panel causality test. The panel causality test employed in this study allows the examination of the Granger non-causality from independent variable to the dependent variable in a heterogeneous panel setting following the procedure outlined by Dumitrescu and Hurlin (2012). We observe a bidirectional causality between CO_2 emissions and GDP. This implies industrial activities increase economic growth while the structural dynamics of the economy accelerates carbon dioxide emissions. In other words, a feedback mechanism exists between environmental deterioration and economic development in EU countries. Hence, a structural change from energy and carbon-intensive economy to a decarbonized economy and services are essential to mitigate climate change and its impacts (Sarkodie and Strezov, 2019a). A feedback mechanism is also observed between: renewable energy and carbon dioxide emissions, nonrenewable energy and carbon dioxide emissions, renewable energy and economic growth, nonrenewable energy and economic growth, natural resource rent and economic growth, and nonrenewable and renewable energy. Both nonrenewable and renewable energy are observed to trigger carbon dioxide emissions and vice versa. Thus, countries increase the penetration of renewable energy technologies in their energy mix when fossil fuel energy consumption accelerates carbon dioxide emissions leading to extreme climate change related events. In another scenario, both nonrenewable and renewable energy triggers economic development and contrariwise. Contrary to the challenges associated with renewable energy technologies, Owusu and Asumadu (2016) noted in the comparison between renewable and fossil fuel energy technologies that, "*renewable energy reduces energy imports and contribute to the diversification of supply options and reduce an economy's vulnerability to price volatility and presents opportunities to enhance energy security*". The role of natural resource rent is key to most economies of the world. Thus, the current study trace feedback causality from natural resource rent and economic growth. As the exploration of a nation's natural resources birth economic growth. However, Destek and Sarkodie (2019) reported that the overexploitation of the available natural resources affects a country's biocapacity (ability for the natural resources to regenerate) while increasing the ecological footprint, leading to an ecological deficit. As such, a shift from vintage technologies that utilize more natural resources to modern technologies that incorporates recycling, reusing, innovation, value-addition and artificial resources that replace natural resources will improve economic development while reducing environmental degradation. Nonrenewable and renewable energy exhibit a mutualistic mechanism in EU countries. Meaning that the incorporation of either of the energy sources into a country's energy portfolio depends on each other to achieve a sustainable production and utilization. While most renewable energy technologies have intermittency and stability issues, fossil fuel energy technologies, on the other hand, has carbon-intensive issues. Hence, Sarkodie and Strezov (2018a) proposed a strategic combination of both energy sources essential to achieving universal access to modern and affordable energy services while mitigating climate change and its impacts. The study found a one-way causality running from natural resources rent to carbon dioxide emissions, natural resources rent to renewable and nonrenewable energy. Meaning that the availability of natural resources propels both renewable and nonrenewable energy consumption. In contrast, overdependence on natural resource rent triggers environmentally pollution in a natural resource dependent economy. As such, diversification and structural change in economic development is required to achieve a sustainable environment.

3.4 Conclusion

The energy economics literature has well-documented studies on the relationship between renewable energy consumption, non-renewable consumption, and economic growth with respect to environmental degradation. This study extends the literature by incorporation of natural resource rent in a carbon function for selected *16* European countries *(*Austria, Belgium, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Portugal, Spain, Sweden, and United Kingdom) over the period 1996-2014. We employed the PMG-ARDL approach to examine the long-run equilibrium relationship between carbon dioxide emissions, economic growth, natural resources rent, renewable, and nonrenewable energy consumption. While a negative and significant long and short run equilibrium relationship is observed between CO_2 and renewable energy consumption, economic growth, natural resources rent, and nonrenewable energy consumption are shown to exert more distortion on environmental sustainability. The plausible explanation to this milestone is credited to the commitment of each country to carbon reduction and cleaner environment by increasing the share of renewable energy in the energy portfolio. More so, most of the countries examined are a signatory to the Kyoto protocol and Paris agreement. Nonetheless, there is still a need to maintain the current momentum in the light of awakening global consciousness toward the attainment of a sustainable environment. In view of this, further studies on this scope should include more countries to capture a large contextual view.

Chapter 4

REVISITING THE ECONOMIC GROWTH AND ELECTRICITY CONSUMPTION NEXUS IN PAKISTAN

4.1 Introduction

Most economies around the globe have recently experienced energy shortage due to the swift increase in energy demand (Balcilar et al. 2010; Dlamini et al. 2015; Sekantsi and Okot 2016; Tamba et al. 2017). This is so, given the integral role energy (electricity) plays in socio-economic growth and development, both in developing and developed nations. The debate on whether economic development precedes energy consumption or vice versa is still heated in the energy economics literature and has led energy scholars to explore the dynamic relationship and causality between electricity consumption and macroeconomic variables like income, gross national product, employment, and energy price among others. Thus, this current study focuses on Pakistan, a country faced with a huge electrification deficit and an underdeveloped energy infrastructure which has crippled its economic productivity.

Recent statistics show that 49,500,000 inhabitants (27% of total population), 9% of urban residents and an alarming 38% of rural residents Pakistan do not have access to electricity in Pakistan (CIA 2018). Thus, the country relies on load shedding to meet her electricity demands (see Khan and Ahmad 2008; Shahbaz and Feridun 2012). Further report reveals that the country's electricity consumption is between 15,000MW to 20,000MW billion per day, yet the current production stands at a mere

11,500 billion MW per day. Furthermore, Khan and Ahmad (2008) assert that the huge electricity deficits pose a huge threat to the Pakistani energy sector and by extension, its economic growth, given the already established relationship between the two variables (electricity and economic growth).

The continuous increase in electricity demand in Pakistan has become more intense and threatens to become more severe in the near future if adequate and timely attention is not given to the energy sector. This study thus seeks to investigate the theme under consideration, given the urgent need for mitigation by energy economists, practitioners and indeed all stakeholders. Our study also seeks to examine the causal long and short run relationships between electricity consumption and economic growth for a developing nation like Pakistan. This study, by way of contribution to the existing energy literature, incorporates carbon dioxide emissions into our econometrics framework to ascertain the extent of environment-income nexus in the econometric modelling on economic growth.

The contribution of this paper to the pool of studies in the energy economics literature is two-fold. First, this is the first study to investigate the current theme for Pakistan in a multivariate framework, to the best of the author’s knowledge. Previously conducted studies were in bivariate framework (Acaravci and Ozturk 2010; Kayhan et al. 2010; Shahbaz and Feridun 2012; Ameyaw et al. 2016; Tamba et al. 2017), and are debated to be flawed and possess misspecification bias (that is, omitted variable bias). This translates into misleading analysis and spurious policy implication. Second, this study leverages on fairly new econometric techniques that circumvent structural break(s). Our study employs Kwiatkowski et al. (1992) stationarity test and Zivot-Andrews (1992) unit root test that accounts for single structural break, while Maki (2012) is employed for long-run equilibrium relationship. The Maki cointegration test can account for as much as five multiple structural breaks. We also use the Toda-Yamamoto (1995) causality test, which is an improved version of the Wald test (MWALD). The Toda-Yamamoto causality test is regarded as superior to the conventional Granger causality test (Lütkepohl and Kratzig 2004). The need for structural break model is preempted by the nature of most macroeconomic and financial datasets, to avoid spurious analysis which previous studies fail to address. Thus, our study extends the literature by methodological innovation and advancement. We also aim to provide energy practitioners and stakeholders ample evidences for adequate policy framework design and decision making.

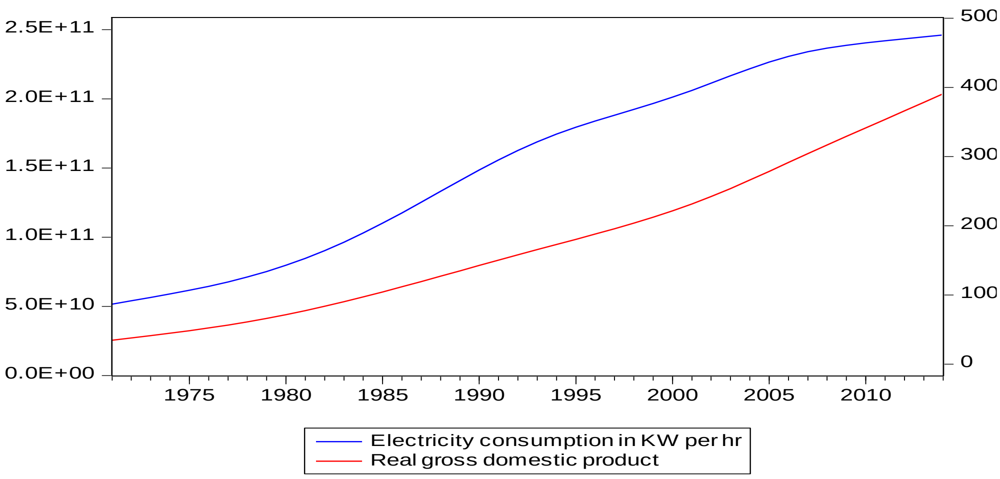

Figure 4**:** Visual Trend of Electricity Consumption and Real GDP for 1971-2014.

Figure 4 reports the visual presentation of trend movement between electricity consumption and real GDP since 1971 to 2014. Hodrick-Prescott (HP) smoothing filter was applied to the dataset for better visual glimpse. It is conspicuous that there exists a co-movement between the variables, and as such, the attention of energy users, energy practitioners, policymakers and all stakeholders is needed, given the implications of this relationship.

The remainder of this study is as follows; Section-2 provides a detailed review of relevant literature with a summary of selected literature survey in Table 13, Section-3 presents the data and econometric procedures, Section-4 reveals the empirical results and discussions, and finally, Section-5 presents the conclusion and policy implications emanating from the study.

4.2 Literature Review

The relationship between energy (electricity) consumption and economic growth has been well documented in the energy economics literature. The seminal study of Kraft and Kraft (1978) on the relationship between energy consumption and economic growth in the United States revealed a unidirectional causality running from economic growth to energy consumption. The study ushered in numerous empirical studies such as Erol and Yu (1987), Asafu-Adjaye (2000), Stern (2000), Oh and Lee (2004), Wolde-Rufael (2006), Yoo and Kim (2006), Narayan and Singh (2007), Narayan and Smyth (2008), Apergis and Payne (2009), Soytas and Sari (2009), Shahbaz et al. (2011), Bélaïd and Abderrahmani (2013), Shahbaz et al. (2014), Akadiri and Akadiri (2018), and Akadiri et al. (2018), Katircioglu *et al*.,(2019)

This current study however focuses on energy (electricity) literature, which can be classified into 4 groups. The first group supports the growth hypothesis (see Altinay and Karagol 2005; Ho and Siu 2007; Shahbaz et al. 2011), asserting that electricity consumption births economic growth, that is, energy consumption drives economic growth. Thus, conservative energy policies will negatively impact economic growth. The second group, in favor of the conservative hypothesis, asserts that economic growth has the tendency to spur electricity consumption, that is, there exists a unidirectional causality running from economic growth to energy (electricity) consumption. Thus, this group supports the conservative strategies and measures (see Jumbe 2004; Jamil and Ahmad 2010; Lean and Smyth 2010; Ameyaw et al. 2016). The third group affirms the feedback hypothesis, and asserts that there is a bidirectional causality between energy (electricity) consumption and economic growth. This pattern of causality supports the conservation hypothesis which suggests that energy conservative policy adversely affects economic growth. Similarly, an increase in economic activity triggers economic growth (Bélaïd and Abderrahmani 2013; Hu and Lin 2013; Tang and Tan 2013; Aslan 2014). Finally, the fourth group affirms the neutrality hypothesis. This group of studies posits that there is no causal relationship between energy (electricity) consumption and economic growth (Acaravci and Ozturk 20108; Nazlioglu et al. 2014).

More recently, literature in the electricity-economic growth nexus has burgeoned with no consensus in empirical outcomes. These variances in the empirics could be attributed to data and sampling procedures applied by the researchers, and the study area which could either be country-specific or a panel of countries. The more pronounced reason could be methodological techniques adopted in estimations. Single-country studies on the electricity-growth nexus include Bélaïd and Abderrahmani (2013), Aslan (2014), Hamdi et al. (2014), Ameyaw et al. (2016), Shahbaz et al. (2017a), and Wang et al. (2017).

[8] For brevity, interested readers can see Payne (2010) literature survey studies on electricity growth nexus.

In the study conducted in Portugal by Shahbaz et al. (2017a), it was revealed that the Portuguese economy is electricity driven, as unidirectional causality was observed running from electricity consumption to economic growth. The study also accounted for financial development and capital formation from 1960 to 2015. Hamdi et al. (2014) focused on the Kingdom of Bahrain and examined the interaction between electricity consumption and economic growth while accounting for the role of capital and foreign direct investment with the aid of Cobb-Douglas production function. The empirical finding lends support to the long-run equilibrium relationship between the variables. The study joins the group of literature in support of bidirectional causality between electricity consumption and economic growth. The same position is also resonated in the studies of Aslan (2014) for the Turkish economy implying feedback causality. The Ghanaian experience documented by the study of Ameyaw et al. (2016) with the aid of Cobb-Douglas growth production function lends credence to the growth-led energy (electricity) hypothesis, thus showing that the Ghanaian economy is not reliant on electricity consumption for its economic growth. In China, Wang et al. (2017) also advanced the nexus between electricity consumption and economic growth by the adoption of a more sophisticated econometric technique. Their study employed bootstrap causality approach, a seemingly unrelated regression approach, for more reliable results. The study joins the group in support of economic growth-induced electricity consumption for the Chinese economy for the sampled period.

Nazlioglu et al. (2014) examined the electricity-growth nexus in Turkey. The authors considered symmetric and asymmetric dynamics in their estimations by implementing linear and non-linear Granger causality test. The linear Granger causality supports the feedback causality in both the short and long run. On the contrary, the non-linear causality that accounts for asymmetry supports the neutrality divide in the electricity-growth literature, thus indicating that the Turkish energy sector and government administrator can embark on the conservative policies without adverse implication on economic growth.

Other scholars have also investigated the electricity-growth nexus for a panel of countries. Examples abound in the empirics. The recent studies of Balsalobre-Lorente et al. (2018) examined the nexus between electricity consumption and economic growth via a carbon emission production function while controlling for trade openness, natural abundance, energy innovation, and carbon dioxide emissions. The study was conducted for Germany, France, Italy, Spain, and the United Kingdom (collectively known as the European Union-5 countries) and asserts that renewable electricity consumption helps to enhance environmental quality for the sampled countries. In the same vein, Shahbaz et al. (2017b) examined the theme under consideration in a neoclassical framework by controlling for oil prices in 157 countries from 1960 to 2014. Cointegration relationship was achieved by Pooled Mean Group (PMG) estimator between capital, labor, oil prices, electricity consumption and economic growth over the sampled regions and period. The study affirms and supports the feedback relationship between electricity consumption and economic growth, thus implying that conservative policies cannot be implemented. The study further buttresses that developing countries rely heavily on electricity consumption to drive their economies. The study also advocates for pragmatic steps to be taken by policymakers and governmental administrators to attain sustainable growth in the long run.

In the case of Mediterranean countries (MC's), Kahouli (2018) explored the relationship between electricity consumption, carbon dioxide emissions, research development and economic growth with the aid of GMM, 3SLS, and SUR as estimation techniques. The study joins the league that supports the electricity-induced growth for the Mediterranean countries investigated. This is also the position of Gulf cooperation countries (GCC) as seen in the study by Salahuddin et al. (2015). Wolde-Rufael (2014), using bootstrap panel Granger causality test for transition countries, examined the electricity-economic growth nexus while accounting for cross-sectional dependence and heterogeneity, and found mixed results among the selected transition countries. Policy directions were offered to the different countries accordingly. Also, Khobai et al. (2018) examined the BRICS experience of the electricity-growth nexus while accounting for carbon dioxide emissions and urbanization. The study affirms the cointegration relationship among the variables and also confirms the conservative hypothesis over the period investigated. Table 13 provides a detailed review of selected studies on electricity consumption-economic growth nexus across diverse countries.

Table 13: Summary of Literature on Electricity Consumption and Economic Growth

Author(s)	Period	Region	Methodology	Variables	Direction of Causality
Chen and Fang (2018)	2003 - 2012	210 Chinese cities	Panel Granger Causality test	Industrial electricity consumption, Total output, Fixed Asset Investment and Public expenditure on	Y⇒ ELC, ELC ⇔ H for China; Y ⇔ ELC, ELC⇒ H for East China; Y⇒ ELC, H⇒ ELC for Middle China; Y⇒ ELC,

				education and science and technology	ELC ⇔ H for West China
Bah and Azam (2017)	1971 - 2012	South Africa	ARDL Bounds Test, Toda and Yamamoto Augmented Granger causality test	Electricity consumption, GDP, domestic credit to private sector and CO_2 emissions	ELC ≠ Y, CO_2⇒ ELC, FD⇒ CO_2
Sarwar et al. (2017)	1960 - 2014	210 countries	PECM Granger causality test	Electricity consumption GDP, GFCF, Population and Oil price	ELC ⇔ Y, OP ⇔ Y, GFCF ⇔ Y,
Salahuddin et al. (2017)	1980 - 2013	Kuwait	ARDL Bounds Test and the VECM Granger causality test	Electricity consumption, CO_2 emissions, RGDP, FD, FDI	Y ⇒ CO_2, ELC ⇒ CO_2, FDI ⇒ CO_2, Y ⇔ ELC, CO_2 ≠ FD, CO_2 ≠ FDI, ELC ≠ FD and ELC ≠ FDI
Osman et al. (2016)	1975 - 2012	GCC countries	Panel VAR Granger	Electricity consumption,	Y ⇔ ELC, Y ⇔ GFCF and ELC ⇒ GFCF

			causality test	GDP and GFCF	
Bildirici (2016)	1980 - 2011	OECD and Non-OECD	ARDL Bounds Testing and Granger Causality Approach	Hydro energy consumption and Real Gross Domestic Product	EC ⇒ GDP in short-run, EC ⇔ GDP in long-run except Brazil and France
Dlamini et al. (2015)	1971 - 2009	South Africa	Bootstrap rolling-window Approach	Electricity consumption and GDP	ELC ⇒ Y for two sub-periods
Shahbaz et al. (2015)	1980 - 2012	12 African Countries	FMOLS, Pedroni Cointegration Test and VECM	Energy intensity, CO_2 and Real Gross Domestic Product	GDP⇔ CO_2, EI ⇒ CO_2
Karanfil and Li (2015)	1980 - 2010	160 countries	Pedroni panel cointegration tests and PECM Granger causality test	Electricity consumption and GDP, Urbanization and electricity net import	Mixed result for sub-samples
Cowan et al. (2014)	1990 - 2010	BRICS countries	Bootstrap panel causality test	Total Electricity consumption, CO_2	ELC ≠ Y, ELC ≠ CO_2 and CO_2 ⇒ Y for Brazil; ELC ⇔ Y, ELC⇎ CO_2

				emissions and RGDP	and $CO_2 \neq Y$ for Russia; $ELC \neq Y$, $ELC \Rightarrow CO_2$ and $CO_2 \neq Y$ for India; $ELC \neq Y$, $ELC \neq CO_2$ and $CO_2 \neq Y$ for China; $Y \Rightarrow ELC$, $ELC \neq CO_2$ and $Y \Rightarrow CO_2$ for South Africa
Hamdi et al. (2014)	1980 - 2010	Bahrain	ARDL Bounds Test	Electricity consumptio n, FDI and GDP	$ELC \Leftrightarrow Y$, $FDI \Leftrightarrow ELC$
Nazlioglu et al. (2014)	1967 - 2007	Turkey	ARDL model, Linear and Non-Linear Granger Causality Test	Electricity consumptio n and Gross Domestic Product	$ELC \Leftrightarrow Y$ for linear causality test, no non-linear causality between ELC and Y
Solarin and Shahbaz (2013)	1971 – 2009	Angola	ARDL Bounds Test and the VECM Granger causality test	Electricity consumptio n, GDP and Urbanisatio n	$ELC \Leftrightarrow Y$, $U \Leftrightarrow ELC$ for the short-run; $ELC \Leftrightarrow Y$, $U \Rightarrow Y$ and $U \Rightarrow ELC$ for the long-run
Akpan and Akpan	1970 - 2008	Nigeria	Multivariat e VECM	Electricity consumptio	$Y \Rightarrow CE$, $ELC \neq Y$

(2012)				n, Carbon emissions and economic growth	
Shahbaz and Lean (2012)	1972 - 2009	Pakistan	ARDL model and Granger causality tests	Electricity consumption, GDP, Real capital and Labor	ELC ⇔ Y
Shahbaz and Feridun (2011)	1971 - 2008	Pakistan	ARDL Bounds Test	Electricity consumption and GDP	Y⇒ ELC
Shahbaz et al. (2011)	1971 - 2009	Portugal	VECM Granger causality test	Electricity consumption, GDP and employment	Y ⇒ ELC, ELC ⇔ E and E⇔ Y for the short-run; Y⇔ ELC, E⇔ ELC and Y⇔ E for the long-run
Balcilar et al. (2010)	1960 – 2006	G-7 Countries	Bootstrap Granger non-causality test	Energy consumption and GDP	EC ⇒ GDP for only Canada, there is no causal links between energy consumption and economic growth for the other countries
Narayan and Smyth (2009)	1974 - 2002	Middle Eastern Countries	Bootstrap Causality Approach	Electricity consumption, exports and GDP	ELC ⇔ Y

Mozumder and Marathe (2007)	1971 - 1999	Bangladesh	Johansen Cointegration Test and Granger Causality Test based on VECM	Electricity consumption and GDP per capita	Y⇒ ELC
Altınay and Karagol (2005)	1950 - 2000	Turkey	Dolada and Lütkepohl (1996) Causality Test	Electricity consumption and GDP	ELC ⇒ Y
Hatemi and Irandoust (2005)	1965 - 2000	Sweden	A Leveraged Bootstrap Approach	Electricity consumption, GDP and Consumer Price Index	Y ⇒ ELC
Narayan and Smyth (2005)	1966 - 1999	Australia	Cointegration Granger Causality Test	Electricity consumption GDP per capita, and Index of employment	Y⇒ ELC, E ⇒ ELC
Shiu and Lam (2004)	1971 - 2000	China	Johansen Cointegration Test and ECM	Electricity consumption and GDP	ELC ⇒ Y
Ghosh (2002)	1950 - 1997	India	Engle-Granger Causality test	Electricity consumption and GDP	Y ⇒ ELC

Notes: The symbols ‘’ ⇒, ⇔, ≠’ indicate unidirectional, bidirectional causality and neutrality hypothesis, respectively. Where ELC is electricity consumption, FDI is foreign direct investment, FD is financial development, U is urbanization, E is employment, EI is energy intensity.

4.2.1 Pakistan Energy Sector: A Synopsis

Pakistan has a huge and increasing population which suffers high electricity deficit in recent times, with over 49,500,000 million residents without electrical access. 27% of the total population lack access to electricity, with 9% of urban residents and an alarming 38% of rural residents affected (CIA, 2018). The country electricity consumption heat 85.9 billion kWh in recent time. Pakistan's electricity system has previous been studied by Dunn (1991), Malik (2007), and Muneer and Asif (2007). Electricity generation, transmission and distribution in Pakistan is handled by two public companies, namely; Water and Power Development Authority (WAPDA) responsible for the entire country with the exclusion of Karachi, and Karachi Electricity Supply Corporation (KESC) responsible for Karachi and her environs. Since the1990s, over 16 Independent Power Producers (IPPs) have also generated electricity in Pakistan, thereby accounting for one-third of the electricity generation in the country.

Pakistan's electricity supply over the years falls below its demand. This gap is being managed by load shedding in the country. The epileptic electricity supply has threatened the Pakistani economy a great deal. This occurrence has also had a toll on investment and investors. Furthermore, Joskow (2003) and Smith (2004) both linked this problem to poor institution and avoidance of electricity tariff by both individuals and institutions. Also, the theft of electrical installations was also identified as part of the bottleneck in the electrification of Pakistan.

4.3 Methodology Framework

4.3.1 Data

This study relies on annual data from 1971-2014 in the consideration of the dynamic relationship between electricity consumption, carbon dioxide emissions and economic growth in Pakistan9. The data span is restricted due to data availability. The data for our study was retrieved from World Bank Development Indicators (2018) (https://data.worldbank.org/indicator). Our study empirically follows the studies of Kayhan et al. (2010), Sekantsi et al. (2016). The variables used in this paper are real gross domestic product constant 2010 USD (RGDP), which is proxy for economic growth, carbon dioxide emissions (CO2) in Kt as indicator for environmental quality (degradation) and electricity consumption (EC) in kWh per capita. The empirical route is as follows; (i) Zivot-Andrews (1992) unit root test and Kwiatkowski et al. (1992) stationarity test are used to validate the asymptotic traits and order of integration of all variables under review to avoid the problem of spurious regression (ii) The estimation of long-run equilibrium relationship is carried out using the Maki (2012) cointegration test and dynamic ordinary least squares (DOLS) for long-run coefficient subsequently (iii) Causal relationships are estimated through the Toda-Yamamoto (1995) Granger causality test.

4.3.2 Model Specification

The econometric model for our study is given as:

$$EC = f(RGDP, CO_2) \tag{13}$$

Logarithm transformation is carried out on equation-13 to achieve homoscedasticity

[9] The data set is trimmed bases on data availability and for uniformity of estimations, given that carbon dioxide emissions and electricity consumption are available to 2014 on the WDI database. available at https://data.worldbank.org/

$$\ln EC = \alpha + \beta_1 \ln RGDP_t + \beta_2 \ln CO_{2,t} + \varepsilon_t \tag{14}$$

where, α signifies constant and $b_{1,} b_2$ are partial slope parameter. Also, lnEC, lnRGDP and $\ln CO_2$ are the natural logarithm for real gross domestic product (RGDP), electricity consumption (EC) and carbon dioxide emissions (CO_2).

4.3.3 Unit Root Test

Stationarity test is vital in time series econometric analyses, to avoid the problem of spurious analysis. The econometrics literature has several unit root test procedures, namely; Augmented Dickey-Fuller (ADF 1981), Phillips and Perron (PP 1988), Elliot et al. (1992), and Ng and Perron (2001). However, all aforementioned tests fail to account for structural break(s) which is known to plague most macro and financial datasets. Thus, to establish the asymptotic traits and order of integration of time series variables, stationarity test is crucial. Zivot and Andrews (1992) unit root test circumvent the abovementioned problem by accounting for a single structural break. The ZA test null hypothesis states unit root where $H_0 : \theta > 0$ against an alternative of stationarity $H_1 : \theta < 0$. Thus, failure to reject H0 implies the presence of unit roots while and rejection denotes stationarity.

4.3.4 Cointegration Test

Cointegration test is crucial because it helps to depict long-run equilibrium bond among variables. Standard conventional cointegration tests (Engle and Granger 1987; Johansen and Juselius 1990; Johansen 1991) fail to account for structural break(s). It is well known in economics and finance literature that most macro data possess breaks/jumps. We thus argue that previous tests may give spurious analysis (Westerlund and Edgerton 2007).

The new breed of cointegration tests that account for structural breaks include Gregory and Hansen (1996), Carrion-i-Silvestre and Sansó (2006), Westerlund and Edgerton (2007), and Hatemi-J, (2008). However, it is also argued that economic series are highly unpredictable with jumps and several breaks. It is on this premise that Maki (2012)[10] proposed a cointegration procedure that accounts for multiple structural breaks. It however requires all series to be integrated of order one.

The formulae for Maki (2012) are given as:

Model A: Break in intercept and without trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \delta' x_t + u_t \tag{15}$$

Model B: Break in intercept and coefficients and without trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \delta x_t + \sum_{i=1}^{m} \delta_i x_t D_{i,t} + u_t \tag{16}$$

Model C: Break in intercept and coefficients and with trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \delta x_t + \sum_{i=1}^{m} \delta_i x_t D_{i,t} + u_t \tag{17}$$

Model D: Break in intercept, coefficients and trend

$$z_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \sum_{i=1}^{m} \beta_i t D_{i,t} + \delta x_t + \sum_{i=1}^{m} \delta_i x_t D_{i,t} + u_t \tag{18}$$

Here, $t = 1, 2, \ldots, T$, y_t and $x_t = (x_{1,t}, x_{2,t}, \ldots, x_{k,t})'$ are observable $I(1)$ variables, the $D_{i,t}$ is a dummy, where $D_{i,t}=1$ when $t > T_{bi}$ and $D_{i,t}=0$ otherwise, where T_{bi} indicates possible break point with $i = 1, 2, \ldots, m$, and u_t is an equilibrium error.

[10] The authors are appreciative to Daiki Maki of the faculty of Economics, Ryukoku University for the availability of the codes in GAUSS that facilitated simulation of the cointegration results.

4.3.5 Estimation of Long-Run Coefficients

Long-run equilibrium coefficients precede the establishment of cointegration relationship among series under consideration in this study. To this end, Dynamic Ordinary Least Squares (DOLS) estimation test is utilized to ascertain the magnitude of long-run equilibrium. The advantages of the DOLS include; (i) It can be estimated irrespective of the order of integration of series, but the dependent variable is expected to be integrated of order one. (b) It also eliminates serial correlation issues arising from the estimation of the model and other internalities (Esteve and Requena 2006).

The DOLS formulate model is presented as:

$$\ln EC = \beta_0 + \beta_1 \ln CO_{2,t} + \beta_2 \ln RGDP_t + \sum_{i=-q}^{q} \varphi_i \Delta \ln CO_{2,t-i} + \sum_{i=-q}^{q} \gamma_i \Delta \ln RGDP_{t-i} + u_t \quad (19)$$

Here, q represents the optimum lag level as suggested by Schwarz Information Criterion.

4.3.6 Causality Test

Conventional regression does not depict causation. Thus, the need for causality arises, given the inherent policy implication from the directional causality flow. To this end, our study relies on the Toda-Yamamoto (1995) causality approach for causation and predictability power among the series under review. The Toda-Yamamoto (TY) is an improved version of the Wald test. The Toda-Yamamoto (TY) has obvious merits relative to traditional Granger causality test. The TY causality is resilient and gives robust estimates. In addition to being resilient, the TY technique is unique, as it can be estimated regardless of the order of integration of variables under review. TY procedure is structured in a Vector Autoregressive framework VAR with (K+d_{max}). Where, K is the optimal order of integration in the VAR, and d_{max} is the maximum integration order.

The VAR (k+d_{max}) is constructed as;

$$\ln EC = \beta_0 + \sum_{i=1}^{k} \beta_{1i} \ln EC_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln EC_{t-j} + \sum_{i=1}^{k} \alpha_{1i} \ln CO_{2,t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln CO_{2,t-j} + \sum_{i=1}^{k} \delta_{1i} \ln RGDP_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln RGDP_{t-j} + \varepsilon_{1t} \quad (20)$$

$$\ln CO_2 = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \ln CO_{2,t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln CO_{2,t-j} + \sum_{i=1}^{k} \beta_{1i} \ln EC_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln EC_{t-j} + \sum_{i=1}^{k} \delta_{1i} \ln RGDP_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln RGDP_{t-j} + \varepsilon_{2t} \quad (21)$$

$$\ln RGDP = \delta_0 + \sum_{i=1}^{k} \delta_{1i} \ln RGDP_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \ln RGDP_{t-j} + \sum_{i=1}^{k} \alpha_{1i} \ln CO_{2,t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \ln CO_{2,t-j} + \sum_{i=1}^{k} \beta_{1i} \ln EC_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \ln EC_{t-j} + \varepsilon_{3t} \quad (22)$$

4.4 Empirical Results

In time series analysis, the need for inspection of visual plots (eyeball test) is crucial. Figure 5 shows the visual plot of the series in this current study. Figure 5 reveals noticeable evidence of possible structural break(s). Thus, the need for estimators that accounts for such is crucial. Table 14 reports the descriptive statistic for each variable. Table 14 reveals that all series are negatively skewed. Also seen is normally distributed series, with the exception of electricity consumption which is significant at 10 percent level. Furthermore, Table 15 presents the Pearson correlation coefficient results between variables. A positive significant correlation coefficient exists between all the series in this study. This pattern of association provides useful insight in the study area.

Table 14: Descriptive Statistics of the Variables for Pakistan

	lnEC	*lnCO_2*	*lnRGDP*
Observations	44	44	44
Mean	5.55	11.11	25.12
Median	5.81	11.23	25.24
Maximum	6.19	12.02	26.05
Minimum	4.51	9.85	24.04
Std. Dev.	0.56	0.72	0.62
Skewness	-0.55	-0.31	-0.26
Kurtosis	1.82	1.75	1.84
Jarque-Bera	4.75	3.58	2.99
Probability	0.09	0.17	0.22
Sum	244.21	488.75	1105.42
Sum Sq. Dev.	13.41	22.03	16.63

Note: EC, CO and RGDP represent Electricity Consumption, Carbon Dioxide consumption and Real GDP, respectively

Table 15: Pearson Correlation Estimates

	lnEC	lnCO_2	lnRGDP
lnEC	1		
T- statistic	-----		
P- value	-----		
lnCO_2	0.99	1	
T- statistic	43.75	-----	
P- value	0.00*	-----	
lnRGDP	0.99	1	1
T- statistic	37.59	86.47	-----
P- value	0.00*	0.00*	-----

Note: Correlation is significant at * 1 percent and ** 5 percent, respectively.

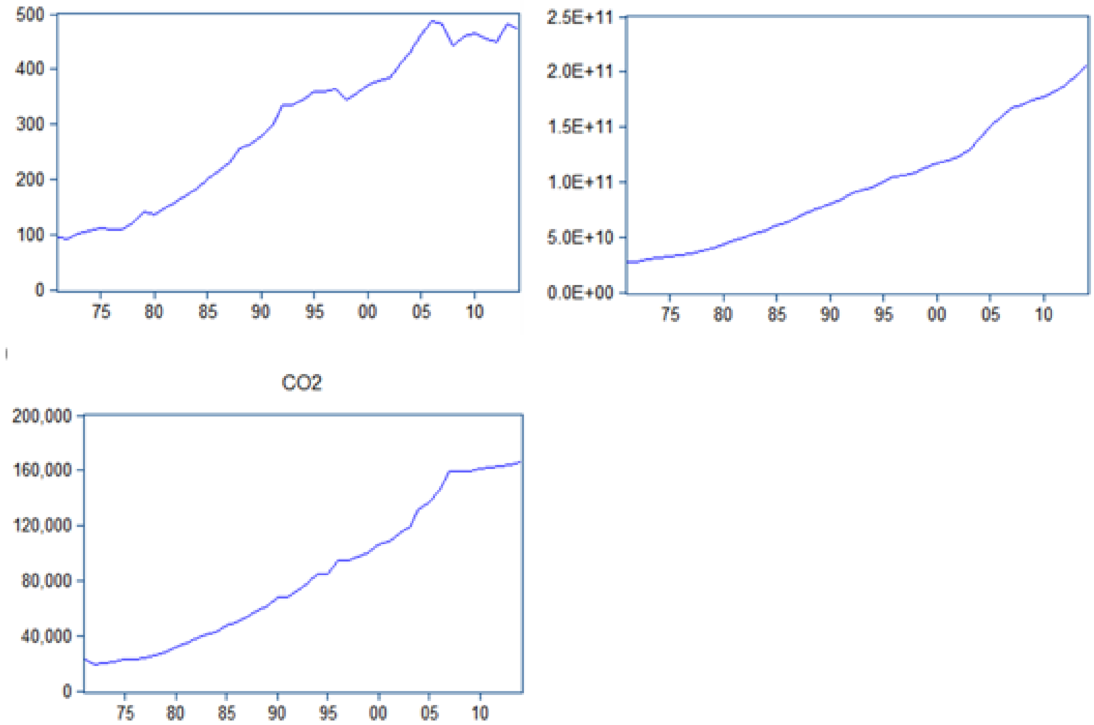

Figure 5: Visual Plot of Variables in their Level Form.

According to the results from Table 16, Kwiatkowski et al. (1992) stationarity test for *lnEC, lnCO2,* and *lnRGDP* are all integrated of order 1, that is, *I*(1), which means that the series are not stationary in levels, but stationary at first differences at 1 percent significance level. Similarly, Table 5 reports the ZA unit root test results. The null hypothesis that there is a unit root under a single structural break cannot be rejected at their level forms for *lnEC, lnCO2,* and *lnRGDP*. All the variables however became stationary at their first difference, *I*(1).

Table 16: KPSS Unit Root Analysis

	Level		First Diffences	
	H_0: $I(0)$		H_0: $I(0)$	
Series	KPSS[a]	KPSS[b]	KPSS[a]	KPSS[b]
lnec	0.21**	0.79*	0.1	0.52***
lnCO₂ → $lnCO_2$	0.19**	0.82*	0.17**	0.24
lnrgdp	0.19**	0.83*	0.09	0.31

Note: *, **, *** denotes significance at the 1,5 and 10 percent levels, respectively.
[a]Test allows for a constant and a linear trend; one-sided test of the null hypothesis that the variable is stationary; 1, 5, 10 percent critical values equals 0.21, 0.14, 0.11, respectively.

[b]Test allows for a constant; one-sided test of the null hypothesis that the variable is stationary ; 1, 5, 10 percent critical values equals 0.73, 0.46, 0.34, respectively.

Table 17: ZA [1992] Tests for Unit Root Under a Single Structural Break

	Statistics (Level)			Statistics (First Difference)			
	ZA_I	ZA_T	ZA_B	ZA_I	ZA_T	ZA_B	Conclusion
lnEC	-1.68	-3.89	-3.45	-7.1*	-6.61*	-6.77*	*I*(1)
Time Break	1981	1983	1991	1978	1986	2007	
Lag Length	0	0	0	0	0	0	
$lnCO_2$	-1.15	-1.91	-1.77	-3.89	-4.96*	-6.2*	*I*(1)
Time Break	2008	1991	1993	2007	2007	2004	
Lag Length	1	1	1	1	1	1	
lnRGDP	-3.38	-3.42	-3.33	-6.43*	-5.76*	-6.24*	*I*(1)
Time Break	1980	1989	1980	1993	1981	1993	
Lag Length	1	1	1	0	0	0	

Note: EC is electricity consumption, CO_2 is carbon dioxide consumption, and RGDP is real gross domestic product. All of the variables are at their natural logarithms. ZA_I represent the model with a break in the intercept; ZA_T is the model with a break in trend; ZA_B is the model with a break in both the trend and intercept. * indicates significance at the 1 percent level.

Table 17 reports Zivot-Andrews (1992) unit root test results, suggesting that all the data series are integrated of the same order when breaks are allowed. Based on these results, Maki (2012) cointegration test is most appropriate to analyze long run relationship among the variables[11]. The long-run equilibrium relationship between electricity consumption, CO_2 emissions, and real GDP under multiple structural breaks

[11] For brevity, the results of the Johansen cointegration also reconcile with the Maki cointegration test results. The simulation can be made available upon request.

is reported in Table 18. The null hypothesis of no cointegration is rejected under the existence of multiple structural breaks for different models of Maki (2012).

Table 18: Maki (2012) Cointegration Test Under Multiple Structural Breaks

Number of Break Points		Test Statistics [Critical Values]	Break Points
m≤1			
	Model 0	-4.71 [-5.00]	2009
	Model 1	-4.83 [-5.35]	1979
	Model 2	-4.63 [-5.55]	1991
	Model 3	-4.93 [-6.05]	1991
m≤2			
	Model 0	-4.98 [-5.21]	1997; 2007
	Model 1	-5.89 [-5.51]*	1979; 2006
	Model 2	-5.07 [-6.09]	1991; 2007
	Model 3	-6.31 [-6.65]	1975; 1991
m≤3			
	Model 0	-5.59 [-5.39]*	1987; 1997; 2007
	Model 1	-6.38 [-5.69]*	1979; 1990; 2006
	Model 2	-5.70 [-6.51]*	1979; 1991; 2007
	Model 3	-7.28 [-7.14]*	1975; 1991; 2007
m≤4			
	Model 0	-5.61 [-5.55]*	1983; 1987; 1997; 2007
	Model 1	-6.91 [-5.83]*	1979; 1990; 1995; 2006
	Model 2	-5.73 [-6.87]	1979; 1991; 1997; 2007
	Model 3	-7.97 [-7.63]*	1975; 1991; 1997; 2007
m≤5			
	Model 0	-6.03 [-5.76]*	1983; 1987; 1997; 2007; 2010
	Model 1	-6.98 [-5.99]*	1979; 1985;1990; 1995; 2006
	Model 2	-7.74 [-7.28]*	1974; 1979; 1991; 1997; 2007
	Model 3	-9.31 [-8.12]*	1975; 1979; 1991; 1997; 2007

Note: Numbers in brackets shows critical values at 5 percent significance level from Table 1 of Maki (2012). * indicates significance at 5percent level.

The dynamic ordinary least square (DOLS) approach is applied to find long-run coefficients and the results are provided in Table 19. CO_2 emissions have inelastic, positively statistically significant effects on electricity consumption. However, economic growth has inelastic, positive and statistically insignificant at all significance levels.

Table 19: DOLS Estimation of the Level EC Equation

Variable	Coefficient	Std. Error	T-statistic	P-value
lnCO_2	0.87***	0.46	1.88	0.06
lnRGDP	0.77	0.69	1.12	0.27
Constant	-22.55***	12.29	-1.83	0.07
Trend	-0.44*	0.01	-3.65	0.00
R-squared	0.99			
S.E.of Regr.	0.05			
Long-run variance	0.01			

Note: *, **, *** denotes significance at the 1,5 and 10 percent levels, respectively

Toda-Yamamoto (1995) causality test is employed to find the direction of the causal relationship between the variables. According to Table 20, there is a unidirectional relationship running from electricity consumption (EC) to carbon dioxide emissions ($C0_2$). Similarly, causal relationship is seen running from economic growth to electricity consumption. This implies that any percentage change in CO_2 emissions and economic growth in Pakistan causes change in electricity consumption. Furthermore, our empirical findings validate the economic-electricity growth nexus. Energy-intensive economic activities such as industrial and agricultural production processes increase the demand for energy. On the other hand, there is a tradeoff between environmental quality and economic growth. This claim, popularly referred to as the environmental Kuznets Curve (EKC) hypothesis, was first validated by Grossman and Krueger (1991).

Figure 6 shows the flow chart of the causality results. This study reviews causal effect from economic growth to electricity consumption, thus validating the conservative hypothesis. However, this study also reviews causal effect from electricity consumption to carbon dioxide emissions, implying that industrial activities trigger increased carbon emissions flaring which in turn translates into environmental degradation.

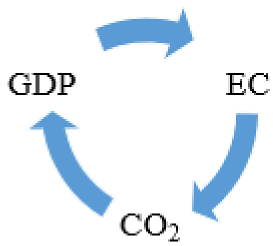

Figure 6: Causality Flow Chart.

Table 20: Toda-Yamamoto (1995) Causality Analysis

Hypothesis	Chi-square P-value	Decision
lnEC does not cause *lnCO*$_2$	0.01**	Reject
lnCO$_2$ does not cause *lnEC*	0.28	Fail to Reject
lnRGDP does not cause *lnEC*	0.02**	Reject
lnEC does not cause *lnRGDP*	0.38	Fail to Reject
lnCO$_2$ does not cause *lnRGDP*	0.79	Fail to Reject
lnRGDP does not cause *lnCO*$_2$	0.13	Fail to Reject

Note: ** indicates 5 percent significance level.

4.5 Concluding Remark/Policy Implications

This study investigates the causal interaction among electricity consumption, real gross domestic product and carbon dioxide emissions in Pakistan within a multivariate econometric framework that accommodates structural break(s), given the asymptotic traits of most financial and economic datasets. The data for this study was sourced from the World Bank development indicators database (https://data.worldbank.org/indicator) from 1971-2014. Our study leverages on relatively new econometric estimators that thrive in the presence of structural breaks and also give robust and reliable estimates. The unit root properties and asymptotic traits of the series are validated by Zivot-Andrews (1992) unit root test that accounts for a single structural break and Kwiatkowski et al. (1992) stationarity test. Tables 4 and 5 report the unit root test with KPSS stationarity test and ZA unit root test. The empirical results are in harmony and reveal that all series are integrated of order one. For long-run equilibrium relationship, Maki (2012) was utilized with null hypothesis of no cointegration.

Our study finds cointegration among the series in the presence of structural breaks. This implies that a long-run bond exists among electricity consumption, real gross domestic product and carbon dioxide emissions. Next, our study examines direction of causality by Toda-Yamamoto (1995) Granger causality test. The TY causality test reveals the following; (i) a unidirectional causality is found running from electricity consumption to carbon dioxide emission. This implies that electricity consumption triggers industrialization and translates into environmental degradation in Pakistan. (ii) Similarly, a unidirectional causality is also found running from economic growth to electricity consumption. Thus, our findings resonate with the economic growth-induced electricity consumption hypothesis (Mehrara 2007; Jamil and Ahmad 2010; Baranzini et al. 2013; Gokmenoglu et al. 2015). For example, similar to this study, Itodo et al. (2017) also affirm that increased economic growth increases industrial production activities, and by extension, increases carbon dioxide emission. On the contrary, Dlamini et al. (2015) find unidirectional Granger causality running from electricity consumption to GDP with the adoption of bootstrap rolling window techniques, while Hamdi et al. (2014) find feedback causal effect between electricity consumption and economic growth in Bahrain. Also, Soytas and Sari (2006) interestingly show no causal interaction among the bloc of countries studied. The variance in results from the various studies could be attributed to methodological disparity and differing sample selection.

The causality analysis shows a unidirectional causality running from electricity consumption to CO_2 and from RGDP to electricity consumption. Thus, this study validates the conservative hypothesis in the energy economics literature. Furthermore, from the dynamic causality test result, more economic activities trigger increased income level at both individual and corporate fronts. This translates into increased demand for electricity, and also births industrialization. However, increase in industrial activities has detrimental impact on environment quality.

In summary, the key policy recommendation of our study is that government officials/ energy policymakers who design the energy/ environment framework in Pakistan should embark on conservative energy policies as such policies will not have adverse effects on economic growth. However, there is a need for them to adopt a policy mix that curbs environmental degradation, since there is a causal relationship between electricity consumption and carbon dioxide emissions. The need to spread the energy portfolio to include renewable energy alternatives such as solar, wind and biofuel is paramount in the quest to achieve green environment in Pakistan.

Chapter 5

ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH NEXUS IN ZIMBABWE REVISITED: FRESH EVIDENCE FROM MAKI COINTEGRATION

5.1 Introduction

There is a close link between the utilization of electricity and the economic development of any country. The electricity supply to the country's citizens affects directly the growth of a country economically. There has been a vivid recognition of the importance of electricity consumption to the growth of the economy, not only by the economists but by policymakers, engineers, businessmen, government and energy agencies. As outlined by the United States Energy Information Administration (EIA) (EIA, 2018). A country's economy and its energy use are linked. Short-term changes in electricity use are often positively correlated with changes in economic output measured by gross domestic product (GDP). However, the underlying long-term trends in the two indicators may differ. All these equal, a growing economy leads to greater energy and electricity use.

In the last twenty years, the demand for the consumption of energy has been increasing abruptly, mostly for gas and oil, the main causes being the rapid increase in the economy growths of nations like the United States, India and China, to name a few. This led to an increase in industrialization, a rise in living standards and upsurge rates of urbanization, thus directly fueling the electricity demand in the whole world. Energy demand increases, especially for oil, saw an outrageous increase in oil price globally resulting in an enormous windfall for countries like the Gulf Corporation Council (GCC) countries which are oil-exporting. These include Saudi Arabia, Kuwait, Bahrain, Oman, the United Arab Emirates (UAE) and Qatar. In order for these countries to then transform their economies, they then invested in other economic sectors including but not limited to, the tourism sector, infrastructure and education sectors, thus directly influencing electricity demand in the GCC countries (Osman et al., 2016).

According to (Karanfil and Li, 2015), the causal nexus between electricity consumption and economic growth is classified into four hypotheses categories. The categories are:(1) The feedback hypothesis, which accentuate the interrelationship between electricity consumption and economic growth; (2) The growth hypothesis, which gives an assumption that electricity in a fundamental factor in the growth of the economy, thus implying that there is a close relationship between electricity and economic growth; (3) The neutrality hypothesis, which speculates no causal link and; (4) The conservation hypothesis which theorizes a causal nexus that runs from economic growth to electricity consumption. It is of paramount importance to determine the causality direction and relationship between electricity consumption and economic growth in Zimbabwe so as to efficiently suggest policy modifications or implications.

Additionally, expansive studies on the causal nexus between the consumption of energy and the growth of the economy have been done, and the outlined results from these studies have proved informative. This then catalyzed the recent interests in studies of the relationship between the consumption of electricity and the growth of the economy employing methodologies that are almost indistinguishable from the interest variables are comparable. Another important factor is the availability of both micro-level and macro-level data, thus attracting more researchers into this field of research, some of the economists' the pioneering studies being that of (Kraft, J., Kraft, 1978) on economic growth and energy consumption. Electricity has a huge impact on mostly growing economies like Zimbabwe and it is considered a major input of production (Rafindadi and Ozturk, 2016), hence a study of the causal nexus between the electricity consumption and economic growth is of paramount importance. Research in this area is of even greater importance to Zimbabwe since the country heavily depends on conventional energy production means. These sources of energy production are not only depleting but they are unclean, not environmentally friendly and unsustainable, thus the policymakers should now incorporate renewable energy resources in the energy portfolio to ensure sustainability. As much as Zimbabwe is not utilizing any renewable energy resources on a large scale, studies by (Samu, R. and Fahrioglu, 2017; Samu et al., 2016), have proven that Zimbabwe has vast solar resources nationwide that can be utilized for large-scale electricity production.

5.2 Literature Review

There have been several studies in the area of the relationships between both macroeconomic and microeconomic variables by employing different methodologies. It is possible to categorize the causal nexus examinations into small, medium or large-scale studies. Studies by region have been performed by several researchers in trying to find the relationship between electricity consumption and economic growth, these include, (Katircioglu,2014; Angelique G. Nindi and Nicholas M. Odhiambo., 2014; Bélaïd and Abderrahmani, 2013; Cowan *et al*., 2014; Golam Ahamad and Nazrul

Islam, 2011; Jianlin Wang ; Jiajia Zhao and Hongzhou Li, 2017; Michael L.Polemis ; Athanasios S; Dagoumas b, 2013; Rafindadi and Ozturk, 2017a; Samuel Asumadu-Sarkodie and Phebe Asantewaa Owusu, 2016; Zhang et al., 2017), among others. Additionally, many noteworthy studies by (Rafindadi, 2015, 2014; Rafindadi et al., 2018; Rafindadi and Ozturk, 2017a, 2015; Rafindadi and Yusof, 2015) have outlined the relationship between energy consumption and other variables like environmental pollution, financial development and trade openness for several locations worldwide. This sudden increase in the interests is partially related to many factors. Some of the main ones will be outlined in this present study.

Some of the recent studies examining the relationship between electricity consumption and economic growth were performed by (Akinwale, 2013; Aslan, n.d.; Bélaïd and Abderrahmani, 2013; Hamdi et al., 2014; Jianlin Wang ; Jiajia Zhao and Hongzhou Li, 2017; Kahouli, 2018; Personal et al., 2017; Shahbaz et al., 2011) . Furthermore, (Mezghani and Ben Haddad, 2017), conducted an empirical study of electricity consumption in Saudi Arabia. After employing the Time-Varying Parameters Vector Autoregressive (TVP-VAR) model to study the relationship between carbon dioxide levels and electricity consumption, they determined that TVP-VAR model they used in their study was of use for determining the dynamics between carbon dioxide emissions and electricity consumption.

Several other studies by region, also incorporating the nexus between the quality of the environment and economic growth based on the presence of the Environmental Kuznets' Curve (EKC) have been published (Baek, 2015; De Bryn SM, JCJM Van der Bergh, 1998; Egli H, 2002; Jalil and Mahmud, 2009; Kang et al., 2016; Lim, 1997; Rafindadi, 2016a). In the former Soviet Republics, there exists a co-integration between electricity consumption and gross domestic product (Bildirici and Kayıkçı, 2012). In their study (Rafindadi and Ozturk, 2017b) determined how economic growth is affected by other factors like trade openness and financial development. This causal relationship was determined by utilizing the Granger causality in which they determined that South Africa's energy demand is stimulated by financial development. Additionally utilizing a time series data, (Rafindadi, 2016b), analyzed the nexus between CO_2 emissions, economic growth and energy consumption in Nigeria. Findings from this study revealed that even though economic growth results in a decrease in energy demand, it results in an increase in carbon dioxide emissions, and so does energy consumption.

(Eyup Dogan, 2014) did an analysis of the energy consumption and economic growth for low-income countries in Sub-Saharan Africa. Evidence from this study outlined that the time series data in Zimbabwe is not stationary and only became stationary after the second differences of the time-series were taken. Further analysis of the results from the Johansen co-integration test by (Eyup Dogan, 2014), proved that there is no causality linkage and there is no long-run relationship between energy consumption and economic growth in Zimbabwe. In studying the impact that energy use has on the economic growth of Zimbabwe, (Adam Willie, 2014), outlined that there is a co-integration between energy use and economic growth in Zimbabwe and also that an economic growth was caused by energy using Granger causality test. Employing a bi-variate causality test framework, (Kunofiwa Tsaurai, 2013a), concluded that there was no direct relationship between economic growth and energy consumption in Zimbabwe.

According to recent statistics for Zimbabwe, 8,500,000 inhabitants are without electrification. 60 % of the total population lack electrification. Furthermore, in the urban area, 20% are without electricity access while an overwhelming alarming 79% resides in rural areas (CIA, 2018). The overwhelming electricity deficit identified in the study area has drawn the attention of energy practitioners and policymakers. The motivation of this present study is vivid considering that no studies in for the causal nexus between electricity consumption and economic growth in Zimbabwe have gone beyond bi-variate analysis given the inconclusive empirical findings in the energy economics literature. Thus, this present study seeks to examine the causality relationship and long run and short-run dynamics between electricity consumption, carbon dioxide emissions and economic growth in a trivariate framework. This paper distinct from the bulk of literature in terms of scope by incorporating carbon dioxide emissions into our econometrics framework that captures for environmental degradation. Previous studies (Tamba *et al.*, 2017; Shahbaz & Feridun, 2012; Kayhan *et al.*, 2010; Acaravci & Ozturk, 2010) based their arguments on a bivariate framework which arguably flawed with specification bias that is, omitted variable bias and by extension misleading policy implication.

To the best of the author's knowledge, the only existing electricity consumption-economic growth nexus study for Zimbabwe was done by (Kunofiwa Tsaurai, 2013b), in a paper titled 'Is there a relationship between electricity consumption and economic growth in Zimbabwe?'. In this study, a bi-variate time series framework was employed for the time period 1980-2011. Unfortunately, in (Kunofiwa Tsaurai, 2013b) study, by utilizing the bi-variate causality test framework, the analysis failed to provide a causality nexus between energy consumption and economic growth thus concluding a presence of an indirect bi-directional causality between the electricity consumption and energy growth in Zimbabwe.

The study of Kraft and Kraft (1978) on the nexus between income and energy consumption for the United State serve as an ushering to other studies in the energy economics literature. From the Kraft and Kraft (1978), we observe that there is a link between economic growth and energy (electricity) consumption. The current study explores the theme, which has been less study in sub-Saharan Africa especially our focus country (Zimbabwe). Thus, we seek to re-examine the theme under consideration, though accounting for the role of environmental degradation. The current study relies on convention logic as well as empirical backing. As the most nations across the globe increase in urbanization given the interconnectedness of nations on each other (Shahbaz *et al*.2018). It comes with her energy demand; this increase energy demand needs come with her environmental cost and implication(s). This is conceptualized in the energy economic literature as the environmental Kuznets curve hypothesis advanced by Simon Kuznets (1955), and subsequently popularizes by Grossman and Krueger (1991). This is where an inverse relationship exists between income level of a nation and environmental quality[12]. This study also draws strength from the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) framework developed by (Dietz & Rosa, 1994; York *et al*.2005). The aforementioned background informed the choice of the current choice of the variables to explore the electricity-growth hypothesis over the sampled period.

[12] For interested reader on the Environmental Kuznets Curve hypothesis (see Shahbaz & Sinha,2019)

The novelty of this present study is in methodological innovation and advancement. We employed relatively new econometrics technique like Zivot-Andrews (1992) unit root test for stationarity properties of the series. The Zivot-Andrews (1992) unit root test accounts for single structural break while for long-run equilibrium relationship Maki (2012) cointegration was applied that accommodates for multiple structural breaks (s) whilst for direction of causality our paper relies on Toda-Yamamoto (1995) causality test a modified version of Wald test (MWALD) in a vector autoregressive framework. This causality test is known to possess superior properties than the conventional Granger causality test (Lutkephol & Kratzig 2004), the estimates are more reliable and robust. The essence of the structural break model was to account for a break(s) given the nature of most macroeconomics/financial data to avoid spurious regression trap and analysis, which previous studies did not address.

The rest of this study is outlined as follows. Section 3 presents a brief background on the electricity sector in Zimbabwe. Section 4 renders the method and techniques applied for the study. While in section, 5 empirical analysis and interpretation are reported. The concluding remarks are in section 6. The last section offers the policy direction(s) for policymakers and all stakeholder available in section 7.

5.2.1 Electricity Sector in Zimbabwe: A Synopsis

The Zimbabwe electricity sector is overshadowed by the Zimbabwe Electricity Supply Authority (ZESA) Holdings which is a utility that is government owned. The subsidiaries are the Zimbabwe Electricity Transmission and Distribution Company (ZETDC) which is the company that runs the transmission and distribution services and networks. The ZETDC also handles regional trading through that Southern African Power Pool (SAPP). Another subsidiary for ZESA Holdings is the Zimbabwe Power

Company which manages the five major power stations in Zimbabwe namely; the Kariba South hydropower station, Hwange thermal power station, Harare thermal power station, Munyati thermal power station and the Bulawayo thermal power station (African Development Bank Group, 2018). Additionally, some Independent Power Producers (IPPs) are also available for the generation of electricity in Zimbabwe. These include the Charter IPP which is a 500MW co-generation power plant and the Nyamigura IPP which is a 1.1 MW hydroelectric plant. Both of these entities sell their electricity to the national grid, though some small IPPs exists as well but independently dispose of their generated electricity. Figure 1 shows the institutional arrangements in the Power sector in Zimbabwe.

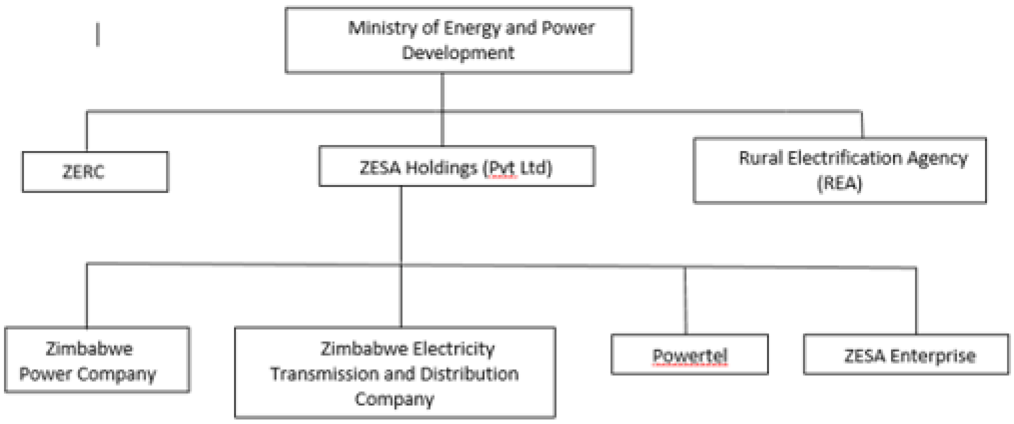

Figure 7: The Institutional Arrangements in the Power Sector in Zimbabwe.

The following are detailed operations of the institutions in the power sector of Zimbabwe

- The Ministry of Energy and Power Development (MEPD)

  The function of the ministry is to formulate the energy policy, monitor the performance and regulation of the energy sector as well as promoting new and renewable energy sources. The ministry supervises all the other institutes in Figure 1 with responsibilities in the energy sector.

- Zimbabwe Power Company (ZPC),

  The Zimbabwe Power Company is responsible for all generating stations and for the supply of power to the transmission grid.

- Powertel

  These are responsible for providing communication services to the power companies, and offer data services to the public.

- Rural Electrification Agency (REA)

  The Rural Electrification Agency (REA) is responsible for grid extension in rural areas and for supplying specific institutions, such as schools, clinics, government offices, and community-initiated projects.

- Zimbabwe Electricity Regulatory Commission (ZERC)

  The ZERC reports to the Minister of Energy and Power Development. The mandate of ZERC includes promotion of competition and private sector participation in the power sector, licensing and regulation of businesses engaged in the generation, transmission, distribution, and supply of electricity, arbitration and mediation of disputes, establishing operating codes and standards for the sector and issuing guidelines, and advising stakeholders about electricity services.

- Zimbabwe Electricity Transmission and Distribution Company (ZETDC)

  ZETDC is responsible for transmitting and distributing electric power and for its sale, including meter reading, billing, cash collection, and credit control of the retail business. It is also responsible for regional trade in power.

The total installed generation capacity in Zimbabwe is 1,960 MW. The installed fossil fuel capacity is 1,220MW and the hydro capacity is 750MW. In terms of percentage, Coal constitutes 62% and the rest 38% is Hydro (Samu et al., 2016). As of June 30, 2015, the total annual energy consumption of Zimbabwe is 12.57 billion kWh (CIA world factbook, 2016). This entry consists of total electricity generated annually plus imports and minus exports, expressed in kilowatt-hours. The discrepancy between the amount of electricity generated and/or imported and the amount consumed and/or exported is accounted for as loss in transmission and distribution**.** Zimbabwe has been suffering a huge electricity deficit since it only generates a total of 1300MW against a peak demand of 2200MW (Samu, R. and Fahrioglu, 2017) which results in a national electrification rate of about 40 per cent with the electrification rate of rural areas around 19 per cent.

The rest of this paper is sectioned as following; following in the next section 3 is the methodological framework that explicitly details data and econometrics procedures. Section 4 focuses on empirical results and discussion and finally, section 5 provides a conclusion and possible policy implications

5.3 Methodological Framework

5.3.1 Data

The current study employs second-generation time series econometrics techniques to consider the dynamic nexus between electricity consumption, carbon dioxide emissions and economic growth for the case of Zimbabwe. The current study period spans from 1971-2014, the data span is restricted based on the availability of data. The data were retrieved from the World Bank Development Indicators (WDI CD-ROM, 2018). This study leverages on the studies of Sekantsi *et al.* (2016) and Kayhan *et al*.

(2010) for empirical backing. This study proxy economic growth as real gross domestic product (RGDP) constant 2010 USD, carbon dioxide emission (CO_2) in Kt while electricity consumption (EC) in kWh per capita. Table 21 renders the summary description of data employed in this study.

Table 21: Summary Description and Data Source

Variable Name	Symbol	Description	Source
Gross domestic product	RGDP	Real income represented by GDP constant (2010 USD$)	WDI (2018)
Carbon dioxide emissions	CO_2	Measured in Kt tones	WDI (2018)
Electricity Consumption	EC	Captured as electricity consumption (kWh per capita)	WDI (2018)

Source: Authors compilation.

The empirical path of this study is as follows (1) Stationarity test via Zivot Andrews (1992) unit root test to identify the asymptotic characteristics of the variables and the maximum order of integration of each series so as to circumvent the spurious regression trap. (2) The estimation of long-run equilibrium relationship through Maki (2012) co-integration test and finally (3) Estimation of causation and direction with the aid of Toda-Yamamoto (1995) Granger causality test.

5.3.2 Model Specification

In order to examine the electricity growth nexus, our study functional form follows the studies of (Kayhan *et al*. (2010; Sekantsi *et al.*2016). The econometrics model is given as:

$$EC = f(RGDP, CO_2) \tag{23}$$

$$LnEC = \alpha + \beta_1 LnRGDP_t + \beta_2 LnCO_2 + \varepsilon_t \tag{24}$$

Here, α represents intercept and $\beta_{1,}\beta_2$ are partial slope parameter. LnEC, Ln RGDP and $LnCO_2$ are the natural logarithm for electricity consumption, real gross domestic product and carbon dioxide emissions respectively to achieve homoscedasticity among series.

5.3.3 Stationarity

In order to establish the asymptotic traits and maximal order of integration of time series variables, stationarity test is crucial. However, various unit root test abounds in the applied economics literature namely: (Augmented Dickey-Fuller ADF, 1981; Phillips & Perron PP, 1988; Ng and Perron, 2001; Elliot et al., 1996) among others. The above-mentioned tests fail to account for structural breaks which are known to plague most macro/financial series. Thus, Zivot and Andrews (1992) ameliorate the aforementioned issue. Zivot- Andrews (ZA) unit root test accounts for a single structural break. The ZA test comprises of three models given as:

$$ModelI : \Delta Y = \beta_1 + \beta_2 t + \delta Y_{t-1} + \phi DU_t + \sum_{i=1}^{K} \alpha_i \Delta Y_{t-1} + \mu_t \tag{25}$$

$$ModelT : \Delta Y = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma DU_t + \sum_{i=1}^{K} \alpha_i \Delta Y_{t-1} + \mu_t \tag{26}$$

$$ModelB : \Delta Y = \beta_1 + \beta_2 t + \delta Y_{t-1} + \phi DU_t + \sum_{i=1}^{K} \alpha_i \Delta Y_{t-1} + \mu_t \tag{27}$$

Here, the dummy variable DU_t shows the shift that occurs at each point where the break happens either at (intercept, trend or both intercept and trend). The ZA test has a null hypothesis of the unit root where $H0 : \theta > 0$ against the alternative stationarity $H1 : \theta < 0$ that is, failure to reject H0 implies the presence of unit root and rejection means stationarity.

5.3.4 Cointegration

Cointegration test is needed to test the long-run equilibrium convergence of the given series. Standard conventional Cointegration test fails to account for structural break among series. Westerlund and Edgerton (2007). Thus, we claim they are spurious and give misleading relationship. Several cointegration tests that account for a single structural break in the series are (Hatemi-J, 2008; Westerlund & Edgerton, 2007; Carron-i-Silvestre & Sanso, 2006; Gregory & Hansen, 1996). On the contrary, accounting for a single structural break in economic variables is doubtful, given the unpredictable nature of most macro/financial series. Thus, the estimation of such estimators is flawed with long-run equilibrium relationship among such series. It is on the above premise, that Maki (2012)[13] advanced a Cointegration test that accounts for multiple structural breaks. However, in order to adequately apply the Maki (2012) Cointegration test all series are required to be stationary ~I (1). The equations proposed by Maki (2012) are presented as:

Model 1: Break in intercept and without trend

$$x_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \delta' y_t + u_t \tag{28}$$

Model 2: Break in intercept and coefficients and without trend

$$x_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \delta' y_t + \sum_{i=1}^{m} \delta_i' y_t D_{i,t} + u_t \tag{29}$$

Model 3: Break in intercept and coefficients and with the trend

$$x_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \delta' y_t + \sum_{i=1}^{m} \delta_i' x_t D_{i,t} + u_t \tag{30}$$

Model 4: Break in intercept, coefficients and trend

[13] The authors are grateful to Prof. Daiki Maki of the faculty of Economics, Ryukoku University for the availability of the codes in GAUSS that facilitated the Cointegration simulation.

$$x_t = \mu + \sum_{i=1}^{m} \mu_i D_{i,t} + \beta t + \sum_{i=1}^{m} \beta_i t D_{i,t} + \delta' y_t + \sum_{i=1}^{m} \delta_i' y_t D_{i,t} + u_t \tag{31}$$

Here, the D_i is a dummy, where $D_{i=}1$ when t $>T_b$ and D_i=0, where T_b indicates a possible break point.

5.3.5 Estimation of Long-Run Coefficients

The need for long-run coefficients is necessary, given the establishment of long-run Cointegration relationship in our study. That is, there exists a long-run equilibrium relationship among the series under review. To this end, the Dynamic Ordinary Least Squares (DOLS) estimation technique is employed. The merit of the DOLS approach includes (i) the technique can be applied regardless of the order of integration of the regression. However, the dependent variable is required to be integrated of order one that is ~ I (1). (ii) The techniques also aid in circumventing for serial correlation issues arising from the model and other internalities. See (Esteve & Requena, 2006).

The Dynamic ordinary least squares model can be given as;

$$\ln EC_t = \beta_0 + \beta_1 \ln RGDP_t + \beta \ln C02_t + \sum_{i=-q}^{q} \alpha_i \Delta \ln RGDP_{t-i} + \sum_{i=-q}^{q} \phi_i \Delta \ln C02_{t-i} + \varepsilon_t \tag{32}$$

Here, q denotes the optimum lag level as obtained by the Schwarz Bayesian Information Criterion (SBIC).

5.3.6 Causality Test

The need for causation and direction among variables is essential for policy implications. Conventional regression does not actually depict causation; thus, causality test is crucial. This current study relies on the Toda- Yamamoto (1995) causality technique. The Toda-Yamamoto (TY) is a modified version of the Wald test (MWALD) with a superior advantage against conventional Granger causality. The technique is known to give more efficient and consistent estimates. Furthermore, the TY approach is also known to be resilience in the presence of a mixed order of integration among series. The TY approach is structured in a Vector Autoregressive framework VAR (K+ d_{max}). Here, K represents the optimal order of integration in the VAR, while d_{max} is the maximum integration order. The VAR (K + d_{max}) is given below as:

$$LnEC_t = \theta_{2j} + \lambda_{2j}\Sigma_{t-1} + \sum_k \theta_{22tk} LnEC_{t-k} + \sum_k \theta_{21tk} LnRGDP_{t-k} + \sum_k \theta_{23tk} LnC02_{t-k} + \mu_{1t} \tag{33}$$

$$LnRGDP_t = \theta_{2j} + \lambda_{2j}\Sigma_{t-1} + \sum_k \theta_{22tk} LnRGDP_{t-k} + \sum_k \theta_{21tk} LnEC_{t-k} + \sum_k \theta_{23tk} LnC02_{t-k} + \mu_{2t} \tag{34}$$

$$LnC02_t = \theta_{2j} + \lambda_{2j}\Sigma_{t-1} + \sum_k \theta_{22tk} LnC02_{t-k} + \sum_k \theta_{21tk} LnEC_{t-k} + \sum_k \theta_{23tk} LnRGDP_{t-k} + \mu_{3t} \tag{35}$$

5.4 Empirical Results and Discussions

The preliminary visual plot of series is necessary in time series econometric analysis. This is in order so, to have a glimpse of the nature of variables. Figure 8 presents the graphical plot in their natural logarithm form. The graphical plot shows possibility of structural break(s). Thus, it is pertinent to account for such breaks in the econometric analysis to avoid spurious analysis. To this end, the current study utilizes estimation techniques that account for a structural break(s). Table 22 reports the summary statistics and correlation matrix for the series under review. All series are normally distributed except for electricity consumption. Also seen is the negative skewedness exhibited by all series. The results of the correlation matrix are very insightful. There exists a positive and significant relationship between economic growth and carbon dioxide emissions. This is true for the case study. Also revealed by the correlation matrix is the significant positive association between electricity consumption and economic growth. This is obvious for Zimbabwe given her swift growing population. Although correlation analysis gives a glimpse of the sort of relationship between variables. However, the correlation analysis is not sufficient to substantiate our claims.

It on the premise, which this study proceeds to conduct more econometrics analysis to either refute or validate our study arguments.

Table 22: Summary Statistics

	LNEC	LNRGDP	$LNCO_2$
Mean	6.695	23.103	9.324
Median	6.764	23.088	9.265
Maximum	6.945	23.498	9.787
Minimum	6.275	22.630	8.631
Std. Dev.	0.188	0.260	0.271
Skewness	-1.215	-0.150	-0.059
Kurtosis	3.224	1.838	2.320
Jarque-Bera	10.914	2.640	0.873
Probability	0.004	0.267	0.646
Correlation Estimation			
Observations	LNRGDP	LNEC	$LNCO_2$
LNRGDP	1		
t-Stat	-----		
P-value	-----		
No. Obs.	44		
LNEC	-0.134	1	
t-Stat	-0.876	-----	
P-value	0.386	-----	
No. Obs.	44	44	
LNCO2	0.6811	0.3362	1
t-Stat	6.0285	2.3136	-----
P-value	0.000	0.0257	-----
No. Obs.	44	44	44

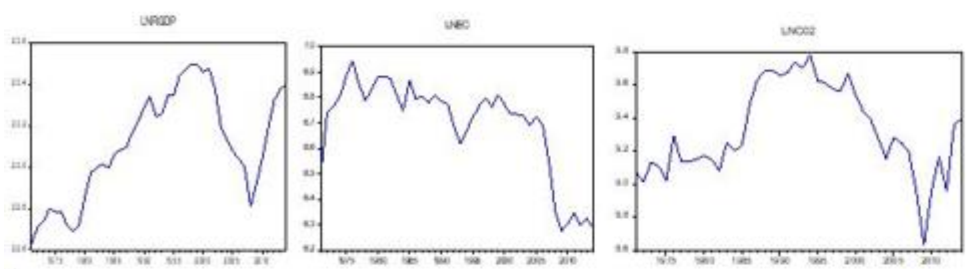

Figure 8: Graphical Plot of Variables under Review in their Natural Logarithm Form.

Table 23: Zivot-Andrews (1992) Unit Root Test Under Single Structural Break.

Variables	Statistics (Level)			First Difference			
	ZA_B	ZA_T	ZA_I	ZA_B	ZA_T	ZA_I	Lag
LnRGDP	-3.02	-2.86	-4.61	-5.96**	-4.40**	-4.38**	I(1)
Break year	2002	2002	2002	2002	2006	1999	
Lag Length	1	1	1	1	1	1	
LnC02	-3.78	-3.03	-3.25	-7.91**	-7.63**	-7.76**	I(1)
Break year	1986	1991	1986	2000	2007	1995	
Lag Length	1	1	1	1	1	1	
LnEC	-4.44	-3.86	-5.50	-5.27**	-6.19**	-6.61**	I(1)
Break year	2007	2003	2007	2007	2007	1994	
Lag Length	1	1	1	1	2	1	

Note: RGDP is a real gross domestic product, EC is electricity consumption and CO_2 is carbon dioxide emission. All series are in their natural logarithm form. Here, ZA_B represents a model with a structural break in both trend and intercept, ZA_T denotes model with a break in trend while ZA_I represents a model with a break in the intercept. Also, ** signifies a rejection of the null hypothesis of a unit root at 5% significance level.

This study relies on the ZA unit root test that accounts for a single structural break to validate the maximum order of integration of the series under review. Table 23 shows that electricity consumption, real gross domestic product and carbon dioxide emissions possess unit root, that is, they are non- stationary given the failure to reject the null hypothesis of a unit root. However, after first differencing all series became stationary. Thus, we conclude that all series are integrated of order one ~I (1). Furthermore, given the same order of integration of series conducted, this study proceeds to investigate the long-run equilibrium relationship via Maki (2012) Cointegration test that accounts for multiple structural breaks.

Table 24: Maki Cointegration Test Accounting for Multiple Structural Breaks

Number of Break Points		Test Statistics [Critical Values]	Break Points
$T_B \leq 1$			
	Model 0	-5.69 [-5.00]*	1999
	Model 1	-5.83 [-5.35]*	1973
	Model 2	-5.68 [-5.55]*	1980
	Model 3	-5.99 [-6.05]	1978
$T_B \leq 2$			
	Model 0	-5.81 [-5.21]*	1999;2003
	Model 1	-7.45 [-5.51]*	1973;2003
	Model 2	-5.88 [-6.09]	1980;2010
	Model 3	-5.99 [-6.65]	1978;2006
$T_B \leq 3$			
	Model 0	-5.83 [-5.39]*	1999;2003;2007
	Model 1	-7.50 [-5.69]*	1973;2003;2012
	Model 2	-5.88 [-6.51]*	1980;1990;2011
	Model 3	-6.53 [-7.14]	1978;1995;2006
$T_B \leq 4$			
	Model 0	-6.94[-5.55]*	1989;1990;2003;2007
	Model 1	-7.51[-5.83]*	1973;2003;2010;2012
	Model 2	-6.88[-6.87]*	1980;1990;2007;2011
	Model 3	-8.53[-7.63]*	1978;1995;2001;2006
$T_B \leq 5$			
	Model 0	-7.18[-5.76]*	1987;1989;1999;2003;2007
	Model 1	-7.51[-5.99]*	1973;2003;2008;2010;2012
	Model 2	-7.88[-7.28]*	1980;1986;1990;2007;2011
	Model 3	-8.53[-8.12]*	1978;1988;1995;2001;2006

Note: numbers in [ ] denotes critical values at 0.05 level obtain from Maki (2012) generic article while * signifies statistical significance at 0.05 significance level.

Table 4 reports the estimation results, as seen above there exists a long-run equilibrium convergence between electricity consumption, carbon dioxide emissions and real gross domestic product for the case of Zimbabwe over the sampled period. The Cointegration evidence is provided under the null hypothesis of no Cointegration under various structural break models as given in Table 24.

In addition to the cointegration test. Table 25 reports the DOLS results reflecting the long-run coefficients of the series under review. Table 5 reveals that economic growth has an inelastic, positive and statistically significant effect on electricity consumption while carbon dioxide emission (CO_2) has a positive inelastic impact on electricity consumption in the long-run. Our study findings lend supports the growth induced electricity hypothesis. As 1% increase in economic growth translate into 0.787% increase in energy consumption and specifically electricity consumption in Zimbabwe. Similarly, same positive statistical trend was observed between CO_2 emissions and electricity consumption. This outcome has environmental cost and implications as increase electricity consumption increase CO_2 emissions. Increase in CO_2 emission deplete the quality of the environment. This implies that the energy consumption choice in Zimbabwe is not from cleaner energy source more of fossil fuel that triggers increase CO_2 emissions. Thus, this is a call for policymakers, energy consultants and all stakeholder to refocus the energy portfolio in Zimbabwe to cleaner energy sources. Our study finding is in line with the studies of (Katircioglu,2014; Agbaje & Idachaba, 2018; Akinwale *et a*l., 2013) for the case of Nigeria.

Table 25: Dynamic Ordinary Least Square (DOLS) for Long-run Coefficients

Regressors	Co-efficient	Std. Error	t-Statistic	P-value.
LNRGDP	0.787	0.221	3.561	0.002
LNCO2	0.702	0.210	3.347	0.003
C	18.362	3.817	4.810	0.000
R-squared	0.718			
Adjusted R-squared	0.588			
S.E. of regression	0.112			
Long-run variance	0.034			

Note: optimum lag was obtained by Schwartz Bayesian information criterion (SBIC) while long-run covariance is expunged by Bartlett kernel and Newey –west is fixed at 3.

Subsequently, the directional flow among series is achieved through the Toda-Yamamoto (1995) causality test is employed. Table 26 reports the TY causality results. There exists unidirectional causality running from electricity consumption (EC) to economic growth (RGDP). Thus, validating the electricity-led growth hypothesis in Zimbabwe. That is, increase energy consumption causes increase income level for our study area. Further empirical evidence also revealed a bi-directional causality running from RGDP and CO_2 and vice versa. The bi-directional causality also possesses its policy implications. That is, an increase in economic activities increases carbon dioxide emissions (CO_2) also increase in industrial activities also births environmental challenge see (Bekun *et al.*,2018; Itodo *et al.*, 2017; Gokmenoglu *et al.*, 2015). See Figure 9 for the causality routes.

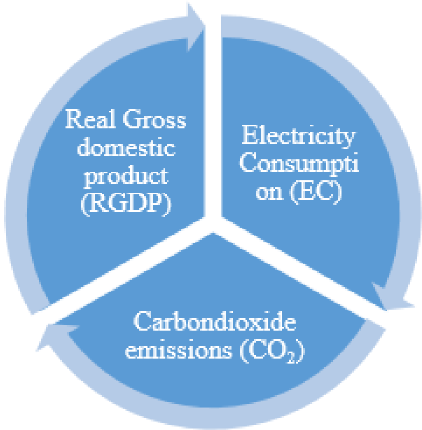

Figure 9: Causality Routes.

Table 26: Toda-Yamamoto (1995) Causality Test

	Dependent Variables			Block Exogeneity
Excluded variables	Ln EC	Ln RGDP	LnC02	ALL
Ln EC		0.848 (0.654)	1.004 (0.605)	2.194 (0.700)
Ln RGDP	5.552 (0.062)		4.968 (0.083)	8.373 (0.078)
LnC02	0.202 (0.903)	5.850 (0.053)		7.925 (0.094)

Note: numbers in () are probability values.

5.5 Concluding Remarks

Energy (electricity) consumption plays an essential role as key determinant that stimulates economic growth in developed, emerging and developing economies. The energy economics literature has well-documented studies in this regard. However, there been no consensus on empirical findings. Thus, this study revisits the electricity-growth nexus in Zimbabwe by offering a new perspective to the topical topic by the inclusion of carbon dioxide emissions to the study econometrics framework. The current study distinct from previous by accounting for environmental degradation (CO_2). This study also accounted for a structural break in the econometrics framework.

These form the strength of the current study, given the precision and robustness of estimates and coefficients for onward policy implication. The empirical investigation was based on annual frequency data from 1971-2014. Empirical findings show that all the variables considered for the study were integrated of order one. As such, cointegration analysis under multiple structural breaks reals a long-run equilibrium relationship between electricity consumption, real gross domestic product and carbon dioxide emissions over the sampled period. Subsequently, long run regression of the DOLS validates the growth induced electricity consumption. Thus, implying that increase economic growth will increase more increase energy consumption. This is true for the case study given the fast pace of urbanization, as more industrialization is experienced it translates into more energy (electricity) demand. However, there is a tradeoff for environmental quality as we observe also a positive statistically significant relationship between CO_2 and electricity consumption. This implies that the Zimbabwe economy is energy driven though not cleaner energy sources. This outcome resonates the findings of Shahbaz et al (2017) for the Portuguese economy.

The Causality analysis is revealing as unidirectional causality was observed from electricity consumption to economic growth. This is in agreement with the electricity led growth hypothesis. This is contrary to the finding of Nazlioglu *et al*. (2014) for the Turkish economy found neutrality hypothesis. The plausible explanation to the variance in findings could be estimation techniques and sample structure. The current study modeled for a possible structural break, which could affect the estimation results not accounted for in earlier studies. Further causality analysis also reveals feedback causality between economic growth and carbon emissions. This outcome is informative to environmental and governmental scholars on the need for environmental consciousness.

5.5.1 Policy Implications

The global increase need for energy (electricity) consumption in both developed and developing economies has drawn the attention of policymakers, energy economist and environmental economist to energy sources and cleaner energy alternatives. This becomes necessary given the contribution of greenhouse gas (GHG) to environmental degradation and global warming. The current study empirical findings give credence to the electricity induced economic growth hypothesis. Thus, implying the heavy dependency of Zimbabwean economy on her energy sector. As such the government administrator of the Zimbabwean economy should as a matter of urgency place more attention on her energy sector given it a driver for economic growth. The feedback causality seen from the causality has its environmental implication on Zimbabwe it is a call for cleaner and environmental energy sources like renewable energy. Both governmental bodies and most governmental agencies have advocated the driver to cleaner energy sources across the globe. The study of Emir and Bekun (2019) advocates the role of renewable energy sources to Romanian economy. Furthermore, the bidirectional causality hypothesis implies that energy conservative policies will adversely impede economic activities given that the economy is energy dependent. This finding resonates with the studies of see (Balsalobre-Lorente *et al*., 2018; Shahbaz *et al*., 2017; Ameyaw *et al*., 2016; Tang & Tan, 2013; Hu & lin, 2013). The revelations from the study imply that government administrator, energy specialist need to focus more on policymakers to design environmentally friendly laws and regulations like the Kyoto Protocol treaty. The Zimbabwean economy needs to join as a signatory to the Paris Agreement to strengthen her commitment to environmental quality. Thus, the need for a subscription to more renewable energy sources like biofuel, wind energy, photovoltaic energy sources like solar energy sources which are more environmentally friendly is recommended for the Zimbabwean economy given increase CO_2 emissions. The government and decision-makers cannot undertake renewable energy policy measures without adverse effect on economic growth. Thus, is a need for caution in policy design and implementation is required given that the Zimbabwean economy is energy dependent. As for direction for other scholars, the need for similar studies on the theme is necessary for Africa whiling accounting for a possible structural break and more recently asymmetry in the econometrics modeling. A panel of studies are also necessary to either validate or refute our study position or already publishable studies.

Chapter 6

CONCLUSION

This dissertation attempts to explore the interaction between energy consumption (renewable and non-renewable) energy sources consumption and its environmental implications. As mentioned previously, this dissertation comprises of four sections.

In chapter two, the causal analysis between energy use and economic growth reveals a unidirectional causality. Thus, the results validate the energy-induced growth hypothesis. This means that energy conservative policy/strategies will harm the initial economic development in South Africa, which is instructive for government administrators. Interestingly, our analysis investigated an inverted U-shaped relationship between energy consumption and economic growth in the long run. This is a warning sign for South Africa to strengthen its commitment to the Kyoto Protocol and the Paris Agreement.

The next chapter focus on a panel of selected countries on the relationship between renewable energy consumption, non-renewable consumption, and economic growth with respect to environmental degradation. The study found a negative and significant long and short run equilibrium relationship is observed between CO_2 and renewable energy consumption, economic growth, natural resources rent, and nonrenewable energy consumption are shown to exert more distortion on environmental sustainability. The plausible explanation to this milestone is credited to the commitment of each country to carbon reduction and cleaner environment by increasing the share of renewable energy in the energy portfolio. More so, most of the countries examined are a signatory to the Kyoto protocol and Paris agreement. Nonetheless, there is still a need to maintain the current momentum in the light of awakening global consciousness toward the attainment of a sustainable environment. In view of this, further studies on this scope should include more countries to capture a large contextual view.

The subsequent chapter focus on the electricity consumption and economic growth nexus relationship for the case of Pakistan over recent time series while accounting for environmental quality by the inclusion of carbon dioxide emission as additional variable to the model construction. The study found a unidirectional causality running from electricity consumption to CO2 and from RGDP to electricity consumption. Thus, this study validates the conservative hypothesis in the energy economics literature. Furthermore, from the dynamic causality test result, more economic activities trigger increased income level at both individual and corporate fronts. This translates into increased demand for electricity, and also births industrialization. However, increase in industrial activities has detrimental impact on environment quality. In summary, the key policy recommendation of our study is that government officials/ energy policymakers who design the energy/ environment framework in Pakistan should embark on conservative energy policies as such policies will not have adverse effects on economic growth. However, there is a need for them to adopt a policy mix that curbs environmental degradation, since there is a causal relationship between electricity consumption and carbon dioxide emissions. The need to spread the energy portfolio to include renewable energy alternatives such as solar, wind and biofuel is paramount in the quest to achieve green environment in Pakistan.

Finally, the last chapter dwell on the electricity led- growth hypothesis for Zimbabwe. The study validates the growth induced electricity consumption. Thus, implying that increase economic growth will increase more increase energy consumption (electricity). This is true for the case study given the fast pace of urbanization, as more industrialization is experienced it translates into more energy (electricity) demand. However, there is a tradeoff for environmental quality as we observe also a positive statistically significant relationship between CO_2 and electricity consumption. This implies that the Zimbabwe economy is energy driven though not cleaner energy sources. This outcome resonates the findings of Shahbaz et al (2017) for the Portuguese economy. The Causality analysis is revealing as unidirectional causality was observed from electricity consumption to economic growth. This is in agreement with the electricity led growth hypothesis.

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