Muhammad Shahbaz
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Econometrics of Green Energy Handbook

Economic and Technological Development

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Chapter 1
Impact of Energy Use Segregation on Carbon Emissions: The Role of FDI in Net Importing and Net Exporting Countries

Avik Sinha, Oana M. Driha, Daniel Balsalobre-Lorente, and José María Cantos-Cantos

Abstract This paper proposes an empirical model for exploring the effect of foreign direct investment, income, renewable and non-renewable energy consumption, and oil price on carbon emissions in net exporting countries (NECs) and net importing countries (NICs) for the period of 1991–2015. Following the conceptual framework of environmental Kuznets curve (EKC) hypothesis and empirical IPAT framework, the analysis has been carried out. The empirical results indicate that foreign direct investment, income, and renewable energy consumption have an N-shaped association with carbon emissions. On contrary, the impact of non-renewable energy consumption on carbon emissions is positive and the impact of oil price on carbon emissions is negative. Moreover, the empirical evidence recommends long-run policies in connection with the promotion of clean technologies, less dependence on natural resources, and advancement in environmental awareness and incentives for replacing old polluting technologies.

Keywords FDI · Net export · Net import · IPAT · Carbon emissions

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1.1 Introduction

In recent years, the increase of greenhouse gases emissions from continuous economic progress is a persistent and serious challenge to the world. Carbon dioxide (CO_2) emission from fossil fuels consumption is regarded to be the main source of the global warming. Hence, since 2002, investment in renewable energy in OECD countries has represented more than 1 trillion US dollars, and renewable energy supply grew on average by 2.7% per year between 1971 and 2014 as compared to 1.0% per year for total primary energy supply (Factbook 2015). Our study tries to bring more light on the environmental degradation process, exploring the connection between carbon emissions, as a proxy for economic degradation, foreign direct investment, economic growth, energy use, and natural resources in selected EU countries. The analysis is carried out separately for net export and net import countries. Following Balsalobre et al. (2019), an N-shaped behavior in the linkage between foreign direct investment and environmental degradation is tested aiming to validate a transition between pollution haven hypothesis and pollution halo hypothesis (PHH) for selected EU countries between 1990 and 2015.

The European Union, as a developed block, promotes clean manufacturing processes. The exploration of the pollution haven hypothesis (PHH) tries to demonstrate how pollution-intense production activities tend to move toward regions with less restrictive regulations and more environmental permissive standards. Consequently, the PHH would help to understand the environmental damage engendered by the manufacturing offshoring in European countries (Kearsley and Riddel 2010). Our main hypotheses are explored under an EKC context, where the connection between economic growth and environmental degradation is also considered nonlinear (Balsalobre et al. 2015). The consideration of an N-shaped EKC allows us to explore the technical obsolescence process in selected EU countries. This result helps us to establish policy recommendation associated with the necessity of enhancing energy measures, the promotion of more efficient energy processes, and the improved management of natural resources. The natural resources and the energy use are considered as driving forces of economic growth, being widely explored in empirical EKC literature (Managi 2006; Caviglia-Harris et al. 2009; Kaika and Zervas 2013).

Our main hypotheses relate to the EU strategy (EC 2015) that includes a minimum 10% electricity interconnection for all member states by 2020. The Commission expectations will put downward pressure on energy prices, in order to reduce the energy dependence. The EC (2015) programmed, in its Renewable Energy Roadmap, a target to increase the level of renewable energy in the EU's overall mix to 20% by 2020. On March 19, 2015, the European Council concluded that the EU is committed to building an Energy Union with forward-looking climate policy based on the Commission's framework with five priority dimensions—energy security, solidarity and trust, a fully integrated European energy market, energy efficiency—contributing to the moderation of demand and decarbonization of the economy, research, innovation, and competitiveness (EC 2015).

The European Union (EU) countries offer an opportunity to empirically analyze both the EKC hypothesis and the pollution haven hypothesis (PHH), justified by the fact that EU is one most regulated and developed regions in the world, characterized by relatively high incomes and economic stability, as well as strengthened environmental regulations (Mazur et al. 2015). Giovanis (2012) considers that the specific factors, which appear in EU, are relevant to consider the premise that the "cost of environmental degradation does not necessarily increase in rich countries or households" because of higher consumption levels resulting from increased incomes.

In last four decades, the evolution of FDI flows has suffered a dramatical increase, in both developed and developing countries (Garsous and Kozluk 2017). During the last decade, FDI inflows increased considerably in European countries, for instance, 198.59 million USD to Austria or to Bulgaria with 33.38 million USD. The greatest average decrease in the period 2000–2013 was recorded in Germany (down 13,196.59 million USD), while in the UK, FDI inflows fell by an average of 6523 million USD.

For example, in China, between 1997 and 2008, manufacturing signified 70% of total FDI inflows for an amount of USD 388,679 million (Liu and Daly 2011). In India, between 2000 and 2015, manufacturing FDI accounted for roughly 50% of total FDI inflows, or USD 123,069 million (Garsous and Kozluk 2017). Previous evidence has confirmed that FDI generates welfares, for both host and investor countries, which facilitate more efficient production patterns, know-how, technology transfer or development (De Mello 1997; OECD 2002). The present study explores the carbon emission determinants, considering the existence of EKC and PHH in European countries. Relevant literature has considered the role of FDI in host countries and how it has impacted over trade openness process. Host country's export performance is essential as an engine of economic growth, assuming that FDI flows contribute to financial development and the arrival of technology from advanced and developed countries to the host developing country. In consequence, this mechanism allows the host country to compete in international markets (Tekin 2012).

The existence of PHH contributes to the international division of labor though the redesigned by the international capital flows. It also confirms that reduced environmental standards mixed with high FDI flows increase the environmental damage (Copeland and Taylor 2004). Our study presents several novelties, first of the including in same model the cubic EKC and cubic FDI's behavior.

The two hypotheses discussed above, the halo effect and the environmental Kuznets curve (EKC), are interrelated. The halo effect follows the productivity literature in spirit, which examines the productivity spillovers by FDI, both at the firm and macroeconomic levels. Positive environmental impact is triggered if the multinational corporations (MNCs) encourage the dissemination of environmentally clean technologies and management practices. This occurs when the foreign firm engages in contracts only with environmentally responsible domestic counterparts.

Therefore, our paper tries to provide a better understanding of the relationship between economic growth, foreign direct investment, and carbon emissions for a panel of European countries, considering as additional key factors, energy use and natural resources, in order to avoid omitted variables. This article goes forward the

EKC and PHH analyses, distinguishing between net export and net import countries. To reach robust results, we have applied PMG-based ARDL to estimate the impact of income, FDI, fossil fuel and renewable energy consumption, and crude oil prices on CO_2. In consequence, our study presents a novel approach to the EKC and PHH, where trade aperture is taking into account. The N-shaped EKC admits the exploration of technical obsolescence (Álvarez et al. 2017a), while the N-shaped connection between FDI and environmental degradation suggests a transition from dirty to clean foreign investments (Balsalobre et al. 2019).

The rest of the paper is structured as follows: Sect. 1.2 provides a literature review. In Sect. 1.3, there is a conceptualization of empirical methodology. Section 1.4 presents discussion of empirical results. The study concludes in Sect. 1.5 with a discussion of some policy implications.

1.2 Literature Review

The growing economic literature validates the connection between economic growth and energy use as main driver forces of environmental degradation process (Kraft and Kraft 1978; Grossman and Krueger 1991), while additional studies also consider that foreign direct investment (FDI) flows is connected with environmental degradation (Copeland and Taylor 1994, 2004). These studies provide empirical evidence that considers that lax environmental regulations increase the competitiveness of host countries. Consequently, FDI flows contribute to delocalization process of dirty production to developing countries that present less environmental restrictive regulations (Cole 2004; Aliyu 2005; Waldkirch and Gopinath 2008). This process implies a comparative advantage to attract dirty industries (Copeland and Taylor 1994). From the perspective of international trade, when multinational firms are located in countries with stringent environmental standards, FDI flows enable firms' movements to environmentally laxer countries (Chung 2014; Neequaye and Oladi 2015; Millimet and Roy 2016). Despite the enormous literature that connects FDI and economic growth as main driving factors of carbon emissions, which empirical model presents as novelty the join both variables in a cubic shape, with the inclusion of additional explanatory variables as energy use, oil prices and natural resources, in order to enrich previous empirical literature.

1.2.1 Economic Growth and Environmental Degradation

During last decades, different studies have considered the existence of a relationship between economic growth and environmental degradation. In an early stage was considered the existence of an inverted U relationship between economic growth and environmental degradation (Grossman and Krueger 1991; Panayotou 2003; Selden and Song 1994). This connection, defined by Panayotou (1993) as environmental

Kuznets curve (EKC), suggests the existence of a trade-off between economic growth and environment in a developing stage of economic growth, till economies reach a certain income-level economic growth, where ascending income levels contribute to correct environment (Stern 2004). Traditionally, scale composition and technical effect are the causers of this transition (Grossman and Krueger 1995), being considered the technical effect the main influence in the correction environmental degradation process (Torras and Boyce 1998; Andreoni and Levinson 2001; Álvarez et al. 2017a, b). When societies adopt energy innovations processes, employing high-tech and efficient procedures, it contributes to reduce pollution levels (Andreoni and Levinson 2001; Markandya et al. 2006; Balsalobre et al. 2015). Otherwise, this perspective, of environmental correction crash with the existence of a shift of dirty process from developed countries to developing one, with laxer regulations, under a pollution havens scheme. These movements would imply that developed countries, with stricter environmental standards, export their heavy manufacturing to the developing countries with lower standards (Kearsley and Riddel 2010). Additional studies evidence the existence of a technical obsolescence effect, which reduces environmental correction process after a developed stage of economic growth and environmental correction (Torras and Boyce 1998; Álvarez et al. 2017a, b). This new stage, of ascending income levels with rising pollution path, implies that scale effect has overcome technical and composition effect, under an N-shaped EKC's scheme (Fig. 1.1). When economic growth and innovation are deficient to avoid scale effect (exceeding once more composition and technical effects), it drives to a new stage of ascending environmental degradation.

Figure 1.1 reflects the income–environmental pollution relationship in the long term, under an N-shaped EKC scheme (Shafik and Bandyopadhyay 1992; Selden and Song 1994; Grossman and Krueger 1995; Torras and Boyce 1998; Balsalobre et al. 2015; Álvarez et al. 2017a). This N-shaped scheme reveals the potential return

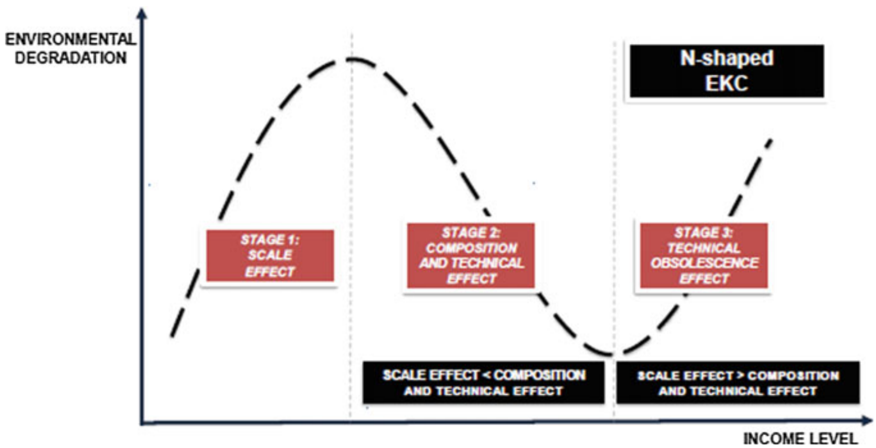

Fig. 1.1 N-shaped EKC and the technical obsolescence effect

to rising emissions once economic systems have reached a decontamination stage (Balsalobre and Álvarez 2016).

1.2.2 FDI and Environmental Degradation

Lee (2013) investigates how foreign direct investment (FDI) net inflows impacts over clean energy use, economic growth to reduce CO_2 emissions. The test results indicate that FDI has played an important role in economic growth for the G20, whereas it limits its impact on an increase in CO_2 emissions in the economies. The research finds no compelling evidence of FDI link with clean energy use. The role of capital investment in economic growth has been considered one of the basic principles in economics. Several researchers conclude that the rate of capital formation determines the rate of economic growth (Blomström and Kokko 1996; Tsang and Yip 2007). While there is a large amount of literature investigating the link between economic growth and energy demand, the impact of FDI on the demand for energy is a topic that has received little attention. Mielnik and Goldemberg (2002) found a positive relationship between FDI and energy intensity in a sample of 20 developing countries. Sadorsky (2010) also found a positive and statistically significant relationship between FDI and energy consumption in a sample of 22 developing economies. Numerous economic literature connects FDI with environmental degradation, through the consideration of the pollution haven hypothesis (PHH) (Zhang 2011; Omri and Kahouli 2014; Farhani and Shahbaz 2014; Neequaye and Oladi 2015; Shahbaz et al. 2015; Abdouli and Hammami 2017). Traditionally has been assumed that developed countries, with restrictive environmental regulations and taxes that increase manufacture costs, allocate dirty investments in developing countries with laxer regulations to attract FDI (Zhu et al. 2016). List and Co (2000) show that stricter regulations reduce the entry of new industries, where decisions about FDI's location are trained by the degree of environmental regulations. Therefore, the difference in the cost of production is determinant in FDI decisions for multinational firms (Helpman and Krugman 1985; Slaughter 2003). Under the theory of comparative advantage, Eskeland and Harrison (1997) confirm the existence of the pollution haven hypothesis (PHH) when the costs for pollution control begin to matter for some industries in some countries, while other countries gain comparative advantage in those industries if pollution control costs are lower there. In line with this finding, several studies reflect similar evidence which confirms the PHH in Mexico and Brazil, Al-Mulali (2012) in Middle East countries, Kivyiro and Arminen (2014) in sub-Saharan African countries, while Zheng and Sheng (2017) confirm the PHH in China. Copeland and Taylor (2003) confirm the existence of the pollution haven hypothesis (PHH) connected with the existence of a scale effect which dominates composition and technical effect that implies that ascending FDI produce environmental degradation (Zeng and Zhao 2009; Al-Mulali and Tang 2013; Shahbaz et al. 2015; Ouyang and Lin 2015). In line with this consideration, Shahbaz et al. (2015) find a nonlinear correlation between FDI and environmental degradation for high-, middle-, and low-income countries. This process is connected with the idea proposed by Grossman and Krueger (1995) who decomposed the economic growth on the scale, composition, and technical effect. Otherwise, PHH is not supported by some current studies, which consider that FDI contributes to improve environment, explained by the "pollution halo" hypothesis validated by other researchers (Cole and Elliott 2005; Cole et al. 2006; Wagner and Timmins 2009; Yi et al. 2017). So, additional evidence postulates that FDI flows reduce pollution in host countries (Eskeland and Harrison 2003; Kim and Adilov 2012; Atici 2012; Zhu et al. 2016; Zhang and Zhou 2016; Abdouli and Hammami 2017). Eskeland and Harrison (2003) find that multinational firms are less polluting than comparable local firms in developing countries. Atici (2012) shows that FDI does not tend to increase pollution levels in the ASEAN countries. Zhu et al. (2016) explore the impact of FDI, economic growth, and energy consumption on carbon emissions in five ASEAN countries (ASEAN-5). They provide empirical evidence for the pollution halo hypothesis Abdouli and Hammami (2017) examine the causality between environmental quality, FDI, and economic growth by using data on 17 Middle East and North African (MENA) countries over the period 1990–2012. The results show that FDI stocks—lagged by two periods (years)—lead to a decrease of the environmental degradation, which is measured as carbon emissions per capita, due to the pollution halo effect. Then, the pollution halo hypothesis suggests that technical effect is more intensive than scale effect (Gallagher 2009; Tamazian and Rao 2010; Liu et al. 2017). When multinational firms shift energy-efficient processes, clean technologies to host countries, it contributes to reduce emissions (Hanna 2010). Eskeland and Harrison (2003) and Huang et al. (2018) admit that FDI flows improve cleaner production technology in local enterprises, where technology spillover effect, induced by FDI, is likely to lessen the environmental degradation.

Kim and Adilov (2012) justify the existence of pollution halo hypothesis because host countries contain higher environmental standards for foreign companies compared to the environmental standards for local firms. Hence, foreign companies present more cautious in order to respect local environmental regulations, and also, they generate less pollution compared to local firms. The pollution halo hypothesis considers that multinational industries have access to less polluting production and more efficient methods compared to local firms, consequently they apply cleaner technologies in host countries (Kim and Adilov 2012). Finally, this study validates both the pollution haven hypothesis and the pollution halo hypothesis by examining the effects of FDI on carbon emissions for a dataset of 164 countries over a period of 44 years. They show simultaneously support the pollution halo hypothesis and the pollution haven hypothesis, concluding that the both hypotheses are not contradictory.

Considering previous literature, which connects environment with technical obsolescence (Álvarez et al. 2017b), the N-shaped relationship between FDI and environmental degradation induces to corroborate the existence of technical obsolescence, where societies transit from PHH to pollution halo hypothesis and PHH again (Fig. 1.2).

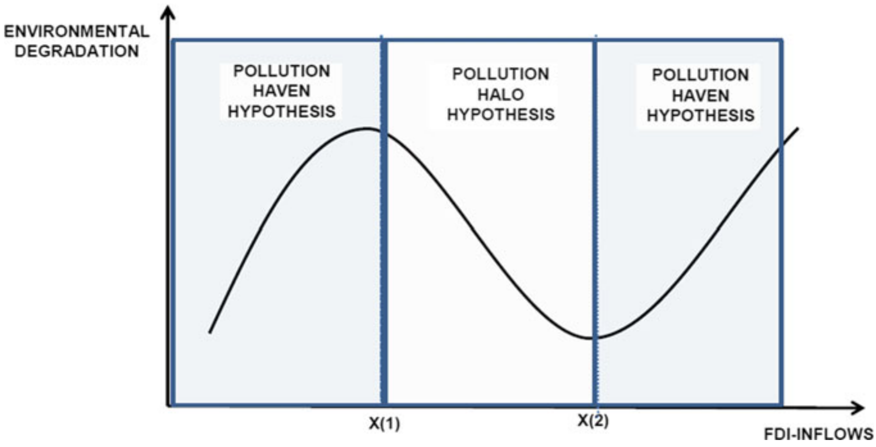

Fig. 1.2 FDI-environmental degradation relationship. PHH and pollution halo hypothesis

In line with Kim and Adilov (2012) who consider plausible the existence of both effects, the existence of an N-shaped relationship between FDI and environment reflects a novelty in economic literature, validating the existence of driving forces that enhance the scale effect over composition and technical effect in this relationship. This N-shaped behavior between FDI flows and environment reflects how ascending FDI flows, once they have arisen a direct relationship between FDI and environmental correction, can generate environmental degradation, under a stage of high development. Consequently, the N-shaped relationship between FDI and environment explains the existence of technical obsolescence that struggles environment, even though FDI inflows are recognized as a fundamental driver for the adaption of modern (green) technologies lower carbon emissions (Paramati et al. 2016).

1.2.3 Energy Use and Environmental Degradation

Most studies reveal that ascending FDI levels enhances industrial development which in return means more energy consumption and higher level of environmental pollution (Zhu et al. 2017; Abdouli and Hammami 2017). Moreover, previous literature has presented the effect that energy use exerts on carbon emissions (Kraft and Kraft 1978; Grossman and Krueger 1995; Apergis and Payne 2009; Baek and Kim 2011; Amri 2016; among others). Since Kraft and Kraft (1978), economic growth-energy nexus has been one of the major research lines in energy economics literature where there is strong support for this relationship. Economic growth requires intense energy use which is satisfied by mostly fossil fuels. This process connects economic growth-energy consumption and environmental degradation. In a first stage of development, societies are impulse by the use of energy use (Kraft and Kraft 1978; Shahbaz et al. 2013, 2014; Alper and Oguz 2016), which negative relationship between economic growth, energy consumption, and environmental degradation has been widely explored in the economic literature (Apergis and Payne 2009; Baek and Kim 2011).

Amri (2016) splits between renewable energy consumption and non-renewable energy consumption 75 countries in the period 1990–2010. The results show a positive relationship between FDI and renewable energy consumption as well as between FDI and non-renewable energy consumption. This empirical finding reflects that the contribution of FDI to energy consumption is more important in developed countries. By contrast, Mielnik and Goldemberg (2002) conclude that the energy intensity decreases as FDI increases. They consider 20 developing in the period 1971–1999 to conclude that the use of modern technologies is likely to increase the efficiency of FDI. Doytch and Narayan (2016) show similar findings, distinguishing between renewable and non-renewable industrial energy consumption, and they use a sectoral distribution of FDI.

Otherwise, Jebli et al. (2016) investigated the causal relationships between per capita carbon emissions, gross domestic product (GDP), renewable and non-renewable energy consumption, and international trade for a panel of 25 OECD countries over the period 1980–2010. Their main results reflect that non-renewable energy increases carbon emissions and increasing trade or renewable energy reduces carbon emissions. Ito (2016) examine the link between carbon emissions, renewable and non-renewable energy consumption, and economic growth for a panel of 31 developed countries over the period 1996–2011. They find that renewable energy consumption contributes to the reductions in carbon emissions. Alam et al. (2016) found that CO_2 emissions have increased with increased income and energy consumption in all four countries. Besides, by testing the environmental Kuznets curve (EKC) hypothesis, they demonstrate that CO_2 emissions will decrease over the time when income increases in India, Indonesia, China, and Brazil over the period 1970–2012. Antonakakis et al. (2017) indicate bidirectional causality between total economic growth and energy consumption for 106 countries classified by different income groups over the period 1971–2011.

1.2.4 Oil Prices and CO_2 Emissions

The level of real oil prices may presumably affect carbon emissions through two ways regardless of their indirect effect via GDP. The effect of oil prices on GDP is widely recognized and has been received notable attention in the empirical literature (Kilian and Vigfusson 2013). The existing empirical literature gives us light on the consideration of oil prices in the EKC framework (Heil and Selden 2001; Richmond and Kaufman 2006). These authors reflect the importance of oil prices and indicate that measures oriented to increase domestic prices on the most polluting energies constitute a valuable tool to reduce the level of carbon emissions. Richmond and Kaufman (2006) suggest that including energy prices in the model could have a considerable impact on the estimated income coefficients. In fact, in the analyzed context, the inclusion of energy prices removed statistical support for typical turning points.

Sadorsky (2009), though an empirical model of renewable energy consumption for the G7 countries, finds a positive and statistically significant relationship between real GDP per capita, CO_2 per capita, and renewable energy consumption. The empirical results also reveal that oil price increases have negative impact on renewable energy consumption. Zhang and Cheng (2014) found that the industry carbon emissions increase with the rise in international oil prices, and vice versa, the industry carbon emissions decrease. Hammoudeh et al. (2014) explore the impact of crude oil prices, natural gas prices, coal prices, and electricity prices on carbon emission in the USA. They settle that higher oil prices are effective in reducing energy consumption and arresting its associated fossil pollution when the carbon market is constricted.

Davis and Kilian (2011) analyze the impact of oil taxes on carbon emissions control, though the analysis of gasoline prices. The empirical results showed that when US oil taxes increased by 10 cents per gallon, the carbon emissions dropped by 1.5%. Li et al. (2012) decompose the oil prices into tax and non-taxable prices components exploring the effects of US refined oil taxes on consumer behavior. They found that an increase of 5 cents in tax will reduce, in short term, oil consumption by 1.3%. This study concluded that oil reduction relates to energy dependence and the increase of the government tax. Sterner (2007) proved that fuel tax in China exerts a direct impact in the pollution levels, concluding that a fuel tax abolishment would suppose an environmental damage as consequence of a carbon rebound effect. Jiao et al. (2013) find that the understanding of China's CO_2 emission reduction target relies on the decrease share of fossil fuel consumption. Montag (2015) argued that regulatory mechanisms are necessary to control transport pollution, being fuel taxes the main instrument to control transport pollution. Mi et al. (2016) found that the China's regions where fossil energy use is more prominent imply higher carbon emissions. Zhao et al. (2018) showed that the elasticity of gasoline demand is not so high during the low crude oil price period. But because of the huge carbon emission of China, adjusting taxes and fees still can affect the consumption of gasoline and the CO_2 emissions. At the low oil price period, the customs prefer to use gasoline-powered autos and large, powerful autos.

1.2.5 Natural Resource Rents and Environmental Degradation

In recent decades, Europe has experimented an ascending management and development of resources, connected with a global change in natural environment, with increasing demands for food, fresh water, timber, or fuel (Shahbaz et al. 2019). This situation has governed the necessity of policy frameworks concerning resources with increased focus on climate change mitigation and adaptation (Lim et al. 2004); the resource nexus (Kurian and Ardakanian 2015) and sustainable development (Sinha and Sengupta 2019). Globally, EU policy has programmed an extensive framework for resource efficiency and climate change policy, including a variety of long-term (non-binding) objectives. In this sense, the Roadmap to a Resource Efficient Europe (EC 2015) includes a vision for 2050, wherein "the EU's economy has grown respecting resource constraints and environmental boundaries, thus contributing to global economic transformation … all resources are sustainably managed." For instance, priority objective 2 of the 7th Environment Action Programme (EU 2013) recognizes the need to "turn the Union into a resource-efficient, green, and competitive low-carbon economy."

This study considers the existence of a positive connection between the use of natural resources and environment. We also include natural resources, which are considered as clean sources, that imply the public and policymakers to be interested in renewable energy sources (Danish et al. 2017). Balsalobre et al. (2018) find that natural resources contribute positively to control per capita carbon emissions in the European Union. This study validates that countries with abundant natural resources reduce their imports of fossil sources, reducing emissions levels.

Limitations concerning resource-national legal systems also establish a wide variety of limitations on how rights concerning resources are exercised in different circumstances. Interactions with natural resources are, for example, limited by: spatial and development planning; prior authorization requirements for the use and development of resources; reservation of resources for future use or strategic reasons; protected areas and other forms of spatial management (Dudley 2008).

Otherwise, some studies reveal that foreign direct investment (FDI) is an important driver of technology transfer, economic growth and development, but many resource-rich countries do not attract as much FDI as resource-poor countries. Natural resources are often extracted by foreign multinationals that bring in capital and knowledge. However, resource FDI is very capital intensive and we conjecture that it leads to fewer spillover effects into the non-resource sectors of the host economy because it relies less on local subcontractors or suppliers. Non-resource FDI, on the other hand, seems to promise more scope for spillover effects and is therefore more attractive for receiving countries. If resource FDI indeed crowds out non-resource FDI, then this is an additional channel, through with natural resource abundance can be a drag on economic development. In addition, the resource curse states that natural resource exports harm growth prospects, even after controlling for the effects of initial income per capita, human capital, investments, trade openness and institutional quality on economic growth (Sachs and Warner 1997). However, in countries with good institutions the curse is turned into a blessing, whereas in countries with bad rule of law natural resource dependence harms growth prospects (Mehlum et al. 2006).

1.3 Mathematical Model and Data

Present study aims at analyzing the impacts of FDI and renewable energy consumption on CO_2 emissions for the NICs and NECs. With a view to analyze these impacts, we have adapted the IPAT framework developed by Ehrlich and Holdren (1971). The empirical model to be tested in this study is designed in accordance with this framework. In keeping with standard EKC literature and IPAT framework, we have specified the following empirical specification for estimating the EKC:

$$\mathrm{CO}_{2_{it}} = f\left(\mathrm{FDI}_{it}, \mathrm{FDI}_{it}^2, \mathrm{FDI}_{it}^3, Y_{it}, Y_{it}^2, Y_{it}^3, E_{it}, \mathrm{RN}_{it}, \mathrm{RN}_{it}^2, \mathrm{RN}_{it}^3, \mathrm{OP}_{it}\right) \quad (1.1)$$

where CO_2 is the per capita carbon emissions, Y is the per capita GDP, FDI is the per capita foreign direct investment, E is the per capita non-renewable energy consumption, RN is the per capita renewable energy consumption, OP is the crude oil price, i is the cross sections ($i = 1, \ldots, N$), and t is the time series ($t = 1, \ldots, T$).

Now, if we look at the IPAT framework, then the theoretical underpinning of the empirical model can be elucidated. According to this framework, the association between environmental impact (I), population (P), level of economic activity (A), and technology (T) can be designated as:

$$I = P \times A \times T \quad (1.2)$$

According to this framework, environmental degradation or pollution is impacted by population, the economic activities or the level and nature of energy consumption, and level of technological development. However, Dietz and Rosa (1994, 1997) suggested an empirically testable version of this model, and that version of the model is generally referred to as the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. The model shown in Eq. (1.1) is designed following this specification only, where CO_2 is considered as the proxy of pollution, Y is considered as the proxy of affluence, and E, RN and OP are considered as the proxies of technological development. The parameters in per capita terms are achieved by dividing the proxies of I, A, and T by P. Taking a cue from this discussion, the empirical models to be tested in this study are as per the following:

$$\mathrm{CO}_{2_{it}} = a_0 + a_1\mathrm{FDI}_{it} + a_2\mathrm{FDI}_{it}^2 + a_3Y_{it} + a_4Y_{it}^2 + a_5E_{it} + a_6\mathrm{RN}_{it} + a_7\mathrm{OP}_{it} + \epsilon_{it} \quad (1.3)$$

$$\begin{aligned}\mathrm{CO}_{2_{it}} = {} & b_0 + b_1\mathrm{FDI}_{it} + b_2\mathrm{FDI}_{it}^2 + b_3\mathrm{FDI}_{it}^3 + b_4Y_{it} + b_5Y_{it}^2 + b_6Y_{it}^3 \\ & + b_7E_{it} + a_6\mathrm{RN}_{it} + a_7\mathrm{OP}_{it} + \epsilon_{it}\end{aligned} \quad (1.4)$$

$$\begin{aligned}\mathrm{CO}_{2_{it}} = {} & c_0 + c_1\mathrm{FDI}_{it} + c_2\mathrm{FDI}_{it}^2 + c_3\mathrm{FDI}_{it}^3 + c_4Y_{it} + c_5Y_{it}^2 + c_6Y_{it}^3 \\ & + c_7E_{it} + c_6\mathrm{RN}_{it} + c_7\mathrm{RN}_{it}^2 + c_8\mathrm{RN}_{it}^3 + c_9\mathrm{OP}_{it} + \epsilon\end{aligned} \quad (1.5)$$

In the later sections of this study, Eq. (1.3) has been referred to as *Model I*, Eq. (1.4) has been referred to as *Model II*, and Eq. (1.5) has been referred to as *Model III*. This segregation allows us to look into the individual impacts of FDI and renewable energy consumption on CO_2 emissions.

While carrying out the empirical analysis of the data, we started with checking the order of integration for the model variables, and this was carried out by employing second generation unit root tests developed by Pesaran (2007). Application of these tests was validated by the presence of cross-sectional dependence in the data, and it was tested by employing the cross-sectional dependence (CD) test by Pesaran (2004) and Chudik and Pesaran (2015). Subsequent to finding the order of integration, we have employed the Westerlund (2007) and Westerlund and Edgerton (2008) cointegration test, for checking the cointegration properties in the data, in the presence of cross-sectional dependence. Once the presence of cointegrating association is confirmed, we have employed the autoregressive dynamic lag (ARDL) models using pooled mean group (PMG) estimates to estimate the Eqs. (1.3)–(1.5). Along with estimation of the models specified for this study, we have also carried out the Dumitrescu and Hurlin (2012) heterogenous panel causality tests, in order to check the robustness of the results, along with discovering the possible causal associations among variables.

For this study, data has been collected for per capita CO_2 emissions in thousand metric tons of oil equivalent, per capita GDP in constant 2010 USD, per capita renewable energy consumption in billion kWHs, per capita fossil fuel energy consumption in billion kWHs, and these data have been collected from the World Bank indicators (World Bank 2018), for NICs and NECs over a period of 1991–2015. Before proceeding with the analysis, all the variables have been log-transformed, so as to smoothen the data, and for obtaining the elasticity terms, as well.

1.4 Results and Analysis

Before applying the unit root tests, we need to check for the applicability of the first or second-generation unit root tests, and in this pursuit, we have to check the possibility of cross-sectional dependence in the data. In order to achieve this, we have applied Pesaran (2004) cross-sectional dependence test and Chudik and Pesaran (2015) weak cross-sectional dependence test. The results of this test are reported in Table 1.1. The results signify that the cross-sectional dependence is significantly present among the model variables. Based on this result, we can now proceed for the second-generation unit root tests.

For checking the order of integration among the variables, we have applied the cross-sectional Im-Pesaran-Shin (CIPS) and cross-sectionally augmented Dickey–Fuller (CADF) unit root tests devised by Pesaran (2007). These tests are second-generation unit root tests, which assume the cross-sectional dependence in a panel

Table 1.1 Results of cross-sectional dependence tests

Variables	Pesaran (2004)		Chudik and Pesaran (2015)
	Test statistics	ρ	Test statistics
C	29.31[a]	0.616	3.721[a]
FDI	7.76[a]	0.289	2.337[b]
FDI^2	7.07[a]	0.237	3.388[a]
FDI^3	4.82[a]	0.215	2.785[a]
Y	45.73[a]	0.959	6.654[a]
Y^2	45.76[a]	0.959	6.704[a]
Y^3	45.77[a]	0.960	6.737[a]
E	25.44[a]	0.554	4.079[a]
RN	41.36[a]	0.867	3.685[a]
RN^2	41.33[a]	0.866	2.483[a]
RN^3	41.28[a]	0.866	2.269[a]
OP	47.66[a]	0.999	21.938[a]

[a]Value at 1% significance level
[b]Value at 5% significance level

dataset. CIPS test is an extension of the Im-Pesaran-Shin (IPS) (2003) with single factor with heterogeneous loading across the cross sections. It is a cross-sectionally augmented IPS Dickey–Fuller-type test, which takes account of cross-sectional means of the level and lagged differences to the IPS-type regression. In this test, the p-value of the Breusch–Godfrey Lagrange multiplier test of each specific regression is reported. Here, the null hypothesis of homogeneous non-stationary is tested against the alternate hypothesis of heterogeneous alternatives. On the other hand, CADF test is based on the mean of the augmented Dickey–Fuller (ADF) t-statistic of every panel member. Null hypothesis of this test is that all of the series in the panel are non-stationary, against the alternate hypothesis of only a section of the series are stationary. The results of these tests are recorded in Table 1.2, and it is visible from the results that the variables are free from unit roots after first differentiation. Therefore, it can be concluded that the variables are integrated to order one, i.e., the variables are $I(1)$ in nature. The robustness of the unit root test results was further verified using Hadri and Rao (2008) panel unit root test with structural breaks, and the results are reported in Table 1.3. For each of the variables, structural breaks were identified for every country, and all the variables were found to be stationary after first difference, i.e., the variables are $I(1)$ in nature. With this result, we can proceed for the cointegration tests.

For checking the cointegrating association among the variables, we have employed Westerlund (2007) and Westerlund and Edgerton (2008) panel cointegration tests. These tests are conducted in presence of the cross-sectional dependence in the panel data. The results of these tests are reported in Tables 1.4 and 1.5, and they show the significant cointegrating association among the variables. They results confirm the

Table 1.2 Results of unit root tests

Variables	CIPS		CADF	
	Level	First diff.	Level	First diff.
C	−2.402	−5.206[a]	−1.825	−4.034[a]
FDI	−3.724[a]	−5.919[a]	−2.012	−4.218[a]
FDI^2	−3.689[a]	−5.900[a]	−1.615	−4.527[a]
FDI^3	−3.615[a]	−5.655[a]	−1.781	−3.807[a]
Y	−1.826	−3.360[a]	−1.729	−3.369[a]
Y^2	−1.767	−3.361[a]	−1.700	−3.305[a]
Y^3	−1.712	−3.336[a]	−1.673	−3.245[a]
E	−2.071	−4.749[a]	−1.896	−4.011[a]
RN	−1.801	−4.454[a]	−2.081	−3.517[a]
RN^2	−1.782	−4.470[a]	−2.067	−3.519[a]
RN^3	−1.767	−4.481[a]	−2.050	−3.517[a]
OP	−3.299[a]	−5.948[a]	−2.041	−3.955[a]

[a]Value at 1% significance level

long-run equilibrium among the model variables for the period of 1991–2015 in the sample countries.

Estimation results of long run coefficients are reported in Table 1.6. Let us begin with the Model I for NIC panel. The coefficients of *Y* and Y^2 are positive and negative, respectively, and they are statistically significant, as well. The EKC has been found to be inverted U-shaped in this case, and the turnaround point is $21,078.06. For CO_2 emissions, there are several evidences of inverted U-shaped EKCs, and a summary of those studies can be found in the review of EKC studies by Shahbaz and Sinha (2019). Though the NICs are characterized by high industrialization, the economic growth pattern has been found to have a positive impact on the environmental quality, and this phenomenon is visible in the turnaround point for *Y*, which is within the sample range. It signifies that the nature of economic growth is helping toward the betterment of environmental quality by catalyzing technological innovation to reduce GHG emissions. On the other hand, the possible technological transfer via FDI route might exert a positive impact on the environmental quality, and this can be seen in the very low turnaround point (=$3.17) for the inverted U-shaped association between FDI-CO_2 emissions. This shows that the nature of technological transfer is helping for the betterment of environmental quality. The impacts of renewable and non-renewable energy consumption are positive and negative, respectively. As these nations are highly dependent on fossil fuel-based energy consumption; therefore, rise in crude oil price is expected to have a negative impact of energy consumption and on consequential CO_2 emissions. The coefficient of OP has been found to be negative.

Now, we will look at Model II for the NICs. The impact of FDI on CO_2 emissions takes an N-shaped form, with the turnaround points at $1.41 and $12.40. The

Table 1.3 Results of Hadri and Rao (2008) panel unit root test with structural breaks

	Austria	Belgium	Denmark	Finland	France	Greece	Ireland
Variable: C							
Test statistic	0.114	0.140	0.123	0.154	0.061	0.050	0.062
Optimum lag	1	1	1	1	1	1	1
95%	0.251	0.245	0.249	0.278	0.099	0.109	0.103
99%	0.369	0.447	0.375	0.386	0.139	0.141	0.128
Selected model	3	3	3	3	4	4	4
Breakpoint	2008	2008	2008	2008	2008	2008	2008
Variable: FDI							
Test statistic	0.092	0.064	0.090	0.092	0.216[a]	0.631[a]	0.495
Optimum lag	1	1	1	1	2	4	4
95%	0.134	0.461	0.474	0.436	0.135	0.139	0.134
99%	0.198	0.778	0.755	0.684	0.194	0.178	0.204
Selected model	4	1	1	1	4	4	4
Breakpoint	2005	1995	1995	1995	2001	2001	2001
Variable: Y							
Test statistic	0.049	0.067	0.056	0.149	0.167	0.135[a]	0.086
Optimum lag	1	2	2	1	1	1	1
95%	0.453	0.465	0.455	0.262	0.262	0.088	0.470
99%	0.706	0.730	0.679	0.392	0.401	0.121	0.679
Selected model	1	1	1	3	3	6	1
Breakpoint	1991	1991	1991	2008	2008	2008	1991
Variable: E							
Test statistic	0.146	0.067	0.087	0.101	0.050	0.047	0.083
Optimum lag	2	1	1	1	1	1	2
95%	0.217	0.218	0.455	0.462	0.471	0.136	0.134
99%	0.319	0.314	0.679	0.700	0.706	0.198	0.183
Selected model	3	3	1	1	1	4	4
Breakpoint	1999	1999	1995	1995	1995	2004	2004
Variable: RN							
Test statistic	0.124	0.184	0.132	0.129	0.058	0.121	0.045
Optimum lag	2	2	2	2	1	2	1
95%	0.313	0.331	0.313	0.312	0.320	0.314	0.414
99%	0.468	0.508	0.460	0.468	0.461	0.457	0.599
Selected model	3	3	3	3	3	3	3
Breakpoint	2010	2010	2010	2010	2010	2010	2013
Variable: OP							

(continued)

Table 1.3 (continued)

	Austria	Belgium	Denmark	Finland	France	Greece	Ireland
Test statistic	0.145	0.412[c]	0.146	0.179	0.948[a]	0.132	0.550[b]
Optimum lag	1	1	1	1	4	1	4
95%	0.451	0.461	0.474	0.436	0.438	0.461	0.483
99%	0.619	0.778	0.755	0.684	0.706	0.815	0.699
Selected model	1	1	1	1	1	1	1
Breakpoint	1991	1991	1991	1991	1991	1991	1991

	Italy	Luxembourg	The Netherlands	Portugal	Spain	Sweden	United Kingdom
Variable: C							
Test statistic	0.061	0.061	0.041	0.207[c]	0.073	0.084	0.090
Optimum lag	1	1	1	2	1	1	1
95%	0.107	0.100	0.066	0.252	0.254	0.233	0.241
99%	0.136	0.133	0.087	0.377	0.376	0.311	0.364
Selected model	4	4	6	3	3	3	3
Breakpoint	2008	2008	2004	2008	2008	2007	2007
Variable: FDI							
Test statistic	0.162	0.099	0.063	0.173[a]	0.213[a]	0.163[b]	0.072
Optimum lag	1	1	1	2	3	2	1
95%	0.349	0.185	0.141	0.126	0.067	0.136	0.436
99%	0.551	0.247	0.197	0.170	0.081	0.178	0.692
Selected model	3	3	4	4	6	4	1
Breakpoint	2011	2004	2004	2004	2004	2004	1995
Variable: Y							
Test statistic	0.065	0.064	0.059	0.062	0.065	0.083[b]	0.049
Optimum lag	1	1	1	1	1	1	1
95%	0.475	0.464	0.468	0.466	0.468	0.083	0.479
99%	0.692	0.720	0.718	0.710	0.752	0.112	0.741
Selected model	1	1	1	1	1	6	1
Breakpoint	1991	1991	1991	1991	1991	2007	1991
Variable: E							

(continued)

Table 1.3 (continued)

	Italy	Luxembourg	The Netherlands	Portugal	Spain	Sweden	United Kingdom
Test statistic	0.079	0.339[a]	0.321[a]	0.289[a]	0.100	0.138	0.129
Optimum lag	2	4	4	4	2	2	2
95%	0.136	0.135	0.132	0.136	0.134	0.239	0.244
99%	0.200	0.187	0.182	0.191	0.188	0.353	0.350
Selected model	4	4	4	4	4	3	3
Breakpoint	2004	2004	2004	2004	2004	2007	1998
Variable: RN							
Test statistic	0.141	0.240[a]	0.242[a]	0.290	0.295	0.179	0.125
Optimum lag	2	2	2	2	2	2	2
95%	0.412	0.135	0.132	0.410	0.411	0.405	0.290
99%	0.581	0.187	0.182	0.630	0.618	0.635	0.445
Selected model	3	4	4	3	3	3	3
Breakpoint	2013	2004	2004	2013	2013	2013	2009
Variable: OP							
Test statistic	0.168	0.334	0.646[b]	0.169	0.562[b]	0.667[a]	0.143
Optimum lag	1	4	4	1	4	2	1
95%	0.436	0.457	0.458	0.470	0.466	0.436	0.436
99%	0.749	0.653	0.789	0.629	0.699	0.663	0.692
Selected model	1	1	1	1	1	1	1
Breakpoint	1991	1991	1991	1991	1991	1991	1991

[a]Value at 1% significance level
[b]Value at 5% significance level
[c]Value at 10% significance level

Table 1.4 Results of Westerlund (2007) cointegration test

Statistic	Value	*Z*-value	*p*-value	Robust *p*-value
Gt	−2.019	1.493	0.932	0.000
Ga	−5.024	3.962	1.000	0.000
Pt	−5.759	1.839	0.967	0.000
Pa	−3.144	2.933	0.998	0.000

Table 1.5 Results of Westerlund and Edgerton (2008) cointegration test

	Test statistic (1)	*p*-value	Test statistic (2)	*p*-value	Test statistic (3)	*p*-value
$LM\tau$	−2.002	0.023	−2.336	0.010	−2.597	0.005
$LM\phi$	−1.430	0.076	−1.628	0.052	−2.151	0.016

Note Model (1): model with a maximum number of five factors and no shift; Model (2): model with a maximum number of five factors and level shift; Model (3): model with a maximum number of five factors and regime shift

low first turnaround point indicates the effectiveness of technology transfer via FDI route. This finding falls in the similar lines with the finding for Model I. However, the low second turnaround point demonstrates the ineffectiveness of technology transfer to control the GHG emissions. This finding contradicts the finding regarding FDI-CO_2 emissions in Model I. The environmental impact of economic growth pattern is divulged by means of the N-shaped EKC, with the turnaround points at $29,673.16 and $831,156.25. While the first turnaround point is within the sample range, the second turnaround point is higher than the highest value of *Y* in the sample. Therefore, the economic growth pattern is found to be effective in controlling the CO_2 emissions, and this result contradicts the finding for FDI-CO_2 emissions association. The impacts of renewable energy consumption, non-renewable energy consumption, and oil price are in the similar lines with that of the Model I. The negative environmental impact of FDI has been reinforced in the findings of Model III. Low turnaround points ($1.10 and $800.34) of the N-shaped FDI-CO_2 emissions reinstate the finding of Model II. This finding refutes the finding of Shahbaz et al. (2019). The turnaround points of the N-shaped EKC association, i.e., $1477.61 and $2,744,962.06, indicate the sustainability of the economic growth pattern. The impacts of fossil fuel consumption and oil price on CO_2 emissions remain the same as previous two models. However, the renewable energy consumption-CO_2 emissions association takes an N-shaped form, with first turnaround point at 3.62 units and the second turnaround points being much outside the sample range. This signifies that the growth in renewable energy consumption helps in improving the environmental quality, by reducing the level of CO_2 emissions.

Now, let us move toward the Model I for NEC panel. The coefficients of Y and Y^2 are positive and negative, respectively, and they are statistically significant, as well. The EKC has been found to be inverted U-shaped in this case, and the turnaround point is $70,732.94. Though the turnaround point is higher compared to that of the case of the NICs, it is within the sample range, thereby indicating the positive impact of economic growth pattern on the environmental quality. It signifies that the nature of economic growth is helping toward the betterment of environmental quality by catalyzing technological innovation to reduce GHG emissions for NECs. On the other hand, the possible technological transfer via FDI route might has exerted a negative impact on the environmental quality, and this can be seen in the monotonically increasing association between FDI-CO_2 emissions. This shows that the nature of technological transfer is attributing to the deterioration of environmental quality.

Table 1.6 Results of ARDL models using PMG estimates

Independent variables	NIC panel			NEC panel			Full panel		
	Model I	Model II	Model III	Model I	Model II	Model III	Model I	Model II	Model III
Long-run coefficients									
FDI	0.5213[b]	0.2943[b]	0.0382[a]	0.0304[c]	0.0101[c]	0.1451[c]	0.0702[c]	1.0546[c]	1.0660[b]
FDI^2	−0.2262[b]	−0.4859[b]	−0.2004[b]	−0.0340[b]	−0.0177[a]	−0.2740[a]	−0.0615[c]	−0.1901[c]	−0.1960[b]
FDI^3	–	0.1132[a]	0.0197[b]	–	0.0029[c]	0.0863[c]	–	0.0114[a]	0.0120[a]
Y	14.6811[a]	58.9544[b]	0.8764[b]	0.1340[c]	1.0972[a]	44.6614[b]	3.1330[c]	128.1026[b]	3.7598[c]
Y^2	−0.7373[a]	−5.025[c]	−0.0896[b]	−0.0050[c]	−0.2342[b]	−3.3509[b]	−0.1652[c]	−11.5686[b]	−0.3115[c]
Y^3	–	0.1400[b]	0.0027[c]	–	0.0088[b]	0.0742[b]	–	0.2454[c]	0.0075[b]
E	0.4335[a]	6.5110[a]	1.2552[a]	1.1945[a]	0.9971[a]	3.8146[a]	0.9617[a]	1.0929[c]	1.2728[a]
RN	−0.0009[c]	−6.1493[b]	14.4045[a]	−0.1627[c]	−0.0488[a]	66.8540[a]	−0.1152[b]	−0.5321[a]	14.0186[b]
RN^2	–	–	−5.9013[c]	–	–	−6.9137[a]	–	–	−6.3051[c]
RN^3	–	–	0.1576[c]	–	–	0.1469[a]	–	–	0.1247[c]
OP	−0.0578[c]	−0.2808[a]	−0.0533[a]	−0.0694[b]	−0.1204[b]	−1.1743[b]	−0.0888[a]	−0.0093[c]	−0.0917[c]
Short-run coefficients									
ΔFDI	0.0029	0.0266	0.0062[c]	−0.0221[c]	0.2348[c]	0.6075[c]	0.0083	0.1958[c]	0.1459
ΔFDI^2	−0.0007	−0.0112	−0.0030	−0.0046	−0.0363[b]	−0.1541[a]	−0.0054	−0.0811[c]	−0.0508[b]
ΔFDI^3	–	0.0008	0.0076[b]	–	0.0043[c]	0.0108[a]	–	0.0133[c]	0.0064
ΔY	0.7441	109.5398[b]	113.4672[b]	1.0844[b]	222.6508[c]	55.3695	0.2309	12.1716	33.3373[b]
ΔY^2	−0.0358	−11.1153[b]	−11.5741[b]	−0.0538[b]	−20.7443[c]	−5.3520[b]	−0.0100	−1.4137	−3.4699[a]
ΔY^3	–	0.3756[b]	0.3922[b]	–	0.6446[c]	0.1703	–	0.0532	0.1206[c]
ΔE	0.8779[b]	0.7805[a]	0.1278[a]	0.9564[a]	0.3874[b]	0.8709[c]	0.6072[a]	1.3202[a]	1.3656[a]

(continued)

Table 1.6 (continued)

Independent variables	NIC panel			NEC panel			Full panel		
	Model I	Model II	Model III	Model I	Model II	Model III	Model I	Model II	Model III
ΔRN	0.1092	−0.0760	1.2724	0.2276[c]	0.1187	43.4088[c]	0.1247	0.2380	0.9903
$ΔRN^2$	–	–	−0.7126	–	–	−11.9449	–	–	−4.0262[c]
$ΔRN^3$	–	–	0.2680[b]	–	–	1.1737[b]	–	–	0.3451
ΔOP	−0.0169[c]	−0.0381[c]	−0.0274[c]	−0.0012[b]	−0.0444[a]	−0.0125	−0.0002	−0.0029	−0.0247[c]
ECT	−0.3335[c]	−0.4999[a]	−1.1692[c]	−0.4027[a]	−0.8756[a]	−0.3641[c]	−0.5254[a]	−0.3856[b]	−0.6748[b]

[a] Value at 1% significance level
[b] Value at 5% significance level
[c] Value at 10% significance level

The impacts of renewable and non-renewable energy consumption are positive and negative, respectively. As these nations are highly dependent on fossil fuel-based energy consumption; therefore, rise in crude oil price is expected to have a negative impact of energy consumption, and on consequential CO_2 emissions. The coefficient of OP has been found to be negative.

Now, we will look at Model II for the NECs. The impact of FDI on CO_2 emissions takes an N-shaped form, with the turnaround points at \$1.36 and \$42.96. The low first turnaround point indicates the effectiveness of technology transfer via FDI route. This finding falls in the similar lines with the finding for Model I. However, the low second turnaround point demonstrates the ineffectiveness of technology transfer to control the GHG emissions. This finding contradicts the finding regarding FDI-CO_2 emissions in Model I. The environmental impact of economic growth pattern is divulged by means of the N-shaped EKC, with the turnaround points at \$16.07 and \$3,157,499.85. While the first turnaround point is within the sample range, the second turnaround point is higher than the highest value of Y in the sample. Therefore, the economic growth pattern is found to be effective in controlling the CO_2 emissions, and this result contradicts the finding for FDI-CO_2 emissions association. The impacts of renewable energy consumption, non-renewable energy consumption, and oil price are in the similar lines with that of the Model I. The negative environmental impact of FDI has been reinforced in the findings of Model III. Low turnaround points (\$1.36 and \$6.09) of the N-shaped FDI-CO_2 emissions reinstate the finding of Model II. The turnaround points of the N-shaped EKC association, i.e., \$21,104.55 and \$563,498,096.23, indicate the sustainability of the economic growth pattern. These results fall in the similar lines with Sinha et al. (2017). The impacts of fossil fuel consumption and oil price on CO_2 emissions remain the same as previous two models. However, the renewable energy consumption-CO_2 emissions association takes an N-shaped form, with first turnaround point at 392.03 units and the second turnaround points being much outside the sample range. This signifies that the growth in renewable energy consumption helps in improving the environmental quality, by reducing the level of CO_2 emissions.

Lastly, let us move toward the Model I for full panel. The coefficients of Y and Y^2 are positive and negative, respectively, and they are statistically significant, as well. The EKC has been found to be inverted U-shaped in this case, and the turnaround point is \$13,127.25. The turnaround point is within sample range, thereby indicating the positive impact of economic growth pattern on the environmental quality. On the other hand, the possible technological transfer via FDI route might exert a positive impact on the environmental quality, and this can be seen in the very low turnaround point (=\$1.77) for the inverted U-shaped association between FDI-CO_2 emissions. This shows that the nature of technological transfer is helping for the betterment of environmental quality. The impacts of renewable and non-renewable energy consumption are positive and negative, respectively. As these nations are highly dependent on fossil fuel-based energy consumption, rise in crude oil price is expected to have a negative impact of energy consumption and on consequential CO_2 emissions. The coefficient of OP has been found to be negative.

Now, we will look at Model II for the full panel. The impact of FDI on CO_2 emissions takes an N-shaped form, with the turnaround points at \$202.89 and \$331.73. The low first turnaround point indicates the effectiveness of technology transfer via FDI route. This finding falls in the similar lines with the finding for Model I. However, the low second turnaround point demonstrates the ineffectiveness of technology transfer to control the GHG emissions. This finding contradicts the finding regarding FDI-CO_2 emissions in Model I. The environmental impact of economic growth pattern is divulged by means of the N-shaped EKC, with the first turnaround point at \$1305.66 and the second one being much outside the sample range. Therefore, the economic growth pattern is found to be effective in controlling the CO_2 emissions, and this result contradicts the finding for FDI-CO_2 emissions association. The impacts of renewable energy consumption, non-renewable energy consumption, and oil price are in the similar lines with that of the Model I. The negative environmental impact of FDI has been reinforced in the findings of Model III. Low turnaround points (\$194.18 and \$275.92) of the N-shaped FDI-CO_2 emissions reinstate the finding of Model II. The turnaround points of the N-shaped EKC association, i.e., \$7244.46 and \$146,260,052.95, indicate the sustainability of the economic growth pattern. The impacts of fossil fuel consumption and oil price on CO_2 emissions remain the same as previous two models. However, the renewable energy consumption-CO_2 emissions association takes an N-shaped form, with first turnaround point at 3.16 units and the second turnaround points being much outside the sample range. This signifies that the growth in renewable energy consumption helps in improving the environmental quality, by reducing the level of CO_2 emissions.

In order to examine the causal association among the model parameters, we have employed the Dumitrescu and Hurlin (2012) panel causality test, and the empirical results are provided in Table 1.7. The results show bidirectional causal associations between economic growth and CO_2 emissions, oil price and CO_2 emissions, renewable energy consumption and CO_2 emissions, renewable energy consumption and economic growth, oil price and renewable energy consumption. Moreover, unidirectional causal association found to be running from FDI to economic growth, FDI to oil prices, renewable energy consumption to FDI, and economic growth to oil prices.

1.5 Concluding Remarks

By far, we have analyzed the impact of income, FDI, fossil fuel and renewable energy consumption, and crude oil prices on CO_2 emissions for 14 NICs and NECs over the period of 1991–2015. The analysis has been carried out using the theoretical framework of EKC hypothesis, while considering the cross-sectional dependence among the panel member nations. In methodological terms, we have employed second-generation unit root and cointegration techniques with cross-sectional dependence, and PMG-based ARDL to estimate the impact of income, FDI, fossil fuel and renewable energy consumption, and crude oil prices on CO_2 emissions. We have found evidence of N-shaped EKC for income-CO_2 emissions association, FDI-CO_2 emissions association, and renewable energy consumption-CO_2 emissions association.

Table 1.7 Results of Dumitrescu and Hurlin (2012) panel causality tests

Null hypothesis	Causality direction	*W*-bar-stat.	*Z*-bar-stat.	Prob.
FDI does not homogen. cause *C*	*C* ≠ FDI	1.4985	1.3189	0.1872
C does not homogen. cause FDI		1.3549	0.9391	0.3477
Y does not homogen. cause *C*	*C* ↔ *Y*	6.1615	13.6559	0.0000
C does not homogen. cause *Y*		3.2736	6.0154	0.0000
OP does not homogen. cause *C*	*C* ↔ OP	8.4760	19.7797	0.0000
C does not homogen. cause OP		2.9888	5.2620	0.0000
RN does not homogen. cause *C*	*C* ↔ RN	2.1381	3.0111	0.0026
C does not homogen. cause RN		3.9146	7.7114	0.0000
FDI does not homogen. cause *Y*	FDI → *Y*	1.7547	1.9966	0.0459
Y does not homogen. cause FDI		1.4148	1.0974	0.2724
FDI does not homogen. cause OP	FDI → OP	2.2337	3.2641	0.0011
OP does not homogen. cause FDI		1.4756	1.2584	0.2083
FDI does not homogen. cause RN	FDI ← RN	0.7976	−0.5356	0.5922
RN does not homogen. cause FDI		2.2406	3.2824	0.0010
Y does not homogen. cause OP	*Y* → OP	5.4245	11.7061	0.0000
OP does not homogen. cause *Y*		0.6264	−0.9884	0.3230
Y does not homogen. cause RN	*Y* ↔ RN	3.4233	6.4114	0.0000
RN does not homogen. cause *Y*		3.6905	7.1184	0.0000
RN does not homogen. cause OP	OP ↔ RN	7.3441	16.7849	0.0000
OP does not homogen. cause RN		4.7807	10.0029	0.0000

One of the main contributions of this study is to analyze the impacts of income, FDI, segregated energy consumption by source, and oil price on CO_2 emissions within an empirical framework, thereby divulging the differential impact of these parameters while varying their degrees, in keeping with the EKC hypothesis framework. The economic growth pattern seems to have positive impact on the environmental quality. Surprisingly, for FDI, when the degree of impact was increased, the negative impact of FDI on the environmental quality was proving out to be more prominent, thereby demonstrating the negative impact of technological transfer via FDI route on the environmental quality. The impacts of renewable and non-renewable energy consumption on CO_2 emissions are found to be logically perfect, so as the case of the impact of oil prices. In such a scenario, these nations should have stringent policies in terms of scrutinizing the technologies being utilized in these nations. Moreover, the governments in these nations should also encourage the usage of renewable energy solutions, by gradually replacing the fossil fuel solutions. This will not only help them in sustaining the economic growth, but also will help them in reducing the level of CO_2 emissions and in import substitution for fossil fuels. The respective governments in these countries should also intervene in protecting the rights for public goods, so that the nations can protect the pool of natural resources and, consequently, can catalyze the economic growth endogenously.

In such a situation, implementing the nation-wide renewable energy solutions for the households might not be a good initiative, as this might hamper the economic growth owing to the cost of renewable energy solutions. Therefore, this implementation can be carried out in a phase-wise manner, in which the existing fossil fuel resources will be gradually replaced with the renewable energy solutions. Firstly, the industrial consumers will be targeted, and they will be provided the solutions at the prescribed rate of government. For enforcing this, the banks can provide loans at subsidized rate. Then, the revenue received from this phase will be used to provide the solutions to the small-scale sector and households at rental basis. They will be provided the solution free for a fixed period of time, and after that, they will be charged at a lower price, compared to the industrial counterpart. In this way, the gradual phase-wise shifting will take place without causing much damage to the economic growth pattern, and the sustainable development will be ensured in parallel.

Once these solutions will be in place, then the increased growth rate in these countries will allow them to procure clean technology solutions from developed nations, and the negative impact on environmental quality will be decreased gradually. This will also gradually enhance the quality of technology being adopted via the FDI route. This will have an overall positive impact on the environmental quality. Simultaneously, the rise in the technological diffusion across the member nations will not only create a wide number of vocational opportunities, but also will ensure the social security in the economic system by ensuring better access to education, health, and ecological facilities.

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Chapter 2
The Impact of Oil Prices on CO_2 Emissions in China: A Wavelet Coherence Approach

Faik Bilgili, Erhan Mugaloglu, and Emrah Koçak

Abstract This paper observes the possible co-movements of oil price and CO_2 emissions in China by following wavelet coherence and wavelet partial coherence analyses to be able to depict the short-run and long-run co-movements at both low and high frequencies. To this end, this research might provide the current literature with the output of potential short-run and long-run structural changes in CO_2 emissions upon a shock (a change) in oil prices in China together with the control variables of world oil prices, fossil energy consumption and renewable consumption and urban population in China. Therefore, this research aims at determining wavelet coherencies between the variables and phase differences to exhibit the leading variable in potential co-movements. By following the time domain and frequency domain analyses of this research, one may claim that the oil prices in China have considerable negative impact on CO_2 emissions at high frequencies for the periods 1960–2014 and 1971–2014 in China. Besides, one may underline as well other important output of the research exploring that the urban population and CO_2 emissions have positive associations, move together for the period 1960–2014 in China. Eventually, this paper might suggest that authorities follow demand-side management policies considering energy demand behavior at both shorter cycles and longer cycles to diminish the CO_2 emissions in China.

Keywords Wavelet coherence · Wavelet partial coherence · Oil price · CO_2 emissions · Urbanization · China

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Abbreviations

AR	Autoregressive
ARMA	Autoregressive moving average
CO_2	Carbon dioxide
CWP	Cross wavelet power
CWT	Continuous wavelet transformation
FT	Fourier transformation
GDP	Gross domestic product
GHG	Greenhouse gasses
MA	Moving average
MEPS	Minimum energy performance standards
MW	Megawatts
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added tax

2.1 Introduction

China has been in a process of rapid economic development with openness and reform policies that began since the end of the 1970s. The country has shifted from a central planning economy to a market economy. During this structural change process, China experiences developments in many fields such as industrialization, urbanization, physical infrastructure, institutional structure, lifestyle, technology and motorization (Guo et al. 2017; Ma et al. 2012; Zhang et al. 2017a, b). Today, China is the major producer and exporter country in the world (Qi et al. 2014). In parallel with these developments, China's population and urbanization level have increased rapidly in the last three decades (Luo et al. 2017). It is emphasized that there is an increase in energy demand in the background of this brilliant development process of China (Bilgili et al. 2017; Dong et al. 2017a, b). However, China's energy structure is based on fossil energy sources such as coal, oil and natural gas. According to the International Energy Agency (IEA 2017a), China supplies approximately 85–90% of its energy needs from fossil sources. Moreover, China's share of global energy demand in 2016 is 23%. For this reason, China is the most important country in the world responsible for greenhouse gas emissions (Dong et al. 2017a, b; Wang et al. 2017). Because of the fact that China's contribution to global CO_2 emissions is 28% (IEA 2017b), its environmental and energy policies directly affect global CO_2 emissions. Recently, researchers and policy makers focus on the following issue: What are the main driving forces of China's CO_2 emissions? In this context, this paper provides the current literature with the output of potential short- and long-run structural changes in CO_2 emissions upon a shock (a change) in oil prices in China together with the control variables of world oil prices, fossil energy consumption, renewable consumption and urban population. The potential contribution of this paper is twofold.

First, China's domestic oil prices have been regulated by the government since the 1980s. Basically, China's domestic oil prices have followed international oil prices. However, the policy authorities have aimed to isolate the domestic markets from the volatility of oil prices in global markets. It should be noted that even though most government regulations have been reduced since 1999, energy prices are still controlled by the government, leading to a deterioration in energy prices (Anand 2016). While policy makers hope that such price arrangements would benefit the country's economy and the environment, distortions in the price mechanism may actually produce negative effects. Especially distortive price signals can increase environmental pollution by promoting energy consumption (Ju et al. 2017). Research on the economic effects of the oil price regulation system in China is noteworthy. On the other hand, there is a gap in the literature regarding the impact of this important price system on environmental quality and pollutant emissions (Ju et al. 2017; Zhang and Xie 2016). We expect to provide new findings to the literature with this empirical research.

Secondly, there has been a global expectation that oil prices will be low in recent periods, and these low prices will continue for a long time. As known, there has been an important event arising in the energy sector that is a rapid fall in crude oil prices from 2014 to 2015. Brent crude oil price reaches its lowest level, less than $40 per barrel, since 2008. This fall in oil prices does not seem to be transitory as International Monetary Fund re-elected Director Christine Lagarde predicts that crude oil prices will probably stay low for longer than expected because even the energy security concerns due to Syrian conflict and political controversies in the Middle East could not put pressure on the prices since 2014 (Bloomberg 2016). Unfortunately this decline in oil prices may give rise to substitute oil to natural gas in the heating of buildings, change the energy mix in the manufacturing sector through fossil fuels and the consumer preferences while choosing the electricity appliances or vehicles, or miles traveled (Pereira and Pereira 2014; Wang 2015; Wang and Li 2016; Yang and Timmermans 2012; Zhang et al. 2014). Remarkably, McCollum et al. (2016) analyze how the future oil prices uncertainties affect the energy sector and economy worldwide by simulating through an integrated assessment model (MESSAGE). They find that long-standing high or low oil prices could alter the energy mix dynamics of countries in energy production: Low oil prices are expected to weaken carbon mitigation initiatives on the contrary high oil prices support them. Besides any permanent decrease in fossil fuel prices may affect renewable energy investment decisions negatively (Wang 2015; Wang and Li 2016). The low level of crude oil prices together with commodity prices is expected to improve overall income in the economy, which would increase energy demand (World Bank 2015). Both substitution and income effects of the fall in oil prices can be seen as a risk for China to reduce CO_2 emissions. This paper is to investigate whether this downfall in oil prices is a threat for China's reduction of CO_2 in the short and long run, while high oil price argument was often treated as an opportunity. For this reason, understanding the effects of energy price controls and low oil prices on CO_2 emissions provides significant output for policy authorities.

The rest of the paper is as follows: (a) Sect. 2.2 reviews the literature. (b) Sect. 2.3 introduces the wavelet methodology. (c) Sect. 2.4 presents the empirical results of wavelet coherency and phase analysis. (d) Sect. 2.5 provides conclusions, discussion and some policy recommendations.

2.2 Literature Review

Oil prices may affect carbon emissions through three channels; first falling oil prices would increase carbon intensity in the manufacturing sector by altering energy mix and efficiency in production (Zhang et al. 2014). As renewable energy sources are considered as the most likely substitute of oil and its derivations (Apergis and Payne 2014; Sadorsky 2009), any change in oil price may directly affect the demand for renewables. Winchester and Ledvina (2017) support this result by constructing a dynamic stochastic general equilibrium model in which the energy production mix is simulated under alternative fossil price scenarios. They conclude that higher fossil fuel prices could boost biofuel production in the long run, therefore less GHG emission. As the second point, falling oil prices would have a stimulating economic growth effect which has a positive effect on carbon emissions (Canadell et al. 2007; de Bruyn et al. 1998; Pereira and Pereira 2014; Wang 2010). Regarding the relationship between oil price and economic growth, Hamilton (2003) shows that there is a clear evidence of nonlinear relation between an oil price change and economic growth during the post-war period in the USA indicating that the oil price increases are expected to be much more important than oil price decreases. Finally, the decline in oil prices affects carbon reduction costs through reduced marginal emission reduction tax (Wang and Li 2016). Recently, environmental concerns about falling oil prices in the USA seem to be realistic and remarkable.

The empirical findings in the literature focus on oil prices, oil consumption, renewable energy and the environment nexus. However, few studies have focused on the relationship between oil consumption, oil prices and environmental quality (Maji et al. 2017). For this reason, we evaluate the studies that examine the relationship between oil prices and CO_2 emissions. de Bruyn et al. (1998) investigate the relationship between economic growth, oil prices and greenhouse gas emissions in the Netherlands, UK, USA and Germany during the period 1960–1993 through empirical methods. The results indicate that an increase in oil prices in the USA has a negative effect on CO_2 emissions. There is no significant relationship between oil price and CO_2 emissions for other countries. Lindmark (2002) examines the relationship between CO_2 emissions, technology, economic growth and fuel prices in Sweden in the period 1870–1997. The results show that the increase in fuel prices is a mitigating effect on CO_2 emissions. He and Richard (2010) explore the impact of economic growth, industrialization, trade and oil prices on CO_2 emissions in Canada from 1948 to 2004. Their study suggests that the increase in oil prices reduces CO_2 emissions. Payne (2012) analyzes the effect of oil prices on CO_2 emissions in the

USA during the years between 1949 and 2009. The results imply a long-run significant negative impact of oil price on CO_2 emissions in the USA. The following papers show that the increase in oil prices is a mitigating effect of CO_2 emissions by reaching similar results (Hammoudeh et al. 2014; Wang and Li 2016; Zhang and Zhang 2016; McCollum et al. 2016; Maji et al. 2017).

Contrary to expectations, some studies in the literature show that the increase in oil prices has an increasing effect on CO_2 emissions, while others support the hypothesis of neutrality and reveal that there is no significant relationship between oil prices and CO_2 emissions. Sadorsky (2009) explores the relationship between oil prices, CO_2 emissions, renewable energy and economic growth in G-7 countries. Empirical findings suggest that CO_2 emissions and economic growth have an increasing effect on renewable energy. On the other hand, it is concluded that oil prices have a weak effect on renewable energy. Salim and Rafiq (2012) examine the relationship between economic growth, oil prices, renewable energy and CO_2 emissions in the developing countries. Their findings indicate that oil prices do not have a significant influence on renewable energy and CO_2 emissions. Zhang and Zhang (2016) investigate the effect of oil prices on CO_2 allowance prices in China with the daily data for the period 2013–2015. The results of the study reveal that oil prices have a positive influence on CO_2 emissions' allowance price. Nwani (2017) estimates the relationship between oil prices, energy consumption and CO_2 emissions in Ecuador from the period 1971–2013 through an autoregressive distributed lag (ARDL) approach. The study shows that the increase in oil prices has an increasing effect on CO_2 emissions. Blazquez et al. (2017) examine the impact of oil price shocks on the CO_2 emissions in Spain. The paper shows that oil price shocks do not have a significant effect on CO_2 emissions.

Finally, we evaluate the literature on the relationship between oil consumption and CO_2 emissions. Lim et al. (2014) analyze the causality relationship between oil consumption, economic growth and CO_2 emissions in the Philippines. Causality test results depict that there is a bidirectional relationship between oil consumption and both CO_2 emissions and economic growth. Alam and Paramati (2015) estimate the impact of economic growth, oil consumption, financial development, industrialization and trade openness on CO_2 emissions in developing countries that consume the majority of oil. Estimation results confirm that oil consumption and economic growth have a significant impact on CO_2 emissions. Saboori et al. (2017) investigate the relationship between oil consumption, economic growth and CO_2 emissions in China, Japan and South Korea. Empirical findings are as follows: (1) It is revealed that petroleum consumption in China is an important cause of economic growth and CO_2 emissions. (2) Oil consumption in Japan is an important reason for economic growth. However, there is no causality relationship between petroleum consumption and CO_2 emissions. (3) Oil consumption in South Korea is an important cause of economic growth and CO_2 emissions. Moreover, this relationship is bidirectional, and economic growth and CO_2 emissions also affect oil consumption.

Table 2.1 summarizes the literature findings. Researches often use time series and panel data analysis methods. The findings of the research differ according to country, period and method.

Table 2.1 Summary of empirical literature on oil price/oil consumption and CO_2 emissions

Author(s)	Country	Period	Methodology	Conclusion
de Bruyn et al. (1998)	Netherlands, UK, USA and Germany	1960–1993	Panel data analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions
Lindmark (2002)	Sweden	1870–1997	Time series analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions
Sadorsky (2009)	G7 countries	1980–2005	Panel data analysis	The impact of oil prices on renewable energy consumption and hence on CO_2 emissions is weak
He and Richard (2010)	Canada	1948–2004	Time series analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions
Payne (2012)	USA	1949–2009	Time series analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions
Salim and Rafiq (2012)	Developing countries	1980–2006	Panel data analysis	Oil prices are not a significant influence on renewable energy and CO_2 emissions
Hammoudeh et al. (2014)	USA	2006–2013 (monthly)	Time series analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions allowance price
Lim et al. (2014)	Philippines	1965–2012	Time series analysis	Increase (decrease) in oil consumption increase (decrease) CO_2 emissions

(continued)

Table 2.1 (continued)

Author(s)	Country	Period	Methodology	Conclusion
Alam and Paramati (2015)	Developing countries	1980–2012	Panel data analysis	Increase (decrease) in oil consumption increases (decreases) CO_2 emissions
Wang and Li (2016)	OECD	No period	SWOT analysis	Increase (decrease) in oil prices reduces (increases) carbon intensity
Zhang and Zhang (2016)	China	2013–2015 (daily)	Time series analysis	Increase (decrease) in oil prices increases (decreases) CO_2 emissions allowance price
McCollum et al. (2016)	Worldwide	No period (simulation)	Integrated assessment model	Low oil prices weaken carbon mitigation initiatives
Blazquez et al. (2017)	Spain	1969–2003	Dynamic stochastic general equilibrium (DSGE) model and time series analysis	Oil price shocks are not a significant effect on CO_2 emissions
Saboori et al. (2017)	China, Japan and South Korea	1980–2013	Time series analysis	Increase (decrease) in oil consumption increases (decreases) CO_2 emissions (for China and South Korea) No causality relationship between petroleum consumption and CO_2 emissions (for Japan)

(continued)

Table 2.1 (continued)

Author(s)	Country	Period	Methodology	Conclusion
Nwani (2017)	Ecuador	1971–2013	Time series analysis	Increase (decrease) in oil prices increases (decreases) CO_2 emissions
Maji et al. (2017)	Malaysia	1983–2014	Time series analysis	Increase (decrease) in oil prices reduces (increases) CO_2 emissions
Kumar and Managi (2009)	80 countries	1971–2000	Directional output distance function estimation	Increase in oil prices induces technological progress in renewable energy
Yang and Timmermans (2012)	Netherlands	Survey	Pseudo-panel survey methodology	The effect of rise in oil prices on carbon emissions is ambiguous

2.3 Wavelet Methodology

This section briefly explains (i) the continuous wavelet transformation of economic and financial time series besides its features and advantages over Fourier transformation. Then, it describes (ii) complex Morlet wavelet transformation after introducing the mother wavelet selection criteria and (iii) the tools of wavelet transformation that are wavelet coherency and phase differences.

2.3.1 The Continuous Wavelet Transformation

Spectral transformation decomposes the predominant business cycles, trends and seasonal characteristics of signals into frequency–time domain. While Fourier transformation reveals major frequencies of a particular signal, it is lack of determining where these frequencies are located in time horizon.[1] Unlike Fourier transformation, wavelet transformation is capable of delivering contemporaneous information over a

[1]Fourier Transformation (FT) can decompose any periodic and some non-periodic signal into a sine/cosine function. FT of an arbitrary signal $z(t)$ can be written as $B(f) = \int_{-\infty}^{\infty} b(t)\exp(-i2\pi ft)\mathrm{d}t = \int_{-\infty}^{\infty} b(t)[\cos(2\pi ft) - i\ \sin(2\pi ft)]\mathrm{d}t$, where $B(f)$ is a function of frequency f and $i = \sqrt{-1}$ is the complex or imaginary number. Alternatively, this equation can be

signal in frequency as well as time domain. This gives to the researchers an advantage of observing how main cycles and trends alter in a specific time interval (Wen 2002) and how transition among periods happens (Merrill et al. 2008). As the wavelet transformation is well localized in time, it turns out to be more practical and advantageous to analyze economic and financial time series that most are structured non-stationary and strongly trended (Aguiar-Conraria et al. 2013; Gençay et al. 2002; Jammazi and Aloui 2012). Therefore, wavelet analyses have a rising popularity in economics and finance literature including those of Gençay et al. (2002, 2005), Crowley (2007), Aguiar-Conraria and Joana Soares (2011), Bilgili et al. (2016), Jammazi and Aloui (2012), Khalfaoui et al. (2015), Kim and In (2007), Reboredo et al. (2017) and Vacha and Barunik (2012).

A wavelet function, which is a square differentiable function of time,[2] $\vartheta(.) \in L^2(\mathbb{R})$, can be defined as,

$$\vartheta_{(m,n)}(t) = \frac{1}{\sqrt{m}}\vartheta\left(\frac{t-n}{m}\right), \quad n \in \mathbb{R} \text{ and } m \in \mathbb{R}^+. \tag{2.1}$$

where $\vartheta_{(m,n)}(t)$ denotes a wavelet daughter and its mother wavelet $\vartheta(.)$ is a function of scale and location parameters m and n, respectively. Location parameter, n, shows where the wavelet's center is located in time. Scale or dilation parameter, m, is to discover cycles or trends in different frequencies by compressing or enlarging the wavelet spectrum. Moreover, higher (lower) the scale m generates longer (shorter) wavelets capturing long-run relations (short-run dynamics) and low (high) frequency properties of time series. Therefore, there is an obvious contrary relation between scale and frequency.

The continuous wavelet transformation (CWT) of a given time series of $k(t) \in L^2(\mathbb{R})$ regarding its wavelet function $\vartheta_{(m,n)}(t)$ can be written as:

$$W_k(m,n) = \int_{-\infty}^{\infty} k(t)\frac{1}{\sqrt{m}}\overline{\vartheta\left(\frac{t-n}{m}\right)}\mathrm{d}t, \quad n \in \mathbb{R} \text{ and } m \in \mathbb{R}^+, \tag{2.2}$$

In Eq. 2.2, complex conjugation has been denoted by the bar over the mother wavelet function $\vartheta(.)$ and $W_k(m,n)$ represents CWT.[3] In addition to square differentiability, the admissibility condition, which requires that the time series $k(t)$ should be converted back from its wavelet transformation, is defined as below:

$$G_\vartheta = \int_{0}^{\infty} \frac{|H(f)|^2}{f}\mathrm{d}f < \infty, \tag{2.3}$$

written with radian frequencies as $B(w) = \int_{-\infty}^{\infty} b(t)\mathrm{e}^{-iwt}\mathrm{d}t = \int_{-\infty}^{\infty} b(t)[\cos(wt) - i\ \sin(wt)]\mathrm{d}t$, where $w = 2\pi f$ denotes radian frequency.

[2]If a wavelet is square integrable $\vartheta(t) \in L^2(\mathbb{R})$, then it must satisfy $\int_{-\infty}^{\infty} \vartheta(t)^2\mathrm{d}t < \infty$.

[3]The conjugate of a complex number, $b + hi$, is simply $b - hi$. If it has only real value rather than complex, its conjugate will be itself.

where G_ϑ denotes the admissibility constant and $H(f)$ represents the FT of wavelet $\vartheta(t)$. When there is to be no zero-frequency element in FT of wavelet, $H(0) = \int_{-\infty}^{\infty} \vartheta(t)\mathrm{d}t = 0$, wavelet would have zero mean implying that the negative and positive cycles vanish each other. Torrence et al. (1998) state that, for each scale value, a comparison between different time series' CWT's would be possible when wavelet supports unit energy property, $\int_{-\infty}^{\infty} |\vartheta(t)|^2\mathrm{d}t = 1$.

2.3.2 Complex Morlet Wavelet

Mother wavelet families consist of lots of instances including those well-known wavelets of Haar, Mexican hat, Daubechies, Cauchy, Coiflets and Morlet. While each wavelet mother function is structured differently, it becomes important to choose the most fitting mother wavelet that overlaps better with the oscillatory features of a given time series. Since complex CWT provides evidence on both amplitude and phase structure of a signal, analysts can make a comparison between the locations of cycles of different signals. Because of this feature of complex CWT, empirical applications in economic time series are suggested to employ complex transformation (Aguiar-Conraria et al. 2008).

This paper uses complex Morlet wavelet transformation in its analysis part as well. Grossmann and Morlet (1984) first introduced the complex Morlet wavelet function, which is defined as:

$$\vartheta_\delta(t) = \frac{1}{\pi^{1/4}}\left(\exp(i\delta t) - \exp\left(\frac{-\delta^2}{2}\right)\right)\exp\left(\frac{-t^2}{2}\right), \tag{2.4}$$

where δ denotes central frequency parameter of complex Morlet wavelet $\vartheta_\delta(t)$. If the location parameter is $\delta > 5$, the value of $\exp(-\delta^2/2)$ becomes negligibly small then Eq. 2.4 turns into Eq. 2.5 as;

$$\vartheta_\delta(t) = \frac{1}{\pi^{1/4}}\exp(i\delta t)\exp\left(\frac{-t^2}{2}\right) \tag{2.5}$$

When the central frequency parameter is equal to six, $\delta = 6$, a substitutability between scale and frequency parameters becomes possible that lets Morlet wavelet function be defined as a function of frequency as well. Complex Morlet wavelet transformation is often preferred in order to analyze economic and financial signals in regarding literature including those of Aguiar-Conraria et al. (2008, 2013), Crowley (2005), Madaleno and Pinho (2014), Percival and Walden (2006) and Rua and Nunes (2009).

2.3.3 Wavelet Coherence and Phase Difference

When the admissibility condition sufficiently holds, it allows two-way conversion of time series from its wavelet transformation $W_k(d, l)$ into itself $k(t)$ again. Then, $k(t)$ can be written as a function of CWT as:

$$k(t) = \frac{1}{G_\vartheta} \int_0^\infty \left[\int_{-\infty}^\infty W_k(m, n) \vartheta_{(m,n)}(t) \mathrm{d}n \right] \frac{\mathrm{d}m}{\mathrm{d}^2}, \quad n \in \mathbb{R} \text{ and } m \in \mathbb{R}^+ \tag{2.6}$$

Wavelet power equation can be derived from the unit energy property of mother wavelet function as below,

$$\|k\|^2 = \frac{1}{G_k} \int_0^\infty \left[\int_{-\infty}^\infty |W_k(m, n)|^2 \mathrm{d}n \right] \frac{\mathrm{d}m}{\mathrm{d}^2}, \quad n \in \mathbb{R} \text{ and } m \in \mathbb{R}^+ \tag{2.7}$$

where $\|k\|^2$ and $|W_k(m, n)|^2$ denote the preserved energy of $k(t)$ and the wavelet power, respectively. Wavelet power $|W_k(m, n)|^2$ determines the distribution energy of $k(t)$ in the frequency–time plane.

The intercourse tools of wavelet analysis, which are cross-wavelet power (CWP), wavelet coherency, partial wavelet coherency and phase difference, enable researchers to examine the time–frequency dependencies between two different time series (Aguiar-Conraria and Soares 2011). CWP measures the local covariance between two time series, which is first expressed by Hudgins et al. (1993). For given separate time series $k(t)$ and $x(t)$, CWP formula can be written as below:

$$W_{kx}(m, n) = W_k(m, n) \overline{W_x(m, n)}, \tag{2.8}$$

where $W_{kx}(m, n)$ symbolizes the CWP, and $W_k(m, n)$ and $W_x(m, n)$ denote individual CWT of time series $k(t)$ and $x(t)$, respectively. Similarly, m and n denote scale and location parameters, respectively, in Eq. 2.8. Wavelet coherency indicates the areas where both time series significantly co-move in the spectrum. Aguiar-Conraria et al. (2013) state that wavelet coherency $R_{kx}(m, n)$ between time series $k(t)$ and $x(t)$ can be defines as below:

$$R_{kx}(m, n) = \frac{|S(W_{kx}(m, n))|}{\sqrt{S(W_k(m, n)) S(W_x(m, n))}}, \tag{2.9}$$

where S denotes a smoothing operator. Liu (1994) suggests that cross and single wavelet power should be necessarily smoothed in both scale and time, otherwise coherence estimation might result spuriously high. In analogy with the coefficient of correlation parameter of linear regression, wavelet coherence gets a value between 0 and 1 that denotes from no coherency to high coherency.

As it is discussed above, complex wavelet transformation enables to compute the phase difference of each time series, which provides information about the exact location of cycles, and therefore, it captures the direction and the lead–lag structure of the relationship. The phase difference $\phi_{k,x}$ can be written by using CWT as:

$$\phi_{k,x} = \tan^{-1}\left(\frac{\Im(W_{kx}(m,n))}{\Re(W_{kx}(m,n))}\right), \quad \text{with } \phi_{k,x} \in [-\pi, \pi]. \tag{2.10}$$

for a given complex cross wavelet transformation, $W_{kx}(m,n)$, its imaginary and real parts can be denoted by $\Im(W_{kx})$ and $\Re(W_{kx})$, respectively. If $\theta_{k,x} \in \left[\left(-\frac{\pi}{2}, -\pi,\right); \left(\frac{\pi}{2}, \pi\right)\right]$, then there is a negative correlation between series, on the contrary if $\theta_{k,x} \in \left(\frac{\pi}{2}, \frac{-\pi}{2}\right)$, then there is s positive relation between series. Moreover, if there is an exact phase difference of π or $-\pi$, this implies a negative correlation or an anti-phase relation; on the other hand, if there is an exact phase difference of zero, both time series progress entirely jointly at a specific frequency interval. Consistent with lead–lag relation, if $\theta_{k,x} \in \left[\left(-\frac{\pi}{2}, 0\right); \left(\frac{\pi}{2}, \pi\right)\right]$, then $k(t)$ leads $x(t)$; time series $x(t)$ is leading if $\theta_{k,x} \in \left[\left(0, \frac{\pi}{2}\right); \left(-\pi, -\frac{\pi}{2}\right)\right]$.

2.4 The Results of Wavelet Coherency and Partial Wavelet Coherency Analyses

Through wavelet coherency and partial wavelet coherency analyses, we aim at observing the potential possible short-run and long-run co-movements between oil prices and CO_2 emissions at different frequencies in China. As we analyze the data for oil prices and emissions, we also employ other relevant data for control variables such as world oil prices, fossil fuel energy production, renewable energy production, population and urban population to follow well-identified models. The literature reveals that these control variables have a significant impact on CO_2 emissions (Dong et al. 2018; Sarkodie and Adams 2018; Sarkodie and Strezov 2018; Zhang et al. 2017a, b). The full descriptions, relevant codes and available periods of the data are given in Appendix in Table 2.2.

The wavelet coherence and partial wavelet coherence estimations are presented by Figs. 2.1, 2.2a, 2.3a, 2.4a and 2.5a and in each figure, the black curve (contour) exhibits the 5% significance level of the wavelet coherence output through an ARMA (1, 1) representation. AR (1) and MA (1) terms of the ARMA model denote the autoregressive with one lag and moving average with one lag, respectively. The color code bars next to the figures reveal the range from weak coherency (blue) to strong coherency (red) between the variables. The color code, therefore, depicts the range from possible weakest coherence (dark blue) and to strongest coherence (dark red). The dark blue and dark red, thereby, refer to the low energy of association and high energy of association between the variables, respectively. Then, one may consider the energy of association the power of correlation ranging from 0.05 to 0.95.

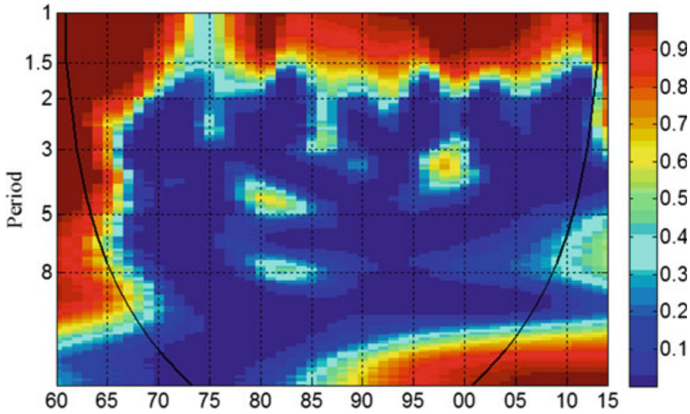

Fig. 2.1 Wavelet coherency (oil price, CO_2 total), 1960–2014

Figure 2.1a depicts wavelet coherency between real oil price and total CO_2 emissions for the period 1960–2014 in China by considering simultaneously (a) the time series observations, and (ii) frequencies ranging from 1 to 8 years.

Figure 2.1a reveals, then, some weak and strong coherencies between oil price and total CO_2 emissions at high-frequency periods (1–1.5-year frequency) for the periods 1960–1970 and 1977–2014. When the control variable of world oil price is added into the model, the wavelet coherencies become more explicit as depicted in Fig. 2.2a. The wavelet partial coherency given in Fig. 2.2a explores additionally the strong co-movements between oil price and CO_2 emissions at 2-year, 4-year and 5–8-year frequencies. Figure 2.2a exhibits well stronger coherencies between the variables at higher periods (lower frequencies).

Following Fig. 2.2a–c show the phase differences at 1–2-year and 2–4-year frequencies as Fig. 2.2d and e exhibit the phase differences within 1–3 frequency bands. At 1–2 frequency band, the oil prices, as the leading variable for the periods, 1982, 1987–1994, 1997–1999, 2005–2014, decreases CO_2 emissions in China. One of the plausible reasons for this output might be a possible switch from fossil fuel to renewables due to an increase in the ratio of oil price in China to the oil price of in the world.

This decline in emissions, due to the increase in oil prices, appears in the years of 2009–2014 at 2–4-frequency band, 1–3-frequency band (Fig. 2.2d) and 3–8-year frequency band (Fig. 2.2e). The decrease in CO_2 emissions at 3–8-year frequency band, however, seems to be significant just for the period 2004–2010 (Fig. 2.2a).

The immediate result from the outputs from Fig. 2.2a–e is that the strong and significant negative impact of oil price on CO_2 emissions appears more considerable at higher frequencies (1–2-year cycles). Within 1–2-year cycles, there also exist positive co-movements between variables, as oil price leads, from 1967 to 1982 and in 1995.

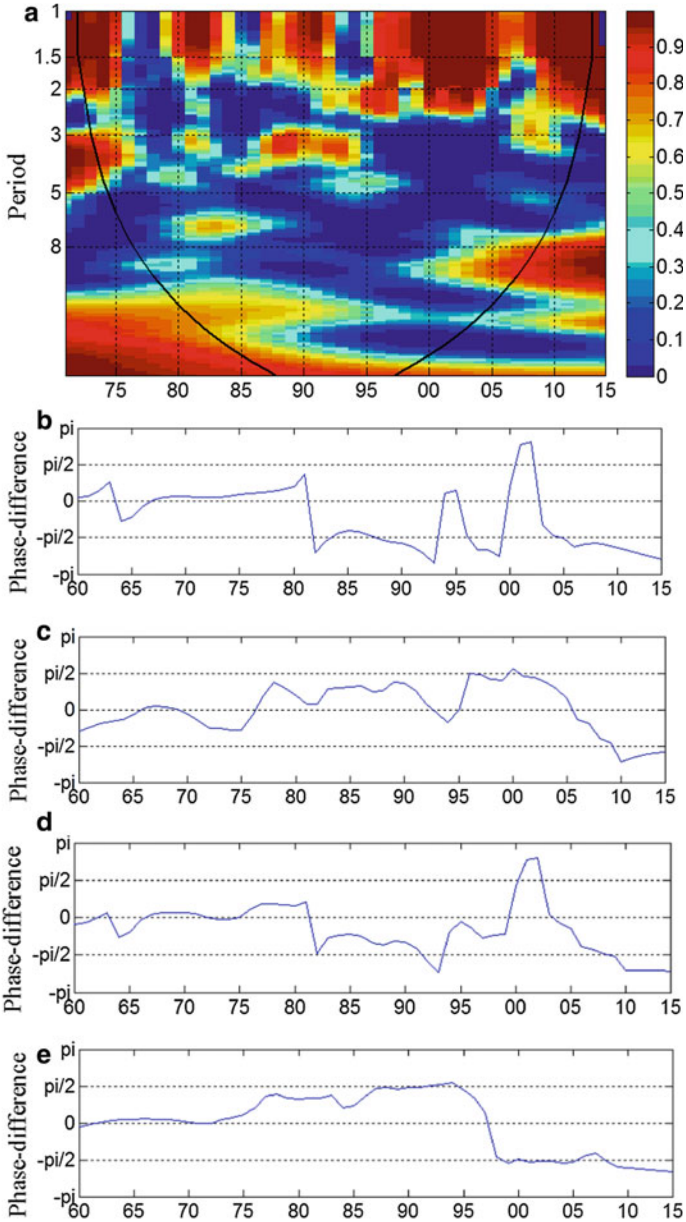

Fig. 2.2 **a** Wavelet partial coherency (oil price, CO_2 total || world oil price), 1960–2014. **b** 1–2-frequency band, 1960–2014. **c** 2–4-frequency band, 1960–2014. **d** 1–3-frequency band, 1960–2014. **e** 3–8-frequency band, 1960–2014

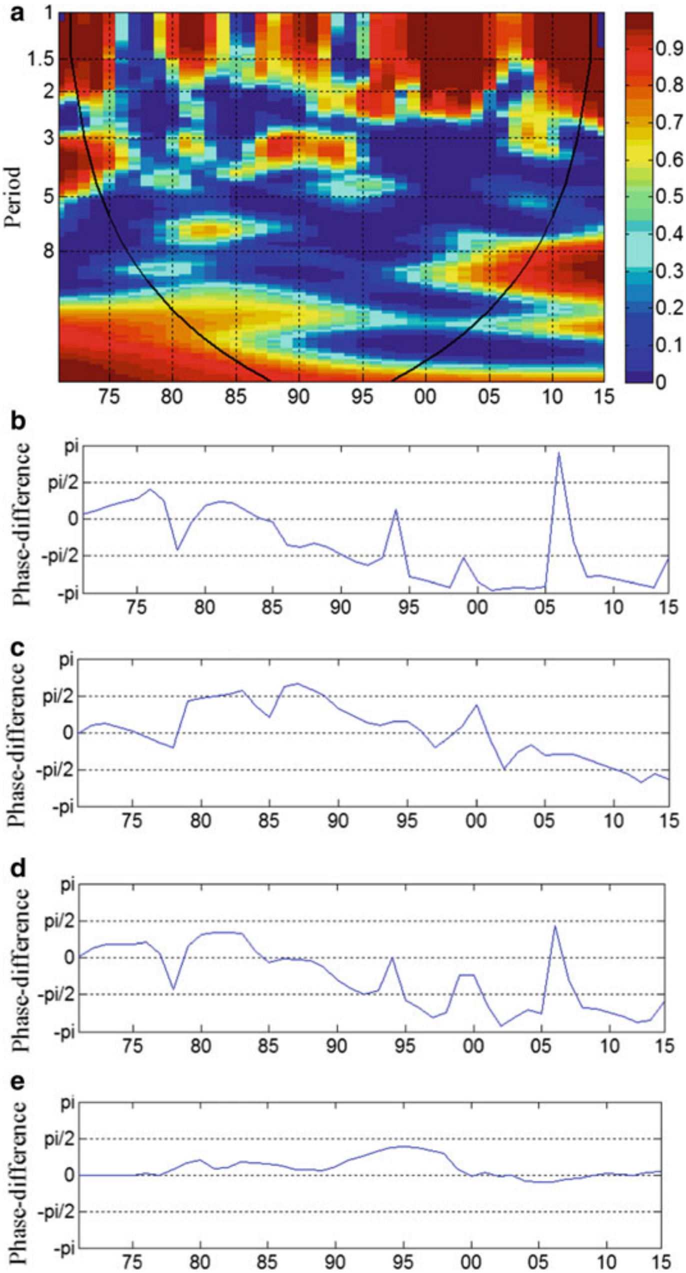

Fig. 2.3 **a** Wavelet partial coherency (oil price, CO_2 total ‖ world oil price, fossil fuel), 1971–2014. **b** 1–2-frequency band, 1971–2014. **c** 2–4-frequency band, 1971–2014. **d** 1–3-frequency band, 1971–2014. **e** 3–8-frequency band, 1971–2014

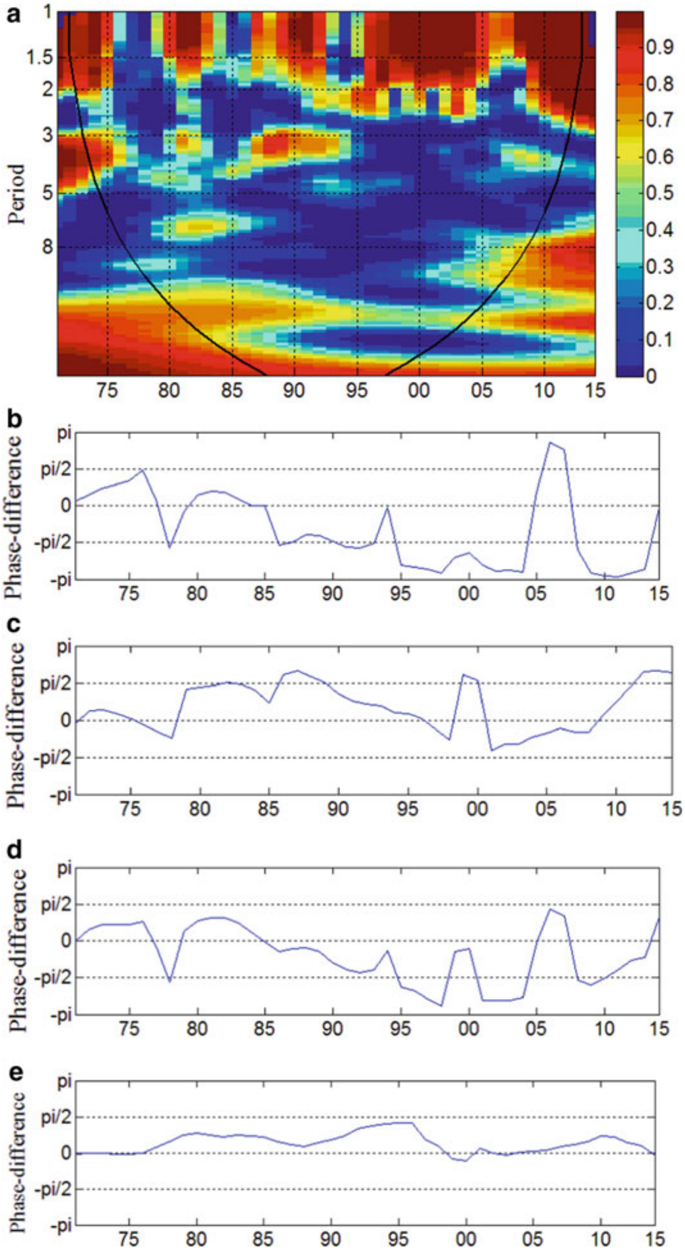

Fig. 2.4 **a** Wavelet partial coherency (oil price, CO_2 total || world oil price, renewables), 1971–2014. **b** 1–2-frequency band, 1971–2014. **c** 2–4-frequency band, 1971–2014. **d** 1–3-frequency band, 1971–2014. **e** 3–8-frequency band, 1971–2014

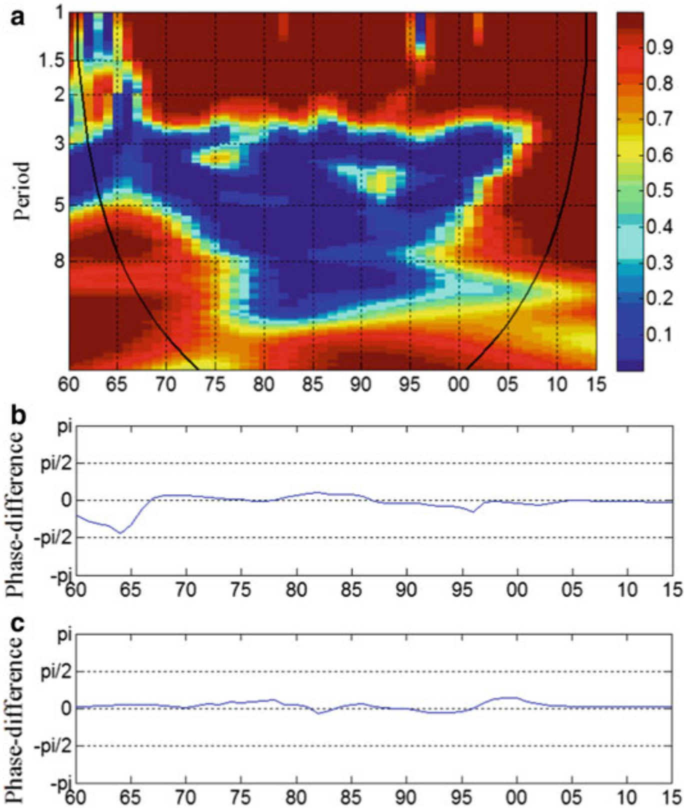

Fig. 2.5 **a** Wavelet partial coherency (urban pop, CO_2 total || world oil price), 1960–2014. **b** 1–3-frequency band, 1960–2014. **c** 3–8-frequency band, 1960–2014

As we launched the same wavelet coherence and wavelet partial coherence estimations by employing per capita CO_2 emissions instead of total CO_2 emissions, we observed that the main output has not changed. We do not plot here the relevant figures but exhibit them in Appendix section.

We added additionally the fossil fuel energy consumption (% of total energy) as control variable into the model and we have observed that the short-term-cycle (1–2-year frequency) co-movements of the variables become stronger than the co-movements of the variables given in Fig. 2.2a (without control variable of fuel oil consumption) for the period 1995–2014. Besides, Fig. 2.3a yields strong coherencies at 8-year frequency during 2004–2010. Since the available data points of fossil fuel consumption cover the period 1971–2014, as is given in Table 2.2 in Appendix, the wavelet model has been adjusted from the period 1960–2014 to the period 1971–2014.

Figure 2.3a, eventually, indicates the strong coherencies between oil price and CO_2 emissions with the control variables of world oil price and fossil fuel consumption. Figure 2.3b–e reveal the phase differences underlying the fact that the negative significant impact of oil price on CO_2 emissions in China becomes more apparent in short cycles (high frequencies). The Chinese oil prices influence the CO_2 emissions negatively during 1995–2005 and 2007–2014 according to Fig. 2.3b depicting phase differences at 1–2-frequency band. Figure 2.3e, on the other hand, indicates that there exist positive co-movements between oil price and CO_2 emissions from 1977 to 2000 as the oil price is leading. One might, however, not consider this output significant, since there is no strong association between oil price and the emissions for the period 1975–2003 at 3–8-frequency band as is indicated in Fig. 2.3a.

The output of Fig. 2.4a confirms the output of Fig. 2.3a. Although Figs. 2.3a and 2.4a look like similar, with a thorough investigation, one may depict that the explanatory power of fuel oil consumption at 2.5-year frequency and 8-year frequency (Fig. 2.3a) is slightly greater than that of renewable consumption at same frequencies (Fig. 2.4a). The main interpretation, however, about the short-run and long-run causality from oil price to carbon emissions has not changed. The real oil price changes affect the CO_2 emissions reversely at higher frequencies and do not influence much the emissions significantly at higher periods (lower frequencies) in China.

Figure 2.4b–e plot the partial phase differences obtained from wavelet partial coherence analyses to observe the co-movements of the variables at the same or opposite direction(s) and yield that oil price leads CO_2 emissions and increase in oil price diminishes the emissions at 1–2-year frequency between 1995 and 2005 between 2007 and 2014 and at 1–3-year frequency during 1995 and 2005 and 2007–2010.

The negative effect of oil price on emissions emerges at a longer time horizon with higher frequencies as its influence on carbon emissions gets weak in higher time periods (low frequencies).

Due to this weak coherency between oil price and CO_2 emissions at 3–8-year cycles, we estimated a new model in which we can observe the possible co-movements of urban population and CO_2 emissions in China with the control variable of world oil price for the period 1960–2014.

Figure 2.5a reveals the results that the urban population and CO_2 emissions have strong coherencies at both high and low frequencies. The energy demand by representative individual living urban areas in general tends to increase by following the average luxury lifestyle and hence brings about an immediate issue of the potential increase in CO_2 emission as indicated by Sugihara and Tsuji (2008). On the other hand, Liu et al. (2016) underline the fact that the urban energy consumption, for instance, of Beijing in China, has been improved by decreasing the proportion of coal consumption and by increasing the proportion of natural gas consumption and other clean energies rose. Figure 2.5b and c indicate that the urban population and CO_2 emissions tend to move together in the same direction (positive correlation) at 1–3-frequency band and 3–8-frequency band during 1960–2014.

2.5 Conclusions, Discussion and Some Policy Recommendations

The estimation output of this paper yields two highlights. Firstly, the relative increase in oil price in China, in comparison with the World oil price, is an important factor that affects CO_2 emissions negatively at shorter cycles (higher frequencies), secondly, the co-movements between urban population and emissions explore that they have a positive correlation and move together.

By following the time domain and frequency domain analyses of this research, one may claim that the oil prices in China have considerable negative impact on CO_2 emissions at high frequencies for the periods 1960–2014 and 1971–2014 in China. This result shows that the deterioration in energy prices resulting from energy price regulations adversely affect the environment. Likewise, Ju et al. (2017) conclude that the deterioration in oil prices contributed to the economic development of China and negatively affected the environment. Ju et al. (2017) emphasize that research on price regulations in China provides evidence for the need for energy controls. This paper provides significant output for potential researchers and policy authorities on the impact of oil price controls on CO_2 emissions in China.

Besides, one may underline as well other important output of the research exploring that the urban population and CO_2 emissions have positive associations, move together for the period 1960–2014 in China. Eventually, this paper might suggest that authorities follow demand-side management policies considering energy demand behavior at both shorter cycles and longer cycles to diminish the CO_2 emissions in China (Bilgili et al. 2017).

China accounts for the 80% of the global CO_2 emissions increase since 2008 (Liu et al. 2013). As the largest energy-related carbon emitter country of the world, with a 24% share of global GHG emissions, China's energy policies have a prominent role for achieving worldwide carbon emission targets (EPA 2016). By the ratification of Paris Agreement in 2015 adopted under the United Nations Framework Convention on Climate Change (UNFCCC), China pledges to reach its carbon emission peak until 2030, or earlier if possible, to drop carbon intensity of income by at least 60% below 2005 levels by 2030 (according to Copenhagen Accord in 2009, China commits to reduce carbon intensity by 40% below 2005 levels by 2020) and increase the share of non-fossil energy sources to 20% in the total energy supply.

China has been implementing a series of minimum energy performance standards (MEPS), compulsory and voluntary energy labeling programs, carbon taxes for vehicles and introducing new strategic action plans for energy development for over 25 years. China imposes different tax rates for vehicles proportional to the size of vehicle engines since 1994. In 2008, this tax has been decreased to 1% in favor of engines of 1.0 L and less and increased to between 25 and 40% disfavor of cars with higher size engines. Besides the Chinese government had differentiated energy prices for high energy-consuming industries for a limited time interval from 2004 to 2012 (Hu et al. 2012).

China improves its socio-economic targets with energy efficiency, transformation in the energy mix, expansion on clean energy investments and more control on enterprises' energy consumption levels in the last four five-year plans on National Economic and Social Development. Although tenth five-year plan (2001–2005) established some objectives for renewable energy production by introducing income tax reductions and VAT exemptions for renewable energy projects, it did not set any future environmental or energy intensity target (IEA 2017c). Achieving these goals will reduce renewable energy expansion and dependence on oil and other fossil fuels.

However, the 11th five-year plan (2006–2010) has revealed a target of reducing the energy intensity by an average of 4% per year, which is equivalent to 20% below 2005 levels compared to 2010 levels. Besides this plan has targeted to construct new wind farms with a total 100 Megawatts (MW) capacity and withdrawal of old-fashioned inefficient and small coal-fired plants from the energy production market IEA (2017d, e). As a result of this action, the carbon emissions from the Chinese electricity sector reached its most likely peak, which is 40% of China's total GHG emissions in 2014, by falling use of coal (Green and Stern 2015).

The 12th five-year economic development plan (2011–2015) highlights green development, environmental protection and energy conservation by incorporating required energy targets aiming to increase non-fossil energy consumption share to 11.4% of total primary energy consumption, reducing energy intensity by 16% and carbon intensity (CO_2 emission per unit of income) by 15%, by 2015 IEA (2017e). Like the preceding development plan does, this plan also contains particular targets for improvement of renewable energy production by constructing additional capacities to hydro and wind power plants together with supporting research and development of clean and efficient energy production technologies. The 13th and the last five-year economic development plan emphasizes on the regulation of top carbon-emitting enterprises of China and encourages those operate with efficient energy management and monitoring systems. According to this plan, China confirms that its total energy consumption will not exceed 3.375 billion metric tons of oil equivalent (or below 5 billion metric tons of coal equivalent) (NDRC 2016).

As a conclusion, until the 11th five-year plan (2006), China's energy efficiency targets were not presented, and renewable energy policies were negligible and just the efficiency labeling standards and vehicle-carbon taxes were set (Hallding et al. 2009). After 2006, energy efficiency targets (reduction of 20% and 16% by 2010 and 2015, respectively), investment subsidies on renewable energy technologies and minimum renewable energy production share target (at least 11.4% of total primary energy consumption by 2015) have given acceleration to the clean energy markets' expansion. Although coal consumption has predominantly the highest share in China's energy mix and is expected to remain for the near future (EIA 2016), China successively reduces the carbon intensity of GDP by improving energy efficiency and diminishing use of coal in the energy mix (Teng and Jotzo 2014). Although China's energy-related emissions are growing (Boyd 2012). China's abatement efforts improve fortunately the success probability of the world to achieve the 2 °C climate target (Garnaut 2014).

One may extend the discussion about the environmental, demographical facts, natural endowments, targets, achievements, endogenous and exogenous dynamics, obstacles and environmental quality targeted in China considering mainly the adverse effect of residential and industrial demand for fossil energy on environmental quality and CO_2 emissions. The future possible researches on the determinants of CO_2 emissions in China might, hence, need to consider other potential variables, such as clean energy prices, urbanization, ruralization, energy efficiency in urban and rural areas, awareness (schooling, media, researches, health expenditures due to environmental pollution, etc.), as well as the oil price in China, world oil price, fossil energy consumption and renewable consumption in China.

Appendix

See Figs. 2.6, 2.7 and Table 2.2.

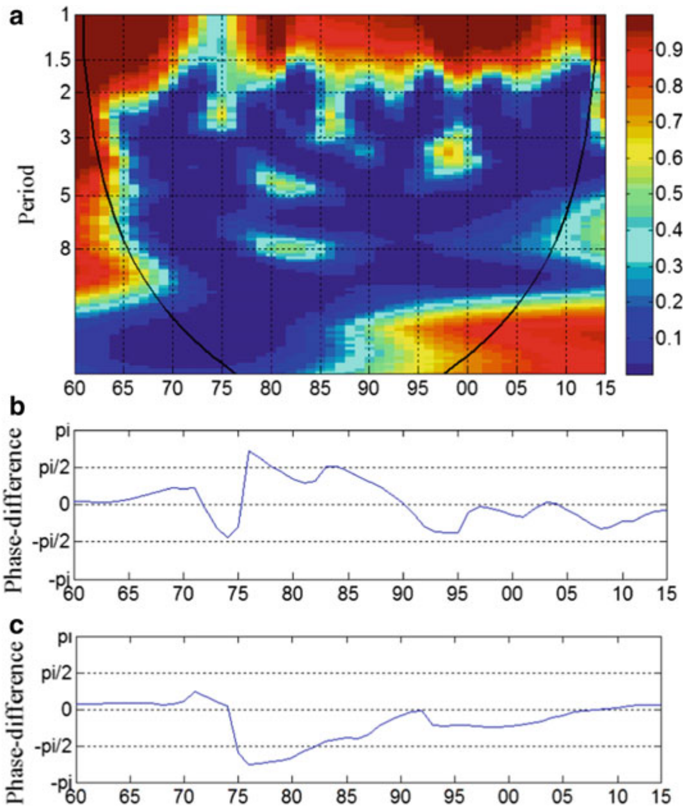

Fig. 2.6 **a** Wavelet coherency (oil price, CO_2 per capita), 1960–2014. **b** 1-3-frequency band, 1960–2014. **c** 3–8-frequency band, 1960–2014

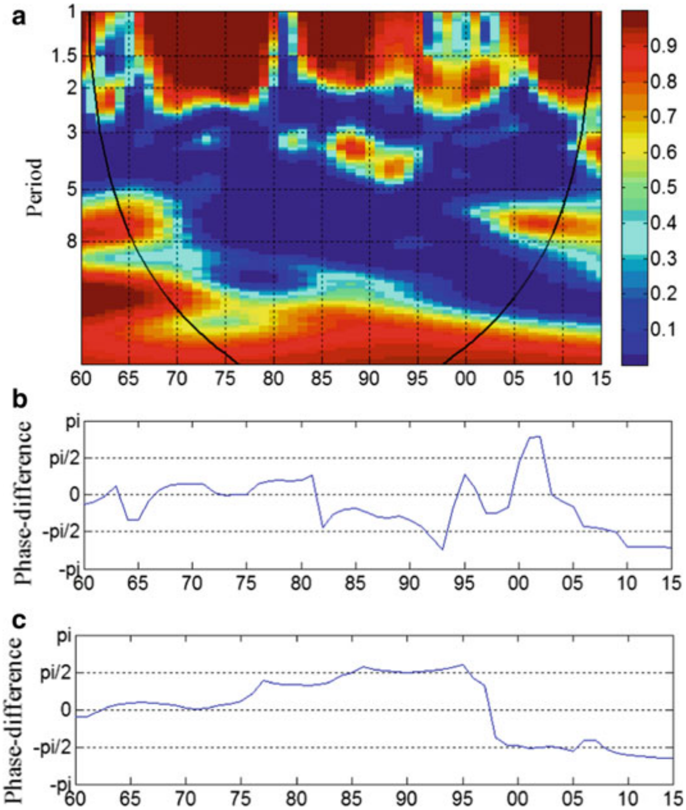

Fig. 2.7 **a** Wavelet partial coherency (oil price, CO_2 per capita || world oil price), 1960–2014. **b** 1–3-frequency band, 1960–2014. **c** 3–8-frequency band, 1960–2014

Table 2.2 Variables, codes, available periods

Variable	Code	Available period
CO_2 emissions (kt)	EN.ATM.CO2E.KT	1960–2014
CO_2 emissions (metric tons per capita)	EN.ATM.CO2E.PC	1960–2014
Oil price in China in $ 2016	BP/CRUDE_OIL_PRICES	1960–2014
Oil price in the World in $ 2016	BP/CRUDE_OIL_PRICES	1960–2014
Combustible renewables and waste (% of total energy)	EG.USE.CRNW.ZS	1971–2014
Fossil fuel energy consumption (% of total)	EG.USE.COMM.FO.ZS	1971–2014
Urban population (% of total)	SP.URB.TOTL.IN.ZS	1960–2014
Population, total	SP.POP.TOTL	1960–2014

Source World Bank, World Bank Indicator, https://data.worldbank.org/country/china, January, 2018

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Chapter 3
The Effect of Internet Use on Air Quality: Evidence from Low-Income Countries

Burcu Ozcan and Esma Gultekin Tarla

Abstract This chapter aims at analyzing the effects of information and communications technology (ICT) on air pollution level of low-income country panel over the period 1995–2015. In order to achieve this, the second-generation panel data models allowing for cross-sectional dependence have been employed. The long-run estimation results indicate that percentage of Internet users, a proxy for ICTs, leads to an increase in carbon dioxide (CO_2) emission level in low-income countries. Besides, among the control variables of the model, income and energy consumption appear to increase to CO_2 emission level while financial development and trade openness do not have any significant effects on air quality level of low-income country panel. Based on these results, a number of policy implications could be suggested. For instance, investments into the ICT sector should be encouraged by both government and private sector via subsidies and grants.

Keywords Information and communications technology · Air pollution · Economic growth · Panel data model · Low-income countries

3.1 Introduction

Human being has transformed the world and caused its fragile environment to deteriorate at an increasingly rapid rate, particularly since the beginning of the industrial age in the late eighteenth century (Sui and Rejeski 2002). As such, it could be stated that industrialization has contributed to national growth policies via mechanization of production, but has also created environmental problems as a by-product. In this sense, mechanization of production processes, i.e., sectoral transformation from agrarian-based economy to industrial-based economy, has created more environmental waste and pollution while increasing national output levels. However, in

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the course of time, governments started searching for solutions for rising and upcoming environmental threats at both the national and the international political agendas. In particular, as a result of transformation from an industrial society to a knowledge society in the 1960s, technology and knowledge started being used as policy tools for the struggle against environmental problems. Moreover, the oil price shocks in the 1970s were of great importance because they created a general interest in finding out the ways of reducing national energy demand and air pollution level by adopting a greater usage of information technology (IT) (Salahuddin and Alam 2015). In this way, IT was accepted as a useful and alternative way to gain more efficient economic growth with less energy (Sadorsky 2012).

The above-mentioned developments indicate that energy, in the form of oil and electricity, and information and communications technologies[1] (ICTs) played pivotal roles in the processes of industrialization and economic growth over the last hundred years (Cho et al. 2007). As stated by Funk (2015), for more than 50 years, we have been witnessing some huge and rapid improvements in the IT sector, and those improvements have reduced resource utilization and provided us a higher quality of life by redesigning our world. ICTs have consistently offered innovative products and services that are now an integral part of the daily life (GESI 2008). Therefore, knowledge society takes an advantage of technology and information for fostering a good life for both the current and the future generations by invigorating biological diversity, technological usability, economic wealth for all, political participation of all, and cultural wisdom (Fuchs 2008). As such, knowledge society that arises from the societal change processes driven by the rapid spread of ever-cheaper information and communications technologies takes us gradually forward into a post-industrial society (Hilty 2008). These developments in the areas of information and technology provide a clear evidence of strong relationships between ICTs, economic growth, and environmental quality.

Based on the rising importance of information and technology worldwide, we try to find an answer to the question whether the rising demand for ICT devices alleviates or aggravates environmental quality level based on a sample of low-income countries. Concerning the effect of ICTs on the environment, there exist two opposite viewpoints: The first viewpoint states that ICTs can alleviate environmental pollution by reducing energy demand and creating dematerialization, i.e., substitution of physical goods by virtual good (see Peng 2013; Ropke and Christensen 2012; and Sui and Rejeski 2002), while the second viewpoint indicates that ICTs worsen environmental pollution given that installation and operation of new ICT devices increase demand for electricity (see Al-Mulali et al. 2015; Ropke and Christensen 2012; and Matthews et al. 2001).Therefore, the net environmental effect of ICTs is not known a priori and deserves a special research interest.

[1]"Information and communications technology (ICT) is a broader term for information technology (IT), which refers to all communication technologies, including the Internet, wireless networks, cell phones, computers, software, middleware, videoconferencing, social networking, and other media applications and services enabling users to access, retrieve, store, transmit, and manipulate information in a digital form" (see http://aims.fao.org/es/information-and-communication-technologies-ict).

The sample of analysis is the panel of 23 low-income countries consisting of Bangladesh, Kenya, Benin, Burkina Faso, Burundi, Chad, Gambia, Ghana, Guinea-Bissau, Congo, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Central African Republic, Ruanda, Senegal, Sierra Leone, Tanzania, Tonga, and Uganda. The ICT use levels of low-income countries are lower compared to those of middle- and high-income countries. For instance, according to World Development Indicators (World Bank's 2019), the percentage of individuals using the Internet was about 16% in low-income countries, whereas it was about 58% in upper-middle-income countries, 34% in lower-middle-income countries, and 85% in high-income countries in 2017. Therefore, we believe that revealing the net environmental effect of ICT use for the low-income countries will provide policy-makers to develop appropriate political strategies. The remainder of the chapter has been organized as follows: Sect. 3.2 explains the positive and negative effects of ICTs on the environment; Sect. 3.2.1 deals with the substitution effects and dematerialization process; Sect. 3.2.2 explains the compensation effects (income effects) and rebound effects; Sect. 3.3 provides a brief literature summary; Sect. 3.4 describes data and model; Sects. 3.5 and 3.6 explain the methodological approach used and empirical findings, respectively; finally, the chapter is concluded with some important policy implications in Sect. 3.7.

3.2 Effects of ICT on Energy Demand and the Environment

Regarding the environmental effects of ICTs, there exist three different views named “the first-order effects,” “the second-order effects,” and “the third-order effects” (Fichter 2003; Hilty 2008; Hilty et al. 2006; Houghton 2010; Zhang and Liu 2015; Zadek et al. 2010). The first-order effects indicate that ICT sector is responsible for higher CO_2 emission rate as the production and the use of ICTs create material flows and electronic waste, use hazardous materials, and increase energy consumption (Fichter 2003). In this sense, the first-order effects include the direct effects of ICTs such as energy consumption and e-waste (Houghton 2010). The second-order effects are derived from the usage of ICTs in the other processes because ICTs have an effect on the life cycle of another product, which is optimized (optimization effect) or which is used less often (substitution effect) or more frequently (induction effect) (Hilty 2008). The second-order effects, the indirect effects of ICT applications such as intelligent transport systems, smart buildings, and smart grids, might be beneficial or damaging for the environment (Houghton 2010). Last, the third-order effects, which are derived from the integration of ICTs into everyday life (Zadek et al. 2010), are defined as the adaptive reactions of societies to the availability of ICT services. These effects create structural transformation in the economy and affect lifestyles and consumption patterns of the society, which, in turn, affect the environmental quality level of the society (Hilty et al. 2006).

Based on the above-mentioned views, it could be stated that there is no consensus yet on the net effects of ICTs on energy demand and environmental quality. On the one hand, smartphones and other personal ICT devices allow users to share data, pictures, and videos, creating positive network effects among users; on the other hand, sharing them also increases the demand for electricity (Sadorsky 2012). Moreover, the production of ICT devices has a high energy density; for instance, the production of a desktop computer with a 17-inch CRT monitor consumes 6400 megajoules of total energy and 0.26 tons of fossil fuel (Peng 2013). In addition, the use of ICT products not only consumes electricity, but also leads to CO_2 emissions. Utilization of a desktop computer can result in 0.1 tons of CO_2 emissions per year (Peng 2013).

The effects of the Internet on the energy demand are explained by Romm (2002) as follows:

1. On the one hand, the Internet holds the prospect of increasing energy intensity by
   - increasing delivery of products by relatively inefficient means,
   - increasing shipping in general, as the globalization fostered by the Internet makes it easier to purchase objects from very far away, and
   - increasing the frequency of personal and business travel, as people prefer meeting the widely dispersed people they have met on the Internet in person.
2. On the other hand, the Internet holds the likelihood of reducing transportation energy intensity by
   - replacing some commuting with telecommuting,
   - replacing some shopping with teleshopping,
   - replacing some air travel with teleconferencing,
   - enabling digital transmission or e-materialization of a variety of goods that are today shipped by truck, train, and plane,
   - improving the efficiency of the supply chain, and
   - increasing the capacity utilization of the entire transportation system.

The positive and negative effects of ICTs on energy demand and the environment can be explained via some specific notions discussed below.

3.2.1 Substitution Effects and Dematerialization Process

Regarding its positive effects, IT is accepted as a solution to obtain more efficient economic growth with less energy demand (Sadorsky 2012). There exists a special notion named “IT as a solution” or “IT for green” (see Cai et al. 2013; Dedrcik 2010; Salahuddin et al. 2016), which accepts ICT sector as a beneficial solution in reducing CO_2 emissions throughout all economic sectors. In this approach, IT is accepted as a mean to achieve national environmental sustainability goal by using energy in a more efficient and a sustainable way. ICT contributes to energy saving and reduction of CO_2 emissions by improving energy efficiency in different sectors of the economy through the optimization of each link of product systems (Zhang and Liu 2015). The positive effect of ICTs on the environment is reflected in the *substitution effects* that represent the reduction of electricity demand through the replacement of an old energy-intensive production technology by a new one (Cho et al. 2007; Coroama et al. 2012). There is a growing consensus about the idea that ICTs may have a role in reducing the greenhouse gases (GHGs) emissions by both raising the efficiency of existing production processes and enabling the substitution effects (Coroama et al. 2012).

Many traditional industries implementing ICTs in their operation processes have been transformed into smart industries such as smart transportation, smart agriculture, smart management, smart logistics, smart building, and so on. Those ICT-enabled transformations have resulted in better production control and monitoring, more efficient resource management, better transportation and logistics management, less energy waste, and less polluting emissions throughout economy (Peng 2013; Zadek et al. 2010). According to Romm (2002), the Internet provides two types of gains by improving energy intensity: First, the structural gains occur if there is a shift in the industrial structure away from iron and steel, chemicals, and other smokestack industries toward electronics, communications, and other IT industries (Takase and Murota 2004). Second, efficiency gains are obtained with overall efficiency rise throughout the system as a whole, occurring when businesses change their activities in some ways that can reduce energy intensity. According to the Smart 2020 Report (GESI 2008), ICTs will cause higher energy efficiencies in other sectors, and thereby, they will contribute to the reduction of carbon emissions five times larger than the total emissions from the ICT sector in 2020.

The second concept highlighting the positive effects of ICTs on the environment is the *dematerialization,* which represents a knowledge society making use of ICTs to provide immaterial services where material goods were produced, transported, and disposed previously (Hilty 2008). The virtual goods replace material devices. For instance, the shifts from books to bytes, from compact disks to MP3s, from snapshots to JPEGs, and from checkbooks to clicks are the products of the dematerialization process in which electrons substitute for atoms (Sui and Rejeski 2002). In these cases, ICTs are used to substitute "bits of information" such as downloads, virtual meetings, and e-commerce for more energy-intensive physical products, and travel and retail premises (Zadek et al. 2010). Transformation from an "industrial society" to a knowledge society represents a less resource-intensive and a weightless economy given that there is an important process called dematerialization of production (Fuchs 2008). Nowadays, trade and transportation of many products and services over the Internet result in dematerialization, which reduces the amount of physical transport and increases the efficiency of transportation (Fuchs 2008). Thus, it could be stated that ICTs reduce the negative environmental effects of traditional industries by allowing more efficient ways of production and distribution.

E-commerce, online shopping, teleworking, and teleconference, which are likely to have environmental effects, are the products of dematerialization process. We are currently witnessing a growing interest in online shopping. The Internet is turning to be the modern agora free from the limitations of space and time (Sui and Rejeski 2002). However, there are some debates on the effects of the rising interest in online shopping (e-commerce) on the environmental quality, as well. A group of scholars (see Al-Mulali et al. 2015; Ropke and Christensen 2012; Matthews et al. 2001) suggests that online shopping worsens air pollution by causing more energy consumption. For instance, Al-Mulali et al. (2015) suggest that the number of required vehicles to deliver the purchased items to the buyers will increase in the case of online shopping, resulting in more energy consumption in transportation sector. Given that a lorry or a car delivers goods individually, the savings in energy consumption from private transport might be outweighed by the additional energy consumption related to distribution (Ropke and Christensen 2012). Moreover, even though e-commerce can reduce the use of warehouses as well as trips to the shopping malls, it is generally based on a transportation system that is more energy and pollution-intensive; e.g., aircraft may replace trucks and rail (Matthews et al. 2001).

Another group of scholars (see Matthews et al. 2002; Romm 2002; Sui and Rejeski 2002) states that online shopping reduces energy demand and CO_2 emission level compared to shopping by car. In this sense, Romm (2002) argues that a 20-mile round-trip to purchase two 5-pound products at malls consumes about one gallon of gasoline, whereas having those packages transported 1000 miles by truck or air freight consumes nearly 0.1 and 0.6 gallons, respectively. Online sale of products could be beneficial to the environment because in this situation, emissions from vehicles driven to shopping malls can be avoided while retail space, inventories, and waste can be reduced (Matthews et al. 2002). Additionally, by moving businesses online and marketing by pixels instead of packages, e-commerce can reduce the need for such wasteful products such as printed catalogues, telephone books, newspapers, and magazines (Sui and Rejeski 2002). Therefore, the net impact of e-commerce is not known a priori. Teleconference and telework are also the products of dematerialization process. Coroama et al. (2014) state that GHG emissions caused by an international conference could be reduced substantially by organizing it as a teleconference since it will reduce the frequency of traveling. Likewise, telework, allowing knowledge workers to overcome spatiotemporal distances and to work from home, would reduce the need for transport and thus environmental pollution (Fuchs 2008). As sum, through demobilization (i.e., less shopping and business trips), online shopping, teleworking, and telecommuting lead to conservation of energy by reducing fuel consumption (Sui and Rejeski 2002).

3.2.2 Compensation Effects (Income Effects) and Rebound Effects

There is some suspicion about the view that ICT development creates a substantial reduction in energy consumption due to some concerns about the negative side effects of ICT development (Ishida 2015). As stated by Sui and Rejeski (2002), it is so early to paint a rosy picture for the positive environmental effects of the emerging digital economy. There exist two negative environmental effects of ICTs, namely the compensation effects and the rebound effects. The *compensation effects (income effects)* of ICTs work against the substitution effects and indicate that installation and operation of new ICT devices increase the demand for electricity (Cho et al. 2007). The use of smartphones and ICT devices to share data, videos, and pictures creates a positive network effect among users; however, the activity of sharing and using them also raises the demand for electricity (Sadorsky 2012). For instance, Facebook's global yearly electricity consumption is of 0.5 terawatt hours (TWh), amounting approximately to 500 W (Wh) per user (Gelenbe and Caseau 2015). The electricity consumption related to ICT devices, e.g., communication networks, personal computers, and data centers, increases at a rate of nearly 7% per year (Salahuddin and Alam 2015), and the production and use of ICT devices are estimated to be responsible for about 1–3% of global CO_2 emissions (Houghton 2010; Peng 2013; Zadek et al. 2010). Given that production and disposal of ICTs generate waste and toxic emissions, the emergence of knowledge society is accepted as a new stage in the material reality of capitalism instead of an immaterial society (Fuchs 2008). There is a special notion, "green IT" or "IT as a problem" (Cai et al. 2013; Dedrcik 2010; Peng 2013; Salahuddin et al. 2016), which underlines the negative effects of ICTs on the environment. This approach holds ICT sector responsible for the air pollution and asserts that the sector should implement environmentally friendly devices to combat its own carbon footprint. However, the Smart 2020 Report prepared by GESI (2008) stated that ICT sector, by enabling energy efficiencies in other sectors, will save carbon emissions five times larger than the total emissions from the entire ICT sector in 2020.

The second concept counteracting the positive energy and environmental effects of ICTs is the *rebound effects* that work against the efficiency of energy and resource use. The rebound effects represent the paradox that efficiency gains in ICT devices and machines can increase the demand for them (Coroama et al. 2012). The rebound effects occur in the case that efficiency of providing a service is increased and that there is not any factor restricting the demand for the service (Hilty 2008). In this sense, if a good gets cheaper in terms of its price or any effort necessary to obtain it, the demand for that good usually increases, and thus, efficiency improvements do not indicate savings on the input side (Hilty et al. 2006). In other words, energy efficiency gains resulting from the deployment of ICTs can create additional pressure on the demand for ICT devices. For instance, the increasing usage level of ICTs at work and home has led to significant increases in carbon footprint of the ICT sector and this might be accepted as one of the most crucial rebound effects (Peng 2013). The new technologies such as LCDs, laptops, and tablets are smaller and more energy efficient; however, the improvements in energy efficiency are outweighed by a fast growth in the number of devices (Heddeghem et al. 2014). Therefore, it appears that the share of electricity consumption of the ICT industry will increase unless the efficiency improvements of the sector can keep up with the growing proliferation of those devices (Zadek et al. 2010).

3.3 Literature Review

Environmental effects of information technologies have started to be analyzed since the early 1990s. The current literature is based on two main research categories: The first category analyzes the effects of ICTs on energy demand (especially electricity demand) (see Collard et al. 2005; Ropke et al. 2010; Sadorsky 2012; Saidi et al. 2017; Salahuddin and Alam 2015; Schulte et al. 2016; Shahbaz et al. 2016; Solarin et al. 2019; Wang and Han 2016). The second category focuses on the effects of ICTs on environmental quality (see Amri et al. 2019; Asongu et al. 2018; Danish et al. 2018; Haseeb et al. 2019; Higón et al. 2017; Lee and Brahmasrene 2014; Lu 2018; Park et al. 2018; Salahuddin et al. (2016); Shabani and Shahnazi 2019).

In the first category, there are time series studies analyzing the effects of ICTs on energy demand. Of them, Collard et al. (2005) modeled electricity demand using a proxy for the ICTs and concluded that increased usage of software and computers in the services sector of France raised the electricity density in production from 1986 to 1998. Ropke et al. (2010) questioned the impact of ICTs on the sectoral electricity consumption of Denmark with a case study from 2007 to 2008. They found that growing usage level of ICTs in daily life increased electricity consumption in the household sector. For the United Arab Emirates (UAE), Shahbaz et al. (2016) examined the effects of ICT and economic growth on electricity consumption for the period 1975–2011 by using Bayer–Hanck cointegration test, the innovative calculation approach, and the Granger causality test. They obtained that ICTs increase the demand for electricity, but they provide lower electricity prices. Additionally, they ascertained an inverted U-shaped relationship between ICT and electricity. In a similar way, Solarin et al. (2019) investigated the effects of ICT, financial development, and economic growth on electricity consumption during the period 1990–2015 for Malaysia by employing the Gregory–Hansen cointegration test and Toda–Yamamoto causality test. Their results confirmed a positive effect of ICTs on electricity consumption. A similar result was obtained by Salahuddin and Alam (2015), who examined the short- and long-term effects of economic growth and Internet use on electricity consumption in Australia for the period 1985–2012 through the autoregressive distributed lag model (ARDL).

Within the nexus of ICT and energy demand, there are some panel data studies. Among them, Schulte et al. (2016) analyzed the relationship between ICT and energy demand for 27 industries from 10 Economic Cooperation and Development Organization (OECD) countries by using the least squares dummy variable (LSDV) estimator and seemingly unrelated regression (SUR) methods for the period 1995–2007. They obtained that ICTs are associated with a significant decrease in total energy demand and electricity consumption. Similarly, Wang and Han (2016), for a panel of 30 Chinese provinces, analyzed the effects of ICT investments on energy intensity during the period 2003–2012 by using the Driscoll–Kraay panel method and panel error correction model. They found that ICT investments reduced energy intensity in the long-run. In contrast, Sadorsky (2012) found that ICTs increased electricity consumption in 19 developing economies from 1993 to 2008 by utilizing the generalized method of moments (GMM). A similar result was gained by Saidi et al. (2017), who found that ICT increased electricity consumption for a panel data set of 67 countries by using GMM from 1990 to 2012.

In the second research category, the studies (time series or panel data studies) examined the effects of ICTs on environmental quality. For instance, Amri et al. (2019) investigated the relationship between CO_2 emission, total factor productivity, and ICT for the Tunisian economy through the autoregressive distributed lag (ARDL) model approach from 1975 to 2014 and obtained an insignificant effect of ICT on CO_2 emissions. Among panel data studies, Salahuddin et al. (2016) obtained that 1% increase in Internet usage caused 0.16% increase in CO_2 emissions in the panel of OECD countries for the period 1991–2012. A similar result was reported by Park et al. (2018), who examined the relationship between ICT, financial development, economic growth, and CO_2 emissions in 23 European Union (EU) countries between 2001 and 2014 through the pooled mean group (PMG) estimator. They found that 1% increase in the number of Internet users raises CO_2 emissions by 0.08%. Another study carried out was by Danish et al. (2018), who explored the relationships between ICT, financial development, economic growth, and electricity consumption for the Next Eleven (N-11) countries by employing the panel mean group (MG) and augmented mean group (AMG) estimators during the period 1990–2014. Their results confirmed a positive relationship between ICT use and CO_2 emissions. Besides, Lee and Brahmasrene (2014) investigated the relationship between ICT, CO_2, and economic growth in 9 Asian countries during the period 1991–2009 by utilizing the Fisher-type Johansen panel cointegration test, and panel FMOLS and DOLS estimators. They confirmed the significant and positive effects of ICTs on both CO_2 emissions and economic growth. Also, Higon et al. (2017) searched the relationship between ICT and environmental sustainability for 142 countries by using the fixed effect panel data model for the period 1995–2010 and obtained an inverted U-shaped relationship between ICT and CO_2 emissions. Finally, Shabani and Shahnazi (2019) examined the relationship between energy consumption, GDP, CO_2 emissions, and ICT for sectors in the Iranian economy through the panel dynamic OLS estimator for the period 2000–2013. Their findings confirmed a positive and a significant effect of ICT on CO_2 emissions in the industrial sector, while a negative effect was discovered in the transportation and service sectors.

Some of the panel data studies confirmed that ICT reduces emission level of CO_2. For instance, Asongu et al. (2018) analyzed the effect of ICT on CO_2 emissions by using GMM model for 44 Sub-Saharan African countries in the period 2000–2012. The results indicate that ICT had no effect on CO_2 emission in the early stages; but there was a negative effect in the later stages. Likewise, Haseeb et al. (2019) searched the effects of ICT, globalization, energy consumption, financial development, and economic growth on environmental quality level in BRICS from 1994 to 2014 by using dynamic seemingly unrelated regression (DSUR). Their results revealed that ICT caused some significant negative effects on CO_2 emissions. A recent study in this group has been carried out by Lu (2018), who investigated the effects of ICT, energy consumption, financial development, and economic growth on CO_2 emissions by employing a common correlated effects mean group (CCEMG) estimator in 12 Asian countries from 1993 to 2013. Their findings provided a negative effect of ICT on CO_2 emissions.

3.4 Model and Data

The sample includes 23 low-income countries, namely Bangladesh, Kenya, Benin, Burkina Faso, Burundi, Chad, Gambia, Ghana, Guinea-Bissau, Congo, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Central African Republic, Ruanda, Senegal, Sierra Leone, Tanzania, Tonga, and Uganda. The related countries have been selected based on the classification of the World Bank (2015)[2]. Time period has been determined as the years from 1995 to 2015 due to unavailability of some data points. The dependent variable of the model is the carbon dioxide (CO_2) emission per capita (measured in kilograms). A number of studies, specifically the studies testing the environmental Kuznets curve (EKC) hypothesis (see Al-Mulali 2011; Apergis and Payne 2010; Ghosh 2010; Ozcan 2013), utilize CO_2 emissions as a proxy for air pollution. The main independent variable of the study is the Internet users per 100 people used as a proxy for ICTs in many studies (see Afzal and Gow 2016; Lin 2015; Sadorsky 2012; Saidi et al. 2017; Salahuddin and Alam 2015; Salahuddin and Gow 2016; Salahuddin et al. 2016). Additionally, some other control variables that are likely to affect CO_2 emission level are also included in the model like GDP per capita (constant 2010 US $) and energy use (kg of oil equivalent per capita). GDP and energy consumption are the essential variables mostly included in the models of the EKC studies (see Al-Mulali 2011; Apergis and Payne 2010; Farhani and Rejeb 2012; Haggar 2012; Pao and Tsai 2010). Increases in energy consumption are expected to raise air pollution. According to the EKC hypothesis, air pollution increases with the increase in income level in the early stages of development. However, once the income reaches a certain threshold level, an increase in the income level causes the reduction of air pollution. Therefore, EKC hypothesis posits an inverse U-shaped ($\cap$) relationship between income and CO_2 emissions. Accordingly, while the coefficient of energy consumption is expected to be positive, the coefficient of the income variable is likely to be positive or negative. Another control variable included in the model is the level of financial development (see Dogan and Turkekul; 2016; Jalil and Feridun 2011; Ozturk and Acaravci 2013; Tamazian et al. 2009; Zhang 2011). As a proxy for financial development, domestic credit to private sector (percentage of GDP) is employed. The net effect of financial development on CO_2 emissions is unclear. On the one hand, financial development helps companies to buy new equipment and to invest in new projects by reducing financial costs, enriching financial channels, and distributing operational risks, which increases both energy consumption and CO_2 emissions (Ozturk and Acaravci 2013). On the other hand, financial development provides countries the opportunity to obtain environmentally friendly

[2](See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519).

and clean production technologies and, thus, contributes to the reduction of environmental pollution (Tamazian et al. 2009). The last control variable of the model is trade openness (percentage of total exports and imports of goods and services in GDP) (see Choi et al. 2010; Islam et al. 2013; Karsalari et al. 2014; Shahbaz et al. 2011). The net effect of trade openness on the environment is not certain because there exists a tripartite approach regarding the relationship between trade openness and environmental quality in the literature (Choi et al. 2010; Copeland and Taylor 1994): scale effect, composition effect, and technical effect. The scale effect suggests that the increase in the amount of trade increases output, energy consumption, and, thus, CO_2 emissions. The composition effect emphasizes the reallocation of trade goods of a country. In other words, free trade offers countries a chance to specialize in the production of goods with which they have comparative advantage. Thus, based on whether the sectors in which the country specializes need more energy, energy consumption decreases and environmental quality improves or energy consumption increases and environmental quality deteriorates. Finally, the technical effect indicates that trade liberalization will improve the environmental quality by leading to more efficient use of energy during the production through technology. Therefore, the effect of trade openness on CO_2 emissions depends on which of these three effects are more dominant. If the scale effect is dominant, the coefficient of trade openness is positive; if the technical effect is dominant, the coefficient of trade openness is negative; if the composition effect is dominant, the sign of coefficient is uncertain. The variables, Internet users, GDP, financial development, and trade openness are obtained from the World Bank's (2019) database. CO_2 emission data are from the Emissions Database for Global Atmospheric Research (EDGAR) of the European Commission (2016), while energy consumption data are provided from the U.S. Energy Information Administration (EIA) (2019).

The main model of the study has been determined as follows based on the existing studies in the relevant literature (see Ozcan and Apergis 2018; Ozturk et al. 2016; Salahuddin et al. 2016).

$$\mathrm{PCO_2} = f(\mathrm{PGDP}, \mathrm{ICT}, \mathrm{PENC}, \mathrm{FD}, \mathrm{TO}) \quad (3.1)$$

In Eq. (3.1), per capita CO_2 emission level (PCO_2) is defined as the function of per capita real income level (PGDP), percentage of Internet users (ICT), per capita energy consumption (PENC), trade openness (TO), and financial development (FD). The variables of interest are included in the model in natural logarithmic forms considering the studies in the literature, and thereby, Eq. (3.2) is obtained:

$$\begin{aligned} \mathrm{lnPCO}_{2i} = {} & \alpha_i + \delta_i t + \beta_{1i}\mathrm{lnPGDP}_{it} + \beta_{2i}\mathrm{lnICT}_{it} \\ & + \beta_{3i}\mathrm{lnPENC}_{it} + \beta_{4i}\mathrm{lnTO}_{it} + \beta_{5i}\mathrm{lnFD}_{it} + \varepsilon_{it} \end{aligned} \quad (3.2)$$

where $i = 1, 2, \ldots, N$ refers to the number of countries in the panel and $t = 1995, 1996, \ldots 2015$ is the time period of the study. α_i and $\delta_i t$ represent the country-specific fixed effects and deterministic trend, respectively. ε_{it} is the country-specific random error term with zero mean. β_1, β_2, β_3, β_4, and β_5 denote the long-term elasticity coefficients of CO_2 by the relevant variables.

3.5 Methodology

3.5.1 Cross-Sectional Dependence Tests

The globalizing world order leads to a dependency among the macroeconomic data of the countries. Economic shocks in a country not only affect economic data of that country, but also affect the economic data of other countries. Therefore, it should be tested whether the economic data have interdependencies across cross-sectional units, i.e., countries. The following cross-sectional dependence tests are used in the analysis: the LM tests (Breusch and Pagan 1980), the CD_{LM} and CD tests (Pesaran 2004), and the LM_{adj} test (Pesaran et al. 2008).

The Lagrange multiplier (LM) test, developed by Breusch and Pagan (1980), is based on the mean square estimation of bidirectional correlations. Under the standard continuity condition, it has a chi-square distribution asymptotically ($T \rightarrow \infty$) with the N(N − 1)/2° of freedom. The LM test is effective when the time dimension is greater than the cross-sectional dimension ($T > N$). For other cases, Pesaran (2004) developed the CD_{LM} and CD tests. The LM test statistic is shown as follows:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{3.3}$$

where $\hat{\rho}_{ij}$ is a sample estimate of the bidirectional correlation of the residuals, and its properties can be expressed as follows:

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^{T} e_{it} e_{jt}}{\left(\sum_{t=1}^{T} e_{it}^2\right)^{1/2} \left(\sum_{t=1}^{T} e_{ij}^2\right)^{1/2}}, \tag{3.4}$$

where e_{it} is obtained by the ordinary least squares (OLS) method. The *LM* test has asymptotically the chi-square distribution with degree of freedom $N(N-1)/2$, but this test is not valid in the case of $N \rightarrow \infty$. For this reason, Pesaran (2004) developed another test statistic (CD_{LM}) that will be used in case that both the cross section and the time dimension are large. Pesaran (2004) describes the test procedure as follows:

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T \hat{\rho}_{ij}^2 - 1\right) \tag{3.5}$$

This test statistic does not follow a chi-square distribution as the LM test statistic of Breusch and Pagan (1980), but follows a standard normal distribution.

Another test statistic, the *CD* test statistic, was proposed by Pesaran (2004) in case of $N > T$; it is defined as:

$$\text{CD} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \tag{3.6}$$

Finally, Pesaran et al. (2008), for the state of first for $T \to \infty$ and then $N \to \infty$, developed the test statistic in Eq. (3.7) to correct the small sample bias of the LM statistic.

$$\text{LM}_{\text{adj}} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{\rho}_{ij}-\mu_{Tij}}{v_{Tij}} \tag{3.7}$$

where μ_{Tij} and v_{Tij} indicate the mean and variance, respectively. LM_{adj} test statistic has a standard normal distribution ($\text{LM}_{\text{adj}} \to_d N(0, 1)$). The null and the alternative hypotheses of the test statistic are defined as follows:

H_0: There is not any cross-sectional dependence.
H_1: There is a cross-sectional dependence.

3.5.2 Smith et al. (2004) Panel Unit Root Tests

Smith et al. (2004) developed their first test statistic defined in Eq. (3.8) based on the Im et al. (IPS 1997) unit root test.

$$\frac{\sqrt{N}\left\{\bar{t}-E(t_i)\right\}}{\sqrt{\text{Var}(t_i)}} = \bar{t}_s \tag{3.8}$$

The test statistic, $\bar{t}_s$, utilized the Dickey–Fuller (DF) test and has a standard normal distribution. $E(t_i)$ and $\text{Var}(t_i)$ in Eq. (3.8) are the DF mean and variance. The restrictive distributive problems of IPS require the presence of the second moments of t_i. Therefore, the Lagrange multiplier (LM) test statistics, first developed by Solo (1984), should be taken into consideration. In this case, the new test statistic is defined as follows:

$$\frac{\sqrt{N}\left\{\overline{\text{LM}}-E(\text{LM}_i)\right\}}{\sqrt{\text{Var}(\text{LM}_i)}} = \overline{\text{LM}}_s \tag{3.9}$$

where $\overline{\text{LM}}$ is the mean of each LM_i, and thereby, the obtained equation is shown as $\overline{\text{LM}} = N^{-1}\sum_{i=1}^{N}\text{LM}_i$. In addition to the development of DF test statistics with LM test statistics, Leybourne et al. (2002) found two different modifications of DF: the weighted symmetric (WS) test described by Pantula et al. (1994) and the Max test developed by Leybourne (1995). Equations (3.10) and (3.11) describe these two test statistics:

$$\frac{\sqrt{N}\left\{\overline{\text{Max}}_i - E(\text{Max}_i)\right\}}{\sqrt{\text{Var}(\text{Max}_i)}} = \overline{\text{Max}}_s \tag{3.10}$$

$$\frac{\sqrt{N}\left\{\overline{\text{WS}} - E(\text{WS}_i)\right\}}{\sqrt{\text{Var}(\text{WS}_i)}} = \overline{\text{WS}}_i \tag{3.11}$$

The final test is expressed as a more powerful variant of the LM test. This test provides the LM_{f_i} ve LM_{r_i} test statistics based on forward and backward regressions as in previous procedures. The minimums ($\text{Min}_i = \text{Min}\left(\text{LM}_{f_i}, \text{LM}_{r_i}\right)$) are used to achieve the test statistic which is defined in Eq. (3.12) based on the equation of $\overline{\text{Min}} = N^{-1}\sum_{i=1}^{N}\text{Min}_i$.

$$\frac{\sqrt{N}\left\{\overline{\text{Min}} - E(\text{Min}_i)\right\}}{\sqrt{\text{Var}(\text{min}_i)}} = \overline{\text{Min}}_s \tag{3.12}$$

The above-mentioned five test statistics of Smith et al. (2004) have a unit root null hypothesis and allow for heterogeneous autoregressive roots under the alternative hypothesis. Therefore, the rejection of the null hypothesis implies that stationarity does hold for at least one panel member.

3.5.3 Westerlund (2008) and Pedroni (1999, 2004) Cointegration Tests

The Durbin–Hausman (DH) cointegration test, developed by Westerlund (2008), allows the analysis of the cointegration relationship when the dependent variable is not stationary at the level value, i.e., $I(1)$, and the independent variables are stationary at the level, i.e., $I(0)$, or at the first differences, i.e., $I(1)$. The DH test allows cross-sectional dependence with a factor model. In this process, the error terms of Eq. (3.2) are obtained by unique innovations and unobservable factors common to the panel members (Auteri and Constantini 2005). The error terms of Eq. (3.2) are modeled by Eqs. (3.13)–(3.15):

$$\varepsilon_{it} = \lambda_i' \text{F}_t + \text{e}_{it} \tag{3.13}$$

$$F_{jt} = \rho_j F_{jt-1} + u_{jt} \tag{3.14}$$

$$e_{it} = \emptyset_i e_{it-1} + v_{it} \tag{3.15}$$

F_t is a k-dimensional vector of the common factors, while $j = 1, 2, \ldots,$ k and F_{jt} is a vector compatible with λ_i. The stationarity of F_t is ensured if we assume that $\rho_j < 1$ holds for all j. The statement explains that the combined regression error z_{it} only depends on the integration of the e_{it} during its integration, with its own disruption. Accordingly, testing the null hypothesis of cointegration in the data generation process means testing if $\emptyset_i = 1$. The following two panel test statistics, the panel test statistic (DH_p) and the group-mean test statistic (DH_g), are obtained.

$$\text{DH}_g = \sum_{i=1}^{n} \widehat{S}_i \left(\overline{\emptyset}_i - \widehat{\emptyset}_i\right)^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{3.16}$$

$$\text{DH}_p = \widehat{S}_n \left(\overline{\emptyset} - \widehat{\emptyset}\right)^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{3.17}$$

The main difference between DH_p and DH_g test statistics stems from the difference in the formulation of the alternative hypothesis. The hypotheses for the panel tests are

$$H_0^p : \emptyset_i = 1 \text{ for all } i,$$
$$H_1^p : \emptyset_i = \emptyset \text{ for all } i \ \emptyset < 1$$

In this situation, it is assumed that there exists a common value for the autoregressive parameter under both the null and the alternative hypotheses. Therefore, if this assumption is valid, the rejection of the null hypothesis provides evidence in favor of cointegration for all i. The hypotheses for the group tests are specified as:

$$H_0^g = \emptyset_i = 1$$
$$H_1^g = \emptyset_i < 1 \text{ at least for some } i$$

According to the above hypotheses, no common value is assumed for the autoregressive parameter. Thus, the rejection of the null hypothesis does not provide any evidence of cointegration for all units. The rejection of the null hypothesis provides evidence of cointegration at least for some panel members.

As a robustness check, we have also employed Pedroni's (1999, 2004) cointegration tests. There exist seven cointegration tests. Among these seven tests, four tests include within effects and three tests include between effects. Specifically, the within statistics are calculated by summing both shares and denominators separately according to N dimension. The between statistics are obtained by dividing the numerator by denominator before being added to Ndimension. The related test statistics are defined as follows:

$$\text{Panel } \nu\text{-stat.}: \; T^2 N^{\frac{3}{2}} Z_{\hat{\nu}_{N,T}} = T^2 N^{\frac{3}{2}} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \tag{3.18}$$

$$\text{Panel } \rho\text{-stat.}: \; T\sqrt{N} Z_{\hat{\rho}_{N,T}-1} = T\sqrt{N} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right) \tag{3.19}$$

Panel t-stat. (*non-parametric*):

$$Z_{t_{N,T}} = \left(\tilde{\sigma}_{N,T}^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-\frac{1}{2}} \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right) \tag{3.20}$$

Panel t-stat. (*parametric*):

$$Z_{t_{N,T}}^* = \left(\tilde{s}_{N,T}^{*2} \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*} \Delta \hat{e}_{i,t}^{*} \tag{3.21}$$

Group ρ-stat.:

$$T N^{-1/2} \widetilde{Z}_{\hat{\rho}_{N,T}-1} = T N^{-\frac{1}{2}} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right) \tag{3.22}$$

Group t-stat. (*non-parametric*):

$$N^{-1/2} \widetilde{Z}_{t_{N,T}} = N^{-\frac{1}{2}} \sum_{i=1}^{N} \left(\hat{\sigma}_i^2 \sum_{t=1}^{T} \hat{e}_{i,t-1}^2 \right)^{-\frac{1}{2}} \sum_{t=1}^{T} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right) \tag{3.23}$$

Group t-stat. (*parametric*):

$$N^{-\frac{1}{2}} \widetilde{Z}_{t_{N,T}}^* = N^{-\frac{1}{2}} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{s}_i^{*2} \hat{e}_{i,t-1}^{*2} \right)^{-\frac{1}{2}} \sum_{t=1}^{T} \hat{e}_{i,t-1}^{*} \Delta \hat{e}_{i,t}^{*} \tag{3.24}$$

Equations (3.18)–(3.21) represent within effects, while Eqs. (3.22)–(3.24) reflect the between effects. The null and alternative hypotheses for the cointegration tests are defined as follows:

The hypotheses belonging to the equations with within effects are:

$$H_0: \; \gamma_i = 1 \text{ for all } i$$

$$H_1 : \gamma_i = \gamma < 1 \text{ for all } i,$$

The hypotheses belonging to the equations with between effects are:

$$H_0 : \gamma_i = 1 \text{ for all } i$$
$$H_{1:} : \gamma < 1 \text{ for all } i$$

3.5.4 Panel ARDL Estimator of Pesaran et al. (1999)

The panel autoregressive distributed lag (panel ARDL) model developed by Pesaran et al. (1999) is based on the estimation of the unconstrained error correction model by the OLS method. Equation (3.2) is designed as the panel ARDL estimation via Eq. (3.25).

$$\begin{aligned} \ln PCO_{2_{it}} = \alpha_i &+ \sum_{j=1}^{p} \beta_{ij} \ln PGDP_{i,t-j} + \sum_{j=0}^{q} \delta_{ij} \ln ICT_{i,t-j} \\ &+ \sum_{j=0}^{k} \theta_{ij} \ln PENC_{i,t-j} + \sum_{j=0}^{l} \gamma_{ij} \ln TO_{i,t-j} \\ &+ \sum_{j=0}^{m} \omega_{ij} \ln FD_{i,t-j} + \varepsilon_{it} \end{aligned} \tag{3.25}$$

Pesaran et al. (1999) additionally suggest that employing the re-parameterized Eq. (3.26) is more suitable.

$$\begin{aligned} \Delta \ln PCO_{2_{it}} = \alpha_i &+ \varphi_i LNPGDP_{i,t-1} + \delta_i^* \ln ICT_{it} + \theta_i^* \ln PENC_{it} + \gamma_i^* \ln TO_{it} \\ &+ \omega_i^* FD_{it} + \sum_{j=1}^{p-1} \beta_{ij}^* \Delta \ln PGDP_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{**} \Delta \ln ICT_{i,t-j} \\ &+ \sum_{j=0}^{k-1} \theta_{ij}^{**} \Delta PENC_{i,t-j} + \sum_{j=0}^{l-1} \gamma_{ij}^{**} \Delta \ln TO_{i,t-j} \\ &+ \sum_{j=0}^{m-1} \omega_{ij}^{**} \Delta \ln FD_{i,t-j} \end{aligned} \tag{3.26}$$

The following notations are specified in Eq. (3.26).

$$\varphi_i = -\left(1 - \sum_{j=1}^{p} \beta_{ij}\right), \delta_i^* = \sum_{j=0}^{q} \delta_{ij}, \theta_i^* = \sum_{j=0}^{k} \theta_{ij}, \gamma_i^* = \sum_{j=0}^{l} \gamma_{ij}, \omega_i^* = \sum_{j=0}^{m} \omega_{ij} \tag{3.27}$$

ε_{it} is an error term distributed independently along i and t; φ_i is the error term expected to be negative; $\delta_i^*, \theta_i^*, \gamma_i^*,$ and ω_i^* are the long-run coefficients, while $\beta_{ij}^*, \delta_{ij}^{**}, \theta_{ij}^{**}, \gamma_{ij}^{**}$ ve ω_{ij}^{**} are the short-run coefficients.

Pesaran et al. (1999) propose two estimators, the mean group estimator (MGE) and the pooled mean group estimator (PMGE). The MGE is not sufficiently restrictive because it does not impose any restriction on the ARDL specification parameters and the small sample power is not high. Therefore, while allowing short-term dynamics to differ between countries, the PMGE has been developed to allow long-term parameters to be the same.

3.6 Empirical Results

3.6.1 Results for Cross-Sectional Dependence and Panel Unit Root Tests

Before proceeding to the empirical analysis, we first provide some statistical features of variables of interest, as seen in Table 3.1.

As shown in Table 3.1, GDP per capita has the highest mean (6.27) while CO_2 emissions per capita have the lowest mean (−1.93). Besides, GDP per capita has the highest maximum value (8.21) while CO_2 emissions per capita have the lowest minimum value (−3.15); the standard deviations of variables range from 0.95 (lnFD) to 0.32 (lnTO). After that, to select the right panel unit root test, we first need to test the cross-sectional dependence across variables. In the presence of cross-sectional dependence, the second-generation panel unit root tests should be utilized instead of the first-generation tests. For this goal, the LM test (Breusch and Pagan 1980), the

Table 3.1 Statistical features of variables

Descriptive statistics	$\ln PCO_2$	lnPENC	lnFD	lnPGDP	lnICT	lnTO
Mean	−1.931	4.063	2.235	6.270	0.697	3.927
Median	−2.153	3.944	2.394	6.209	0.271	3.942
Maximum	0.841	6.700	4.171	8.215	3.680	4.879
Minimum	−3.158	1.966	−0.891	5.087	0.000	2.939
Standard dev.	0.704	0.839	0.952	0.533	0.865	0.324
Obs. number	598	598	598	598	598	598

Source Author's own calculation based on data

Table 3.2 Cross-sectional dependence test results

Variables	LM	CD_{LM}	LMadj	CD
$lnPCO_2$	2785.925[a] (0.000)	112.602[a] (0.000)	112.142[a] (0.000)	41.866[a] (0.000)
lnPGDP	3070.767[a] (0.000)	125.265[a] (0.000)	124.805[a] (0.000)	28.422[a] (0.000)
lnICT	5841.001[a] (0.000)	248.417[a] (0.000)	247.957[a] (0.000)	76.335[a] (0.000)
lnPENC	2103.745[a] (0.000)	82.275[a] (0.000)	81.815[a] (0.000)	6.762[a] (0.000)
lnFD	2143.587[a] (0.000)	84.047[a] (0.000)	83.587[a] (0.000)	35.634[a] (0.000)
lnTO	1171.485[a] (0.000)	40.832[a] (0.000)	40.372[a] (0.000)	18.648[a] (0.000)
Model	569.416[a] (0.000)	14.066[a] (0.000)	12.136[a] (0.000)	10.617[a] (0.000)

Notes The null hypothesis indicates the nonexistence of cross-sectional dependence
[a]refers to the rejection of null hypothesis at 1% significance level

CD and CDLM tests (Pesaran 2004), and the LM_{adj} test (Pesaran et al. 2008) have been employed and their results have been reported for both the variables of and the model in Table 3.2.

As can be seen in Table 3.2, the null hypothesis of cross-sectional independence is rejected at 1% significance level for both the variables of interest and the model defined in Eq. (3.2). Therefore, we have to employ the unit root tests and cointegration tests that take cross-sectional dependence into account. For this purpose, we utilize the panel unit root test, modeling the cross-sectional dependence via bootstrap, developed by Smith et al. (2004). The results of panel unit root test are given in Table 3.3.

As provided in Table 3.3, except trade openness (TO) variable, all variables are nonstationary, i.e., they have unit root, whereas they are stationary in their first differences, i.e., they do not have unit root. As such, trade openness is integrated of order zero, i.e., $I(0)$, while the remaining variables are integrated of order one, i.e., $I(1)$. Based on these results, we can ascertain if there is a cointegration, a long-run relationship between the variables defined in Eq. (3.2). To achieve this purpose, we utilize the cointegration test proposed by Westerlund (2008), which allows for cross-sectional dependence and that independent variables to be $I(0)$ or (1). Additionally, the panel cointegration tests of Pedroni (1999, 2004) are utilized as robustness aim. The results of cointegration tests are given in Table 3.4.

Based on the Durbin–Hausman group test (DH_g test statistic), the null hypothesis of no cointegration is rejected at 5% significance level. Besides, four out of seven Pedroni's (1999, 2004) cointegration tests, the panel PP, the panel ADF, the group PP, and the group ADF, have evidence of a long-run relationship (cointegration) between variables at 1% significance level.

Table 3.3 Results for Smith et al. (2004) unit root tests

	Level					First differences				
Variables	$\bar{t}$	$\overline{LM}$	$\overline{Min}$	$\overline{Max}$	$\overline{WS}$	$\bar{t}$	$\overline{LM}$	$\overline{Min}$	$\overline{Max}$	$\overline{WS}$
$lnPCO_2$	−3.17[a] (0.00)	8.63 [a] (0.00)	4.39 (0.25)	−1.88 (0.30)	−2.34 (0.21)	−5.16 [a] (0.00)	14.11[a] (0.00)	13.25[a] (0.00)	−4.78[a] (0.00)	−5.25[a] (0.00)
lnPGDP	−2.29 (0.17)	5.34 (0.21)	2.50 (0.94)	−1.29 (0.93)	−1.72 (0.95)	−4.79[a] (0.00)	12.91[a] (0.00)	12.13[a] (0.00)	−4.51[a] (0.00)	−4.86[a] (0.00)
lnPENC	−2.30 (0.26)	5.27 (0.28)	3.65 (0.48)	−1.82 (0.39)	−2.06 (0.55)	−5.36[a] (0.00)	14.19[a] (0.00)	13.51[a] (0.00)	−5.00[a] (0.00)	−5.43[a] (0.00)
lnICT	−0.57 (1.00)	2.60 (0.99)	1.15 (1.00)	−0.03 (1.00)	−0.42 (1.00)	−3.28[a] (0.01)	8.54[a] (0.00)	8.16[a] (0.00)	−3.26[a] (0.00)	−3.74[a] (0.00)
lnFD	−2.23 (0.33)	5.24 (0.35)	2.39 (0.98)	−1.25 (0.98)	−1.67 (0.97)	−4.61[a] (0.00)	12.64[a] (0.00)	11.64[a] (0.00)	−4.26[a] (0.00)	−4.71[a] (0.00)
lnTO	−2.09[a] (0.00)	4.73[a] (0.00)	3.63[a] (0.00)	−1.71[a] (0.00)	−1.85[a] (0.00)	−5.54[a] (0.00)	14.60[a] (0.00)	13.38[a]nnn (0.00)	−4.87[a] (0.00)	−5.30[a] (0.00)

Notes [a]refers to the rejection of unit root null hypothesis at 1% significance level. Maximum lag number has been defined as 3; block size has been set to 100; the number of bootstraps has been selected as 5000. Constant and trend have been used as deterministic terms

Table 3.4 Westerlund (2008) and Pedroni (1999, 2004) cointegration test results

Westerlund (2008) cointegration test results				
DH_g test statistic	−1.828[b]	Prob. value		0.034
DH_p test statistic	−0.720	Prob. value		0.236
Pedroni (1999, 2004) cointegration test results				
Alternative hypothesis: common AR coefficients (within dimension)				
Tests	Statistics	Prob.	Weighted statistics	Prob.
Panel v-stat.	0.676	0.249	−1.274	0.898
Panel rho-stat.	2.526	0.994	1.825	0.966
Panel PP-stat.	−3.632[a]	0.000	−4.955[a]	0.000
Panel ADF-stat.	−3.882[a]	0.000	−5.030[a]	0.000
Alternative hypothesis: individual AR coefficients (between dimensions)				
Tests	Statistics	Prob.		
Group rho-stat.	3.493	0.999		
Group PP-stat.	−4.877[a]	0.000		
Group ADF-stat.	−4.608[a]	0.000		

Notes Westerlund (2008) has a null hypothesis that there is no cointegration. The number of maximum factors is 2, and Newey and West (1994) are used as bandwidth selection. In Pedroni (1999, 2004) cointegration tests, Schwarz information criterion, and the Newey–West automatic selection as bandwidth are used. Constant and trend are used as deterministic terms
[a], [b], and [c]denote significance at 1%, 5%, and 10% significance levels, respectively

After having decided on a long-run relationship between the variables of interest, we can estimate the long-run parameters of variables, i.e., estimations of β_1, β_2, β_3, β_4, and β_5 coefficients in Eq. (3.2). The panel ARDL approach, which allows for the possibility of independent variables to be $I(1)$ or $I(0)$ in the model, is utilized because the trade openness variable is stationary at level. Hausman (1978) test has been employed to decide among the pooled mean group estimator (PMGE) and the mean group estimator (MGE) of the panel ARDL approach. Hausman (1978) test supports the PMG estimation because it confirms homogeneity in the long-run parameters and heterogeneity in short-run parameters. The joint Hausman (1978) test signals that the null hypothesis of homogeneity in long-run parameters cannot be rejected, and thus, we depend on the results of PMGE.

Hausman (1978) test results have evidence in favor of PMG estimation, indicating homogeneity in the long-run parameters, but heterogeneity in short-run parameters. According to the results of PMG, given in Table 3.5, increases in GDP per capita, energy consumption per capita, and percentage of Internet users cause more CO_2 emissions; i.e., income, energy demand, and Internet usage aggravate the air pollution level of low-income countries, by emitting more CO_2 into the air. In short, countries in this group use air-polluting production processes to grow further. Likewise, increases in energy consumption worsen the air quality of the low-income country panel. Although the share of fossil energy resources in total energy consumption for the

Table 3.5 Results for panel ARDL estimation

Pooled mean group estimator (PMGE)				Mean group estimator (MGE)			Hausman test	
Variables	Long-run results							
	Coeff.	Standard deviation	t stat.	Coeff.	Standard deviation	t stat.	Test stat.	Prob.
lnPGDP	0.223[a]	0.042	5.309	0.392	1.026	0.382	0.03	0.87
lnICT	0.097[a]	0.018	5.428	−0.101	0.139	−0.726	2.07	0.15
lnPENC	0.167[a]	0.021	7.990	0.190	0.318	0.597	0.01	0.94
lnFD	−0.021	0.015	−1.394	0.080	0.199	0.402	0.26	0.61
lnTO	−0.026	0.025	−1.065	−0.303	0.587	−0.515	0.22	0.64
Error correction term	0.443[a]	0.080	−5.520	−0.744[a]	0.096	−7.739		
Joint Hausman test							6.07	0.30
Short-run results								
Variables	Coeff.	Standard deviation	t stat.	Coeff.	Standard deviation	t stat.		
lnPGDP	0.099[a]	0.018	5.520	0.464	0.376	1.234		
lnPENC	0.074[a]	0.013	5.520	0.022	0.114	0.196		
lnICT	0.043[a]	0.008	5.520	−0.004	0.059	−0.060		
lnFD	−0.009[a]	0.002	−5.520	0.027	0.061	0.449		
lnTO	−0.012[a]	0.002	−5.520	−0.100	0.129	−0.774		
dlnPCO$_2$(−1)	−0.034	0.033	−1.037	−0.044	0.063	−0.689		
dlnPGDP	0.175	0.193	0.904	−0.218	0.347	−0.63		
dlnPGDP(−1)	0.093	0.234	0.398	−0.33	0.407	−0.811		
dlnPENC	0.021	0.065	0.33	0.022	0.099	0.218		
dlnPENC(−1)	−0.036	0.03	−1.217	−0.082	0.065	−1.266		
dlnICT	−0.002	0.018	−0.135	0.008	0.034	0.245		
dlnICT(−1)	0.027	0.017	1.567	0.064	0.046	1.383		
dlnFD	−0.044	0.029	−1.52	−0.095[c]	0.055	−1.75		
dlnFD(−1)	0.034	0.048	0.702	−0.012	0.048	−0.25		
dlnTO	0.018	0.032	0.563	0.085	0.08	1.064		
dlnTO(−1)	−0.023	0.026	−0.895	−0.01	0.058	−0.176		
Sabit	0.046	0.08	0.575	−0.002	0.247	−0.009		
Diagnostic test results								
	PMGE			MGE				
	χ^2_{SC}	χ^2_{NO}	χ^2_{HE}	χ^2_{SC}	χ^2_{NO}	χ^2_{HE}		
	1.48	1.07	0.00	5.00	0.78	2.13		

Notes χ^2_{SC} is the autocorrelation test statistic of Breusch–Godfrey; χ^2_{NO} is the Jarque–Bera normality test statistic; χ^2_{HE} is the White heteroscedasticity test statistic

[a], [b], and [c]represent 1%, 5%, and 10% significance levels, respectively

low-income countries is quite low (around 21% according to the World Development Indicators, 2019), high utilization level of renewable energy sources such as biofuels and overconsumption of natural resources as energy sources in meeting the basic needs appear to lead to air pollution. These results in terms of income and energy consumption are similar to those of many studies in the EKC literature (see Ang 2007; Halicioglu 2009; Narayan and Narayan 2010; Ozcan 2013; Ozcan and Apergis 2018). Concerning the environmental effect of the Internet usage, as the percentage of Internet users in the low-income countries increases, air pollution increases as well because ICTs are not energy efficient and environmentally friendly as well as residents of low-income countries are not conscious Internet users. The negative effect of ICTs on air quality indicates technological underdevelopment in the low-income countries. Given that substitution effects and dematerialization process are rather low in this country group, the increased Internet usage level results in more air pollution. This finding is in line with those of Park et al. (2018), Danish et al. (2018), and Salahuddin et al. (2016).

Other variables of the model, financial development, and trade openness have not any significant effect on the CO_2 emission level of low-income country panel. In this sense, financial development and trade openness in these countries are not high enough to affect air quality. Besides, the error correction term in the cointegrating equation, as expected, is negative and significant, which, in turn, signals a long-run relationship between the variables defined in Eq. (3.2). In other words, short-term deviations from the equilibrium value of CO_2 will be corrected over time. Besides, the results of diagnostic tests have provided evidence against problems of autocorrelation and heteroscedasticity for the model defined in Eq. (3.2). Finally, our results concerning the financial development are consistent with those of Dogan and Turkekul (2016), Omri et al. (2015), and Ozturk and Acaravci (2013) while our findings about the trade openness are in line with those of Ertugrul et al. (2016), Farhani et al. (2014), and Jalil and Mahmud (2009).

3.7 Conclusion and Policy Implication

In this study, the effects of ICT use on air pollution have been analyzed by using second-generation panel data models over the period 1995–2015 by considering the low-income country panel. To this end, as being proxies for ICTs and air pollution, the percentage of Internet users and CO_2 emissions per capita, respectively, has been used. In addition, per capita income, energy consumption per capita, financial development, and trade openness variables, which are thought to affect CO_2 emission level, have been added to the model as control variables. Firstly, cross-sectional dependence for both the variables of interest and the model has been tested to select the right panel data tests. The presence of cross-sectional dependence has led us to utilize the second-generation panel tests.

The results indicate that energy-inefficient ICT devices, by boosting energy demand, emit more CO_2 into the air because technological development level is rather low in the low-income countries. In addition, the residents of low-income countries do not deliberatively make use of the Internet because their education levels are lower compared to those of high-income countries. Among other determinants of air pollution, income and energy consumption variables appear to worsen air quality of the low-income country panel. The results in terms of income level show that low-income countries have not yet reached the threshold level of income after which economic growth improves air quality. Besides, excessive usage of renewable energy and natural resources to meet the basic needs seems to create more air pollution. The remaining two variables of the model, financial development and trade openness, do not have any significant influence on the air quality level given that commercial and financial relations are not sufficiently developed to have an environmental influence in the low-income country panel.

Based on the above-mentioned results, some crucial policy implications could be suggested. First, due to the fact that economic growth and energy consumption cause air pollution, a revision for the economic development policy of low-income countries on the axis of sustainable development seems necessary. Instead of a development strategy that focuses solely on the purpose of economic growth, a development policy that considers environmental quality as well as growth seems more reasonable. The choice of a growth model in which natural resources and the environment are not sacrificed for further growth is necessary. In terms of energy sources, although the low-income countries have rich natural resources and renewable energy sources, their residents have not been able to benefit from alternative energy sources effectively due to their unawareness. Therefore, public awareness among residents should be established in order to use renewable energy resources more effectively, and thereby, the excessive exploitation of natural resources will be prevented.

In terms of ICT, which is the main variable of the research, investments in the ICT sector should be encouraged through the channel of government and private sector in the form of subsidies and grants. Residents should be made aware of ICTs, in general, and the Internet in particular, through various trainings, courses, and seminars in order to use them with more awareness. Besides, the outputs of the dematerialization process should be utilized more actively. For example, monitoring of newspapers over the Internet instead of buying printed newspapers, meeting the needs of online shopping instead of driving to shopping centers, and conducting conferences in the form of teleconferences instead of long-distance conferences are some solutions of the dematerialization process that may have positive effects on the environment.

Regarding financial development, precautions should be taken to convert the insignificant effect of financial development on the environment to positive. Companies should include more environmentally friendly technologies in their production processes via credit opportunities provided by financial development. The purchased new equipment and new project investments should be arranged in a way that does not harm the environment. Consumers should purchase environmentally friendly ICT equipment with loans provided by financial development. Increasing the share of firms investing in renewable energy (green) in the capital markets and deepening voluntary carbon markets aimed at granting voluntary emission reduction certificates to companies are among the other alternatives to be considered. The insignificant effect of the trade openness, the last determinant of air quality, on the air quality of the low-income country panel can be remedied through advanced and modern technology transfer, which will be accompanied by trade liberalization. Finally, the neutral effect of international trade on the environment in low-income countries can be transformed into a positive one thanks to the import of modern technologies that enables more efficient use of energy in production processes.

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Chapter 4
Optimal Forecast Models for Clean Energy Stock Returns

Victor Troster, Muhammad Shahbaz, and Demian Nicolás Macedo

Abstract This chapter searches for optimal models for forecasting the Wilder Hill Clean Energy Index (ECO), the Standard and Poor's Global Clean Energy Index (SPCLE), the MAC Global Solar Energy Index (SUN), and the European Renewable Energy Index (EURIX). These indices measure the stock market performance of renewable energy companies. We employ fat-tailed distributed models, and we analyze their in-sample and out-of-sample performance for the returns and the 1%-Value-at-Risk (VaR) of renewable energy indices. Heavy-tailed distributed GARCH and GAS are optimal for all renewable energy returns. They also have the lowest out-of-sample mean-squared error and the best coverage for 1%-VaR of renewable energy returns. These findings highlight the relevance of modeling the kurtosis for renewable energy returns, and they are relevant for policymakers and investors who invest in the renewable energy sector.

Keywords Clean energy · GARCH · GAS · Heavy-tailed distributions

JEL Classifications C22 · C52 · G11 · Q42

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4.1 Introduction

Renewable energy assets have gained consideration among investors in recent years. Several studies document a growing demand for renewable energies and an increment in clean energy investments in emerging and developed economies (Kaldellis and Zafirakis 2011; Teske et al. 2011; IRENA 2017; REN21 2017). The increasing interest in clean energy equities by investors may be explained by the growth prospects of the sector, which in turn are based on three reasons. First, there is an increasing concern about the natural environment and decarbonizing the energy system, reflected in the Kyoto protocol and the Paris agreement (Schellnhuber et al. 2016; Klein et al. 2017; Grubb et al. 2018). Moreover, there is a need for mitigating energy security issues such as political instability in oil supplying countries or unexpected increments in the oil demand (Lieb-Dóczy et al. 2003; Ang et al. 2015; Bondia et al. 2016). According to the International Energy Agency, energy security is defined as “the uninterrupted availability of energy sources at an affordable price.” Finally, it is important to invest in technological innovation and developing new energy storage technologies to attain a clean energy system (Sagar and van der Zwaan 2006; Wilson and Grubler 2011; Kittner et al. 2017).

Clean energy indices, such as wind and solar energy, are sold in financial markets that share the same dynamics of highly volatile assets. Besides, clean energy returns may exhibit heavy-tailed distributions since financial returns follow fat-tailed distributions (Gabaix 2009). It is important to model the volatility of renewable energy returns for investors since it affects the performance of their portfolios on renewable energy. Many research papers employed generalized auto-regressive conditional heteroskedasticity (GARCH) models of Bollerslev (1986) to model the volatility of renewable energy data (Henriques and Sadorsky 2008; Kumar et al. 2012; Sadorsky 2012; Wang and Wu 2012; Managi and Okimoto 2013; Ahmad et al. 2018; Kocaarslan and Soytas 2019). Nevertheless, to the best of our knowledge, no study has applied generalized auto-regressive score (GAS) models to model renewable energy returns. GAS models are flexible models that are robust to misspecifications of the conditional density (Creal et al. 2013; Harvey 2013).

This chapter contributes to the literature on clean energy returns as follows. First, it searches for optimal models for forecasting the Wilder Hill Clean Energy Index (ECO), the Standard and Poor’s Global Clean Energy Index (SPCLE), the MAC Global Solar Energy Index (SUN), and the European Renewable Energy Index (EURIX). These indices measure the stock market performance of clean energy companies in the world and Europe. This chapter employs 37 flexible and fat-tailed GAS and GARCH models for modeling clean energy returns. No previous study has used GAS models to forecast clean energy returns and risk. Besides, it compares the out-of-sample performance of all models to find the optimal forecast model for clean energy returns. Finally, this chapter performs several backtesting approaches for daily 1%-Value-at-Risk (VaR) forecasts of clean energy returns. It is important to measure correctly VaR to fulfill market risk capital reserves of the Basel Agreements.

Our findings suggest that heavy-tailed distributed GARCH and GAS models are optimal for all renewable energy returns considered. They also have the best out-of-sample forecast performance and the best coverage for 1%-VaR of renewable energy returns. Therefore, fat-tailed distributed models enhance both in-sample and out-of-sample performance of renewable energy returns and risk. These findings illustrate the relevance of modeling the kurtosis for renewable energy returns.

The rest of the chapter proceeds as follows. Section 4.2 outlines the data and the methodology. Section 4.3 presents the empirical results and discussion. Finally, Sect. 4.4 concludes.

4.2 Data and Econometric Methodology

We employ data on 1458 daily observations of the Wilder Hill Clean Energy Index (ECO), the Standard and Poor's Global Clean Energy Index (SPCLE), the MAC Global Solar Energy Index (SUN), and the European Renewable Energy Index (EURIX). The ECO index is based on US stocks that operate in the promotion and preservation of clean energy. The SPCLE index comprises 30 companies from around the world operating in clean energy-related businesses. The MAC index is made up of US companies involved in the solar energy industry, and the EURIX is built on the largest European renewable energy companies. Our sample period spans from November 14, 2013, to September 18, 2019. We selected this period because of the data availability. We obtained all series from DataStream. Given the closing price P_t of a renewable index at time t, we calculate its logarithm returns as $r_t = 100 \times \ln(P_t/P_{t-1})$.

Table 4.1 reports descriptive statistics (in percentages) for the daily returns on the renewable energy indices. The clean energy indices are nonstationary at the 5% level, whereas the log-returns are stationary. Besides, all returns are non-normally distributed and volatile, with a standard deviation greater than the mean. All returns are negatively skewed, illustrating the usefulness of heavy-tailed distributed models for the conditional volatility of clean energy returns.

We estimate AR(1)-GARCH(1,1) models of Bollerslev (1986) for the daily returns on renewable energy indices as:

$$r_t = c + \varphi_1 r_{t-1} + u_t,\ \ u_t = \sigma_t \varepsilon_t, \tag{4.1}$$

$$\sigma_t^2 = \omega + \alpha u_{t-1}^2 + \beta \sigma_{t-1}^2, \tag{4.2}$$

where $|\varphi_1| < 1$ and ε_t follow a white noise process. Let $z_{t-1} = u_{t-1}\sigma_{t-1}^{-1}$ and $1(\cdot)$ be an indicator function. We model different GARCH specifications for the conditional volatility of u_t:

Table 4.1 Summary statistics: Clean energy returns (in %)

	ECO	SPCLE	SUN	ERIX
Mean	0.01	0.01	-0.03	0.04
Median	0.10	0.03	0.02	0.08
Minimum	−6.46	−5.10	−8.78	−8.05
Maximum	6.34	4.94	8.19	5.72
Standard dev.	1.46	1.10	1.74	1.41
Skewness	−0.24	−0.21	−0.30	−0.38
Kurtosis	1.06	1.80	1.95	2.63
Jarque–Bera	0.00	0.00	0.00	0.00
ADF level	−1.35	−1.69	−1.18	−3.08
ADF first diff.	**−25.21**	**−24.86**	**−23.77**	**−26.26**

Notes: We report summary statistics (in %) for the daily returns on the closing price of the Wilder Hill Clean Energy Index (ECO), the Standard and Poor's Global Clean Energy Index (SPCLE), the MAC Global Solar Energy Index (SUN), and the European Renewable Energy Index (EURIX). Our sample period spans from November 14, 2013, to September 18, 2019. Jarque–Bera is the p-value of the normality test of Jarque and Bera (1980), where the returns are normally distributed under H_0. ADF level and first diff. are the augmented unit root test of Dickey and Fuller (1979) on the level and on the log-returns of the renewable energy indices, respectively. Boldface values of the ADF test statistic indicate the rejection of the null hypothesis of a unit root at the 5% significance level

$$\text{ALL-GARCH}(1,1): \sigma_t^\delta = \omega + \alpha\delta\sigma_{t-1}^\delta\left[|z_{t-1} - b| - \gamma(z_{t-1} - b)\right]^\delta + \beta\sigma_{t-1}^\delta, \tag{4.3}$$

$$\text{APARCH}(1,1): \ \sigma_t^\delta = \omega + \alpha(|u_{t-1}| - \gamma u_{t-1})^\delta + \beta\sigma_{t-1}^\delta, \tag{4.4.}$$

$$\begin{aligned} \text{CGARCH}(1,1): \sigma_t^2 &= \xi_t + \alpha\left(u_{t-1}^2 - \xi_{t-1}\right) + \beta\left(\sigma_{t-1}^2 - \xi_{t-1}\right), \\ \xi_t &= \omega + \rho\xi_{t-1} + \eta\left(u_{t-1}^2 - \sigma_{t-1}^2\right), \end{aligned} \tag{4.5}$$

$$\text{E-GARCH}(1,1): \ \log\left(\sigma_t^2\right) = \omega + \left[\alpha z_{t-1} + \gamma(|z_{t-1}| - E|z_{t-1}|)\right] + \beta\log\left(\sigma_{t-1}^2\right), \tag{4.6}$$

$$\text{GJRGARCH}(1,1): \ \sigma_t^2 = \omega + \alpha u_{t-1}^2 + \gamma u_{t-1}^2 1(u_{t-1} < 0) + \beta\sigma_{t-1}^2, \tag{4.7}$$

$$\text{I-GARCH}(1,1): \ \sigma_t^2 = \omega + \sigma_{t-1}^2 + \alpha\left(u_{t-1}^2 - \sigma_{t-1}^2\right), 0 < \alpha \le 1, \tag{4.8}$$

$$\text{NGARCH}(1,1): \ \sigma_t^\delta = \omega + \alpha|u_{t-1}|^\delta + \beta\sigma_{t-1}^\delta, \tag{4.9}$$

$$\text{T-GARCH}(1,1): \ \sigma_t = \omega + \alpha|u_{t-1}| + \gamma|u_{t-1}|1(u_{t-1} < 0) + \beta\sigma_{t-1}, \tag{4.10}$$

where ξ_t is a permanent component of σ_t^2. Equation (4.3) displays the ALL-GARCH model proposed by Hentschel (1995) that encompasses the most important GARCH models. Equation (4.4) describes the Asymmetric Power ARCH (APARCH) model of Ding et al. (1993) that considers long memory for absolute returns, and it estimates the power of heteroscedasticity (δ) from the data. Equation (4.5) displays the Component GARCH (CGARCH) model of Engle and Lee (1999) that decomposes the conditional variance of the returns into a permanent and a short-run component. Equation (4.6) shows the Exponential GARCH (E-GARCH) model of Nelson (1991) that specifies an asymmetric impact of negative shocks to σ_t^2. Equation (4.7) presents the Glosten–Jagannathan–Runkle (GJRGARCH) model of Glosten et al. (1993) that represents asymmetric shocks to σ_t^2 by applying an indicator function to negative shocks.

Equation (4.8) illustrates the integrated GARCH (I-GARCH) model of Engle and Bollerslev (1986) that assumes persistency in GARCH models. Equation (4.9) shows the nonlinear GARCH (NGARCH) model of Higgins and Bera (1992) that estimates the power of heteroscedasticity (δ) from the data. Finally, Eq. (4.10) displays the threshold GARCH (T-GARCH) model of Zakoian (1994), in which σ_t (instead of σ_t^2) reacts differently to negative and positive shocks. For each model in Eqs. (4.2)–(4.10), the innovations ε_t follow Gaussian (N), t-Student (t), or skewed t-Student (St) distributions.

We employ GAS models based on time-varying parameters, which are flexible and avoid the problem of incorrect specification. We define the conditional distribution of the returns at time t as $P(r_t; \boldsymbol{\theta}_t)$, given a time-varying vector of parameters $\theta_t \in \Theta \subseteq \mathbb{R}^N$ that fully characterizes $P(\cdot; \cdot)$ as follows:

$$\boldsymbol{\theta}_{t+1} = \mathrm{A}_0 + \mathrm{A}_1 \boldsymbol{S}_t(\boldsymbol{\theta}_t) \frac{\partial \log P(r_t; \boldsymbol{\theta}_t)}{\partial \boldsymbol{\theta}_t} + \mathrm{A}_2 \boldsymbol{\theta}_t, \tag{4.11}$$

where A_0, A_1,and A_2 are matrices of coefficients, and $\boldsymbol{S}_t(\boldsymbol{\theta}_t)$ is a positive-definite scaling matrix. Following Creal et al. (2013), we specify $\boldsymbol{S}_t(\boldsymbol{\theta}_t)$ as

$$\boldsymbol{S}_t(\boldsymbol{\theta}_t) = \boldsymbol{I}, \tag{4.12}$$

$$\boldsymbol{S}_t(\boldsymbol{\theta}_t) = E_{t-1}\left[\frac{\partial \log P(r_t; \boldsymbol{\theta}_t)}{\partial \boldsymbol{\theta}_t} \frac{\partial \log P(r_t; \boldsymbol{\theta}_t)}{\partial \boldsymbol{\theta}_t}' \right]^{-\frac{1}{2}}, \tag{4.13}$$

where $\boldsymbol{I}$ is the identity matrix. We denote the specifications for $\boldsymbol{S}_t(\boldsymbol{\theta}_t)$ of Eqs. (4.12) and (4.13) as Identity (Id) and Inverse Squared (InvSq), respectively. We employ the following conditional distributions for calculating the score function: asymmetric t-Student with a left-tail (AST1) or two decay parameters (AST), Gaussian, t-Student, and skewed-t-Student.

We estimate all GARCH and GAS models for all renewable energy returns, and we evaluate their Akaike information criterion (AIC), Bayesian information criterion (BIC), and the maximum value of the log-likelihood (LogLik) function. We test for serial correlation on the GARCH residuals by applying the Ljung–Box test on the standardized squared residuals. To test for correct specification of GAS models, we employ the probability integral transform (PIT) test proposed by Diebold et al. (1998) on the estimated conditional distribution of GAS models. We also run 500 one-step-ahead rolling out-of-sample forecasts to analyze the out-of-sample performance of all models. The out-of-sample period spans from September 22, 2017, to September 18, 2019. We compare the root-mean-squared error (RMSE) of the out-of-sample forecasts of all models.

Further, we apply backtests on 1%-Value-at-Risk (VaR) forecasts for each renewable energy index return. We employ the conditional coverage (CC) test of Christoffersen (1998) on the conditional density of the returns $f(r_t|r_{t-1}, r_{t-2}, \dots, r_1)$ and the dynamic quantile (DQ) test of Engle and Manganelli (2004). We apply the quantile loss measure developed by González-Rivera et al. (2004) to evaluate 1%-VaR forecasts as follows:

$$QL_{t+1}(1\%) = (1\% \ - e_{t+1})(r_{t+1} - \text{VaR}_{t+1}(1\%)),$$

where $e_{t+1} = 1(r_{t+1} < \text{VaR}_{t+1}(1\%))$ is a VaR exceedance for a $\text{VaR}_{t+1}(1\%)$ forecast at $t + 1$. We also calculate the ratio between VaR exceedances and the expected values a priori, the Actual over Expected ratio (AE), $AE = \sum_j^{500} e_{t+j}/(1\% \times 500)$. VaR forecasts with an AE ratio equal to one are optimal. In addition, we compare the mean and maximum Absolute Deviation (ADmean and ADmax) of the 1%-VaR forecasts among all models, which deliver the expected loss given a VaR exceedance (McAleer and Da Veiga 2008). VaR forecasts with lower ADmean and ADmax are preferred.

4.3 Empirical Analysis

Tables 4.2 and 4.3 report the estimation results of the GARCH models of Eqs. (4.2)–(4.10) and the GAS models of Eqs. (4.11)–(4.13) for ECO returns. The Ljung–Box test shows that all GARCH residuals are serially uncorrelated at the 5% level. On the other hand, the PIT test rejects the correct specification of the GAS-N-Id, GAS-N-InvSq, and GAS-t-InvSq at the 5% level (Table 4.3). The AR(1)-ALLGARCH(1,1), AR(1)-E-GARCH(1,1), and AR(1)-T-GARCH(1,1) with a skewed *t*-Student distribution have the lowest AIC and BIC for the ECO returns (Table 4.2). The GAS model with a skewed *t*-Student together with an inverted square score displays the lowest AIC and BIC among all GAS models. Therefore, fat-tailed distributed models display a better in-sample fit for ECO returns. Further, the GAS-t-Id has the lowest out-of-sample RMSE, followed by the AR(1)-CGARCH(1,1)-*t* and the AR(1)-I-GARCH(1,1)-*t*.

Table 4.4 presents backtesting measures for daily 1%-VaR forecasts of ECO returns. None of the GARCH models with the lowest AIC and BIC are optimal for 1%-VaR forecasts. For instance, the DQ test rejects that the AR(1)-ALLGARCH(1,1)-St model has a correct specification for 1%-VaR forecasts at the 1% level, although this model has the lowest AIC among all models. Nevertheless,

Table 4.2 GARCH models for ECO returns

GARCH model	AIC	BIC	LogLik	$Q^2(10)$	RMSE
ALLGARCH(1,1)-N	3.512	3.541	−2552.56	0.79	1.3418
ALLGARCH(1,1)-St	**3.487**	3.523	−2531.99	0.88	1.3419
ALLGARCH(1,1)-t	3.500	3.533	−2542.83	0.87	1.3401
APARCH(1,1)-N	3.517	3.542	−2556.81	0.93	1.3421
APARCH(1,1)-St	3.488	3.521	−2533.66	0.94	1.3419
APARCH(1,1)-t	3.503	3.532	−2545.44	0.94	1.3401
CGARCH(1,1)-N	3.527	3.552	−2564.20	0.71	1.3400
CGARCH(1,1)-St	3.503	3.535	−2544.48	0.71	1.3395
CGARCH(1,1)-t	3.515	3.544	−2554.31	0.71	**1.3390**
E-GARCH(1,1)-N	3.515	3.537	−2556.75	0.90	1.3420
E-GARCH(1,1)-St	**3.487**	**3.516**	−2533.91	0.91	1.3411
E-GARCH(1,1)-t	3.501	3.527	−2545.56	0.91	1.3401
GJRGARCH(1,1)-N	3.516	3.538	−2557.48	0.92	1.3417
GJRGARCH(1,1)-St	3.488	3.517	−2534.39	0.93	1.3416
GJRGARCH(1,1)-t	3.502	3.527	−2545.98	0.94	1.3399
I-GARCH(1,1)-N	3.531	3.545	−2570.02	0.26	1.3404
I-GARCH(1,1)-St	3.504	3.526	−2548.32	0.35	1.3399
I-GARCH(1,1)-t	3.516	3.534	−2558.31	0.34	**1.3390**
NGARCH(1,1)-N	3.527	3.549	−2565.31	0.50	1.3404
NGARCH(1,1)-St	3.502	3.531	−2545.24	0.57	1.3397
NGARCH(1,1)-t	3.514	3.540	−2555.06	0.56	1.3391
GARCH(1,1)-N	3.527	3.545	−2566.17	0.52	1.3404
GARCH(1,1)-St	3.501	3.527	−2545.46	0.60	1.3397
GARCH(1,1)-t	3.514	3.536	−2555.61	0.59	1.3391
T-GARCH(1,1)-N	3.516	3.538	−2557.50	0.92	1.3421
T-GARCH(1,1)-St	**3.487**	**3.516**	−2534.38	0.92	1.3419
T-GARCH(1,1)-t	3.502	3.528	−2546.13	0.92	1.3401

Notes: $Q^2(10)$ is the p-value of the Ljung–Box test on the standardized squared residuals. RMSE is the root-mean-squared error for 500 one-day-ahead rolling forecasts. The out-of-sample period spans from September 22, 2017, to September 18, 2019. The best model for each criterion is in boldface

the AR(1)-NGARCH(1,1)-St is the optimal model for 1%-VaR forecasts of ECO returns since it has the best AE and AD mean ratios together with the highest conditional coverage (CC) of 1%-VaR forecasts. The GAS-St-Id and GAS-St-InvSq also display an AE close to the unity and the highest CC of 1%-VaR forecasts. Overall, both the AE and AD mean ratios enhance when we employ fat-tailed distributed modelsfor 1%-VaR forecasts of ECO returns.

Table 4.3 GAS models for ECO returns

GAS model	AIC	BIC	LogLik	NP	PIT	RMSE
GAS-AST-Id	5119.75	5188.45	−2546.87	13	0.44	1.3710
GAS-AST1-Id	5121.13	5173.97	−2550.56	10	0.26	1.3611
GAS-N-Id	5147.43	5179.14	−2567.71	6	0.01	1.3398
GAS-St-Id	5120.38	5162.66	−2552.19	8	0.10	1.3396
GAS-t-Id	5131.87	5168.87	−2558.94	7	0.07	**1.3384**
GAS-AST-InvSq	5165.67	5234.37	−2569.83	13	0.30	1.3666
GAS-AST1-InvSq	**5107.94**	**5160.79**	−2543.97	10	0.48	1.3571
GAS-N-InvSq	5150.19	5181.89	−2569.09	6	0.01	1.3396
GAS-St-InvSq	5120.38	5162.66	−2552.19	8	0.10	1.3396
GAS-t-InvSq	5133.81	5170.80	−2559.90	7	0.02	1.3393

Notes: NP is the number of parameters. PIT is the p-value of the PIT test of Diebold et al. (1998). We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

Table 4.4 Backtesting measures for daily 1%-VaR forecasts: ECO returns

Model	AE	AD mean	AD max	DQ	CC
ALLGARCH(1,1)-N	0.8	0.52	1.29	0.997	0.869
ALLGARCH(1,1)-St	1.0	0.57	1.40	0.003	0.951
ALLGARCH(1,1)-t	0.8	0.54	1.31	0.973	0.869
APARCH(1,1)-N	1.8	0.58	1.63	0.062	0.230
APARCH(1,1)-St	1.8	0.52	1.67	0.064	0.230
APARCH(1,1)-t	1.6	0.61	1.61	0.038	0.407
CGARCH(1,1)-N	1.0	0.59	1.45	0.002	0.951
CGARCH(1,1)-St	1.0	0.55	1.41	0.002	0.951
CGARCH(1,1)-t	1.0	0.63	1.43	0.002	0.951
E-GARCH(1,1)-N	1.8	0.66	1.76	0.064	0.230
E-GARCH(1,1)-St	1.6	0.57	1.69	0.053	0.407
E-GARCH(1,1)-t	1.8	0.63	1.77	0.066	0.230
GARCH(1,1)-N	1.8	0.64	1.77	0.063	0.230
GARCH(1,1)-St	2.0	0.67	1.74	0.059	0.115
GARCH(1,1)-t	1.8	0.65	1.73	0.072	0.230
GAS-AST1-Id	1.2	0.49	1.50	0.013	0.845
GAS-AST1-InvSq	1.0	0.66	1.47	0.003	0.951
GAS-AST-Id	1.4	0.54	1.56	0.020	0.632
GAS-AST-InvSq	0.4	0.51	**0.77**	0.930	0.306
GAS-N-Id	1.8	0.65	1.82	0.059	0.230

(continued)

Table 4.4 (continued)

Model	AE	AD mean	AD max	DQ	CC
GAS-N-InvSq	2.0	0.65	1.68	0.002	0.115
GAS-St-Id	**1.0**	0.57	1.59	0.967	**0.951**
GAS-St-InvSq	**1.0**	0.57	1.59	0.967	**0.951**
GAS-t-Id	1.6	0.65	1.79	0.036	0.407
GAS-t-InvSq	1.6	0.71	1.71	0.045	0.407
GJRGARCH(1,1)-N	1.0	0.60	1.46	0.002	0.951
GJRGARCH(1,1)-St	**1.0**	0.53	1.34	0.988	**0.951**
GJRGARCH(1,1)-t	1.2	0.59	1.33	**1.000**	0.845
I-GARCH(1,1)-N	**1.0**	0.49	1.30	0.986	**0.951**
I-GARCH(1,1)-St	1.0	0.54	1.41	0.002	0.951
I-GARCH(1,1)-t	**1.0**	0.49	1.29	0.985	**0.951**
NGARCH(1,1)-N	1.0	0.87	1.65	0.003	0.951
NGARCH(1,1)-St	**1.0**	**0.47**	1.35	0.981	**0.951**
NGARCH(1,1)-t	1.4	0.58	1.58	0.981	0.632
T-GARCH(1,1)-N	1.8	0.62	1.76	0.070	0.230
T-GARCH(1,1)-St	1.8	0.62	1.68	0.090	0.230
T-GARCH(1,1)-t	2.0	0.56	1.74	0.070	0.115

Notes: We report the Actual over Expected ratio (AE), the mean Absolute Deviation (AD mean), and the maximum Absolute Deviation (AD max) of 1%-VaR forecasts of ECO returns. CC and DQ are the p-values of the tests of Christoffersen (1998) and Engle and Manganelli (2004), respectively, where the model is correctly specified for 1%-VaR forecasts under H_0. We perform 500 one-day-ahead rolling forecasts. The forecasting period spans from September 22, 2017, to September 18, 2019. We denote the best models (for each criterion) in boldface

Tables 4.5 and 4.6 show the estimation results of the GARCH and GAS models for SPCLE returns. The Ljung–Box test results indicate the residuals are serially correlated for the AR(1)-ALLGARCH(1,1)-St, AR(1)-ALLGARCH(1,1)-t, AR(1)-T-GARCH(1,1)-St, and AR(1)-T-GARCH(1,1)-t at the 5% level. Conversely, all GAS models are correctly specified at the 5% level. The AR(1)-GJRGARCH(1,1) with a skewed t-Student distribution and with a t-Student distribution have the best in-sample fit for the SPCLE returns (Table 4.5). The GAS-t-Id and the GAS-AST1-InvSq present the lowest AIC and BIC among all GAS models. Consistent with the results for ECO returns, fat-tailed distributed models provide a better in-sample fit for SPCLE returns. Further, the AR(1)-CGARCH(1,1)-N, AR(1)-CGARCH(1,1)-t, AR(1)-NGARCH(1,1)-t, and AR(1)-GARCH(1,1)-t have the lowest out-of-sample RMSE.

Table 4.7 displays backtesting results for one-day-ahead 1%-VaR forecasts of SPCLE returns. Consistent with the backtesting results for ECO returns in Table 4.4, none of the GARCH models with the best in-sample fit is optimal for 1%-VaR forecasts of SPCLE returns. The AR(1)-APARCH(1,1)-St is the optimal model for

Table 4.5 GARCH models for SPCLE returns

GARCH model	AIC	BIC	LogLik	$Q^2(10)$	RMSE
ALLGARCH(1,1)-N	2.925	2.954	−2124.47	0.13	0.9255
ALLGARCH(1,1)-St	2.903	2.939	−2106.25	0.03	0.9247
ALLGARCH(1,1)-t	2.902	2.935	−2106.72	0.03	0.9239
APARCH(1,1)-N	2.935	2.960	−2132.65	0.54	0.9246
APARCH(1,1)-St	2.909	2.941	−2111.49	0.42	0.9249
APARCH(1,1)-t	2.909	2.938	−2112.31	0.40	0.9242
CGARCH(1,1)-N	2.936	2.961	−2133.30	0.89	**0.9236**
CGARCH(1,1)-St	2.912	2.945	−2113.84	0.88	0.9240
CGARCH(1,1)-t	2.911	2.940	−2114.33	0.88	**0.9236**
E-GARCH(1,1)-N	2.938	2.960	−2136.16	0.24	0.9245
E-GARCH(1,1)-St	2.911	2.940	−2114.31	0.07	0.9249
E-GARCH(1,1)-t	2.911	2.936	−2115.00	0.06	0.9242
GJRGARCH(1,1)-N	2.934	2.956	−2133.07	0.62	0.9245
GJRGARCH(1,1)-St	**2.908**	2.937	−2111.74	0.54	0.9248
GJRGARCH(1,1)-t	**2.908**	**2.933**	−2112.58	0.54	0.9241
I-GARCH(1,1)-N	2.950	2.965	−2146.84	0.43	0.9239
I-GARCH(1,1)-St	2.917	2.939	−2120.49	0.45	0.9242
I-GARCH(1,1)-t	2.916	2.935	−2121.10	0.44	0.9237
NGARCH(1,1)-N	2.941	2.963	−2138.01	0.81	0.9237
NGARCH(1,1)-St	2.914	2.943	−2116.04	0.77	0.9241
NGARCH(1,1)-t	2.913	2.939	−2116.73	0.76	**0.9236**
GARCH(1,1)-N	2.940	2.958	−2138.03	0.81	0.9237
GARCH(1,1)-St	2.912	2.938	−2116.15	0.77	0.9241
GARCH(1,1)-t	2.912	2.934	−2116.83	0.76	**0.9236**
T-GARCH(1,1)-N	2.936	2.957	−2134.12	0.19	0.9246
T-GARCH(1,1)-St	2.909	2.938	−2112.71	0.05	0.9249
T-GARCH(1,1)-t	2.909	2.934	−2113.42	0.04	0.9243

Notes: $Q^2(10)$ is the p-value of the Ljung–Box test on the standardized squared residuals. We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

1%-VaR forecasts of SPCLE returns since it has the best AE and the highest p-values of the DQ and CC tests. The AR(1)-ALLGARCH(1,1)-N also displays an AE close to the unity and the lowest AD mean ratio. Moreover, the AR(1)-GARCH(1,1)-St, AR(1)-GARCH(1,1)-t, GAS-AST1-Id, GAS-N-Id, and the AR(1)-T-GARCH(1,1)-N also exhibit the optimal AE ratio and the highest conditional coverage for risk forecasts of SPCLE returns.

Table 4.6 GAS models for SPCLE returns

GAS model	AIC	BIC	LogLik	NP	PIT	RMSE
GAS-AST-Id	4259.56	4328.26	−2116.78	13	0.95	0.9285
GAS-AST1-Id	4254.58	4307.43	−2117.29	10	0.92	0.9287
GAS-N-Id	4293.59	4325.30	−2140.79	6	0.11	0.9289
GAS-St-Id	4265.89	4308.17	−2124.94	8	0.95	0.9281
GAS-t-Id	4259.17	**4296.16**	−2122.58	7	0.93	0.9260
GAS-AST-InvSq	4383.11	4451.81	−2178.55	13	0.16	0.9282
GAS-AST1-InvSq	**4254.35**	4307.20	−2117.17	10	0.89	0.9287
GAS-N-InvSq	4292.26	4323.97	−2140.13	6	0.07	**0.9253**
GAS-St-InvSq	4265.89	4308.17	−2124.94	8	0.95	0.9281
GAS-t-InvSq	4262.19	4299.18	−2124.10	7	0.97	0.9277

Notes: NP is the number of parameters. PIT is the p-value of the PIT test of Diebold et al. (1998). We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

Table 4.7 Backtesting measures for daily 1%-VaR forecasts: SPCLE returns

Model	AE	AD mean	AD max	DQ test	CC test
ALLGARCH(1,1)-N	**1.0**	**0.19**	0.55	0.750	**0.951**
ALLGARCH(1,1)-St	0.6	0.34	0.45	0.923	0.613
ALLGARCH(1,1)-t	0.8	0.27	0.60	0.629	0.869
APARCH(1,1)-N	0.8	0.35	0.63	0.667	0.869
APARCH(1,1)-St	**1.0**	0.32	0.50	**0.995**	**0.951**
APARCH(1,1)-t	0.8	0.32	0.59	0.711	0.869
CGARCH(1,1)-N	0.8	0.34	0.44	0.964	0.869
CGARCH(1,1)-St	0.6	0.34	0.45	0.924	0.613
CGARCH(1,1)-t	0.8	0.34	0.59	0.368	0.869
E-GARCH(1,1)-N	1.6	0.34	0.72	0.002	0.128
E-GARCH(1,1)-St	0.8	0.33	0.55	0.564	0.869
E-GARCH(1,1)-t	1.4	0.41	0.90	0.135	0.632
GARCH(1,1)-N	1.2	0.33	0.68	0.251	0.845
GARCH(1,1)-St	**1.0**	0.41	0.73	0.306	**0.951**
GARCH(1,1)-t	**1.0**	0.45	0.84	0.224	**0.951**
GAS-AST1-Id	**1.0**	0.28	0.52	0.194	**0.951**
GAS-AST1-InvSq	0.6	0.34	0.54	0.937	0.613
GAS-AST-Id	0.8	0.45	0.64	0.258	0.869
GAS-AST-InvSq	0.4	0.33	0.42	0.933	0.306
GAS-N-Id	**1.0**	0.44	0.73	0.127	**0.951**

(continued)

Table 4.7 (continued)

Model	AE	AD mean	AD max	DQ test	CC test
GAS-N-InvSq	1.2	0.41	0.92	0.057	0.845
GAS-St-Id	0.6	0.54	0.69	0.787	0.613
GAS-St-InvSq	0.6	0.54	0.69	0.787	0.613
GAS-t-Id	0.6	0.57	0.75	0.826	0.613
GAS-t-InvSq	0.6	0.57	0.81	0.819	0.613
GJRGARCH(1,1)-N	0.6	0.37	0.49	0.924	0.613
GJRGARCH(1,1)-St	0.8	0.28	0.56	0.629	0.869
GJRGARCH(1,1)-t	0.8	0.33	0.68	0.557	0.869
I-GARCH(1,1)-N	0.8	0.25	0.52	0.625	0.869
I-GARCH(1,1)-St	0.8	0.31	**0.41**	0.962	0.869
I-GARCH(1,1)-t	0.6	0.30	0.49	0.964	0.613
NGARCH(1,1)-N	0.8	0.33	0.54	0.567	0.869
NGARCH(1,1)-St	0.8	0.30	0.63	0.639	0.869
NGARCH(1,1)-t	1.2	**0.19**	0.61	0.814	0.845
T-GARCH(1,1)-N	**1.0**	0.42	0.78	0.289	**0.951**
T-GARCH(1,1)-St	1.4	0.38	1.00	0.318	0.632
T-GARCH(1,1)-t	1.2	0.33	0.68	0.239	0.845

Notes: We report the Actual over Expected ratio (AE), the mean Absolute Deviation (AD mean), and the maximum Absolute Deviation (AD max) of 1%-VaR forecasts of SPCLE returns. CC and DQ are the p-values of the tests of Christoffersen (1998) and Engle and Manganelli (2004), respectively, where the model is correctly specified for 1%-VaR forecasts under H_0. The best models for each criterion are in boldface. We perform 500 one-day-ahead rolling forecasts as in Table 4.4

Tables 4.8 and 4.9 present the estimation results for SUN returns. The Ljung–Box test results indicate the residuals are serially correlated for the AR(1)-E-GARCH(1,1)-N and AR(1)-T-GARCH(1,1)-N models at the 5% level. The PIT test rejects the correct specification of the GAS-t-Id and GAS-AST-InvSq at the 5% level. The AR(1)-CGARCH(1,1)-St and AR(1)-NGARCH(1,1)-t have the lowest AIC and BIC, respectively, for the SUN returns (Table 4.8). In addition, the GAS-AST-Id displays the best AIC and BIC among the GAS models. In line with the results for ECO and SPCLE returns, fat-tailed distributed models for the residuals have an optimal in-sample fit for SPCLE returns. Further, the AR(1)-E-GARCH(1,1)-St displays the lowest out-of-sample RMSE among all models.

Table 4.10 shows the results of backtests for daily 1%-VaR forecasts of SUN returns. Consistent with the backtesting analysis of ECO and SPCLE returns in Tables 4.4 and 4.7, none of the GARCH models with the lowest AIC and BIC is optimal for 1%-VaR forecasts of SUN returns. Nevertheless, the AR(1)-E-GARCH(1,1)-St is one of the optimal models for both out-of-sample forecasts of SUN returns and for 1%-VaR forecasts; it has an AE ratio statistically equal to one and the highest

Table 4.8 GARCH models for SUN returns

GARCH model	AIC	BIC	LogLik	$Q^2(10)$	RMSE
ALLGARCH(1,1)-N	3.828	3.857	−2782.76	0.11	1.4848
ALLGARCH(1,1)-St	3.799	3.835	−2759.38	0.19	1.4836
ALLGARCH(1,1)-t	3.800	3.833	−2761.55	0.19	1.4831
APARCH(1,1)-N	3.829	3.854	−2784.34	0.11	1.4847
APARCH(1,1)-St	3.800	3.833	−2761.37	0.12	1.4837
APARCH(1,1)-t	3.802	3.831	−2763.47	0.13	1.4832
CGARCH(1,1)-N	3.825	3.851	−2781.56	0.32	1.4843
CGARCH(1,1)-St	**3.798**	3.831	−2759.96	0.32	1.4829
CGARCH(1,1)-t	3.799	3.828	−2761.34	0.33	1.4828
E-GARCH(1,1)-N	3.830	3.852	−2786.14	0.04	1.4859
E-GARCH(1,1)-St	3.799	3.828	−2761.31	0.07	**1.4822**
E-GARCH(1,1)-t	3.800	3.826	−2763.31	0.08	1.4827
GJRGARCH(1,1)-N	3.828	3.846	−2785.38	0.11	1.4844
GJRGARCH(1,1)-St	3.800	3.826	−2763.44	0.17	1.4829
GJRGARCH(1,1)-t	3.801	3.823	−2765.21	0.18	1.4828
I-GARCH(1,1)-N	3.828	3.849	−2784.37	0.11	1.4845
I-GARCH(1,1)-St	3.800	3.829	−2762.23	0.15	1.4832
I-GARCH(1,1)-t	3.801	3.826	−2764.02	0.16	1.4829
NGARCH(1,1)-N	3.828	3.842	−2786.29	0.08	1.4843
NGARCH(1,1)-St	3.801	3.823	−2765.29	0.11	1.4830
NGARCH(1,1)-t	3.802	**3.820**	−2766.72	0.12	1.4828
GARCH(1,1)-N	3.828	3.850	−2784.88	0.11	1.4843
GARCH(1,1)-St	3.802	3.831	−2763.41	0.17	1.4829
GARCH(1,1)-t	3.803	3.828	−2765.21	0.18	1.4828
T-GARCH(1,1)-N	3.833	3.854	−2788.07	0.05	1.4863
T-GARCH(1,1)-St	3.799	3.828	−2761.77	0.10	1.4839
T-GARCH(1,1)-t	3.801	3.827	−2764.08	0.10	1.4833

Notes: $Q^2(10)$ is the *p*-value of the Ljung–Box test on the standardized squared residuals. We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

conditional coverage rate. In addition, the AR(1)-APARCH(1,1) and the GAS-t-InvSq have the lowest AD mean and AD max ratios for 1%-VaR forecasts, respectively, among the models with an optimal AE ratio. The GAS-t-Id and the AR(1)-NGARCH(1,1)-N models also have an optimal AE together with good AD mean and CC ratios for 1%-VaR forecasts of SUN returns. In consonance with the findings for ECO and SPCLE returns, all backtesting measures enhance when we employ fat-tailed distributed models for 1%-VaR forecasts of SUN returns.

Table 4.9 GAS models for SUN returns

GAS model	AIC	BIC	LogLik	NP	PIT	RMSE
GAS-AST-Id	**5545.20**	**5598.04**	−2762.60	10	0.23	1.4920
GAS-AST1-Id	5546.99	5599.83	−2763.49	10	0.23	1.4926
GAS-N-Id	5550.41	5619.11	−2762.20	13	0.15	1.4875
GAS-St-Id	5663.12	5731.82	−2818.56	13	0.22	1.4901
GAS-t-Id	5595.26	5626.96	−2791.63	6	0.01	1.4825
GAS-AST-InvSq	5592.90	5624.61	−2790.45	6	0.00	1.4863
GAS-AST1-InvSq	5571.23	5613.51	−2777.61	8	0.22	1.4875
GAS-N-InvSq	5571.23	5613.51	−2777.61	8	0.22	1.4875
GAS-St-InvSq	5573.90	5610.89	−2779.95	7	0.38	**1.4866**
GAS-t-InvSq	5578.68	5615.67	−2782.34	7	0.23	1.4867

Notes: NP is the number of parameters. PIT is the *p*-value of the PIT test of Diebold et al. (1998). We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

Table 4.10 Backtesting measures for daily 1%-VaR forecasts: SUN returns

Model	AE	AD mean	AD max	DQ test	CC test
ALLGARCH(1,1)-N	0.8	0.79	1.44	0.807	0.869
ALLGARCH(1,1)-St	0.8	0.82	1.29	0.785	0.869
ALLGARCH(1,1)-t	0.8	0.71	1.59	0.719	0.869
APARCH(1,1)-N	0.8	1.10	1.77	0.685	0.869
APARCH(1,1)-St	**1.0**	0.75	1.33	0.837	**0.951**
APARCH(1,1)-t	0.8	1.05	1.61	0.665	0.869
CGARCH(1,1)-N	0.8	0.72	1.12	0.876	0.869
CGARCH(1,1)-St	0.8	0.77	1.27	0.762	0.869
CGARCH(1,1)-t	0.8	0.81	1.26	0.745	0.869
E-GARCH(1,1)-N	1.4	0.79	1.71	0.305	0.632
E-GARCH(1,1)-St	**1.0**	0.82	1.47	0.702	**0.951**
E-GARCH(1,1)-t	1.4	0.81	1.74	0.209	0.632
GARCH(1,1)-N	1.4	0.80	1.70	0.214	0.632
GARCH(1,1)-St	1.6	0.75	1.76	0.055	0.407
GARCH(1,1)-t	1.2	0.88	1.86	0.230	0.845
GAS-AST1-Id	0.8	0.85	1.79	0.792	0.869
GAS-AST1-InvSq	0.8	0.80	1.79	0.837	0.869
GAS-AST-Id	0.8	0.80	1.74	0.801	0.869
GAS-AST-InvSq	0.4	0.75	1.40	**0.937**	0.306
GAS-N-Id	1.2	0.88	1.77	0.424	0.845

(continued)

Table 4.10 (continued)

Model	AE	AD mean	AD max	DQ test	CC test
GAS-N-InvSq	1.6	0.67	1.66	0.005	0.407
GAS-St-Id	0.6	0.98	1.37	0.920	0.613
GAS-St-InvSq	0.6	0.98	1.37	0.920	0.613
GAS-t-Id	**1.0**	0.73	1.58	0.639	**0.951**
GAS-t-InvSq	**1.0**	0.69	1.52	0.682	**0.951**
GJRGARCH(1,1)-N	0.8	0.81	1.31	0.762	0.869
GJRGARCH(1,1)-St	0.8	0.86	1.61	0.658	0.869
GJRGARCH(1,1)-t	0.8	1.56	5.92	0.000	0.000
I-GARCH(1,1)-N	0.8	0.82	1.56	0.660	0.869
I-GARCH(1,1)-St	0.8	**0.68**	**1.08**	0.872	0.869
I-GARCH(1,1)-t	0.8	0.82	1.40	0.626	0.869
NGARCH(1,1)-N	**1.0**	0.84	1.49	0.725	**0.951**
NGARCH(1,1)-St	0.8	0.75	1.64	0.724	0.869
NGARCH(1,1)-t	0.8	1.03	1.64	0.799	0.869
T-GARCH(1,1)-N	1.2	0.87	1.91	0.245	0.845
T-GARCH(1,1)-St	1.4	0.85	1.84	0.211	0.632
T-GARCH(1,1)-t	1.6	0.74	1.76	0.068	0.407

Notes: We report the Actual over Expected ratio (AE), the mean Absolute Deviation (AD mean), and the maximum Absolute Deviation (AD max) of 1%-VaR forecasts of SUN returns. CC and DQ are the p-values of the tests of Christoffersen (1998) and Engle and Manganelli (2004), respectively, where the model is correctly specified for 1%-VaR forecasts under H_0. The best models for each criterion are in boldface. We perform 500 one-day-ahead rolling forecasts as in Table 4.4

Tables 4.11 and 4.12 show the estimation results for ERIX returns. Table 4.11 indicates that all GARCH residuals are serially uncorrelated at the 5% level. Conversely, the PIT test rejects the correct specification of the GAS-t-Id and GAS-AST-InvSq at the 5% level. The AR(1)-T-GARCH(1,1)-St and AR(1)-T-GARCH(1,1)-t models present the best AIC and BIC, respectively, for the ERIX returns (Table 4.11). Besides, the GAS-AST1-Id and GAS-St-InvSq attain the minimum AIC and BIC among the GAS models for the ERIX returns. Consistent with the results for the other renewable energy returns, fat-tailed distributed models obtain a better in-sample fit for ERIX returns. Yet, the AR(1)-I-GARCH(1,1)-N attains the lowest out-of-sample RMSE for ERIX returns among all models.

Table 4.13 shows the results of backtests for daily 1%-VaR forecasts of ERIX returns. The DQ test rejects the correct specification of almost all models at the 1% significance level. In line with the backtesting results for the other renewable energy returns, none of the GARCH models with the lowest AIC and BIC is optimal for 1%-VaR forecasts of ERIX returns. The GAS-N-Id is the optimal model for 1%-VaR forecasts of ERIX returns since it attains the lowest AD mean and AD max

Table 4.11 GARCH models for ERIX returns

GARCH model	AIC	BIC	LogLik	$Q^2(10)$	RMSE
ALLGARCH(1,1)-N	3.428	3.457	−2491.11	0.90	1.3031
ALLGARCH(1,1)-St	3.375	3.411	−2450.04	0.85	1.3033
ALLGARCH(1,1)-t	3.379	3.411	−2454.14	0.84	1.3036
APARCH(1,1)-N	3.427	3.453	−2491.48	0.90	1.3034
APARCH(1,1)-St	3.375	3.408	−2451.35	0.85	1.3032
APARCH(1,1)-t	3.378	3.407	−2454.88	0.85	1.3035
CGARCH(1,1)-N	3.452	3.477	−2509.31	0.96	1.3037
CGARCH(1,1)-St	3.396	3.429	−2466.78	0.97	1.3041
CGARCH(1,1)-t	3.398	3.427	−2469.26	0.96	1.3048
E-GARCH(1,1)-N	3.428	3.450	−2493.21	0.91	1.3033
E-GARCH(1,1)-St	3.375	3.404	−2452.50	0.87	1.3221
E-GARCH(1,1)-t	3.378	3.404	−2455.77	0.87	1.3663
GJRGARCH(1,1)-N	3.433	3.455	−2496.95	0.91	1.3035
GJRGARCH(1,1)-St	3.381	3.410	−2456.94	0.90	1.3039
GJRGARCH(1,1)-t	3.384	3.409	−2459.71	0.90	1.3046
I-GARCH(1,1)-N	3.468	3.483	−2524.21	0.68	**1.3030**
I-GARCH(1,1)-St	3.401	3.423	−2473.25	0.79	1.3031
I-GARCH(1,1)-t	3.403	3.421	−2475.57	0.76	1.3036
NGARCH(1,1)-N	3.447	3.468	−2506.51	0.97	1.3035
NGARCH(1,1)-St	3.394	3.423	−2466.43	0.93	1.3038
NGARCH(1,1)-t	3.396	3.422	−2468.95	0.93	1.3045
GARCH(1,1)-N	3.448	3.466	−2508.40	0.96	1.3039
GARCH(1,1)-St	3.395	3.420	−2467.66	0.91	1.3041
GARCH(1,1)-t	3.396	3.418	−2470.00	0.91	1.3047
T-GARCH(1,1)-N	3.426	3.448	−2491.48	0.90	1.3034
T-GARCH(1,1)-St	**3.374**	3.403	−2451.44	0.86	1.3032
T-GARCH(1,1)-t	3.377	**3.402**	−2454.92	0.86	1.3035

Notes: $Q^2(10)$ is the *p*-value of the Ljung–Box test on the standardized squared residuals. We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

ratios together with the highest *p*-values of the CC and DQ tests. The AR(1)-E-GARCH(1,1)-N and AR(1)-GARCH(1,1)-N also have a similar out-of-sample performance for risk forecasts. However, these models exhibit an AE ratio far from the unity, indicating an excessive number of actual 1%-VaR exceedances over expected ones. Therefore, normally distributed GAS and GARCH models have good performance for 1%-VaR forecasts of ERIX returns, in contrast to our findings for the other renewable energy returns.

Table 4.12 GAS models for ERIX returns

GAS model	AIC	BIC	LogLik	NP	PIT	RMSE
GAS-AST-Id	4951.64	5004.49	−2465.82	10	0.88	1.3174
GAS-AST1-Id	**4949.51**	5002.36	−2464.76	10	0.74	1.3199
GAS-N-Id	4956.62	5025.32	−2465.31	13	0.78	1.3186
GAS-St-Id	4952.40	5021.10	−2463.20	13	0.90	1.3096
GAS-t-Id	5040.02	5071.72	−2514.01	6	0.01	1.3034
GAS-AST-InvSq	5028.71	5060.41	−2508.35	6	0.01	1.3035
GAS-AST1-InvSq	4950.36	4992.64	−2467.18	8	0.72	1.3043
GAS-N-InvSq	4950.36	4992.64	−2467.18	8	0.72	1.3043
GAS-St-InvSq	4949.82	**4986.81**	−2467.91	7	0.72	1.3047
GAS-t-InvSq	4950.90	4987.90	−2468.45	7	0.66	**1.3042**

Notes: NP is the number of parameters. PIT is the *p*-value of the PIT test of Diebold et al. (1998). We calculate the RMSE as in Table 4.2. The best model for each criterion is in boldface

Table 4.13 Backtesting measures for daily 1%-VaR forecasts: ERIX returns

Model	AE	AD mean	AD max	DQ test	CC test
ALLGARCH(1,1)-N	1.0	1.32	2.75	0.001	0.951
ALLGARCH(1,1)-St	1.0	1.17	2.97	0.001	0.951
ALLGARCH(1,1)-t	1.0	1.22	2.73	0.001	0.951
APARCH(1,1)-N	1.2	1.23	2.95	0.001	0.845
APARCH(1,1)-St	1.4	0.97	3.01	0.009	0.632
APARCH(1,1)-t	1.0	1.27	2.86	0.003	0.951
CGARCH(1,1)-N	1.0	1.27	2.94	0.001	0.951
CGARCH(1,1)-St	0.8	1.41	2.89	0.000	0.869
CGARCH(1,1)-t	1.0	1.16	2.97	0.001	0.951
E-GARCH(1,1)-N	**1.8**	0.96	3.28	0.014	**0.230**
E-GARCH(1,1)-St	1.0	1.33	3.05	0.001	0.951
E-GARCH(1,1)-t	1.4	1.28	3.52	0.001	0.632
GARCH(1,1)-N	**1.8**	0.95	3.28	0.016	**0.230**
GARCH(1,1)-St	1.2	1.47	3.22	0.001	0.845
GARCH(1,1)-t	1.2	1.41	3.21	0.001	0.845
GAS-AST1-Id	1.0	1.38	3.11	0.001	0.951
GAS-AST1-InvSq	1.0	1.37	3.04	0.002	0.951
GAS-AST-Id	1.0	1.37	3.10	0.001	0.951
GAS-AST-InvSq	0.8	1.55	3.04	0.000	0.869
GAS-N-Id	**1.8**	**0.90**	**3.20**	**0.017**	**0.230**

(continued)

Table 4.13 (continued)

Model	AE	AD mean	AD max	DQ test	CC test
GAS-N-InvSq	2.0	0.87	3.39	0.007	0.115
GAS-St-Id	1.0	1.39	3.13	0.001	0.951
GAS-St-InvSq	1.0	1.39	3.13	0.001	0.951
GAS-t-Id	1.2	1.22	3.20	0.002	0.845
GAS-t-InvSq	1.2	1.39	3.59	0.002	0.845
GJRGARCH(1,1)-N	0.8	1.47	2.93	0.000	0.869
GJRGARCH(1,1)-St	1.0	1.30	2.79	0.001	0.951
GJRGARCH(1,1)-t	2.0	1.39	7.58	0.000	0.000
I-GARCH(1,1)-N	1.0	1.24	2.75	0.001	0.951
I-GARCH(1,1)-St	0.8	1.51	2.83	0.000	0.869
I-GARCH(1,1)-t	0.8	1.31	2.67	0.000	0.869
NGARCH(1,1)-N	1.2	1.16	3.13	0.001	0.845
NGARCH(1,1)-St	1.0	1.28	2.77	0.001	0.951
NGARCH(1,1)-t	1.2	1.24	2.91	0.001	0.845
T-GARCH(1,1)-N	1.2	1.43	3.21	0.001	0.845
T-GARCH(1,1)-St	1.4	1.27	3.23	0.000	0.632
T-GARCH(1,1)-t	1.4	1.26	3.37	0.003	0.632

Notes: We report the Actual over Expected ratio (AE), the mean Absolute Deviation (AD mean), and the maximum Absolute Deviation (AD max) of 1%-VaR forecasts of ERIX returns. CC and DQ are the p-values of the tests of Christoffersen (1998) and Engle and Manganelli (2004), respectively, where the model is correctly specified for 1%-VaR forecasts under H_0. The best models for each criterion are in boldface. We perform 500 one-day-ahead rolling forecasts as in Table 4.4

In sum, heavy-tailed distributed GARCH and GAS models have the best in-sample fit for all renewable energy returns. They also exhibit the best out-of-sample forecast performance and the best coverage for 1%-VaR of renewable energy returns. These findings highlight the relevance of modeling the kurtosis for renewable energy returns. For instance, the GAS-t-Id, AR(1)-CGARCH(1,1)-t, and AR(1)-E-GARCH(1,1)-St have the lowest out-of-sample RMSE for ECO, SPCLE, and both SUN and ERIX returns, respectively. In addition, the AR(1)-NGARCH(1,1)-St, AR(1)-APARCH(1,1)-St, AR(1)-E-GARCH(1,1)-St, and GAS-N-Id models are optimal models for 1%-VaR of renewable energy returns. Therefore, fat-tailed GARCH and GAS enhance both in-sample and out-of-sample performance of renewable energy returns and risk. These findings are important for policymakers and investors who invest in the renewable energy sector.

4.4 Conclusions

Clean energy indices, such as wind and solar energy, are sold in financial markets that share the same dynamics of highly volatile assets. Clean energy returns may also exhibit heavy-tailed distributions since financial returns follow fat-tailed distributions (Gabaix 2009). It is important to model the volatility of renewable energy returns for investors since it affects the performance of their portfolios on renewable energy. In this chapter, we search for optimal models for clean energy returns using 37 flexible and fat-tailed GAS and GARCH models. Besides, we compare the out-of-sample performance of all models to find the optimal forecast model for clean energy returns. We also conduct several backtesting approaches for daily 1%-Value-at-Risk (VaR) forecasts of clean energy returns.

Fat-tailed distributed GARCH and GAS models have the best in-sample fit for all renewable energy returns. They also exhibit the best out-of-sample forecast performance and the best coverage for 1%-VaR of renewable energy returns. For instance, the GAS-t-Id, AR(1)-CGARCH(1,1)-t, AR(1)-E-GARCH(1,1)-St have the lowest out-of-sample RMSE for ECO, SPCLE, and both SUN and ERIX returns, respectively. In addition, the AR(1)-NGARCH(1,1)-St, AR(1)-APARCH(1,1)-St, AR(1)-E-GARCH(1,1)-St, and GAS-N-Id models are optimal models for 1%-VaR of renewable energy returns. These findings illustrate the relevance of modeling the kurtosis for renewable energy returns, which are relevant for policymakers and investors who invest in the renewable energy sector.

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Chapter 5
The Causality Between Energy Consumption, Urban Population, Carbon Dioxide Emissions, and Economic Growth

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Abstract This study evaluates the relationship between electric power consumption and urbanization comparing the econometric results of autoregressive distributed lag (ARDL) and vector autoregressive (VAR) for the period 1960–2015. Granger causality is also applied to the Portuguese economy. In this study, we use some hypotheses that describe the link between electric power consumption, urban population, carbon dioxide emissions, and economic growth. The motivation of this research focuses on the relationship between electric power consumption (energy consumption) and urban population, supported by the theoretical and empirical contributions of energy and urban economics. The empirical results show that electric power consumption presents a causality with economic growth, urban population, carbon dioxide emissions, and international trade. This research also proves that there is cointegration between all variables in the long run. This paper presents significant contributions to economic policy, showing that there exists an association between energy consumption and economic growth.

Keywords Energy consumption · Economic growth · Carbon dioxide emissions · Time series

JEL Classification Q43 · Q50

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5.1 Introduction

This chapter analyzes the cointegration between energy consumption, carbon dioxide emissions, economic growth, urban population, and trade. In this context, the arguments of regional and energy economics give support to this issue. Indeed, regional and urban economics show that the population tries to locate close to the urban system since there are more opportunities concerning employment. According to economic geography models (Krugman 1991; Fujita et al. 1999), we observe that the Center or the North is more attractive when compared with the peripheral or semi-peripheral areas. However, the urban population has higher energy consumption, when compared to small municipalities, that is, energy demand in large urban systems is higher. Recent studies by Ozturk and Acaravci (2011), Omri (2013), Shahbaz et al. (2013), Leitão (2015), and Bakirtas and Akpolat (2018) focused on this theme.

Moreover, the relationship of energy with international trade, international investment, as well as economic growth, has increased in the literature, showing the motivation of the researchers to evaluate this link. The scholars have required to correlate these variables using different econometric strategies. The present study uses time series for the case of the Portuguese economy capturing the results obtained between autoregressive distributed lag (ARDL), autoregressive vector (VAR), and Granger causality for the period 1960–2015.

Several studies such as Farabi et al. (2019), Hong et al. (2019), Saqib (2018), Sasana and Aminata (2019) demonstrate that energy consumption is needed to promote economic growth. However, growth encourages climate change and the greenhouse effect with the emission of gases. Consequently, international trade, via export growth strategy, uses excessive energy consumption, this practice is associated with economic growth, sometimes without considering sustainable development.

According to Portuguese publication of the General Direction of Energy and Geology (Direção Geral de Energia e Geologia, Energia em Números 2015: 4), the Portuguese economy presents an energy dependence to the outside world. In 2015, it registered 78.3%, increasing by about 5.9% compared to 2014. From data published by the same government institution, it can be observed that from 2010 onwards, energy dependence has declined concerning the years of the 1990s. From 1996 to 2009, it is always above 80%. Comparing Portugal with the EU-28 average, Portugal ranks 7th concerning energy dependency (Direção Geral de Energia e Geologia, Energia em Números 2015: 5). From this report, it is possible to observe the importance of the energy sector for Portuguese economic activity.

This study aims to contribute to the literature on this topic. At first, the empirical research relates to the long-run relationship between energy and economic growth. The urban population, carbon dioxide emissions, and international trade are also evaluated. This research is organized as follows. The literature review is presented in the next section. The methodology and the hypotheses are considered in section three. The empirical results appear in section four. The conclusions are described in the final of this study.

5.2 Literature Review

The demand energy has been widely discussed in the literature. In the last two decades, scientific articles on the use of fossil energy have increased, evidencing that it generates climate change and global warming. In this context, we present the most relevant literature review that evaluates the link between energy consumption, urban population, and economic growth. The correlation between energy consumption and carbon dioxide emissions (CO_2) and international trade is also considered. The introduction of the urban population is supported by theories of regional and urban economics associated with urban systems (Losch 1967; Christaller 1966; Fujita et al. 1999).

The empirical studies show that economic growth causes climate change and global warming. However, it should be noted that the urban population contributes to a higher energy demand, which in turn, the use of non-renewable energy encourages climate change. The empirical study of Bakirtas and Akpolat (2018) considers the causality between energy consumption, economic growth, and urbanization. Using the period 1971–2014, the authors applied a panel Granger causality to Colombia, India, Indonesia, Kenya, Malaysia, and Mexico, and the econometric results demonstrate that income per capita and urbanization present causality with energy consumption for all economies. Bakirtas and Akpolat (2018) also showed that there is a Granger causality between urbanization and income per capita in Kenya and Mexico. In this line, the empirical study of Khobai and Le Roux (2017) considered the link between energy consumption, CO_2 emissions, urbanization, and international trade in South Africa for the period 1971–2013, applying the vector error corrected model (VECM). The econometric results show that there is a bidirectional causality between energy consumption and economic growth. Khobai and Le Roux (2017) also demonstrate that there exists a unidirectional causality between energy consumption and all variables considered in their study.

The investigation realized by Zheng and Walsh (2019) considers the effects of urbanization, energy consumption, and international trade on economic growth. The authors applied panel data (fixed effects and GMM-System) considering 29 Chinese provinces for the period 2001–2012. The econometric results prove that urbanization encourages economic growth (Zheng and Walsh 2019: 159). Moreover, the study of Zheng and Walsh (2019) also shows that trade is negatively correlated with economic growth, and energy consumption does not endorse economic growth when the authors applied a dynamic panel estimator. In this context, Wang et al. (2018) studied the cointegration between urbanization, economic growth, and carbon dioxide emissions considering 170 countries with different development, for the period 1980–2011, and the empirical results demonstrate that there exist cointegration between variables used.

The case of Saudi Arabia was investigated by Alshehry and Belloumi (2015), considering a time series (unit root test, Johansen cointegration test, Granger causality test, and VECM), and the study proves that in the long run, the energy use, CO_2 emissions, economic growth, and the price of energy are cointegrated.

Urbanization and energy consumption applied to Pakistan were investigated by Shahbaz et al. (2017). The researchers consider the ARDL model and VECM Granger causality to examine the cointegration between the energy consumption, urban population, real income per capita, technology, and use of transportation (Shahbaz et al. 2017: 86). The empirical results show that there is cointegration between variables. When the authors utilize the ARDL model in the long run, it is possible to infer that the variables of the urban population, real income per capita, technology, and use of transportation present a positive effect on energy consumption.

The literature review also considers the correlation between energy consumption, economic growth, and carbon dioxide emissions. Usually, the empirical studies found a positive cointegration between energy consumption and economic growth. Besides, the intensive use of nonclean energy encourages an increase of carbon dioxide emissions, and consequently, climate change, and global warming (e.g., Mirza and Kanwal 2017; Farabi et al. 2019; Saqib 2018). In this context, Bildiric and Ozaksoy (2017) consider the cointegration between energy consumption and income per capita for the period 1980–2012 in African economies. These authors apply an autoregressive distributed lag model (ARDL) and Granger causality. The results show that there is a causality between energy consumption and growth for Botswana, Cameroon, Uganda, and Zambia.

The case for Taiwan, considering the input–output as an econometric strategy, was investigated by Hong et al. (2019). The study proves that energy consumption encourages economic growth. Besides, energy consumption increased after the financial crisis that according to the authors represents sustainable development. Farabi et al. (2019) investigated the correlation between energy consumption and economic growth applied to Indonesia and Malaysia. They concluded that there exists a cointegration between energy consumption and carbon dioxide emissions, energy consumption, and economic growth. The impact of China urbanization on economic growth and energy consumption was studied by Yang et al. (2017), for the period 2000–2010. The authors applied panel data (OLS, fixed effects, and random effects). The econometric results demonstrate that urbanization has a positive impact on energy consumption and economic growth. However, the empirical study of Jafari et al. (2012) presents a different position, i.e., not found a Granger causality between energy consumption and economic growth for the Indonesia case. Nevertheless, the study found a correlation between urban population and energy, showing that energy consumption is crucial in urban regions.

The influence of urbanization and industrialization on carbon dioxide emissions in China was considered by Liu and Bae (2018). The authors applied an ARDL methodology. In the long run, the variables of energy intensity, income per capita, industrialization, and urbanization present a positive impact on CO_2. Besides, the relationship between urbanization and energy demand in the Middle East was considered by Topcu and Girgin (2016), and the econometric results show that there is a causality between urbanization and energy demand.

Another area of research is the relationship between energy and international trade. The energy demand and the liberalization of markets show that there is cointegration between energy consumption and international trade. Economic globalization makes it possible to explain the growing demand for energy from countries that are not efficient in energy production. As a rule, empirical studies find a positive correlation between energy consumption and international trade, demonstrating that a country strategy based on export growth needs high levels of energy. On the other hand, environmental economists have shown that international trade stimulates carbon dioxide emissions, when the countries use nonclean energies, and consequently an increase in the excessive use of energy. Furthermore, the empirical study of Leitão (2015) considered the relationship between energy consumption and foreign direct investment, using panel data (fixed effects and GMM-System), the econometric results show that the international trade presents a positive impact on energy consumption.

The link between economic growth, energy consumption, financial development, international trade, and carbon dioxide emissions in Indonesia was examined by Shahbaz et al. (2013). Using the ARDL model, VECM, and Granger causality, the authors prove that there is a positive association between openness trade and carbon dioxide emissions and energy consumption. In this line, the empirical model of Ozturk and Acaravci (2011) considered 11 MENA countries and the ARDL model as the econometric strategy. The econometric results presented by Ozturk and Acaravci (2011) demonstrate that there is no cointegration between energy consumption and economic growth when the authors examine Iran, Morocco, and Syria. However, this empirical study proves that there exist cointegration and causality between energy consumption and economic growth to Egypt, Israel, Oman, and Saudi Arabia (Ozturk and Acaravci 2011: 2890–2891).

The effects of international trade, energy consumption, and economic growth on CO_2 emissions were studied by Akin (2014). The study used as an econometric strategy a panel cointegration (FMOLS and DOLS), and the econometric results demonstrate that international trade presents a positive effect on energy consumption and CO_2 emissions.

The MENA countries for the period 1990–2011, using dynamic panel data, were considered by Omri (2013). The empirical study proves that international trade has a positive impact on energy consumption in Algeria, Egypt, Kuwait, Saudi Arabia, Syria, and United Arab Emirates (Omri 2013: 662).

The relationship between globalization and energy and growth was investigated by Marques et al. (2017). Considering the ARDL model, the results demonstrate that there is cointegration between globalization, energy consumption, and growth.

Shahbaz et al. (2018) studied the correlation between energy consumption and foreign capital inflows applied to Pakistan. The scholars use an ARDL model and Granger causality for the period 1972–2014. The econometric results show that there exists bidirectional causality between exports, economic growth, and energy consumption.

5.3 Methodology and Hypotheses

This article considers the methodology of cointegration (autoregressive and distributed lag [ARDL]) developed by Perasan et al. (2001), and the development proposed by Kripfganz and Schneider (2016, 2018) to estimate the long-run relationship between electric power consumption, urban population, carbon dioxide emissions, income per capita, and total exports for the period 1960–2015. However, in this research, we also consider the unit root test, vector autoregressive (VAR), and Granger causality to evaluate the correlation between the variables used in this study. The unit root test permits to observe if there exists stationarity between the variables applied in this empirical study. The stationarity properties of the variables of energy consumption, carbon dioxide emissions, income per capita, urban population, and exports were tested by the method of Phillips and Perron (1988). The methodologies of Johansen and Juselius (1990) and Johansen (1988, 1991, 1995) were considered to study the cointegration. Before we estimate the VAR model, we need to consider the test of lag order selection criteria. Lagrange multiplier test was also considering to detect the stability of VAR model. According to the literature, the VAR model is stable if we do not have autocorrelation.

Based on the literature review, we formulate the following hypotheses:

øH_1: Energy consumption causes climate change

The literature review supports that electric power consumption encourages climate change and global warming.

Energy—the variable represents the electric power consumption per capita (kWh per capita) by World Bank and www.iea.org.

CO_2—represents the carbon dioxide emissions in Kt from World Bank.

The empirical studies of Farabi et al. (2019), Hong et al. (2019), Khobai and Le Roux (2017), Alshehry and Belloumi (2015), and Leitão (2015) demonstrate that CO_2 emissions present a positive effect on energy consumption. In this study, climate change is measured by CO_2 emissions.

H_2: There is a bidirectional causality between energy consumption and economic growth

Y—the variable denotes income per capita (constant 2010 US$) from the World Bank.

The previous studies (Sasana and Aminata 2019; Bildiric and Ozaksoy 2017; Magazzino 2015; Naina et al. 2017; Omri 2013) found a positive effect of energy consumption on economic growth. Indeed, economic growth depends on energy efficiency. Therefore, the use of non-renewable energy promotes climate change and global warming problems.

H_3: There is a positive relationship between urban population and energy consumption

In the urban system, energy consumption is higher when compared to small rural clusters.

The empirical studies of Zheng and Walsh (2019), Wang et al. (2018), Shahbaz et al. (2017), Yang et al. (2017), Liu and Bae (2018), Bakirtas and Akpolat (2018), Khobai and Le Roux (2017), and Jafari et al. (2012) give support to our hypothesis.
UrbanPop—signifies urban population, i.e., the population living in urban areas from the World Bank. This variable aims to measure the urbanization effects on energy consumption.
H_4: International trade is directly correlated with energy consumption
A strategy to promote export growth is associated with excessive use of energy demand.

The studies of Shahbaz et al. (2013), Akin (2014), and Leitão (2015) found a positive effect between international trade and energy consumption.

Exports—represents exports of goods and services (constant 2010 US$) source World Bank.

Considering the empirical studies of Ozturk and Acaravci (2011), Shahbaz et al. (2011), Shahbaz et al. (2013), Shahbaz et al. (2015), Elfaki et al. (2018), and Sriyana (2019), the ARDL model assumes the following expression:

$$\begin{aligned}\Delta LogEnergy = {} & \alpha_0 + \alpha_1 LogEnergy_{t-1} + \alpha_2 LogCO_{2t-1} + \alpha_3 LogY_{t-1} \\ & + \alpha_4 \Delta LogUrbanPop_{t-1} + \alpha_5 \Delta LogExports_{t-1} \\ & + \Sigma_{t=1}^{n} \alpha_1 \Delta LogEnergy_{t-1} + \Sigma_{t=0}^{n} \alpha_2 \Delta LogCO_{2t-1} \\ & + \Sigma_{t=0}^{n} \alpha_3 \Delta LogY_{t-1} + \Sigma_{t=0}^{n} \alpha_4 \Delta LogUrbanPop_{t-1} \\ & + \Sigma_{t=0}^{n} \alpha_5 \Delta LogExports_{t-1} + \gamma ECM_{t-1} + e \end{aligned} \tag{5.1}$$

The energy consumption is the dependent variable, and the independent variables considered are the carbon dioxide emissions (CO_2), income per capita (Y), urban population (*UrbanPop*), and total exports (*Exports*).

In Eq. 5.1, all variables are expressed in logarithm form. Δ represents the change in operator; ECM_{t-1} considers the error correction term; γ represents the adjustment of a short and long run.

Considering the contributions of Perasan et al. (2001), Shahbaz et al. (2015), Matthew et al. (2018), and Sriyana (2019), we need to consider two conditions with ARDL methodology:

H_0: $\alpha_0 = \alpha = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5$, represents no relationship in the long run.
H_1: $\alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5$, represents the relationship in the long run.

To test cointegration and stationarity in the long run, we use the ARDL bounds test (Pesaran and Shin 1999; Pesaran et al. 2001). Therefore, the evaluate long-run cointegration used to the STATA software was determinate by the suggestion proposed by Kripfganz and Schneider (2016, 2018). Following the contributions of Edoja et al. (2016), Ullah et al. (2018) vector autoregressive (VAR) assumes the form:

$$Y_t = \alpha + A_1 Y_{t-1} + \ldots A_p Y_{t-p} + e_t \tag{5.2}$$

Y—represents all variables used in this study, i.e., energy consumption, carbon dioxide emissions, income per capita, urban population, and exports.

5.4 Empirical Results

The descriptive statistics and the correlation between the variables used in this research are presented in Tables 5.1 and 5.2. The variables of the urban population (*LogUrbanPop*), carbon dioxide emissions ($LogCO_2$), and income per capita (*LogY*) present higher values when we compare with energy consumption (*LogEnergy*) and exports (*LogExports*). The statistics of Skewness and Kurtosis are essential to evaluate the distribution of the frequencies of the variables compared to the normal distribution (Gaussian). The variables used in this study present negative values for

Table 5.1 Descriptive statistics

	LogEnergy	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
Mean	3.263	4.481	4.125	6.658	0.726
Median	3.313	4.498	4.145	6.667	0.824
Maximum	3.695	4.824	4.358	6.815	1.070
Minimum	2.505	3.915	3.653	6.490	0.300
Std. dev.	0.365	0.272	0.209	0.105	0.250
Skewness	−0.516	−0.528	−0.727	−0.058	−0.220
Kurtosis	2.058	2.044	2.460	1.662	1.370
Jarque-Bera	4.470	4.649	5.525	4.130	6.528
Probability	0.106	0.097	0.063	0.126	0.038
Sum	179.466	246.5070	226.9201	366.2112	39.9736
Sum sq. dev.	7.2146	3.995	2.3706	0.598	3.395
Observations	55	55	55	55	55

Source Own composition based on World Bank Development Indicators

Table 5.2 Correlation between variables

Variables	*LogEnergy*	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
LogEnergy	1.000				
$LogCO_2$	0.975	1.000			
LogY	0.966	0.997	1.000		
LogUrbanPop	0.914	0.977	0.986	1.000	
LogExports	0.060	0.250	0.295	0.418	1.000

Note Observations = 55
Source Own composition based on World Bank Development Indicators

Skewness, demonstrating that the distribution is asymmetric. This type of distribution is designated in the literature by negative or at the left asymmetry.

Regarding the Kurtosis statistics, it evaluates the "flattening" of the curve considering the Gaussian distribution. According to Table 5.1, it is possible to observe that the values are all positive, which is denominated by Kurtosis of the leptokurtic type. Moreover, all explanatory variables show a positive correlation with the dependent variable (energy consumption, see Table 5.2).

Table 5.3 presents the unit roots test for each variable used in this research, considering the Phillips–Perron (1988). According to the literature such as Hamilton (1994), Phillips–Perron's unit root test allows correcting serial correlation and heteroskedasticity by the Newey–West procedure (1987), using lags in the variations of the first differences. The Phillips–Perron test (1988) relies on two statisticians Z (rho)-Phillips–Perron t-test statistic and Z (t)-Phillips–Perron p statistic test. According to Hamilton (1994), the reading of these two statistics can be analyzed in the same way as the Dickey–Fuller test (1979). Thus, the null hypothesis considers that the variable in the analysis has a unit root, and alternatively, the variable will be stationary. In other words, the Phillips–Perron methodology tests whether the null hypothesis is integrated into order 1. The hypothesis rejection demonstrates that the time series are integrated into order n. The variables are stationary, considering the results obtained for the Z (rho) and Z (t) statistics.

Table 5.4 shows the lag selection considering LL—lag order selected by criterion, LR—Sequential modified, FPE—final prediction error, AIC—Akaike information criterion, SBIC—Schwarz information criterion, and HQ—Hannan–Quinn information criterion. Following the literature review such as Hamilton (1994), Lutkepohl (1993), Tsay (1984), and the results obtained in Table 5.4, we select the optimal lag to estimate the VAR model.

The autoregressive and distributed lag model (ARDL) is presented in Table 5.5. All variables were considered in the regression. The adjustment coefficient or error correction coefficient [ADJLogEnergy (-1)] demonstrates that there is a long relationship between variables. The lagged variable of energy is statistically significant at 1% level with a negative sign. In the long run, we can infer that energy consumption tends to decrease. However, in the short run, the energy consumption (*LogEnergyLD*) presents a positive sign showing that in the short run, it is essential for economic growth. In the long term, the coefficients of income per capita (*LogY*) and urban population (*LogUrbanPop*) present a positive effect on energy consumption. These variables are statistically significant at 1% level. Additionally, these results are according to the empirical studies of Bildiric and Ozaksoy (2017), Bakirtas et al. (2018), and by Alshehry and Belloumi (2015). It is also possible to infer a relationship between economic growth and energy use, which shows that energy demand is essential for the development of the economic activity. Besides, urban systems need more energy, i.e., they consume more energy than small population clusters like villages or small cities. Hence, we observe that there is a positive correlation. The econometric model also demonstrates that CO_2 emissions have a positive impact on energy consumption (*LogEnergy*), showing that there exists a relationship between energy consumption and climate change. The coefficient is statistically significant at 1% level. Bildiric

Table 5.3 Unit root rest: Phillips–Perron

Phillips–Peron unit root test	Interpolated Dickey–Fuller			
Variables	Test statistic	1% Critical value	5% Critical value	10% Critical value
LogEnergy				
Z (rho)	−14.506	−18.954	−13.324	−10.718
Z (t)	−7.022	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
$LogCO_2$				
Z (rho)	−18.213	−18.954	−13.324	−10.718
Z (*t*)	−9.183	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogY				
Z (rho)	−18.627	−18.954	−13.324	−10.718
Z (*t*)	−9.985	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogUrbanPop				
Z (rho)	−20.762	−18.954	−13.324	−10.718
Z (*t*)	−11.169	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogExports				
Z (rho)	−18.674	−18.954	−13.324	−10.718
Z (*t*)	−9.084	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
Observations	53			
New–West lags	3			

Note Rejection at 5% level
Source Own composition based on World Bank Development Indicators

Table 5.4 Lag order selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	404.938		2.8e−14	−17.0186	−16.9446	−16.8218
1	752.75	695.62	3.0e−20	−30.7553	30.3109	−29.5744[a]
2	800.056	94.612	1.2e−20[a]	−31.7045	−30.8898[a]	−29.5395
3	825.353	50.593	1.3e−20	−31.7172	−30.5321	−28.568
4	856.775	62.843[a]	1.2e−20	−31.9904[a]	−30.435	−27.8571

Note [a]Represents the optimal lag
Source Own composition based on World Bank Development Indicators

and Ozaksoy (2017), Bakirtas and Akpolat (2018) also found a positive correlation between CO_2 emissions and energy consumption. The coefficient of exports (*LogExports*) presents a positive impact on energy consumption. The variable is statistically significant at 1% level. Leitão (2015), Akin (2014), and Shahbaz et al. (2013) give support to our results. The long-term cointegration between variables will be considered in the next step. Using the ARDL bounds test (Pesaran and Shin 1999) and the Kripfganz and Schneider methodology 2016, 2018), the statistics are presented in Table 5.6. The results demonstrate that there exists a long-run relationship (Fig. 5.1).

Based on the arguments of Johansen and Juselius (1990), and Johansen (1991, 1995, 1988), we apply the test of cointegration for the variables energy consumption (*LogEnergy*), carbon dioxide emissions ($LogCO_2$), income per capita (*LogY*), urbanization (*LogUrbanPop*), and exports (*Log exports*). In Table 5.7, the Trace test shows that there is two cointegration between the variables at the 5% level. The Maximum Eigenvalue test in Table 5.8 indicates that there exists one cointegration.

Table 5.9 presents the diagnostic of the VAR model, considering as H0: no serial correlation, the Lagrange multiplier test demonstrates that VAR is stable in lag 2.

Table 5.10 reports the results of Granger causality. There is bidirectional causality between energy consumption (*LogEnergy*) and income per capita (*LogY*). This result confirms again that energy demand is essential to obtain economic growth. We also observe that there is bidirectional causality between energy consumption (*LogEnergy*) and urban population (*LogUrbanPop*); and the variable of carbon dioxide emissions ($LogCO_2$) and urban population; and income per capita (*LogY*) and urban population (*LogUrbanPop*) (Fig. 5.2).

According to these results, it is possible to infer that there is a positive correlation between energy consumption and urban population, i.e., energy demand increases in urban agglomerations. The results also indicate that large urban systems are more polluting as there is a positive relationship between carbon dioxide emissions and the urban population. On the other hand, the population tends to be concentrated in urban clusters since there is more distribution of income per capita. This result is supported by the arguments of regional and urban economics (e.g., Christaller 1966; Krugman 1991). The empirical studies of Bakirtas and Akpolat (2018), Khobai and Le Roux (2017), Alshehry and Belloumi (2015) also found similar results.

Table 5.5 Energy consumption and Portuguese urban population with Autoregressive and Distributed Lag (ARDL)

Variables	Coef.
ADJ *LogEnergy* (−1)	−0.8952*** (0.001)
Long Run (LR)	
$LogCO_2$	0.2776*** (0.000)
LogY	0.8101*** (0.000)
LogUrbanPop	1.3596*** (0.000)
LogExports	0.1124*** (0.000)
Short Run (SR)	
LogEnergyLD	0.29983* (0.099)
L2D	0.2706 (0.149)
L3D	0.0917 (0.564)
$LogCO_2D1$	−0.030 (0.617)
LogYD1	−0.2002 (0.309)
LD	−0.4641** (0.025)
L2D	−0.3597* (0.050)
L3D	−0.2548* (0.092)
LogUrbanPopD1	−1.8219 (0.179)
LD	1.6506 (0.267)
L2D	0.1014 (0.118)
L3D	0.1061* (0.062)
LogExportsD1	−0.0619* (0.065)
LD	−0.0628** (0.014)

(continued)

Table 5.5 (continued)

Variables	Coef.
L2D	−0.0239 (0.264)
C	−9.3403*** (0.002)
Adj. R^2	0.843

Note Statistically significant at 1% (***), 5% (**), and 10% (*); LD—represents Lag
Source Own composition based on World Bank Development Indicators

Table 5.6 Energy consumption and Portuguese urban population with ARDL: bounds test

Pesaran, Shin and Smith (2001) bounds test

F = 7.039
t = −4.657 Case 3

Sample (4 variables, 47 observations, 16 short-run coefficients)

Kripfganz and Schneider (2018) critical values and approximate *p*-values

	10%		5%		1%		*p*-value	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	2.483	3.928	3.025	4.683	4.321	6.477	0.000	0.006
T	−2.416	−3.522	−2.788	−3.957	−3.543	−4.837	0.001	0.014

Source Own composition based on World Bank Development Indicators

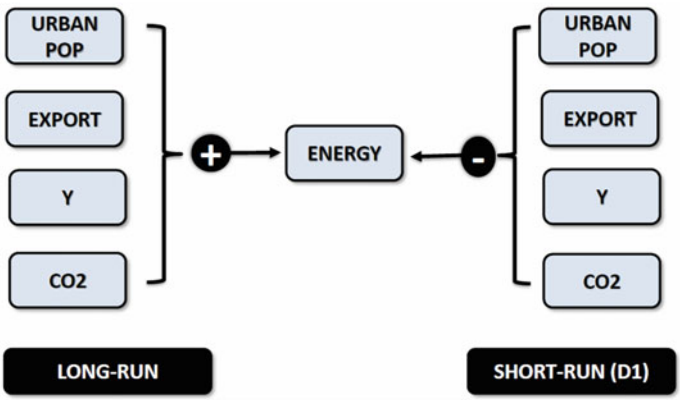

Fig. 5.1 (ARDL) scheme

There is a unidirectional causality between CO_2 emissions and energy consumption (*LogEnergy*), energy consumption, and exports (*LogExports*). The same is valid between $LogCO_2$ (carbon dioxide emissions) and *LogY* (income per capita).

Table 5.7 Energy consumption and Portuguese urban population with Unrestricted Cointegration Rank Test (Trace)

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.532170	91.99467*	69.81889	0.0003
At most 1	0.399609	51.73317*	47.85613	0.0207
At most 2	0.312816	24.69397	29.79707	0.1727
At most 3	0.076392	4.810845	15.49471	0.8286

* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) *p*-values
Source Own composition based on World Bank Development Indicators

Table 5.8 Energy consumption and Portuguese urban population with Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None*	0.532170	40.26150*	33.87687	0.0076
At most 1	0.399609	27.03920	27.58434	0.0586
At most 2	0.312816	19.88312	21.13162	0.0740
At most 3	0.076392	4.211768	14.26460	0.8364
At most 4	0.011240	0.599077	3.841466	0.4389

* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) *p*-values
Source Own composition based on World Bank Development Indicators

Table 5.9 Energy consumption and Portuguese urban population: VAR Diagnostic

Lag		Chi2	Prob > Chi2
2		26.2403	0.39486

Source Own composition based on World Bank Development Indicators

The results show that international trade is associated with excessive use of energy, demonstrating that Portugal should use renewable energy to reduce polluting gases. On the other hand, the results also explain that there is a correlation between carbon dioxide emissions and economic growth. Once again, economic growth seems to simulate climate change.

Table 5.10 Energy consumption and Portuguese urban population with Granger causality

Null hypothesis	Chi 2	Df	Prob > Chi 2
LogEnergy does not Granger Cause $LogCO_2$	2.9501	2	0.229
$LogCO_2$ does not Granger Cause *LogEnergy*	11.303	2	0.004
LogEnergy does not Granger Cause *LogY*	16.76	2	0.000
LogY does not Granger Cause *LogEnergy*	93.159	2	0.000
LogEnergy does not Granger Cause *LogUrbanPop*	314.61	2	0.000
LogUrbanPop does not Granger Cause *LogEnergy*	971.55	2	0.000
LogEnergy does not Granger Cause *LogExports*	7.732	2	0.021
LogExports does not Granger Cause *LogEnergy*	0.2039	2	0.903
$LogCO_2$ does not Granger Cause *LogY*	7.7432	2	0.021
LogY does not Granger Cause $LogCO_2$	0.02184	2	0.989
$LogCO_2$ does not Granger Cause *LogUrbanPop*	180.58	2	0.000
LogUrbanPop does not Granger Cause $LogCO_2$	28.48	2	0.000
$LogCO_2$ does not Granger Cause *LogExports*	0.22605	2	0.893
LogExports does not Granger Cause $LogCO_2$	1.1028	2	0.576
LogY does not Granger Cause *LogUrbanPop*	355.5	2	0.000
LogUrbanPop does not Granger Cause *LogY*	104.38	2	0.000
LogY does not Granger Cause *LogExports*	6.8495	2	0.033
LogExports does not Granger Cause *LogY*	0.0726	2	0.964
LogUrbanPop does not Granger Cause *LogExports*	92.098	2	0.000
LogExports does not Granger Cause *LogUrbanPop*	0.2905	2	0.865

Source Own composition based on World Bank Development Indicators

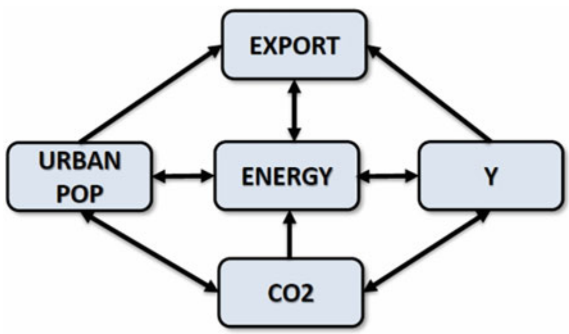

Fig. 5.2 Causality scheme

5.5 Conclusions

This study evaluates the long-term relationship between energy consumption, urban population, economic growth, climate change, and international trade (via export growth), comparing the econometric results between the ARDL model, VAR, and Granger causality. The econometric models that we present demonstrate the relevance of the link between energy consumption and the urban system (urbanization). It is our primary objective in this section to compare the results that we have found with other studies in the same area of knowledge.

Considering the results obtained by ARDL, it is possible to observe that there is a long-run cointegration between the variables used in this study. An analysis in more detail allows indicating that the long-run electric power consumption is adjusted, with a decrease in energy use. The long-run results also show that estimates of the urban population, economic growth, exports, and carbon dioxide emissions have a positive impact on energy consumption. The relationship between growth and energy is positive since the economic activity requires high energy consumption, demonstrating that to occur, economic growth energy is fundamental. This result is according to empirical studies of Shahbaz et al. (2018), Bildiric and Ozaksoy (2017), and Omri (2013).

Large urban systems have higher levels of energy consumption when compared to small cities, as analyzed by Shahbaz et al. (2017), Yang et al. (2017), and Liu and Bae (2018).

Regarding the relationship between carbon dioxide emissions and energy consumption, the positive association shows that excessive use of energy and especially electric power consumption cause climate change and global warming. The empirical studies of Alshehry and Belloumi (2015), and Khobai and Le Roux (2017) support our results.

Considering the data obtained by the Granger causality, we can affirm that these are according to the literature since there is bidirectional causality between the energy and the economic growth and the urban population.

As we mentioned, the econometric results demonstrate that energy consumption decreases in the long term. In terms of recommendations by the economic policy, we think that economic policymakers should consider a strategy to promote the use of renewable energies. The Portuguese state and the European Union should continue to finance sectors of economic activity that use renewable energies since these, in a long-term perspective, become more efficiencies.

Besides, our empirical results demonstrate that exports need excessive use of energy consumption. In this context, the Portuguese state should finance the strategic sectors of the economy based on the use of renewable energies, will be betting on the differentiation of products and factors of innovation and competitiveness, thus developing competitive clusters medium and long term.

Appendix

See Table 5.11.

Table 5.11 Energy consumption and Portuguese urban population growth with VAR model

Variables	*LogEnergy*	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
LogEnergy (−1)	0.9897*** (0.000)	−0.0147 (0.739)	0.3247 (0.144)	0.2852*** (0.004)	0.0028 (0.998)
LogEnergy (−2)	0.1553 (0.373)	0.3645 (0.376)	0.0067 (0.932)	0.2166** (0.019)	−0.0772 (0.938)
$LogCO_2$ (−1)	0.0011 (0.986)	0.7955*** (0.000)	−0.0107 (0.893)	−0.0512 (0.143)	−0.3829 (0.307)
$LogCO_2$ (−2)	0.0567 (0.399)	0.1554 (0.329)	−0.6420 (0.893)	−0.0463 (0.19)	0.3862 (0.314)
LogY (−1)	0.1259 (0.353)	0.7472** (0.020	0.9218**** (0.000)	0.4195*** (0.000)	0.0871 (0.910)
LogY (−2)	0.3511*** (0.004)	−0.8097*** (0.005)	−0.3825*** (0.009)	0.0435 (0.506)	−0.1564 (0.824)
LogUrbanPop (−1)	−0.4489*** (0.000)	−0.8424*** (0.000)	0.6420*** (0.000)	0.1636*** (0.000)	0.0690 (0.830)
LogUrbanPop (−2)	0.0958* (0.085)	0.2143 (0.103)	0.2045*** (0.002)	−0.0795*** (0.007)	−0.1200 (0.705)
LogExports(−1)	0.0705*** (0.006)	−0.0285 (0.636)	−0.0759*** (0.012)	−0.0406*** (0.003)	0.7439*** (0.000)
LogExports(−2)	0.0559** (0.024)	0.0228 (0.696)	0.0531* (0.071)	−0.0248* (0.059)	0.0949 (0.501)
C	2.5787*** (0.000)	3.9686*** (0.000)	3.6984 (0.000)	6.5067*** (0.000)	0.9595 (0.8603)
Adj. R^2	0.99	0.99	0.99	0.99	0.96
P > Chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Log likelihood					766.9181
AIC					−27.91836
HQIC					27.12225
SBIC					−25.83501

Statistically significant at 1% (***), 5% (**), and 10% (*)
Source Own composition based on World Bank Development Indicators

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Chapter 6
Investigation on the Job Creation Effect of Green Energy in OECD Countries

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Abstract This chapter aims to examine the job creation effect of green energy sector developments in 18 OECD countries. For this purpose, the unemployment rates of observed countries are described as a function of economic growth, capital accumulation, government activities and green energy consumption, and constructed empirical model is analyzed with panel data methodologies for the period from 1990 to 2015. The results of empirical analysis show that economic growth and capital accumulation contribute to employment level for the panel of OECD countries, while increasing green energy usage and government activities are not efficient on employment. However, country-specific estimation results reveal that green energy consumption reduces unemployment rate in Canada, France, Israel, Mexico and New Zealand.

Keywords Green energy · Unemployment · Government activities · Economic growth

6.1 Introduction

Economic growth and sustainability of growth are among the priority demands of countries. Every economy aims to achieve macroeconomic and microeconomic targets and in this direction makes the necessary investments with the technological developments. Energy and energy efficiency are the key component to increase the

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efficiency and efficiency of the economy such as accumulation in capital, technological resources and R&D investments which are accelerated after the industrial revolution for all developed and developing countries. However, the negative impacts of greenhouse gas emissions resulting from energy and energy use on human health and the environment have led to the necessity of making a choice between growth and environment. Especially, developed and developing countries have focused on long-term growth target. However, because of the detrimental effects of global warming, pollution and climate change on human health and environment, industrialized countries have committed to reduce greenhouse gas emissions with the Kyoto Protocol established in 1997. According to the IPCC (2018) report, warming from human activity has reached 1 °C in 2017, which is approximately 1 °C above pre-industrial levels (probably between 0.8 and 1.2 °C) and reached 0.2 °C above the levels of last decade (possibly between 0.1 and 0.3 °C). Again, the report stated that climate change is rising faster than expected. Therefore, the use of alternative energy sources and investment in these areas has gradually increased and developed, and developing countries have started to formulate policies on green energy.

Recently, the effect of renewable energy and green energy is gaining weight in total energy consumption and is considered one of the main factors for sustainable development and growth because non-renewable energy sources are seen as the main source of global warming and climate change due to the greenhouse gas emissions (Destek and Aslan 2017: 757). With these developments, it can be stated that world economies are increasingly integrating their growth and development goals into the concept of Green Growth (ILO 2018). According to Global Insights Current and Potential Green Jobs in the U.S Economy Report (2008), there are macroeconomic and microeconomic returns of countries with Green Growth. Besides the macroeconomic benefits such as high efficiency of energy saving and investment supporting the green economy, balance of payments and increasing disposable personal income among countries, microeconomic benefits such as reducing operating costs and lowering household energy expenditures are also present.

According to the International Energy Agency 2019 report, over the past ten years, the sharp costs reduction in solar photovoltaic (PV) and wind power has increased investments in renewable energy technology. Compared to 2017, renewable energy generation increased by 7%. This rate is 90% in solar PV, wind and water energy. Therefore, the use and demand for clean and renewable energy sources are increasing, and this increase is at the center of emerging economies.

When economic growth and renewable energy sources are considered together with Okun's Law, almost every factor that supports economic growth is also directly linked to the labor force (Apergis and Salim 2015: 5614–5615) and jobs creating is related to the distribution of benefits from investments in energy technologies (Gülen 2011: 8). In addition, job creation requires creative policies and interaction in the context of national and global affair (Forstater 2006: 58). The importance of renewable energy is taken into consideration as globally, it will be inevitable for countries to evaluate their labor policies in this context. Therefore, the link between green energy and job creation/ destruction required to explain. Green energy has a job creation effect because of the various supply chains, high labor intensity and high profit margin. The relationship between the labor force and renewable energy sources can be explained by different mechanisms. The first is the concept of "green jobs." The concept of green jobs was created by the countries' renewable energy management and investments in this field, and the labor force started to be discussed in this context. By creating competition in the global economy with the investments in renewable energy sources, it is stated that new business lines and efficiency will increase, and high return opportunities in the short and long term will be obtained (Global Insight 2008: 4). The United Nations Environmental Program describes green jobs as the protection and maintenance of environmental quality in agriculture, manufacturing, research and development (R&D), management and services. In particular, these works, which will support the protection of ecosystem and biodiversity, include reducing energy use and water consumption and increasing efficiency in the management of pollution and waste. In addition, the green job is expected to be a solution to the climate change crisis or at least to minimize environmental damage-based employment (VanWynsberghe 2016: 731). The benefits of green energy in job creation can be expressed as follows (ILO 2016): (1) Green job can create a value chain in logistics, input generation or services sector; (2) The energy supply generated by green energy may contribute to the expansion of existing economic activities in other sectors. (3) Job creation in green energy generation can help create less harmful work conditions. (4) Green job may provide new opportunities for innovative communication between employees and employers.

The other mechanism between renewable energy consumption and unemployment can be explained following (Apergis and Salim 2015: 5615; OECD 2017: 5): (i) the labor force in the related industries is positively affected by investments in renewable energy and the increase in utilization capacity; (ii) savings from imports of fossil fuels are transferred to renewable energy sources. This transfer is referred to as import effect; (iii) the positive impact of this transfer also reduces investments in fossil fuel use and primary investment and consumption resulting from the additional costs of renewable energy sources; (iv) the transition to less polluting economy and the efficient use of resources requires structural changes in production processes and demand. These changes will also change the labor market; (v) employment in green areas can change the employment structure of labor-intensive sectors, particularly by reducing environmental pressure on production of goods and services. For instance, top ten sectors which are responsible for 83% CO_2 emissions of EU-25 countries also account for 28% of total employment, and the value added generated in these sectors is 21%. Similarly, the most polluting industries have a 14% employment rate in OECD countries (OECD 2012). Therefore, unemployment in these areas can create a moderate decline (OECD 2017a). In addition, green energy can create net job creation gains by compensating for labor force losses in dirty industries (ILO 2016). However, the potential for job creation in the renewable energy sector has advantages and disadvantages. The most remarkable of these disadvantages is the high green energy costs. Although many green technologies do not include fuel costs, they have high cost than traditionally energy-producing areas. High labor costs also constitute an important part of the cost structure of green technologies (Gülen 2011:

8). A model has been developed for OECD countries on the impact of costs and the smooth transition of labor (see Fig. 6.1).

In the model, the impact of strategies to reduce climate change in terms of environment and employment is discussed. The model demonstrates that a well-designed emission transmission reduces GHG emissions and also maintains growth. The key point in this figure is that jobs can easily be transferred from sectors where employment will fall, especially from the fossil fuel industries, to sectors such as renewable energy industries where business opportunities are rising rapidly. However, countries that have fossil-based energy will be more affected by this activity. At this stage, the model for OECD countries shows that when seamless adaptation to labor market employment opportunities and losses is achieved, the impact of the Greenhouse Gas Reduction policy on GDP growth is small; however, it shows that the costs have increased significantly if the workers in the labor-diminishing sectors become unemployed elsewhere due to change and incompetence. Therefore, by providing flexibility in labor markets, using carbon tax revenues to reduce taxes on labor income can reduce the negative impact of environmental policies on employment (OECD 2017b). In addition to this, turn toward green job policies requires shifting from coal-based industry to renewable energy production. In order to be successful in this field, it is necessary to introduce supportive tax applications to renewable energy producers and users, to establish renewable portfolio standards and to support other industries (Acey and Culhane 2013: 1047). However, it is limited to measure the impact of renewable energy or green energy policies on the labor force or to determine the effects of job creation and job destruction. In particular, it needs to specify the factors of smooth transitions from dirty industry to green industry. Therefore, the current labor market flexibility is important for green job creation (OECD 2017b).

Against this backdrop, it is a crucial to understand the job creation effect on green energy. Accordingly, the nexus between green energy and job creation has been examined for 18 OECD countries for the period from 1990 to 2015. The reason for focusing on these countries is due to their renewable energy consumption and the rate of primary energy supply. In recent years, the promotion of renewable energy sources in OECD countries has become very important. In particular, policy makers have started to adopt renewable energy programs to improve socioeconomic problems from climate change to unemployment (EU 2009: 16). When the rate of primary energy supply is about 13%, the rate is 9% in OECD countries in 2017. The renewable energy consumption (% of total final energy consumption) is 12% for OECD countries in 2015 (OECD 2019; World Bank 2019). In addition, investments in renewable energy technology and the number of patents applied in these countries are increasing. In the field of environmental technologies, patent rate of the OECD countries in 2015 is %9.6. This rate is above the world average (%9.1) (OECD 2019). So that these countries are able to create the benefit from green job or job creation in the green energy to sustain the green growth and green development.

As the scope of this, by using second-generation panel data methodologies to consider the cross-sectional dependence among OECD countries, the link between green energy consumption, government expenditures, GDP per capita, gross fixed capital formation and unemployment are investigated.

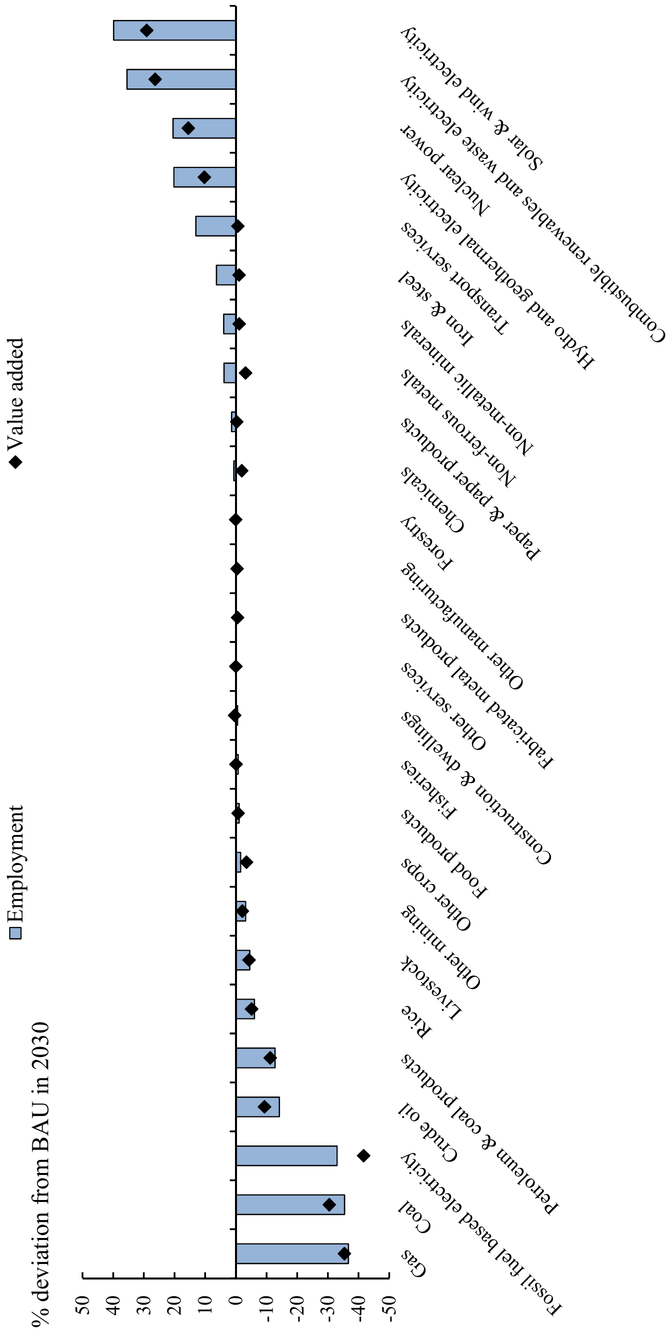

Fig. 6.1 Sectoral changes in employment with ambitious climate change mitigation policies, OECD countries in % deviation from the business-as-usual (BAU) scenario in 2030 (OECD 2017)

The contributions of the study to the current literature offer some advantages in many fronts. First, to the best of our knowledge, this is the first study that investigates the job creating effect of green energy usage in OECD countries. Second, since bivariate empirical models may lead to invalid results, this study uses a multivariate empirical model. Third, the study employs the second-generation panel data methodologies to consider the possible cross-sectional dependence among countries. Fourth, the impact of green energy consumption is also examined for each OECD countries to give policy implications in detail.

The rest of paper has been organized as following: Sect. 6.2 reviews the literature. Section 6.3 explains methodological framework. Section 6.4 reports empirical results. Finally, conclusion and policy implications are in Sect. 6.5.

6.2 Literature

The concept of green economy, which has an important role in the economy of the future in recent years, draws attention especially in terms of its effects. When we look at the effects of the green economy, particularly it is not easy to say anything clear about the impact of green energy on job creation. Because there is a little information in the literature about the link between green economy and job creation, the findings from these few studies seem to conflict (Yu and Jin 1992; Cheng 1995). In the literature about green energy and job creation, some studies express that the investments in renewable energy sources and its technology lead to more labor force than investments in other sectors (Gülen 2011: 8). However, other studies indicate that the concept of green job will not solve any critical environmental problems (Forstater 2006: 589). In addition, Lambert and Silva (2012) stated that there is no clear conclusion about the impact of renewable energy on employment in their studies in which they examine the difficulties in determining the employment effects of renewable energy. They have concluded that the promotion of renewable energy in the region can have a net increase in the employment rate in the country (Sastresa et al. 2010: 679–690), little impact on the national scale (Hillebrand et al. 2006: 3484–3494) or a slight net impact on the international scale (Lambert and Silva 2012: 4673).

Green job is categorized as direct, indirect and induced employment effect on the economy. Direct employment refers to the employment created by the renewable energy sector itself. It covers all business opportunities that will arise during the production or use of renewable energy technologies such as production stages, installation, project management and maintenance repair. Indirect employment includes employment in sectors in the supply chain. In other words, it refers to the employment encountered in the sectors providing input or services to the renewable energy sector (Wei et al. 2010: 920–921). For example, the task of installing solar power electrical panel is a direct employment, while manufacturing the steel that is used to build the solar power electrical panel is an indirect employment. On the other hand, although induced employment does not have a direct connection with the renewable energy sector, it indicates employment changes in other sectors due to the developments in this sector such as non-industry jobs created (Meyer and Sommer 2014: 7; Wei et al. 2010: 921). Yi (2013) examines the impact of promoting renewable energy and energy efficiency on green jobs creation in U.S. metropolitan areas for 2006. According to the results of the regression analysis, clean energy policies in both the state and the local area have a positive effect on the green jobs at the metropolitan level. Blanco and Rodrigues (2009) investigate the impact of wind energy on employment for all EU countries. As a result of the study, wind energy deployment leads to an increase in employment level. Simas and Pacca (2014) examine the effects of renewable energy technologies on employment in Brazil in the context of wind energy. This study concludes that renewable energy technologies make a significant contribution to employment increase especially in the production and construction of wind turbines.

There are a great number of studies examining the energy consumption and economic growth (see as an example, Coondoo and Dinda 2008; Dinda and Coondoo 2006; Akbostanci et al. 2009; Lee and Lee 2009; Cai et al. 2018) or renewable energy and economic growth (see as an examples Menyah and Rufael 2010; Apergis and Payne 2012; Ocal and Aslan 2013; Salim et al. 2014; Destek and Aslan 2017) nexus in the literature review on green energy. The direction of causality between energy consumption and economic growth tested by either employment or real output is impressed by four hypotheses, and a great number of studies are based on these four hypotheses: growth hypothesis, conservation hypothesis, neutrality hypothesis and feedback hypothesis. First, the growth hypothesis expresses that energy consumption increases economic growth directly. This hypothesis is supported the unidirectional causality from energy consumption to real output or employment. Stern (2000) in the US, Wolde-Rufael (2004) in Shanghai and Soytas and Sari (2006) in G7 countries find that the growth hypothesis is valid. Second, the conservation hypothesis implies that there is a unidirectional causality coming from real output to energy consumption. It explains the energy usage is determined by economic growth. Sadorsky (2009) and Brini et al. (2017) find validated the conservation hypothesis. Third, the neutral hypothesis implies that the effect of energy consumption on economic growth is either absent or negligible. This hypothesis shows that there is no causality between energy consumption and GDP growth. According to the study results of Chiou-wei et al. (2008) and Ocal et al. (2013), neutrality hypothesis is supported. Finally, the feedback hypothesis explains that a bidirectional causality is valid between energy consumption and economic growth. This hypothesis is supported with the studies of Yoo (2005), Mahadevan and Asafu-Adjaye (2007), Tiwari (2010) and Zafar et al. (2019).

Some other authors examine the nexus between energy consumption and employment/unemployment. Murry and Nan (1990) probe the link between energy consumption and employment and find that there is a unidirectional causality from total employment to energy consumption in the USA. Cheng (1998) tests the causality relationships between energy consumption and employment in Japan. The findings of the study reveal that the employment causes directly energy consumption, while energy consumption negatively affects the employment level. Cheng et al. (1998)

test the causality relation between energy consumption and employment in the USA. The results reveal that there is no causality from energy consumption to employment, but there is a unidirectional causality from employment to energy consumption. In addition, the reducing energy consumption may have a positive impact on environmental pollution; however, it may not have a significant impact on employment. Chang et al. (2001) research the evidence between output, employment and energy consumption for Taiwan from 1982 to 1997. The empirical results show that there is a bidirectional causality between employment and energy consumption. Moreover, Narayan and Smyth (2005) examine the relationship between real income, employment and electricity consumption in Australia over the period from 1966 to 1999. The empirical results show that in the long run, there is a unidirectional causality from employment to electricity consumption. On the other hand, Oxley et al. (2004) research the nexus between energy consumption and employment and find that there is a unidirectional link electricity consumption to employment in New Zealand for 1960–1999. Payne (2009) investigates the causal relationships between energy consumption and employment in Illinois during 1976–2006, and according to the results of Toda–Yamamoto causality test, there is a unidirectional causality running from energy consumption to employment. This finding supports the growth hypothesis. Ghosh (2009) explains the relationship between real GDP, employment and electricity supply in India from 1970–1971 to 2005–2006. According to the Granger causality test results, the author finds that causality runs from electricity supply to employment without any feedback effect. This finding refers that the supply of electricity leads to a higher employment in India. In addition, Besel (2017) examines the causality between energy consumption and unemployment in Turkey during 1980–2015 and finds that there is a unidirectional causality coming from energy consumption to unemployment rates. Furthermore, Bhutta and Khan (2018) test the linkage between industrial GDP, industrial electricity consumption and industrial employment. The results reveal that there is a long-run relationship between variables and industrial electricity has a close relation with industrial GDP and employment. The findings show that in case of the electricity does not available in the industry, both industrial unemployment will emerge and economic growth will be adversely affected.

In the literature, some researchers use oil price for investigating relationship between energy consumption and unemployment such as Gil-Alana (2003), Yahia and Saleh (2008) and Robalo and Salvado (2008). Papapetrou (2001) in Greece and Chang and Wong (2003) in Singapore and Lescaroux and Mignon (2008) in non-OPEC member 36 countries find that a shock in oil prices has a negative impact on unemployment. However, Umar and Abdulhakeem (2010) investigate the oil price and unemployment nexus in Nigeria for the period from 1970 to 2008 and report that an increase in oil prices reduces the level of unemployment. On the other hand, Chang et al. (2011) in Asia and Ocean Countries and Bouchaour and Al-Zeaud (2012) in Algeria find no relationship between oil prices and unemployment.

George and Oseni (2012) estimate the relationship between unemployment and electricity consumption in Nigeria for the period from 1970 to 2005 and find that unemployment is affected by electricity consumption. An increase in electricity consumption decreases unemployment level. Apergis and Salim (2015) test the relationship between renewable energy consumption and unemployment for 80 countries in 1990–2013. The total empirical results illustrate that the renewable energy consumption has a positive effect on unemployment. In addition, Bilgili et al. (2017) probe the relationships among energy consumption and youth unemployment in 20 European countries spanning the period 1990–2011. According to the results of the study, it reveals that there is a unidirectional causality from energy consumption to youth unemployment levels. Moyo et al. (2017) research the nexus among renewable energy consumption and unemployment in South Africa for the period from 1990 to 2014 and report that the renewable energy consumption effects unemployment negatively in the long run, while there is a insignificant relationship between renewable energy consumption and unemployment in the short run. Rafiq et al. (2018) test the linkage among energy and unemployment for 41 countries during 1980–2014 and report that renewable energy consumption leads to an increase in unemployment. Moreover, Tatli and Barak (2019) test the nexus between energy consumption and female unemployment in 29 OECD countries in 1991–2015. The results of the study show that there is a bidirectional causality nexus between energy consumption and female unemployment. Moreover, unemployment rate of women is adversely affected by energy consumption. Afolayan et al. (2019) examine the effect of electricity consumption on unemployment in Nigeria. According to the results of the study, an increasing in the electric consumption leads to decrease in the unemployment level.

6.3 Empirical Strategy

6.3.1 Empirical Model and Data

In order to examine the job creation effect of green energy in OECD countries, following the study of Apergis and Salim (2015), the empirical model is constructed as following:

$$\ln\mathrm{UNE}_{it} = \alpha_0 + \alpha_1 \ln\mathrm{GDP}_{it} + a_2 \ln\mathrm{CAP}_{it} + a_3 \ln\mathrm{GOV}_{it} + a_4 \ln\mathrm{GEC}_{it} + e_{it} \quad (6.1)$$

where UNE implies the unemployment level, GDP indicates the economic growth, CAP means the capital accumulation, GOV indicates the government activities and GEC is used as a proxy for green energy consumption. In this context, unemployment is proxied by unemployment rates, economic growth is proxied by real GDP per capita in constant 2010 US $, capital accumulation is proxied by gross fixed capital formation share in GDP, government activities are proxied by government expenditures share in GDP and green energy consumption is indicated by renewable energy consumption share in total energy usage. All variables are used in natural logarithmic form, and data sets are obtained from World Development Indicators of World Bank. In empirical analysis, the annual data of 1990–2015 is used.

6.3.2 Methodology

6.3.2.1 Cross-Sectional Dependence Test

The first-generation panel data methodologies are based on the assumption that the shocks of cross-section are independent. However, especially for country group studies, the cross-sectional independence among the countries is almost impossible. Therefore, in this study, we utilized with the cross-sectional dependence (CD) test that developed by Pesaran (2004) to check the possible cross-sectional dependence. The main model of the test can be described as follows:

$$\mathrm{CD} = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(\hat{\rho}_{\mathrm{ij}}\right)N(0,1) \tag{6.2}$$

where N implies the cross-section dimension and T states the time period. In addition, $\hat{\rho}_{\mathrm{ij}}$ is the sample estimate of the pairwise correlation of the residuals.

6.3.2.2 Panel Unit Root Test

We examine the unit root process of variables with CIPS unit root test developed by Pesaran (2007) because the test considers the cross-sectional dependency in the panel. In testing procedure, the null hypothesis of unit root under cross-sectional dependency is tested against the alternative which implies the stationary process. Before describing the formulization CIPS test, the CADF test should be described because CIPS test is mainly based on the CADF unit root test. The main regression model of CADF test can be written as follows:

$$\Delta y_{it} = a_i + \rho_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{k}\gamma_{ij}\Delta\bar{y}_{it-1} + \sum_{j=0}^{k}\delta_{ij} y_{it-1} + \varepsilon_{it} \tag{6.3}$$

where a_i, k and $\bar{y}_t$ are deterministic term, lag order and the cross-sectional mean of time *t,* respectively. In next stage, *t*-statistics are computed with the *ADF* statistics for each cross-section. Then, averaging CADF statistics for each cross-section gives the CIPS statistics as follows:

$$\mathrm{CIPS} = \left(\frac{1}{N}\right)\sum_{i=1}^{N} t_i(N,T) \tag{6.4}$$

Finally, the critical values of CIPS test with different deterministic terms are obtained from Pesaran (2007).

6.3.2.3 Panel Cointegration Test

In this study, the existence of the long-run nexus between variables is tested by the error correction-based panel cointegration method of Westerlund (2007). Yielding the case of heterogeneity and cross-sectional dependence are the main advantages of Westerlund cointegration test. Moreover, when the explanatory variables are weakly exogenous, the test shows better size accuracy and higher power than the residual-based cointegration (Westerlund 2007). In testing procedure, there are four statistics (G_t, G_α, P_t, P_α) to test the null hypothesis of there is no cointegration. G_t and G_α statistics are mean group statistics that are constructed with the assumption of unit-specific error correction parameters. The latter two statistics are computed under the assumption of common error correction parameters across cross-sections.

6.3.2.4 Panel Coefficient Estimator

In study, the impact of explanatory variables on unemployment rate is examined with the common correlated effect mean group (CCE-MG) estimator developed by Pesaran (2006) to take into account the cross-sectional dependence. Before obtaining the coefficients, first the Eq. 6.1 is combined as follows:

$$Y_{it} = \delta_0 + \delta_1 X_{it} + e_{it} \tag{6.5}$$

where Y_{it} is unemployment, $X_{i,t}$ is the vector of independent variables and the residual term (e_{it}) is a multifactor residual term. The multifactor residual terms are constructed as follows:

$$e_{it} = \lambda_i' UF_t + u_{it} \tag{6.6}$$

where UF_t is the $m \times 1$ vector of unobserved common factors. In addition, Pesaran (2006) utilizes with cross-sectional averages, $\overline{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{it}$ and $\overline{X}_t = \frac{1}{N}\sum_{i=1}^{N} X_{it}$ to deal with cross-sectional dependence of residuals as observable proxies for common factors. In the next step, slope coefficients and their cross-sectional averages are consistently regressed as follows:

$$Y_{it} = \delta_0 + \delta_1 X_{it} + a\overline{Y}_t + c\overline{X}_t + \varepsilon_{it} \tag{6.7}$$

Pesaran (2006) refers to the computed OLS estimator $\widehat{B}_{i,\mathrm{CCE}}$ of the individual slope coefficients $B_i = (\delta_1, .., \delta_n)$ as the "Common Factor Correlated Effect" estimator:

$$\widehat{B}_{i,\text{CCE}} = \left(Z_i' \overline{D} Z_i\right) Z_i' \widehat{D} Y_i, \tag{6.8}$$

where $Z_i = (z_{i1}, z_{i2}, \ldots, z_{iT})'$, $z_{it} = (X_{it})'$, $Y_i = (Y_{i1}, Y_{i2}, \ldots, Y_{it})'$, $\overline{D} = I_T - \overline{H}\left(\overline{H}'\overline{H}\right)^{-1}\overline{H}$, $\overline{H} = (h_1, h_2, \ldots, h_T)'$, $h_t = \left(1, \overline{Y}_t, \overline{X}_t\right)$ as the CCE estimators. The CCE-Mean Group estimator is obtained with the average of the individual CCE estimators as follows:

$$\widehat{B}_{\text{CCEMG}} = \sum_{i=1}^{N} \widehat{B}_{i,\text{CCE}}. \tag{6.9}$$

6.4 Empirical Findings

In empirical procedure, considering the possible cross-sectional dependence among observed countries has begun to increase the importance with recent development in panel data econometrics. Therefore, it is important to determine the interdependence among countries and to decide which panel methods should be used on the basis of policy recommendations. Based on this, we first check the possible dependence among OECD countries using with cross-sectional dependence (CD) test of Pesaran (2004) and show the results in Table 6.1.

According to the results from CD test, it can be seen that the null of there is no cross-sectional dependence is strongly rejected, and thus, the dependence among OECD countries is confirmed. This finding means a possible shock in one of the OECD countries may easily be transmitted to the other countries. Therefore, we should use the second-generation panel data methods instead of first-generation tests because using the first-generation panel data methods which ignore the dependency leads to invalid empirical findings.

In the second step of empirical analysis, we used the CIPS unit root test of Pesaran (2007) which allows the cross-sectional dependency to observe the stationary properties of variables, and the results are illustrated in Table 6.2. The results reveal that the null of unit root is not rejected in the level form of variables. However, all variables have become stationary in first differenced form. Because of the finding that all variables are integrated of order one $I(1)$, this finding allows us to examine the possible cointegration relationship between variables.

Table 6.1 Results of cross-sectional dependence test

	lnUNE	lnGDP	lnCAP	lnGOV	lnGEC
CD test	7.450***	58.090***	4.940***	15.650***	12.220***
p-value	0.000	0.000	0.000	0.000	0.000

Note *, ** and *** indicate statistically significance at 10, 5 and 1% level, respectively

Table 6.2 Results of panel unit root tests

	lnUNE	lnGDP	lnCAP	lnGOV	lnGEC
Level					
CIPS stat	−2.329	−2.273	−2.538	−1.841	−2.323
First difference					
CIPS stat	−3.247***	−3.744***	−4.028***	−4.167***	−5.379***

Note Critical values for 1, 5 and 10% level are −2.830, −2.670 and −2.580, respectively. *** indicates statistically significance at 1% level

In the next step, we examine the cointegration relationship between variables using with the ECM-based panel cointegration technique that developed by Westerlund (2007). The panel cointegration test results from Table 6.3 show that the null hypothesis of there is no cointegration is rejected by three (G_a, P_t and P_a) of four statistics. This finding means that there is long-run relationship between unemployment, real GDP, capital accumulation, government activities and green energy consumption, and thus, the long-run impacts of explanatory variables on unemployment should be investigated.

We examine the long-run coefficients of explanatory variables using with common correlated effect (CCE) estimation procedure of Pesaran (2006), and the findings are presented in Table 6.4. At a first glance, it seems green energy consumption does not have a job creating effect in OECD countries because the coefficient of green energy consumption is not statistically significant, while the sign of this coefficient is negative. In addition, we conclude that economic growth reduces unemployment level in OECD countries. This finding is partly consistent with the argument of

Table 6.3 Results of panel cointegration test

	Statistics	*p*-value
G_t	−2.083	0.330
G_a	−1.724*	0.070
P_t	−6.592***	0.000
P_a	−1.548*	0.060

Note *, ** and *** indicate statistically significance at 10, 5 and 1% level, respectively

Table 6.4 Results of panel long-run coefficient estimator

	Coefficient	*t*-stat	*p*-value
lnGDP	−2.074**	−2.430	0.015
lnCAP	−1.204***	−2.980	0.003
lnGOV	0.503	1.240	0.216
lnGEC	−0.014	−0.090	0.930

Note *, ** and *** indicate statistically significance at 10, 5 and 1% level, respectively

Okun's Law. Moreover, we found that increasing capital accumulation reduces the unemployment rate, while government expenditures do not have significant impact on unemployment.

Table 6.5 Country-specific results of panel long-run coefficient estimator

Country	lnGDP	lnCAP	lnGOV	lnGEC
Australia	−1.185 [0.549]	−1.068* [0.055]	1.125 [0.245]	0.370 [0.210]
Canada	−1.982*** [0.000]	−0.078 [0.673]	0.366 [0.190]	−0.906** [0.022]
Finland	−1.027*** [0.004]	−0.604 [0.464]	−0.962 [0.460]	1.028 [0.140]
France	−1.753*** [0.008]	−1.392** [0.013]	0.138** [0.040]	−0.386* [0.094]
Greece	−1.474*** [0.000]	0.467 [0.130]	0.160 [0.700]	0.378 [0.222]
Iceland	1.440 [0.330]	−0.977** [0.024]	1.541 [0.197]	−0.172 [0.901]
Ireland	−0.666 [0.670]	−1.418*** [0.003]	0.739 [0.530]	0.183 [0.588]
Israel	−1.278* [0.094]	−0.243 [0.619]	−0.101 [0.892]	−0.277** [0.034]
Japan	−1.972 [0.172]	0.722 [0.530]	0.928 [0.125]	−0.163 [0.576]
S. Korea	−1.994 [0.331]	−1.502*** [0.000]	−1.859 [0.349]	−0.192 [0.287]
Mexico	−1.892*** [0.002]	0.025 [0.971]	−0.534 [0.521]	−1.844*** [0.007]
Netherlands	−2.278*** [0.000]	−1.384 [0.183]	1.949 [0.136]	−0.181 [0.692]
New Zealand	1.922 [0.116]	−2.703*** [0.000]	−0.238 [0.762]	−0.736* [0.083]
Norway	−1.423 [0.554]	−1.827*** [0.007]	−1.251** [0.045]	0.102 [0.941]
Portugal	−0.664*** [0.007]	0.450 [0.577]	−0.827 [0.483]	0.797** [0.013]
Sweden	−1.324 [0.513]	−1.540*** [0.000]	−2.854** [0.026]	−0.006 [0.989]
Turkey	−1.393 [0.379]	0.602 [0.313]	−0.336 [0.576]	0.940* [0.082]
United States	0.105 [0.395]	−2.206** [0.045]	1.582** [0.028]	0.035 [0.824]

Note *, ** and *** indicate statistically significance at 10, 5 and 1% level, respectively. Numbers in brackets are *p*-values

Finally, we check the country-specific effects of explanatory variables on unemployment rate by CCE estimator. The results from Table 6.5 show that economic growth reduces the unemployment in Canada, Finland, France, Greece, Israel, Mexico, Netherlands and Portugal. Furthermore, capital accumulation reduces unemployment in Australia, France, Iceland, Ireland, South Korea, New Zealand, Norway, Sweden and the USA. However, it is found that government activities do not have positive impact on employment most of the OECD countries excluding Norway and Sweden. On top of it, government expenditures increase unemployment in France and the USA. When we evaluate the impact of green energy consumption on unemployment, it seems green energy sector creates new employment areas in Canada, France, Israel, Mexico and New Zealand. On the other hand, increasing green energy consumption increases unemployment in Portugal and Turkey.

6.5 Conclusions and Policy Implications

This study investigates the role of green energy sector development on employment in 18 OECD countries spanning the period of 1990–2015 by analyzing the long-run impact of economic growth, capital accumulation, government activities and green energy consumption on unemployment rate. In doing so, the second-generation panel data methodologies are employed to take into account the cross-sectional dependence among OECD countries.

The results of empirical study for panel group show that economic growth and capital accumulation reduce unemployment rate in these countries. However, we found the evidence that neither increasing government activities nor increasing green energy usage contributes to employment level of countries. In case of country-specific findings, it is found that economic growth contributes to employment level in many observed countries such as Canada, Finland, France, Greece, Israel, Mexico, Netherlands and Portugal. This finding implies that the Okun's Law is verified for these countries. However, for the countries where economic growth does not reduce unemployment, it can be inferenced that increased wealth is not used to create the new employment areas. Similarly, the employment rate increasing impact of capital accumulation is also confirmed for many OECD countries such as Australia, France, Iceland, Ireland, South Korea, New Zealand, Norway, Sweden and the USA. Therefore, it is concluded that capital accumulation contributes to employment especially in developed OECD countries and it does not reach a level that will create employment increasing effect in less developed OECD countries. In addition, the unemployment reducing effect of government activities is found in Norway and Sweden. It is an expected finding because the government activities of most of the countries do not mainly focus on employment excluding the Scandinavian countries which follows Nordic Welfare State model. On the contrary to the panel evidence, empirical evidences for each country show that green energy consumption reduces unemployment rate in Canada, France, Israel, Mexico and New Zealand. For the other OECD countries, it can be said that the inefficient green energy sector on employment can be associated with higher technological cost of green energy sources.

Overall, based on the empirical findings of this study, some crucial inferences and policy recommendations can be made. First of all, it is a well-known fact that green energy sector developments require advanced technology thus skilled and well-educated labor force. If high-tech green energy investments increase, but employment does not increase sufficiently, this is largely due to the insufficient quality of the labor force for green energy sector. Therefore, the education system of countries where green energy sector developments do not lead to increasing employment should be reviewed and guided according to the needs of the sector. In addition, the governments also should provide some tax benefits, subsidies, price guarantees and easy financing opportunities encouraging the sector to increase employment level of the green energy sector.

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Chapter 7
Human Capital, Green Energy, and Technological Innovations: Firm-Level Analysis

Muhammad Shujaat Mubarik and Navaz Naghavi

Abstract The study had three overarching objectives. The first aim of the study was to comprehensively review the role that a firm's human capital played in promoting energy efficiency and green energy. Second aim was to review the role of technological innovation in the relationship between a firm's human capital and energy consumption (green and non-green). Third aim was to provide any empirical evidence on the relationship between human capital and energy consumption keeping technological innovation as moderator. After reviewing the literature, we developed two equations to examine the quadratic relationship between HC and energy consumption by taking technological innovation as a moderating variable. Pakistan's manufacturing sector was taken as a case, and data from 635 manufacturing firms were used for analysis. The study employed the panel feasible generalized square approach for the analysis. The results confirmed the existence of EKC-type inverted U-shape relationship between HC and non-green energy and an inverted U-shape curve in the relationship of HC and green energy consumption. Our results concurred broadly with the other studies conducted on the HC-energy consumption dyad. Our findings imply that industries with a higher level of HC and technology innovation can quickly substitute non-green energy with green energy consumption.

Keywords Human capital · Green energy · Non-green energy · Panel feasible generalized square · Quadratic relationship · EKC

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7.1 Introduction

It is a proven fact that energy plays a critical role in the industrial development of nations. However, what are the various sources of that energy is a key concern worldwide. Due to the devastating effects of non-green energy (non-renewable energy) on the environment, it is being globally emphasized to substitute it with green energy (renewable energy). In Paris accord, leaders from all the nations agreed to take the sustainable measures to decrease the global temperature to the level of the pre-industrialization era (Salim et al. 2017; IPCC 2014). Firms in every country are facing the increasing pressures to either abandon or reduce their dependence upon non-green energy and switch toward the consumption of green energy. To do so, a number of firms are revisiting their energy policies and trying to take all the possible measures to reduce the non-green energy consumption. Firms are considering both external and internal factors to go green. Human capital (HC), in this context, is appearing as a critical internal factor of a firm that profoundly influences a firm's energy consumption patterns (Lutz et al. 2014). Researchers (e.g., Munro and Lan 2013; Shahbaz et al. 2018) consider HC a major precursor for reducing the non-green energy consumption and turn a firm sustainable. Munro and Lan (2013) argue that a firm's human capital—Munro and Lan (2013) termed it internal human capital—pushes it to use green energy. Studies (e.g., Wheeler and Pargal 1999; Dasgupta et al. 2000; Goldarand and Banerjee 2004; Munro and Lan 2013; Lee et al. 2015; Shahbaz et al. 2018) argue that human capital has a profound effect on a firm's energy consumption. These studies explain that organizations with a higher level of human capital tend to adopt those technologies which are energy efficient and are compatible with green energy sources. Further, the firms with a higher level of human capital may have a higher tendency to use green energy.

Surprisingly, a great body of literature focuses upon the association of human capital and energy consumption at a macro level; however, this relationship has been lesser discussed at the firm level. Particularly, the question as to how human capital development is linked with the consumption of renewable energy is yet to be addressed. Anecdotal evidence and inferences from macro literature (Shahbaz et al. 2018, 2019) suggest a U-shape relationship between human capital and green energy[1] consumption and inverted U-shape between human capital and non-renewable energy consumption. Nevertheless, it is hard to find any scholastic work explicitly studying these relationships at the firm level. This may be one of the reasons that firm-level policies on green energy hardly take into account this paradox. Against this backdrop, we argue that without knowing as to how the green and non-green energy consumption will increase in response to an increase in the human capital of a firm, all the efforts to turn a firm green may not be truly fruitful. This book chapter undertakes this task and doing so contributes to the literature on green energy in the following ways. First, the chapter elucidates on the impacts of a firm's human capital on its energy consumption (both green and non-green). Second, it integrates the work on human

[1] From here onward word "green energy" will be used as substitute of renewable energy, until unless specified.

capital at macro-level with firm-level literature and presents a model to study the association between human capital and energy consumption (green and non-green). Thirdly, the study examines the role of technological innovation in the relationship between human capital and energy consumption. Fourthly, by taking Pakistan as a case, the study provides the empirical evidence on modeled relationships.

The rest of the chapter has been divided into four sections. The subsequent section reviews the literature on human capital, energy consumption, and technological innovation. Section 7.3, methodology, undertakes the research methodology applied to test the proposed framework. The last section concludes the chapter by providing theoretical, managerial, and policy implications.

7.2 Literature Review

7.2.1 Green Energy and Human Capital

Human capital is an essential factor that influences both the demand and supply of energy (green and non-green) in an organization. A number of researchers (e.g., Gangadharan 2006; Blackman and Kildegaard 2010; Manderson and Kneller 2012) argue that an increase in human capital leads to increase consumption of green energy and tends to decrease the consumption of non-green energy. For example, Blackman and Kildegaard (2010), using firm-level data, consider the human capital one of the major factors influencing to firm's choice of technologies. They showed that Mexican firms with a higher level of human capital preferred adopting clean and energy-efficient technologies. In such a case, an increase in the level of human capital tends to decrease the non-green energy consumption. Their argument is rooted in the fact that better-educated workers could be more instrumental in adopting the energy efficiency practices and policies. Contrarily, according to Özçiçek and Ağpak (2017), employees with low human capital (unskilled and low-educated) may possess insensitive behavior toward green energy consumption and may act as a barrier to energy efficiency. On the same lines, Manderson and Kneller (2012) assert that organizations with a greater stock of human capital tend to use the technologies which are energy efficient, compatible with green energy usage, and abate pollution.

Nevertheless, some of the studies (e.g., Fang and Chen 2017; Shahbaz et al. 2019) claim that an increase in human capital increases the consumption of non-green energy. They argue that increasing levels of human capital requires to undertake more tasks requiring more energy to consume. Since the immediate, accessible, and cheaper source of energy is non-green, it is used to meet the increase in energy demand.

Further, some of the researchers (e.g., Kargbo et al. 2016; Fang and Chen 2017) assert that human capital also affects a firm's supply of green energy. Kargbo et al. (2016) mention that the quality of human capital along with financial development and technological management plays a critical role in a firm's supply of green energy.

They claim that firms in large sizes have the capacity to develop green energy generation systems coherent to their needs by collaborating with the local green energy industry. In doing so, these firms can take lead in the drive toward greenness through green energy innovation. After reviewing the literature on human capital and energy consumption, we can find a few major research gaps. First, the majority of the studies discussing human capital-energy association do not differentiate between the firm-level and country-level human capital. These studies generalize the results obtained using the national or cross-national data on the firm-level human capital. In reality, the crude generalization of these results is not only risky but can lead firms toward the ineffective policy formulation and execution. Second, researchers studying the HC-energy association can be divided into two groups. First, the group of researchers claims that the increase in human capital increases the consumption of non-green energy as the increasing levels of HC require to undertake new tasks, which require energy consumption. The immediate, cheaper, and accessible source of energy is non-green energy which is then used to perform new tasks. This leads to an increase in the consumption of energy. The second group of researchers claims that increasing levels of human capital lead to an increase in environmental awareness, knowledge, and skills. It helps organizations to be energy efficient and to substitute the non-green energy consumption with that of green energy. Researchers (Ahmed et al. 2016; Shahbaz et al. 2018) argue that environmental awareness among employees makes tend to change their energy consumption behavior. Employees with higher human capital consume energy more efficiently and also push the organization to adopt green energy. Such employees can also be instrumental in adopting technologies that are more energy efficient and compatible with green energy sources.

The apparently contrasting findings of the studies cited above require referring back to the environmental Kuznets curve (EKC) of Grossman and Krueger (1991). For EKC, the association between environmental degradation and economic development is an inverted U shape. Here, we claim that the relationship between firm-level human capital and the non-green energy consumption is inverted U-shape (Fig. 7.1). It implies that with the increase in a firm's human capital, its consumption of non-green energy increases at the initial stage. After a specific turning point, the consumption

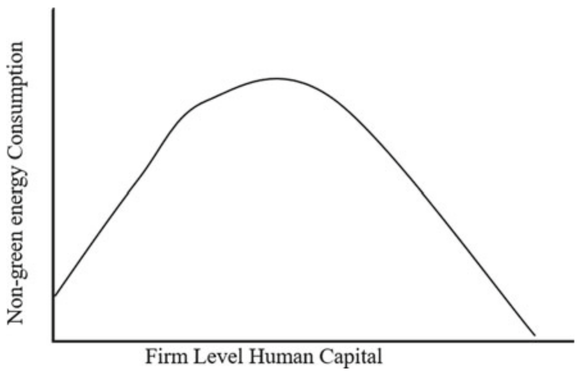

Fig. 7.1 Firm-level human capital and non-green energy consumption. *Source* author

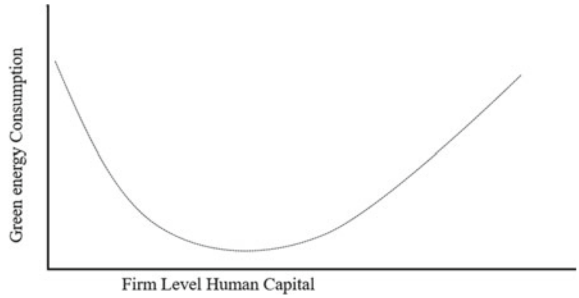

Fig. 7.2 Firm-level human capital and green energy consumption. *Source* author

of non-green energy tends to decrease with every unit increase in a firm's human capital. Further, we claim that the association between a firm's human capital and green energy is U-shape (Fig. 7.2). It implies that at the initial stage, an increase in human capital decreases the proportion of green energy consumption in total energy consumption. After a specific turning point, this relationship becomes direct.

7.2.2 Technological Innovation in Energy-Human Capital Dyad

For the promotion of energy efficiency and green energy, three important factors are required to be looked at. These are human behavioral issues, appliances (technology), and design (Hussaini and Majid 2014). Human capital in interaction with technological innovation can profoundly overcome these three important issues. First, a higher level of human capital—education, awareness, skills, ability—makes employees aware as to why the energy efficiency and shift toward green energy are essential required. By developing employees green behaviors, it overcomes the behavioral issues. Second, the dyad of human capital-technological innovation results in energy effects and green energy compatible technology and designs.

Third, human capital in interaction with technological innovation could produce renewable energy at low costs, which in turn causes energy efficiency. The literature on energy efficiency applauds the role that technological innovation pays in reducing the consumption of non-green energy; however, it becomes more effective when interacting with human capital. This greatly influences firms to shift toward energy-efficient technologies and adopting green energy sources (Li and Lin 2016; Kalim et al. 2019). For Li and Lin (2016), human capital through higher R&D for the latest green energy sources may lead to a quick shift to energy-efficient technologies. Particularly, education being the central dimensions of human capital augments human resources learning capacities, awareness, technological adoption, and innovation. Therefore, individuals possessing a higher level of education may tend to adopt green technological innovations. This may increase the usage of green energy.

Human capital in interaction with technological innovation affects both demand and supply side of green energy. Seetharaman et al. (2016) underscore the lack of human capital and technological innovation as the major hurdles in the way of green energy adoption. Concurring to Seetharman et al. (2016), Shove (2017) mentioned the lack of human capital (measured as knowledge) and a lesser understanding of green energy technologies as the major reasons for inadequate demand of green energy.

From the supply-side perspective, the juxtaposition of HC and the supply of green energy depends upon technological development and innovation capacity and the ability to manage technology diffusion. From a broader perspective, the triad of human capital, technological innovation, and green energy goes hand-in-hand. Where improved human capital may increase the level of innovations, there higher level of technological innovation may result in the consumption of green energy.

Putting together, the literature on the role of technological innovation (e.g., International Energy Agency 2008; Fisher-Vaden et al. 2004; Ke et al. 2013; Li and Lin 2016; Wilson and Tyfield 2018; Kalim et al. 2019) argues that technological innovation influences the human capital's energy consumption patterns. It leads us to draw the argument that technological innovation plays a profound role as a context in HC-energy (non-green and green) consumption patterns.

7.3 Model and Variables

We have developed the following two models to analyze the relationship of human capital with energy consumption (green and non-green) (Table 7.1).

$$NRE_{it} = \beta + \delta_1 HCI_{it} + \delta_2 HCI^2_{it_2} + \delta_3 HCI * TIN_{it} + \delta_4 XCH_{it} + \delta_5 OP_{it} + \varnothing_{it} \tag{7.1}$$

$$RE_{it} = \beta + \delta_1 HCI_{it} + \delta_2 HCI^2_{it_2} + \delta_3 HCI * TIN_{it} + \delta_4 XCH_{it} + \delta_5 OP_{it} + \varnothing_{it} \tag{7.2}$$

7.3.1 Data

We collected the firm-level data from 635 manufacturing sector firms for the last 04 years 2014–2018. The data of these firms are collected each year by Mohammad Ali Jinnah University, Pakistan's Business Research Centre (Table 7.2).

Table 7.1 Measurement of variables

Variable	Measurement	Past researches
Renewable energy consumption	Share of renewable energy in the total final energy consumption (% of total energy consumption)	Hanif et al. (2019)
Non-renewable energy consumption	Share of non-renewable energy (such as fossil fuel) in the total final energy consumption (% of total energy consumption)	Hanif et al. (2019)
Human Capital Index	Average of employees related experience, education, number of training received in a year	Mubarik (2015), Mubarik et al. (2018)
Technology innovation	Average of number of new products introduced in the market, number of patents registered, total patent applications counts	Mubarik (2015), Li et al. (2013), Smith et al. (2005)
Firm size	Log of number of employees	

Table 7.2 Breakup of sample

Industry	Number	%
Textile	188	30
Leather	125	20
Food	139	22
Small-scale engineering	101	16
Sports	82	13
Total	635	

7.3.2 *Method*

We applied panel FGLS (feasible generalized square) model to estimate the developed equations. In panel FGLS, changes in the standard errors are used to incorporate the variances in the cross sections (Davidson and MacKinnon 1993). The performance of FGLS to control heteroscedasticity is robust as compared to other peer models like panel random effect or panel fixed effect model (Hassan et al. 2019). Likewise, due to the modification in standard errors of cross sections, FGLS could be improved to better control the issues of heteroscedasticity and autocorrelation. Below is the mathematical representation of the model:

$$\alpha_{FGLS} = (Y'\varnothing^{-1}Y)^{-1}Y'\varnothing^{-1}z$$

$$Var(\alpha_{FGLS}) = (Y'\varnothing^{-1}Y)^{-1}$$

$$\varnothing = \sum_{n*n} \otimes M_{K_i x K_i}$$

$$\sum_{i,k} = \partial_i \partial_k / T$$

Here, $\varnothing$ is adjusted to include heteroscedasticity and autocorrelation, while computing the coefficients and their standard errors.

7.4 Results and Discussion

FGLS results are exhibited in Tables 7.3 and 7.4. The results of the Wald test confirm the fitness of both models (renewable and renewable). Looking into the positive intercept of renewable energy and the negative intercept of non-renewable energy, it can be easily inferred that the manufacturing sector of Pakistan is shifting toward the usage of renewable energy sources. This can be further triangulated with the fact that a considerable number of textile and leather factories are trying to shift their ancillary activities on renewable energy sources. Further, in case of the role of human capital forms, an inverted U-shape curve as the sign of HCI is positive and the sign of HCI^2 is negative. It shows that increasing human capital first increases the consumption of non-renewable energy sources, and then, after a threshold point, it tends to decrease

Table 7.3 Renewable energy

Variable(s)	Total sample	By industry					
		Textile	Leather	Food	Sports	Metal	Furniture
C	124.31 (0.000)	54.88 (0.000)	93.27 (0.000)	103.29 (0.000)	219 (0.000)	145 (0.000)	176.25 (0.000)
HCI	−1.21 (0.000)	−0.49 (0.000)	−0.41 (0.000)	−0.61 (0.000)	−0.45 (0.001)	−0.89 (0.000)	−0.74 (0.000)
HCI square	0.19 (0.000)	0.17 (0.000)	0.09 (0.000)	0.14 (0.000)	0.08 (0.000)	0.06 (0.001)	0.03 (0.000)
HCI*TIN	0.07 (0.001)	0.08 (0.000)	0.04 (0.008)	0.18 (0.000)	0.06 (0.001)	0.05 (0.004)	0.1 (0.071)
Size	0.12 (0.000)	0.22 (0.000)	0.09 (0.001)	0.18 (0.000)	0.09 (0.001)	0.13 (0.000)	0.05 (0.041)
R square	0.76	0.77	0.63	0.71	0.58	0.55	0.67
Wald test	64.21 (0.000)	82.5 (0.000)	59.21 (0.000)	69.35 (0.000)	52 (0.000)	49.9 (0.000)	67.28 (0.000)

Table 7.4 Non-renewable energy

Variable(s)	Total sample	By industry					
		Textile	Leather	Food	Sports	Metal	Furniture
C	−3.12 (0.000)	−1.98 (0.000)	−2.14 (0.000)	−2.86 (0.000)	−2.45 (0.000)	−3.54 (0.000)	−2.74 (0.000)
HCI	1.76 (0.000)	1.24 (0.000)	0.89 (0.000)	1.51 (0.000)	0.65 (0.000)	1.05 (0.000)	0.97 (0.000)
HCI square	−0.05 (0.000)	−0.07 (0.000)	−0.12 (0.000)	−0.09 (0.000)	−0.03 (0.000)	−0.04 (0.000)	−0.09 (0.000)
HCI*TIN	−0.13 (0.005)	−0.05 (0.000)	−0.09 (0.000)	−0.11 (0.000)	−0.07 (0.000)	−0.06 (0.000)	−0.11 (0.000)
Size	0.09 (0.005)	0.11 (0.000)	0.05 (0.000)	0.14 (0.000)	0.05 (0.000)	0.07 (0.000)	0.08 (0.000)
R square	0.81	0.86	0.79	0.81	0.77	0.73	0.75
Wald test	147.92 (0.001)	271.49 (0.000)	187.12 (0.000)	203.25 (0.000)	176.23 (0.000)	177.00 (0.000)	127.42 (0.000)

the usage of non-renewable energy. Although there is scant literature at the micro-level on the effect of human capital development on non-renewable energy usage, our results concur with the studies conducted at the national level. For example, Ruhul et al. (2017) found a percentage increase in the level of human capital which could reduce the usage of non-renewable energy between 0.20 and 0.45%.

The results of model 2 are exhibited in Table 7.3. The signs of HCI coefficients are inverse to that of model 1. The coefficient of HCI is positive, and the coefficient sign of HCI^2 is negative. It forms a U-shape relationship between human capital and renewable energy consumption. At the macro level, this is well in line with the environmental Kuznets curve (EKC). It implies that increasing the level of human capital at the initial level raises the non-renewable energy consumption. Researchers (e.g. Katircioğlu 2014; Fang and Chen 2017; Auty 2001; Adams-Kane and Lim 2016) claim that total energy consumption increases with the increase in human capital.

The increasing level of human capital increases the requirement of energy and non-renewable energy that could be the cheaper and immediately available source. After reaching human capital, it tends to substitute non-renewable energy consumption with renewable sources (Doğan and Değer 2018). Our results show a significant interacting role of technological innovation ($\beta = 0.07$, $p < 0.05$) in the relationship between human capital and energy consumption. It implies that the increase in technological innovation leads human capital to consume more green energy. However, results in Table 7.2 show that an increase in technological innovation ($\beta = -0.13$, $p < 0.05$) discourages the usage of non-renewable energy. In condense form, innovation in interaction with human capital increases the use of renewable energy and makes non-renewable energy less attractive. These results concur with the study of Shove (2017). Further, as expected, an increase in the size of the firms leads to an increase in the consumption of both renewable and non-renewable energy.

Table 7.5 Threshold point of HCI

	Upper threshold point of HCI			
	Green energy consumption		Non-green energy consumption	
	Coefficient of HCI	Coefficient of HCI^2	Coefficient of HCI	Coefficient of HCI^2
Total sample	−1.21	0.19	1.76	−0.05
Textile	−0.49	0.17	1.24	−0.07
Leather	−0.41	0.09	0.89	−0.12
Food	−0.61	0.14	1.51	−0.09
Sports	−0.45	0.08	0.65	−0.03
Metal	−0.89	0.06	1.05	−0.04
Furniture	−0.74	0.03	0.97	−0.09

The turning point values of HCI are exhibited in Table 7.5. Comparing inter-industry results of green and non-energy consumption, it could be observed that the sports sector's turning point comes earlier as compared to the rest of the industries. It implies that a moderate improvement in human capital in the sports industry can decrease the consumption of non-green energy by substituting it with that of green energy. On the other hand, turning points in the metal industry are at a quite higher side, depicting that a substantial increase in human capital is required in order to substitute the non-green energy consumption with green energy consumption. The results of the metal industry show that a moderate increase in the level of human capital will increase the consumption of non-green energy and will increase emissions. Our findings are well aligned with the Mubarik et al. (2016, 2018). Particularly, Mubarik et al. (2016) argue that levels of human capital in metal and leather industries are low. Owing to these low levels of human capital, developing human capital in the first stage will increase the consumption of non-green energy. Subsequently, it will lead to a decrease the consumption of non-green energy. On the broader canvas, the results confirm the presence of an inverted U-shape relationship between HC and non-green energy. Our findings also confirm the presence of an inverted U-shape curve in the relationship between HC and green energy consumption.

7.5 Conclusion

The chapter has three overarching objectives. The first objective was to comprehensively review the role that a firm's human capital plays in promoting energy efficiency and green energy. Second objective was to review the role of technological innovation in the relationship between a firm's human capital and energy consumption (green and non-green). Third objective was to provide any empirical evidence on the relationships modeled in objective one and two. In doing so, we took Pakistan as a case. After reviewing the literature from the last 30 years from the major repositories, we could found that human capital-energy consumption juxtaposition captivated the attention of scholars around 02 decades ago. Since then, a plethora of scholastic work has been done in this area; however, the majority of the literature focused on human capital at a macro-level without differentiating the firm-level human capital. Further, on the basis of the review, we could unveil that firm human capital can have an inverted U-shape relationship with non-green energy consumption and U-shape relationship with green energy consumption. Some of the researchers named it human capital Kuznet curve getting inspiration from environment Kuznet curve (EKC). The previous studies also depicted that human capital in interaction with technological innovation can be better instrumental in reducing energy consumption. This led us to model the technological innovation as the moderator in the out model. After reviewing the literature, we developed two equations. The first equation modeled green energy as the dependent variable by taking human capital as the independent variable and technological innovation as moderator, whereas the second equation modeled non-green energy as depending on a variable by taking the same independent and moderating variables. To test the model, we took the manufacturing sector of Pakistan as case, and data from 635 manufacturing sector firms were used. By applying FGLS, we examine the quadratic relationship of human capital with green and non-green energy consumptions. Our results confirmed the presence of inverted U-shape relation between human capital and non-green energy consumption in all selected manufacturing industries of Pakistan. Results also confirmed a U-shape relationship between human capital and green energy consumption in the same sample. Our results concurred broadly with the other studies conducted on the HC-energy consumption dyad. Our findings imply that industries with a higher level of HC and technology innovation can quickly substitute non-green energy with green energy consumption.

7.6 Implications

Based on the findings of a study, we offer some practical implications. First and foremost is the need to conduct research studies on the role of firm-level human capital in green and non-green energy consumption. These studies can take into account the cross country industries to examine as to how developing human capital can help a firm to substitute green energy with non-green energy consumption. Secondly, on the basis of our findings, we argue that industries with a comparatively high level of capital are close to the turning points from where the increase in human capital will lead to an increase in the green energy consumption and decrease in non-green energy consumption. For example in Pakistan, according to Mubarik (2016) and Mubarik et al. (2018), the textile sector and food sector have comparatively higher levels of human capital. Working in such sectors can yield some immediate results in the shape of energy efficiency. In short, a nation can gauge the level of human capital across industries, and the industries with a higher level of human capital can be incentivized to further develop their human capital. Thirdly, employers can be given certain incentives to hire employees with a post-school education (human capital).

7.7 Limitations and Future Research Direction

Since the developed models have been examined in the context of Pakistan, the results may be generalized cautiously. Our measure of human capital may not be compressive enough to encapsulate all of its aspects. Therefore, we suggest future researchers take the HC index taking the behavioral aspects of employees as well. We included only firm size as the control variable in the study. Future researchers can add other variables like firm ownership and age for more robust results.

In addition to energy efficiency, we suggest future researchers to examine the role of human capital in energy sufficiency. The debate on the HC-energy sufficiency dyad is absent from major policy debates. Reducing energy usage with the help of firm human capital development, energy sufficiency is equally important. Energy sufficiency strategy aims to reduce and control the usage of electricity at a sustainable level. The firms need to set the optimal level of energy conservation keeping in view the environmental limitations (Rockström et al. 2009; IPCC 2014). Along with energy efficiency and the sustainable green energy supply, using various renewable sources of energy, energy sufficiency appears to be a third strategic pillar of the sustainable energy sector. Energy sufficiency contrasts with energy efficiency. The former focuses on reducing energy input through changing the quality or quantity of utilities, whereas the later aims to reduce energy input without changing the utilities (Brischke et al. 2015). The usage of energy is largely dependent upon a firm's business processes, machinery, and type of infrastructure (Shove 2017). Hence, while examining a firm's energy sufficiency, a single product or machine is not the unit of analysis. Instead, the analysis focus on a bunch of needs requiring technical services and consequently energy inputs. In this context, energy sufficiency also considers basic changes in the employees' behavior, production patterns, and organizational practices having an influence on energy consumption.

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Chapter 8
Contemporary Dimensions of Econometrics of Green Energy: A Review of Literature

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Abstract Green energy is the significant system of renewable energy that represents the sustainability dominion of energy. It comes under government limelight and is a convincing agenda to establish green economy structures and energy systems. Literature suggested industrial models for green and sustainable energy, using technological support and innovation for energy evolutions through extensive sustainable energy programs. Green and sustainable energy is efficient and demands least energy incorporation and decreasing disparities and impacts progressively towards green energy. Efficient energy usage establishes correspondent welfare for energy usage and the environment. Climate concerned regulation and green innovativeness focus on the regulations and the usage of renewable energy sources. Moreover, FDI boosts green energy and green innovation while condensed the usage of fossil energy in developed and developing countries. Moreover, countries need focus on energy bases; hence, they can divert towards green energy and ascents business towards green energy, while accepting the determining factors of energy strains and usage of clean or green energy, since it is vital for establishing improved energy guidelines for future. Continuous efforts are required to focus on modern green bases of energy to prevent harmful and damaging influence of conventional energy usage and energy production. Researches showed significant association between energy usage, industries production and economies progression. However, the growth of green energy bases provides a significant resolution to deal with concerns like energy safety and environmental variations. Where, the steady substituting of conventional energy means with green energy upholds the efforts on sustainability and climate protection since green energy usage shows a significant positioning in backing economies development and progression for many countries.

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Keywords Clean energy · Energy efficiency · Energy usage · Environmental quality · FDI · Governance · Green energy demand · Green energy production · Green energy usage · Green finance

8.1 Introduction

The continuously utilizing of the energy resources and its damaging impact on the environment repositioning discerning towards energy situations globally. Concerning this, the distress of hastened situation on "global warming" shaping the perspectives globally on immaculate and green energy (Hosseini and Wahid 2015; Hosseini et al. 2013). Green energy is the significant system of renewable energy that represents the sustainability dominion of energy, as it is acquired from the bases which are infinite (Mohan et al. 2018). The foundation for sustainable energy includes bases like airstream, solar, biomass, water, entirely ensues by nature continuously. This form of energy is immaculate and unpolluted. Most of the methods do not discharge greenhouse vapors or lethal leftovers while utilizing those energy sources. These methods represent the suitability of energy bases as human being can depend on them for a long time which are not costly and effective as well (Owusu and Asumadu-Sarkodie 2016).

Currently, the severe climate collapse concerning desiccation, intensifying temperature globally, floods and tornadoes are the visible and startling indicators of changing environmental concerns that increase the demand of attention by human (Chaubey 2013). The environ concerns are getting on the dangerous level, which demands the establishment of "green energy" stratagems for sustaining imminent change and avoiding any deleterious and damaging environ and communal sway (Oh and Kim 2018). Now, the opaque projections of environmental conversion are becoming the key challenge globally. In order to form ecological promising energy systems for upcoming generations, the crisis has to be focused on by promoting green energy (Agarwal et al. 2014). Many countries focusing on energy effectiveness and consider the advancement of sustainable energy as a significant form of facing climate defies (Dai et al. 2016). For example, East Asian states are concentrating on establishing green economy structures and green energy systems (Dent 2014; Yoshida and Mori 2015). Concerning this, China is amongst the largest perceptive states on this matter; the role and positioning of China in this regard is prominent that represents almost the leading one on "Worldwide green Focus" on sustainable energy resources where China is considered as the "sustainable energy giant" (Mathews 2017). Similarly, Canada is amongst the energy resources giant (Prentice 2012), focusing widely on sustainable and green solutions (Stroup et al. 2015), while the USA is also showing encouraging attitude on the issue of climate change and sustainability (Levi 2013). According to Western Climate Initiative, the USA and Canada are joining in grander scale agendas (NA2050), which represents low-carbon initiatives, generating employment opportunities and sustainable energy systems and most importantly helping environ well-being and climate governance mechanisms (Stroup et al. 2015; White House 2013). Likewise, Germany functions as a global platform towards the evolution of the giant industrial economic system to a sustainable and below-carbon energy organism. Varied players, industrial models for green and sustainable energy, technological support and innovation have backed to the origination of German's energy evolutions via extensive sustainable energy programs (Rommel et al. 2018). Green energy philosophy is a concern with technological transformation, innovation, where also linking the economy's arrangements to environ concerned subjects, governing systems (Bauwens 2016).

8.2 Energy Efficiency and Innovations

As the concentration of countries is shifting towards the challenge of environmental changes and energy efficiency, the need for strategies and contrivances concerning energy efficiency are also increasing (Gillingham et al. 2018). From the perspective of environmental concerns, energy efficiency is being focused as a base for ascertaining possible progression and advancement for consuming energy resources with low or no carbon utilization or CO_2 reduction and cost-effectiveness by advancing the arrangements (Gillingham and Palmer 2014). According to Gerarden et al. (2017), strategy makers are concentrating on the arrangements dealing with the systems restricting the dispersion of energy effectual technological up-gradation and more concentrating on the strategies for technological support for ensuring energy efficiency.

Recently, sustainable economy arrangements are establishing a crucial focus of many countries. In order to attain this purpose of alleviating the greenhouse and decreasing the CO_2 emanations countries entails a changeover from the economies arrangements established on extremely contaminating energy bases towards sustainability-centric economies arrangements established on technological support, and consuming energy bases having a damaging effect on climate (Costa Campi et al. 2014). This is indispensable technology-focused transformations which empower a broad retort on environmental need without sacrificing economies progress. But the important question arises that how this objective will be achieved? One vital instrument to accomplish this objective of essential revolution is "innovation" (Sayegh et al. 2017). Schumpeter (1982) asserted that economic progress is determined through innovation, while the impact of technology-based growth on the progression of the association amongst the economies and climate is clarified by the "endogenous growth theory" that emphasized that production systems development with the help of substituting the contaminating energy bases with climate-responsive energy bases (Fernández et al. 2018). Currently, the discussion on sustainability has diverted attention to innovation that is connecting with the diverse players. Innovation practices involve produces and undertakings that are energy efficient and demand least energy incorporation (Sachs et al. 2016). The system of environmental adjustment also pressures the dogma for the sustenance of innovation and the expansion of less-carbon technological systems as a retort to alleviate the environmental changes and green energy needs (Badi 2016). Energy efficiency processes contain distinctive processes for the purpose of plummeting energy usage or innovative and new production methods. However, embracing green and efficient technological systems offers a wide range of prosperity and assistances; still, espousal requires numeral circumstances like sectoral strategic slants and institutions that can seal the institutional and innovativeness breach (Ndichu et al. 2015).

Businesses have to implement climate-friendly objects because they put sway on innovation progressions nonstop (Jakobsen and Clausen 2016). This determines the level of following progress in energy efficiency as the focus of innovation. The businesses that are establishing innovation arrangements as the source of decreasing climate's influences are more into innovation to intensifying energy effectiveness (Costa Campi et al. 2014) where decreasing disparities amongst energy consumption is explained as energy effectiveness. Innovation-centric practices add ominously on lessening energy consumption in businesses (Mulder and De Groot 2012) which impacts progressively towards green energy (Fernández et al. 2018).

8.3 Technical Effect and Advances in Energy Usage

The states are allied via energy, economic structures, climate and sustainability connections. Usage of energy efficiently, especially in industrialized countries, is having importance for the economic structures and overall climate conditions for the coming generations. Whereas, the energy efficiency and its consumption level are dissimilar amongst states contingent with diverse energy usage models (Bilgen and Sarikaya 2016). Though, energy is amongst the fundamental need of the economic system and consider as the main constituent for production, yet, energy usage needs hefty monetary, ecological and safety costs. The efficient usage of energy can result in cost-effectiveness. Many states are focused on establishing efficient energy consumption strategies, covering together basic mechanism which is concentrated on different sectoral demands (Yan et al. 2016). The main apprehension is associated with its impact ecologically and environmental drastic alterations, greenhouse gasses, energy scarceness, sustainable approaches and divergence between states due to the locality of energy bases (Lundgren et al. 2016). All of them represent composite problems interrelated with one another. To grip these problems, the attention and efforts should be diverted towards improving energy efficiency, covering together with the method and tactics (innovatively) on energy generation and the way energy is consumed overall (Viholainen et al. 2016). The development of energy efficiency in consuming is having significance as rising the efficiency together in generating energy and consumption significantly reduces the energy concern emanations in a less costly way and at the same time concerned with the depletion of energy sources (Viholainen et al. 2016), whereas extreme usage of energy imposes large challenging aspects. Therefore, energy usage has haggard worldwide attention. Technology-based innovation offers a vital and substantial part in humanizing energy efficacy. It is accepted that technology and innovation support is one of the substantial tactics for resolving the clashes amongst the supplying and demanding energy, so energy efficacy improves (Wang et al. 2017). Innovation is described as the establishment of unique and creative explanations to economies, environ-centric and collective complications (Jay and Gerand 2015). Moreover, the focus on improving energy efficiency also aids to lessen the producing price. Effectual energy usage offers corresponding welfare along with less natural possessions; it is probable to develop advance technological support for proposing viable and sustainable energy with instantaneous expansions in adeptness (Bilgen and Sarikaya 2016). The progression of economic structures, energy efficiency is getting policy makers' attention and therefore become top agenda for discussion worldwide, especially in developing states where energy depletion has also happening concurrently (Luo and Liang 2016). It is suggested that arrangement on energy does not solely emphasis on the energy efficacy but on other important influences of energy strategies as well (Yuan et al. 2017). Efficient energy usage establishes correspondent welfare for energy usage and the environment. It is probable to produce an innovative mechanism and technological support for promoting renewable energy arrangement along with instantaneous advances inefficiency. The energy usage efficiently has to be applied when probable, as this encompasses the lifecycle of energy bases and reduces climate damages and concerns (Filippini et al. 2014). Energy efficiency mechanisms have a substantial impact on developing states, along with the likelihood of preserving up to 65% of energy reserves from 2006 to 2026. In the coming twenty years, OECD states are anticipated to decrease energy usage from 25 to 30% and from 30 to 45% in developing states (Palm and Reindl 2016; Bilgen and Sarikaya 2016).

8.4 Globalization and Green Energy Dynamics

Climate sustainable domain is appearing as a global concern. UN conference on climate concerns 2015 or conference of parties (COP21) concluded in agreement of 195 states on lessening emanations in order to deal with the issues of climate change (in terms of pollution, ozone layer damage and dangerous weather situations) which results in scarcity, torrents and heat waves (Erzurumlu and Yu 2018). Industries are dependent on the consumption of energy for producing which as a result releases toxic fumes, gases and toxic leftovers which are directly impacting the climate conditions. To understand and look for solving these probes on climate situations and sustainability (Erzurumlu and Erzurumlu 2013) a prompt strategy for developing and establishing the "green" economic structures globally is required in concerned area of interest (Maria et al. 2015).

The current state of fossil-fuelled economic systems and extreme climate change has to divert attention towards inconsistent and hazardous instant for modern societies and collective environmental effects all over the world. An increasing agreement globally, on shifting towards the renewable energy systems, is the need of time since green energy often assumed as a tactic of future replacement and represents the significant stratagem to address the environmental concerns (Burke and Stephens 2017).

In the last period, though, renewable and green energy supporters, communal and environ associated advocates and campaigners are focusing on establishing for "energy democratic arrangements". These energy democratic systems are linked with the modern manifestation of devolved popular key activities/movements of 1970, 1980 and earlier (Love and Isenhour 2016). These primary activities commonly pursued to associate anti-nuclear involvements and apprehensions about the uncertainty on fossil energy sources require attentiveness on regional actions and visions of tech-based arrangements on green energy globally, which substitute energy bases with renewable environmental-friendly domains (Peterson et al. 2015). These activities around the world are dedicated to evolving communal and climate-centric justice with the help of transition on renewable and green energy technologies. These determinations are associated with many prevalent activities on focusing on environmental emergencies by not solely on repelling fossil energy sources usage but also concentrated on green economic programs and communal founded green energy upcoming prospects (Tokar 2015; Love and Isenhour 2016).

A key to this revolution concerning sustainable systems is a crucial renewal of economies, technological supports and establishments. Economies are necessary to be intensely reconsidered and restructured to provide sustenance on anti-CO_2 emissions (Pegels et al. 2018). The energy bases were solely accountable for near 70% of emanation in 2012 worldwide (WRI 2016). As the only market is not successful for achieving these crucial environmental changes, states and establishments worldwide need to interfere as a driving agent of low CO_2 (green energy) revolutions (Lederer et al. 2018). A set of mechanisms are needed to be concentrated by the establishments to ensure these environmental alterations like "green energy stratagems" where these green energy stratagems incorporate strategies for supporting the arrangement of energy system while focusing on the essentials for sustainability (environmentally friendly and preservation of energy sources) (Lütkenhorst et al. 2014). These stratagems are precarious for attaining the objectives of green energy and green economic systems globally (Altenburg and Lütkenhorst 2015).

8.5 Green Economy and Clean Energy Technologies

Strategies and mechanisms for supporting green energy and sustainability based objectives and green economic arrangements, like focus on low fossil releases, energy efficiency and usage, and communal comprehensiveness are required at global level (Lederer et al. 2018; Altenburg and Lütkenhorst 2015). The available mechanism and technological innovations on green energy can be included with the range of stratagems to establish a green economic system (Altenburg and Lütkenhorst 2015; Pegels et al. 2018). Therefore, the UN recognized the prospective for green economic system slants to turn as perilous edges between economies associated and environ relevant problems to encourage sustainability and green energy (Bailey and Caprotti

2014). Mostly, policymakers using mechanisms for leading economic accomplishments concerning ecologically sustainable focus for introducing and expediting fundamental modifications (Chaudhary et al. 2014; Dai 2015). There are aggregate and crucial requisites for handling scarcity including nature-centric reserves like ecological and energy in the setting of the increasing populace and natural reserves over manipulation (Coccia 2014). Technology-centric innovation is evolving in diverse sectors to adjust the usage of energy bases as a communal growth and directing sustainability from the perspective of environmental and communal concerns. These technology-centric innovation and innovative mechanisms are the sources of effectual, uncontaminated and ideal usage of energy bases (Klewitz and Hansen 2014). The concentration was primarily focused on sustainability and progression in the UN "conference on the human environment" 1972, while the focus on innovation and sustainable systems got attention in Brundtland report 1987 (Eteokleous et al. 2016; Lukman et al. 2016). The emphases were diverted towards businesses for establishing, restructuring, acclimating and diffusion of climate-centric comprehensive technological support (Farahani et al. 2014) where in IAMOT 2015 and 2016 conferences, which stressed on the apprehensions like technological focus, innovation and creatively handling on sustainability (Cancino et al. 2016).

As the environmental change in last years like dilapidation, instigated by people trailing, the progress of economies, and increasing populace which desecrating the energy reserves, are the indication of environ concern (Coccia 2014). The environ impact instigated by the economies and practices involved, which devour energy reserves and imposing environmental damages in the twenty-first century was reported (Tsiliyannis 2014). Moreover, the focus on technology-centric innovation required for the sustainability prospects, emphasizing the well-being sustainability not solely by economies and progression and but also through technology and innovation, was increased (Lukman et al. 2016). Environ-centric prospects of sustainable systems and eco-innovation outlooks concerns arises as a reaction on the requisite of energy efficiencies, hence usage through the amalgamation of novel and unique technological mechanism was proposed (Eteokleous et al. 2016). Concerning communal and economy's prospects of sustainable systems, businesses are reconsidering their connotation with associated stakeholders that directly or indirectly affecting by the climate where they functioning, which lead to the need to reestablishing the models, stratagems and restructuring the economic systems (Smart et al. 2017). Assimilating sustainable focused domain, within corporate models, require an efficient outlook which includes international viewpoints and diverse origins of the arrangements and their association (Cancino et al. 2016).

8.6 Green Energy Regulation and Environmental Quality

Extreme and rapid changing in the environmental revolution worldwide, resultant from greenhouse gas releases, remain a warning for survival and contending environmental damages (Twerefou et al. 2019). Worldwide concentration on environmental prospects is growing, which increases efforts for regulations to deal with the climate prospects (Gillingham et al. 2018). Climate concerned regulation and green innovativeness focus depict two vital aspects of the efforts of green energy. However, resources and climate are public possessions, which contain some restrictions on the usage of market contrivances to resolve climate concerned complications. Consequently, it is crucial for states to contrivance eco-friendly and green energy regulations (Feng and Chen 2018). Whereas at the same time, the combination of "innovation domain" and "green domain", green innovativeness is considering an efficient source of dealing with environmental concerns. Hence, there is a significant association amongst the environmental regulating concerns, green innovativeness and green energy domain. According to OECD (2011), environ concerned regulations are the vital effort of promoting green energy.

Currently, the vital mechanism for shifting the efforts of economies towards climate and climate-focused sustainable approaches, like green energy regulatory systems and tax subsidies, regulations and policies are focusing on originating and enabling operational modifications. The emphasis of regulations is concerted towards two dimensions—(1) environ safety and (2) green modification (Dai 2015; Shen 2016). The regulations concerning environ and green energy should cover innovativeness counterpoises at businesses under regulation. The supervisory bodies have to exercise density, humanizing businesses environ associated cognizance, and assist them to establish vibrant objectives for environ protection, whereas at the same time allowing the businesses to adopt the innovativeness required indispensable to attain the set objects (Weiss and Anisimova 2019). The slant should consist of permitting businesses tryout phase in which businesses evaluating modern technological support that can be beneficial to achieve environ-friendly objectives (Bergquist et al. 2013).

However, for states to deal with the focus on green energy, environmental concerns is hardly possible; to get full of its essence and its impact on economic systems and societies widely, states have to harmonize their efforts with other players and establishments having supremacy to regulate widely (Schmitz 2017). This assembly of players or authorities (like UN, UNDP, Economic forums) can upkeep or restrict the change (Hess 2014). An extensive arrangement is essential amongst the stakeholders to achieve the objectives of environmental quality and green energy (Mazzucato 2013). Stout efforts on the mutual advantage of green energy and environmental quality are most vital to organizing substantial influences that can drive the environmental change agenda widely. For example, intergovernmental panel on climate change (IPCC) organizes the states into economy's prospects "energy protection, employing concerns", communal (energy approachability, well-being effects, and environ concern welfares (lessening polluting aspects) (Schmitz 2017; Pegels et al.

2018). While, the scope of mutual advantages dependent on the variety of influences like green technological innovation, prevailing technology capacity, states capability to incorporate, and apply stratagems on green energy hence need due consideration.

8.7 Oil Prices, Energy Shock and Green Energy

Prospects on global climate increasing, whereas, CO_2 releases topmost in 2020, and global warming will be still under 2 °C (IEA 2015) therefore, globally the investing essential to be on rise in renewable or green energy domain, estimated about $130bn in the coming 15 years. It shows that investing requirement is growing, while the influences on growing investing needs due attention (Shah et al. 2018). The key influence on this aspect is associated with the prices of oil, as the oil prices ominously impact investing and producing the need for green energy (Zhu et al. 2014). Oil has the strongest effect on the energy domain and has the strongest impact on the performing capabilities of the industries worldwide; therefore, variation in prices of oil can pressure the economic systems globally (Pradhan et al. 2015).

Global agreements are continuously focusing on the necessity of reducing CO_2 emanations, for example, G8 is ambitious to reduce the emanations by 50% until 2050; the sources of attaining these numbers are becoming crucial. Amongst the regulations focused included the usage of renewable energy sources (Green energy) instead of fossils energy systems. The European Union (UN) stressing for lowering the CO_2 emanations (Apergis and Payne 2014). Therefore, states worldwide are focusing on the intensifying the producing of green energy bases by increasing the taxes on fossil energy (Bhattacharaya et al. 2016). However, the impact of oil prices on green energy is not similar amongst states, contingent with the aspect on whether the state is amongst the oil-exporting or oil-importing states, and its regulations on boosting green energy bases and its economic position (Mejdoub and Ghorbel 2018; Creti et al. 2014). As states have agreed and implemented a range of regulations towards their agenda on green energy and environmental prospects (Polzin et al. 2015). For example, Norway, oil is significantly impacting on the GDP of Norway (Brander et al. 2013). Therefore, Norway has by now a verge against oil price variations. If the prices of oil upsurges, but green energy rest persistent, then Norway is on the position to meet the targets on the usage of green energy instead of oil (Milner 2016). Similarly, the UK, amongst the oil-exporting states, UK is amongst the strongest supporter on green energy within the country, and globally, the bases on green energy is growing rapidly in the domain of electricity like airstream and solar systems (Chan 2016; Ward and Inderwildi 2013). Likely, in the USA, the concerns on oil pricing is different as an oil-importing state till 2013, USA then established the positioning on largest oil-producing, besides this USA start investing in green energy and its applications hence balance start improving (International Energy Agency 2014; Apergis and Payne 2015). However, the impact is dissimilar amongst the states and depends on the positioning of the state as an importer or exporter of oil (Shah et al. 2018). The experts suggest that an increase of oil pricing significantly influences the stocks of green energy businesses as the raise of oil pricing results in green energy more economical contrary to oil (Lee and Baek 2018; Reboredo et al. 2017).

8.8 Green Energy Modeling and Forecasting

The exaction viewpoint for fossil driven energy is progressively indeterminate globally. instead, their industry esteemed by capacity constructed cricks, that are in deterioration and contributing to more decay, usage will require to move towards innovativeness, technological supports and models for subsistence and persistence (Green and Newman 2017). The businesses are concerned about occupied on groping the worldwide energy market base and improve predictions of upcoming scenarios regarding environ-centric policies, green energy usage (Green and Newman 2017).

The energy assortment is gradually shifting; however, this is indeterminate which trend is more reasonable and practical for current and future aspects. Green energy bases are considered as more effective source for producing electricity and other produce, yet the progression is dawdling and reliant on diverse influences (Furlan and Mortarino 2018). Fossil energy systems are on their final period of lifespan, the technology-centric innovation for green energy improving and widening the approachability, but still, it’s slow, as it takes time for establishing the feet until innovation is contemplated as harmless and productive (Sharon 2015). For instance, shale gas was considered as the bases for the green energy system until the climate negative impact has been proved and effects were dangerous (Melikoglu 2014). However, shale gas is considering by China and India; however, the harmful impact can alter the investing aspects in the energy segment (Zhao and Yang 2015; Garg 2012). In response to counter vagueness, forecasting published in 2013 on the total usage of energy globally, and forecasted to escalate up to 56% from 2010 to 2040 (Today in Energy 2013) due to non-OECD states. In this sector, various energy bases act as competing agents (Guseo and Mortarino 2015). Previously, various bases for energy systems have been analyzed equally fossils and green energy systems, within the diffusion model, like oil (Guseo et al. 2015), gas (Darda et al. 2015) and wind (Panse and Kathuria 2015). Currently, for example, the competitive model is attracting attention by states; however, competitive measures are multifaceted, particularly within the diffusion modeling domain (Guseo and Mortarino 2015).

Fossils oil businesses like Exxon and Shell work on observing the international energy domain and established forecasting for upcoming years to understand their invulnerability from possible jeopardies like environmental or green energy regulations or competitiveness of green energy bases (Exxonmobile 2014; Shell 2014). These businesses are certain of international energy demand due to the industrial growth of states around the world. These green energy bases having no capability to encounter this need worldwide (Green and Newman 2017). Many establishments and institutes like IEA, work-energy council, EIA, Shell are working on forecasting the fossil energy necessities worldwide till 2050. BHP Billiton 2015 issues environmental change analysis and analyzes the influence of green energy technological bases on the energy domain and established that though the environmental concern struggling to maintain temperature on the necessary level (Green and Newman 2017). However, the demand for fossil sources probable to increase as developing states shifts towards the industrial domain. Therefore, demand for fossils grows, whereas, at the same time green energy maintains their competitiveness in the market as it considered cost-effective (BNEF 2015). But the fact remains that this impact is fully dependent on the policies adopting and implementing by states and the growth overall (Polzin et al. 2015).

8.9 Foreign Direct Investment and Green Energy Demand

The influence of extreme worldwide environmental changes on human beings and over all natural environ are diverting the attention of regulators to control the damage and sustainable economic systems. This is especially crucial regarding regulation on encouraging the energy investing domain which significantly impacts the environmental changing (Wall et al. 2019). For example, agreement on (UNFCCC—United Nations Framework Convention on Climate Change) developed states are bound to make available monetary assistance to developing states on this agenda. As per the agreement, they conjointly organize USD 100 billion yearly. Whereas, specialists are considering FDI as a resilient prospective to deal with recent issues on worldwide climate (Peake and Ekins 2016). The study conducted by Doytch and Narayan (2016) examined 74 sates (1985–2012) to understand the influence of FDI on green and fossil energy usage; the study concluded that FDI boosts green energy and green innovation while condensed the usage of fossil energy in developed and developing states, whereas if these states focus largely on energy bases, they can divert towards green energy and ascents business towards green energy. The impact of FDI in the developing nation is promising on shifting to energy consumption safely while decreasing the utilization of fossils bases. The influence of FDI significantly impacts in lowering the consumption of fossil energy systems (Khandker et al. 2018). The conception of green FDI is attracting the attention of environmentalists and states that include investing prospects worldwide on the green energy domain. GFDI is beneficial for both industrialized and developing states, as FDI has to contribute significantly towards the growth of environ friendly industrial setups, processes, technological green innovation and expertise which expedites green energy, sustainable domain and climate concerns (Buntaine and Pizer 2015). Moreover, FDI as a whole contributes towards economies and development by offering employment opportunities, the transference of wealth, technological know-how and up-gradation to the states and stimulating region-based competition (Abduli and Hammami 2017). Hence, this is crucial for the states that investing source and state device efficient regulations on boosting the interest of giant companies to invest in green ventures, exclusively in green energy domain (Yue et al. 2016), FDI and development of explicit commercial segments like industrial and infrastructural setups may hit remarkable density on energy possessions and the environmental concerns of nations. Accepting the determining factor of energy strains and usage of clean or green energy is vital for establishing improved energy guidelines for upcoming scenarios. The enlarged economy-centric prominence of FDI raises different queries for the authorities concerning the finest dogmas and stratagems to embolden sustained economy persistence, lessening of carbon, effectual usage of energy and augmented usage of green energy (Lee 2013). The primacies of FDI in context of green energy and green economies amongst states, and especially of giant firm's verdict are deliberated to contain (1) regulatory framework, containing climate, energy, environ and overall regulations on this concern, (2) economies-centric, containing FDI determining agents, like market-centric, capitals focused, efficacy focused and stratagems, (3) commerce easing containing regional and local regulatory focus which enable green energy investing and (4) producing cost including, cost-effectiveness, energy usage effectiveness (Wall et al. 2019; Bisgaard et al. 2012).

8.10 Green Energy Usage and Economic Efficiency in Developed and Developing Economies

From the past few years, the vital part of energy towards the establishment of sound economies structures and progression has been the schema of regulatory bodies and scholars. The focus on the necessity of humanizing worldwide approachability to inexpensive and climate-friendly energy bases and reserves is increasing (Adam et al. 2018). Continuous efforts are made towards fossil to modern green energy bases of energy (Rodríguez-Monroy et al. 2018; Ntanos et al. 2015), whereas because of harmful and damaging influences of fossil energy-producing and using, the necessity for focus on green energy is increasing drastically (Papageorgiou et al. 2015). Therefore, distinctive regulations are establishing to auxiliary support the expansion of the green energy domain. An important climate-centric objective of EU is to meet twenty per cent of energy needs through green energy till 2020, whereas from the perspective of international market, near nineteen per cent of overall energy consumption is making from green energy bases, where the stratagem is focusing to upsurge the consumption of green energy by 50% till 2050 (Ntanos et al. 2018).

UN established the international agenda on attaining the "sustainability of energy" till 2030. The focus is to safeguard the global approach to up-to-date energy systems and to accelerate the position of green energy in the energy market worldwide (Ghouri and Haq 2018; UNEP 2016). According to the New Energy Outlook (2016), the investment prospects are increasing in green energy domain and statistics determined mostly by the latest investment opportunities in developing states. In the coming decades, the approximation is that fossil energy will draw up to \$2bn, whereas green energy bases will draw about \$8bn (Chachoua 2016). The green plan will offer a substitute base of energy for developing economies, increasing efficiency, improving and achieving environment concerns worldwide and ensuring energy fairness (IEA 2015). African renewable energy domain is also compelling to increase the approachability to green energy from the perspective and agenda of decreasing energy scarcity and establishing significant monetary support from investing perspective, establishing financial associations for supporting this global agenda till 2020. This is stimulating on the prospects that green energy technological innovations establishing smart and climate-friendly technological assistance in Africa (Adam et al. 2018).

The study by Salim et al. (2014) concentrated on OECD states from (1980–2011), the assertion established the significant association between energy usage (green energy and fossil energy) and industries producing and economies progression overall. However, the growth of green energy bases provides a significant resolution to deal with concerns like energy safety and environmental variations where the steady substituting of fossil energy means with green energy upholds the efforts on sustainability and climate protection (Salim et al. 2014). Jebli and Youssef (2015) examined the green energy and usage and its significant impact with revenue in developing states; the conclusion demonstrates the positive impact of GDP on the usage of green energy bases in developing states. Similarly, Bolük and Mert (2014), Caraiani et al. (2015) examined the usage of fossil energy and green energy bases, CO_2 gases, and impact on economies' development amongst EU states, and concluded association amongst green energy and GDP. Subsequently, green energy usage shows a significant positioning in backing economies development and progression for many states (AL-Mulali et al. 2013).

8.11 Governance of Green Energy Consumption, Globalization and Financial Markets

Due to the risk of environmental variation and energy reserves scarceness, the environmental concerns are establishing as a crucial subject of regulatory bodies. As a result, industries meet with growing stresses from regulatory bodies to quantify, handling and reportage on fossil energy bases and usage (Amore and Bennedsen 2016). However, many factors affect on sustainable energy domain and determine the connotation of the beginning of green financing arrangement as worldwide drive to enable the efficient usage of energy in sustainability investing arrangement and to observe their sustainable performing to defend and advance the climate concerns in the domain of economies progression (Berensmann et al. 2017). Similarly, defies and prospects for developing better-governing systems concerning green economies worldwide repose ineludible. Furthermore, systems are the basis of awareness and innovativeness (tech-based and establishment based) which can create green economic arrangements and improved governing plans (de Oliveira et al. 2013). The valuation of fossil energy usage or CO_2 emission is establishing a vital domain of global governance on environmental concerns (Oh and Kim 2018). In 2014, the USA focused on green energy programs on priority bases in their planning and investment prospects in the energy domain (Paramati et al. 2016). Whereas because of accelerating in energy usage and greenhouse vapours, regulatory bodies and environment specialists prioritize their focus on green energy as a substitute for fossils bases (Xie et al. 2015). In the last decade, clean and green energy investing has to raise USD$ 310bl in 2014, where both industrialized and developing states financed USD$ 138.9bl and USD$131.3bl in green energy ventures (Omri and Kahouli 2014).

According to IRENA, ventures of G20 represents 70% of overall worldwide investing in energy till 2030. FDI is considered as the crucial element in financing the green energy domain worldwide towards (1) permitting industries for cost-effective and modern green technological innovation ventures, (2) through FDI transmitting of modern technological innovation to state is possible, which assists in humanizing energy effectiveness and usage and (3) states can advance the economies structures and therefore, stimulates green energy investing prospects (Paramati et al. 2016).

In the last three decades, stock markets are occupying a vital part in obtaining supplementary capital in green energy ventures, energy bases and processes. Whereas, states also offer taxation enticements to investment firms in clean and green energy programs, and also making the funding processes relaxed. This enables the firms to obtain financing support easily for green ventures (Lee 2013). At the same time, regulatory authorities are raising the taxation and cost of fossil energy to discourage consumption. Many EU, G20 and OECD states are focusing on decreasing fossil energy consumption. Furthermore, many international institutions and financial institutions are raising the approachability of capital to encourage green schemes especially in developing states (Komal and Abbas 2015). It is crucial to understand that environmental concerns and climate changes are global agenda. The collaboration of diverse players like administrative supports by states, financial institutions, technological innovation and regional alliances can contribute ominously towards clean and green energy programs (Sbia et al. 2014).

8.12 Green Finance, Financial Crisis, Economy and Environment

To meet the objectives of climate prospects and climate agenda worldwide and to move forward towards the green operational modifications, substantial investments are needed in the energy segment due to higher resources need like constructions, industries transporting arrangements and processes (Monasterolo et al. 2017; WEF 2013). Moreover, since green energy effectiveness is recognizing, the approximation is that eight-time raise in yearly investing will be required in 2035; however, renewable energy structures will need 3 times to raise, towards the objectives and agendas of green arrangements and climate change (OECD 2014; IEA 2014). The indication for green financing/funding breach represents deficiency of monetary bases as needed to be concentrating concerning green investing (Buchner et al. 2017); these insufficiencies of financing result in critical limitation for accomplishing the environmental objectives as agreed on COP-UNFCCC (COP 2015, 2016) and also towards technological green innovation (D'orazio and Valente 2019) whereas, the existing financial model towards needed funding is not effective (Mazzucato and Semieniuk 2018), and increasing the functional and financial risks in the subject of "green energy" (Gros et al. 2016). Currently, environmental concerned financial risks are vastly discussed due to the plausible impacts of these jeopardies for green financing structures and overall financial constancy of green economic arrangements (Battiston et al. 2017; Berensmann et al. 2017). These risks are (1) *Evolutions/transition-centric*, the risking factor because of unanticipated and unsystematic evolutions towards lower CO_2 or green bases (Carney 2015), (2) *Corporal*, the plausibility of risks because of collaboration of environmental threats with defenselessness of contact of human and nature (Batten et al. 2016) and (3) *Responsibility* risks containing of groups involved have distressed from the impact of environmental alterations looking for recompenses from the liable ones (Carney 2018). However, states central banks and governing and regulatory bodies, with some exemptions (Carney 2018; Dikau and Ryan-Collins 2017), oversee the environmental agendas practically (Monnin 2018). The clarification for casualness can be associated with the financial models adapting by banking systems, which is not ideal towards apprehending the impact of environ alterations or the complications of economies conversions (Sevillano and Gonzalez 2018). Therefore, new economic and financial frameworks are emerging to deal with the impacts of environmental concerns on financial and economies permanence (Dafermos et al. 2018; Lamperti et al. 2018). However, regardless of the growing cognizance of the adversarial bearing of environmental concerned hazards on financial firmness, the regulatory bodies are not focusing on governing arrangements to deal with these hazards and damages to the financial segment overall. To deal with the environ concern financial damages, academicians and environmental specialists are shifting their concern on the probable risks on the financial segment (Campiglio et al. 2017; Bovari et al. 2018). Regulations on subsidizing and CO_2 taxation systems demonstrating the dearth of responsiveness towards the financial risks connected with the environmental vagaries (WB 2014, 2016) for instance, damage of worth of financial resources (Delis et al. 2018; Caldecott 2017). The choice of integrating "green agendas" amongst the agendas of central banking systems or governing bodies, reliant on the state and associated and concerned official models, is widely debating subject now (DNB 2017; HLEG 2018).

8.13 Employment and Poverty Reduction (Income Inequality) Aspects of Green Energy Production

The key objective for current and upcoming sustainability and green energy defies globally is shaped in various targets implemented by UN "transforming our world" included in schema for 2030 sustainable green energy revolution, where supporting states establish a strong intent of determining an association on three key levels of this sustainable green revolution agenda, namely (1) economy-centric, (2) communal and (3) climate concern, which represent overall 17 aims and 169 objects (UN 2015). These aspects are visibly combined towards the green energy and climate concerns and growth, focusing on agendas of corresponding economies progressions and climates prospects, but at the same time focusing on communal impacts (Emas 2015) which are crucial for vigorous and affluent life and society. Therefore, the objects on the 2030 schema of sustainability and environ concerns are profoundly manifest by human rights prospects and included amongst the 17 objectives (Filho et al. 2018).

Currently, the enlargement of "green economic structures" philosophy worldwide is significantly contributing to the opportunities of green employing prospects. Establishment of green economy structures changing the employment philosophy and is shaping the employment profile established on climate agendas and green technological innovation arrangements (Jones 2015). The conception of "green jobs" is emerging after the global concerns on climate sustainable approaches, where the employments are considered "green" when products and services included the objective of determining, anticipation, restriction and lessening of climate hazards on nature. These green employments add in resolving issues and concerns on fossil fuels and its critical impact on the environmental changes and the activities allowing green energy effectiveness and usage (Battaglia et al. 2018). The debate on the association of "green economic systems" and "green employments" is increasing. As per Yi (2013), the regulations on green economic systems in the USA are creating prospects of employment and having a substantial impact on the employment openings overall. Yi and Liu 2015) also asserted that the climate concerned policies and regulations in China are increasing the employing prospects positively Yi (2014), Yi and Liu (2015) examined the geographic exploration of states discrepancy on green employment because of green energy regulation, and concluded the rise in green employment. Yi (2014) also absorbed green industries' development in the USA, especially the driven agents of green ventures, political prospects, economic standings and other influences, and found influence on green employment through green ventures development. Jung (2015) asserted significant regulatory aspects of South Korea and concluded that green employments have to be encouraged through wide stratagems. Connolly et al. (2016) concentrated on green employing prospects of Scotland and determined an impulsive growing on green agendas and green economic systems, where the governing bodies have to be emphasized on the categories of jobs offered and sustained. The study on Germany emphasized the significant influence of investing in energy segment growth, especially on green economic systems and green energy agendas. The green economic impacts are specified as positive encouraging towards creating employment opportunities (Lehr et al. 2012).

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Chapter 9
The Spillover Effect from Oil and Gas Prices: Evidence of Energy Shocks from Diebold and Yilmaz Index

Lucía Ibáñez-Luzón, Festus Victor Bekun, Andrew Adewale Alola, and Daniel Balsalobre-Lorente

Abstract The current study contributes to the current debate on the energy-growth literature spillovers between crude prices, oil prices, and natural gas liquid composite prices. To this end, the recent novel Diebold and Yilmaz (2012) spillover index is utilized for daily realized data from January 2009 to October 31, 2019. The Diebold and Yilmaz index is employed given its uniqueness to highlight the following directional spillovers, total spillovers, pairwise spillover, and net spillover for the outlined variables. Further empirical investigation to accounts for both secular and cyclical properties is examined within the sampled framework. The study empirical results show a total spillover effect of 13.80% such that the contribution of shock from others is highest for liquefied natural gas (NGLC) price (43.2). The contribution of shocks to Brent price (7.5) and WTI price (3.0) was also received from others. Interestingly, the Brent price is observed to contribute the highest shock to others (41.4) considering the global adoption of the Brent crude oil as against the WTI which also contributes a shock of 12.9 to others. Based on these findings, several policy prescriptions were presented in the concluding section.

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9.1 Introduction

The energy sector is been on a trajectory of paradigm shift in the recent decades ranging from environmental degradation challenges to energy security of supply concerns. Thus, new voices arise clamoring that a change in the current energy model is pertinent. This chapter will explore the evolution of oil and natural gas prices to review some of the macroeconomic fundamentals that have an effect on energy markets. To understand the current energy mix paradigm, it is necessary to look deeper into its most relevant components, which currently are oil and other liquids, coal and natural gas, all of which are fossil fuels. The first component is coal, consumption of which is expected to decrease. The reason behind this is that it is one of the most polluting fossil fuels, and after COP21 agreements, many countries committed to limit its use (Adedoyin et al. 2020)

On the other hand, oil and natural gas consumption is expected to continue rising, even though their exploration, production, and consumption processes are also polluting in nature. Natural gas is expected to grow at a higher rate than other fossil fuels, benefiting from being the less polluting fossil fuel and the substitute of renewable energy sources (RES) in cases of low RES production. Furthermore, natural gas production has increased due to the well-known shale gas revolution.[1]

Looking at the evolution of natural gas and oil prices in the last nine years, it is observed that prices have decreased (Fig. 9.1). This tendency is stronger in the case of natural gas.

There are differences in price-setting among regions. While gas prices in North America are set at liquid trading hubs (mainly at the Henry Hub), in Europe wholesale gas is sold mostly via long-term contracts (where prices are hub-based or oil-linked, and often both). In Asia and emerging countries, gas prices are usually linked to oil prices due to the inexistence of established liquid hubs, explaining the impact of oil volatility over gas prices.

Brent Crude is a major trading classification of sweet light crude oil that serves as a benchmark price used when purchasing oil worldwide. Brent crude is extracted from the North Sea and it is used to price two-thirds of the world traded oil. There has been a 6.8% decrease in the Brent reference price, which was 35.19 €/MWh on September 30, 2010, and has moved to 32.78 €/MWh on September 30, 2019.

Henry Hub is an important market clearing pricing point. It is used in delivery contracts for LNG on a global basis. Gas producers can rely on Henry Hub as a

[1]Shale gas refers to natural gas that is trapped within shale formations. The combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas that were previously uneconomical to produce, and it has rejuvenated the natural gas industry, especially in the USA. It offers liquefaction developers a competitive advantage due to its competitive prices. Thanks to cheaper unconventional gas, the US gas prices have become more competitive resulting in significant LNG exports and liquefaction capacity hikes.

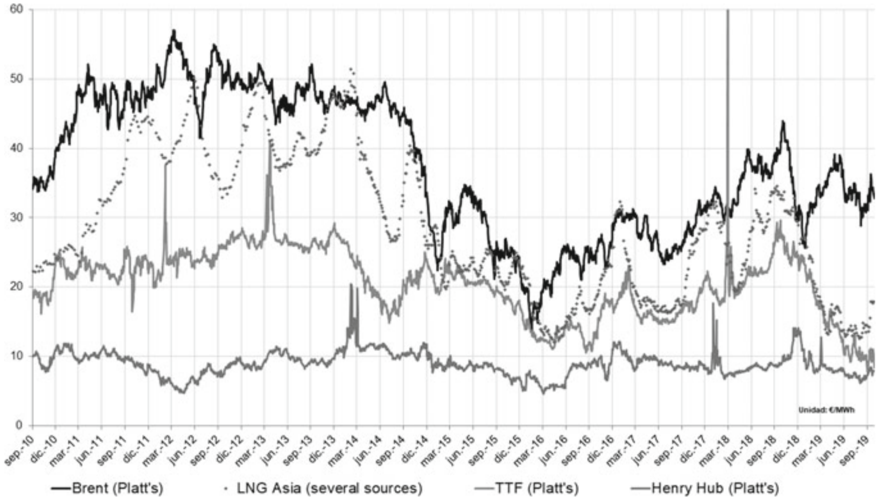

Fig. 9.1 Evolution of natural gas and oil prices (2010–2019). *Source* Own production based on Platts and other sources

source of natural gas spot pricing because of its large trading volume, clear pricing transparency, and high liquidity.

Henry Hub's price has decreased by 16.7% in the aforementioned period, mainly due to the increase in shale gas production. At present, shale gas represents close to 70% of the total US natural gas output and two-thirds of it are exported via pipeline to Mexico or as LNG globally.

Title Transfer Facility (known as TTF)is a virtual trading point for natural gas in the Netherlands. Located between the North Sea and Europe's main gas consumer, Germany, it allows gas to be traded within the Dutch Gas network. TTF products have been standardized to simplify their trading process. With prices relying on supply and demand dynamics, this natural gas hub is the largest European gas trading point, currently considered a benchmark at an EU level. There has been a 53.4% decrease in the day ahead price of TTF, which moved from 17.90€/MWh on September 30, 2010, to 8.35 €/MWh on September 30, 2019. Since the beginning of the year 2019, natural gas prices in Europe have plummeted due to a rising export war between Russia and the USA. According to Carlos Torres-Diaz, head of gas markets research at Rystad Energy, "The clear winners from the war between these two gas powers are the European end consumers, who benefit from record-low natural gas prices, and power prices which have dropped more than 30% in the last six months." Torres-Diaz also observed "As two of the world's largest gas producers, Russia, and the USA are natural competitors in what seems to be a race to the bottom, not only in the lucrative Asian market but now also in Europe. Both countries have sent increasing amounts of gas to Europe despite the low-price environment." Another reason behind this trend is the decrease in the consumption of natural gas and coal and the rise of electricity production with renewable energy sources.

Lastly, *LNG Asia*, it is the main natural gas hub in Asia and a global reference point for LNG trading. LNG Asia has seen a 19% decrease in the price of the index since September 2010. Spot LNG prices are at the lowest level they have been in years. "Asia's LNG prices have been in freefall since September 2018, as ample supply, sluggish demand and robust early stockpiling by China's SOEs (state-owned enterprises) largely capped prices over the winter months." Fitch Solutions reported "These factors, next to elevated growth headwinds and a forecast cooler summer, look set to keep a lid on prices over what should typically be a stronger season for gas demand." China and South Korea drove 85% of the growth for the period; LNG import level reflects a 29% increase from the previous year which can be attributed to "robust state-driven gasification efforts, to cut pollution and diversify away from coal," according to Fitch Solutions. Fitch Solutions notes that "a wave of new LNG supply additions" (many from North America) will "flood the Asia market."

With regard to the drop in oil prices, two differentiated trends have emerged; LNG prices are tending to converge and, a spread reduction between oil-linked and US market-based natural gas contracts. Supply and demand forces play the main role in the evolution of oil and gas prices. A deeper analysis of supply and demand dynamics is required to understand how these two markets are expected to evolve.

9.2 Energy Dynamics in Brief

The relationship between supply and demand determines the price of most goods and services; for this reason, a deep analysis of supply–demand forces is fundamental at this point to establish a connection between these market forces and price volatility in the energy sector. This subchapter goes through some macroeconomic fundamentals, necessary to understand forecasted demand movements. Demand for primary energy is ever-growing. Total energy consumption is expected to grow by 46% between 2018 and 2050. Among the principal reasons behind this are the increase in global population, GDP, and productivity.

The worldwide population has grown at a +11% rate between 2010 and 2018. At the moment, it accounts for 7.730 billion people, is expected to grow by 25%, reaching 9.650 billion people by 2050. Africa as a whole has grown by 25% since 2010 and is expected to grow by 84% between 2018 and 2050. China and India, which are the countries with greater absolute growth from 2010, are expected to keep growing at a high-speed rate, especially India (+21% up to 2050). A deceleration in Chinese growth is expected toward the end of the studied period as displayed in Fig. 9.2.

On the other hand, global energy demand is set to increase significantly driven by expansion in global output and increased prosperity in the developing world. Regarding global output, non-OECD-countries currently account for 56% of worldwide GDP and are expected to account for 86% of total GDP growth from 2018 to 2050. Non-OECD-countries are expected to grow by 226% in the following 32 years in comparison to OECD countries which growth is expected at 67%.

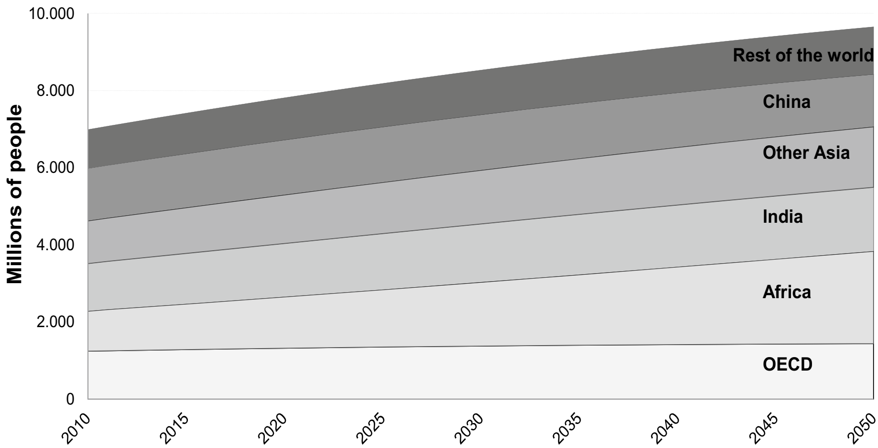

Fig. 9.2 Evolution of worldwide population (2010–2050). *Source* Own production based on EIA data

The country that is expected to grow at the greatest rate is India (+438%), followed by other Asian economies (+280%). Together Chinese and Indian GDPs are expected to account for around half of global GDP growth in 2050. On the contrary, Japan and Russia are expected to grow at the slowest rate, Japan at 9% and Russia 44%. The share of the African GDP in 2050 will account for 8% of global GDP while the weight of African population is expected to be 25%. On its yearly outlook, BP attributes this disparity to weak productivity.

Increases in per capita GDP account for 80% of the global expansion and lifts more than 2.5 billion people from low incomes, as pointed out by BP on its yearly outlook. The emergence of a large and growing middle class in the developing world is an increasingly important force shaping global economic and energy trends. GDP per capita is expected to grow at a rapid rate (up to 30% before 2050), with China (+69%) and India (+66%) displaying the highest rates of per capita GDP growth. The Chinese GDP per capita is expected to overpass Europe toward 2050. This rising prosperity and improvement in living standards supports increasing energy consumption per head (Fig. 9.3).

OECD and non-OECD countries are expected to follow different paths when it comes to energy demand since macroeconomic fundamentals are evolving differently. In 1990, OECD countries accounted for almost two-thirds of energy demand, with the developing world accounted just for one-third. In 2018, the OECD accounted for less than half of energy demand. In 2050, the situation is forecasted to be the reverse, with OECD countries accounting for one-third of global energy demand. At a time when the industrialization process is growing in some areas, Africa and Asia are on the way to achieving universal access to electricity by 2030. Since 2000, millions of new consumers have achieved access to electricity, and these figures will continue to rise rapidly.

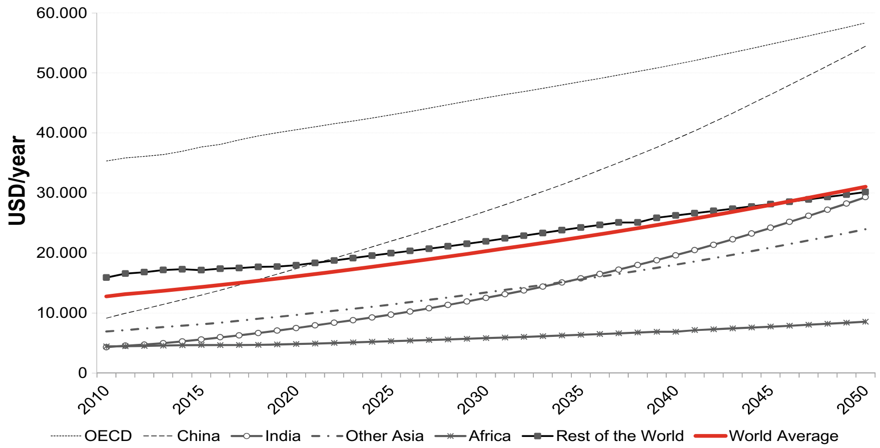

Fig. 9.3 Evolution of per capita GDP (2010–2050). Source Own production based on EIA data

Asia is expected to grow more in terms of primary energy demand in comparison to other regions. Currently representing 37% of global primary energy demand, it is expected to account for 43% of global energy demand by 2050. The Asian region accounted for nearly 40% of global energy demand in 2018 and this share has been rising rapidly. The main drivers if this growth are India and China; these two countries will continue growing at a rapid rate in the coming years. In 2018, India's energy demand accounted for onequarter of China's energy demand, whereas by 2050, the Indian demand is expected to account for half of the Chinese demand. This can be attributed to the efforts by the Chinese government to move towards an increasingly sustainable pattern of economic growth.

Africa's energy demand is expected to increase by 2%, a minimal increase in comparison with its expected population growth. Africa, by 2050, will be the home to one-quarter of the worldwide population; however, its energy demand will account for just 6% of the global primary energy demand. OECD countries are expected to reduce its energy consumption, due to a decrease in energy intensity in those countries.

Figure 9.4 presents primary energy demand distribution in 2018 and the forecasted one in 2050.

Coming back to oil and natural gas markets, both fossil fuels will continue playing an important role in the future. Natural gas consumption is expected to rise all over the world, without exception. This is especially true for China. In 2013, the Chinese government introduced the Air Pollution and Control Program, and ever since natural gas has played a fundamental role as the preferred alternative to coal. According to the International Energy Agency, in the next five years, China will become the world's leading importer of natural gas. China is expected to account for 37% of the global increase in natural gas consumption between 2017 and 2023, more than any other

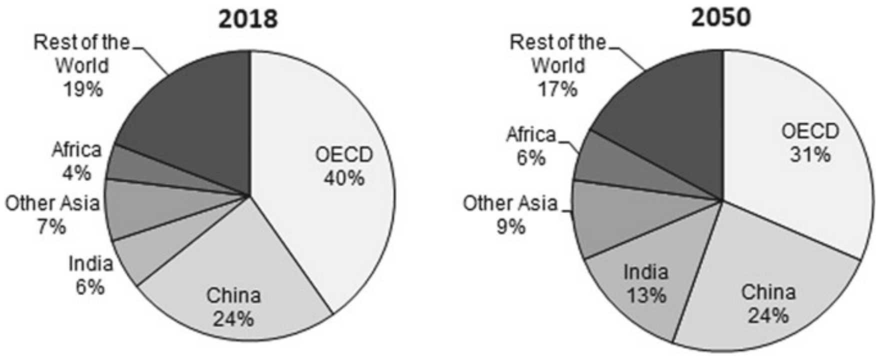

Fig. 9.4 Primary energy demand distribution. *Source* Own production based on EIA data

country. China's gas consumption is expected to move from being half that of the EU at the moment to 75% higher by 2040 (Fig. 9.5).

Regarding liquid fuels, its consumption is expected to show the greatest increase in India and greatest decrease in the OECD countries, due to environmental policies claiming for cleaner energy sources. India is estimated to display the biggest oil consumption growth between 2018 and 2050. Despite its efforts to reduce CO_2 emissions and increase usage of sustainable energy sources, the country will need to fill the demand gap with oil to cope with its expanding demand needs (Fig. 9.6).

On the supply side, the global pattern of energy production is also shifting, with strong growth in US energy production and a slowing in the expansion of Chinese

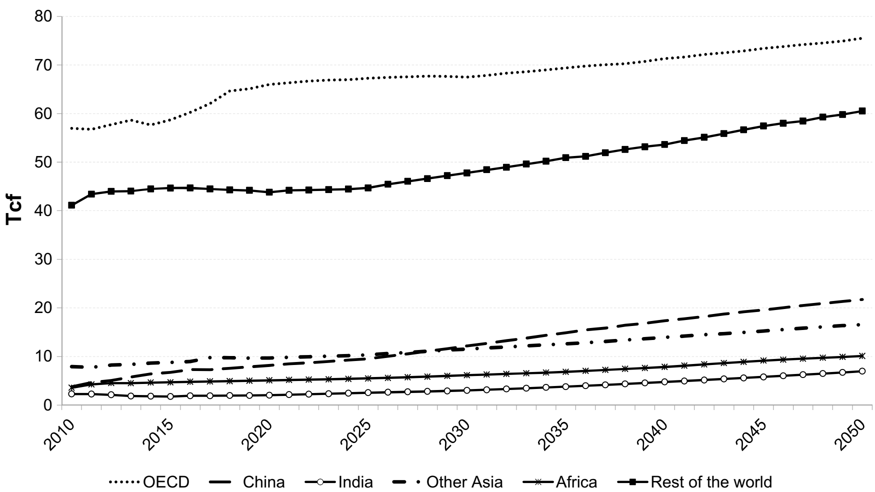

Fig. 9.5 Natural gas consumption evolution (2010–2050). *Source* Own production based on EIA data

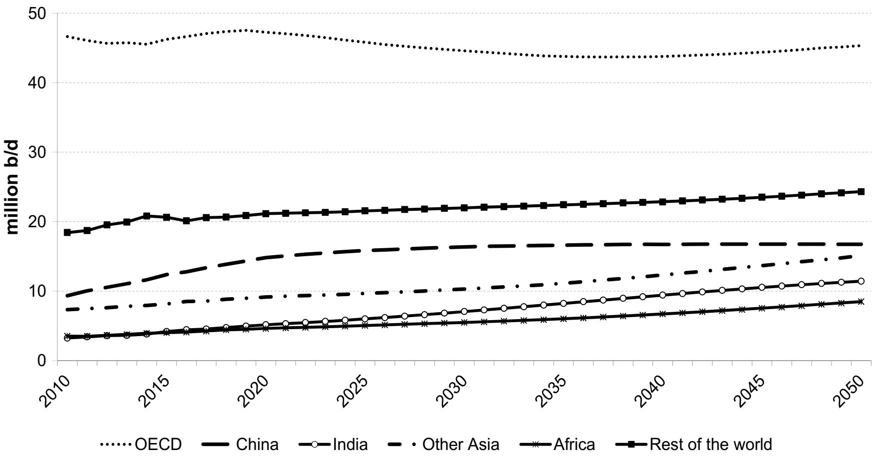

Fig. 9.6 Liquids consumption evolution (2010–2050). *Source* Own production based on EIA data

energy supplies. The US growth is related to the increase of shale oil and gas production from the Permian region. China, on the contrary, slows down due to an adjustment toward a more sustainable pattern of economic growth. The Middle East remains an elemental source of energy while Russian production is expected to slow down, even though it continues being the main oil and gas exporter.

Natural gas and oil will continue being key for growth. Oil will continue to be the most consumed energy source, while gas will be the fastest-growing fossil fuel, both fundamental components of the future energy mix.

9.2.1 Energy-Related Crises

Energy is essential for growth because it is a necessary input for every sector and a productivity driver. The linkage between economics and energy lead to energy security concerns at governmental levels.

Energy consumption affects various aspects of economic activity, having influence over long-run GDP growth and improvements in quality of life simultaneously. The reason for this is that energy is required in all industrial processes; therefore when there are energy shortages producing price spikes, they have a negative multiplicative effect over industrial costs. Then, higher industrial costs are translated into higher retail prices, leading to consumption crises. Higher energy prices lead to both a reduction in aggregate demand and a shift in expenditures which in turn cause a ripple effect throughout the economy, as firms adjust their production plans.

Some of the most relevant economic crises have been directly connected to energy crises. As good examples of this, the energy crises that took place in 1974 and 1981 proved the existence of nexus between energy consumption and economic growth since the late 1970s. Several economists (e.g., Kraft and Kraft 1978; Erol and Yu 1987; Soytas and Sari 2003; Alola 2019; Alola et al. 2019) explored the relationship between short- and long-run energy consumption and growth. The biggest threats leading to likely future energy crises currently are energy security of supply and climate change.

9.2.2 Energy Security of Supply and Market Concentration

Energy is scarce, which means that in the majority of the countries, internal production is not enough to meet demand needs (especially in countries that rely primarily on fossil fuels for energy production). On the other hand, a few countries have control over worldwide oil and gas production, often located in politically unstable areas. Concerns regarding the security of supply arise because there is a high reliance on energy (mainly fossil fuels) producers, and fossil fuel production is concentrated in a few countries.

One of the most recent energy crises where security of supply was compromised was the EU- Ukrainian crisis that brought focus on EU dependence on Russian gas. Russia currently accounts for as much as 34% of EU gas imports (2015), and for many new member states in Eastern Europe, the share is much higher. Supply disruptions derived from the crisis proved the importance for non-producing countries to have a diversified supply source portfolio. Security of supply is not just related to disruptions but also price volatility. According to the International Energy Agency, *security of supply means access to adequate supply of energy at a reasonable cost, proper investment in infrastructure and proper functioning of the system.*

Oil and gas reserves[2] are highly concentrated in a few hands. In 2018, 66% of natural reserves and 84% of crude oil reserves were held by ten countries. Natural gas CR3 is 44% while oil CR3 is 42%, meaning that three countries have power over more than 40% of global proven reserves in each market. Venezuela possesses the largest crude oil reserves (302.25 Billion Btu), followed by Saudi Arabia (170 Billion Btu), Canada (170.5 Billion Btu), and Iran (157.2 Btu). In the case of natural gas, Russia possesses the largest proven natural gas reserves (1688.33 Tcf), followed by Iran (1190.83 Tcf) and Qatar (850.1 Tcf) (Fig. 9.7).

On the other hand, most oil and gas producers are state-owned monopolies. In Russia, more than 50% of oil and gas production is owned by the Russian Federation state. There are other oil and gas state-owned monopolies such as BBOC in Nigeria or SONATRACH in Algeria, which are 100% owned by their governments not allowing private investments.

Ten countries own more than 60% of natural gas reserves and more than 80% of crude oil reserves, thus having direct influence over the rest of the countries

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[2] Energy reserves are estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions.

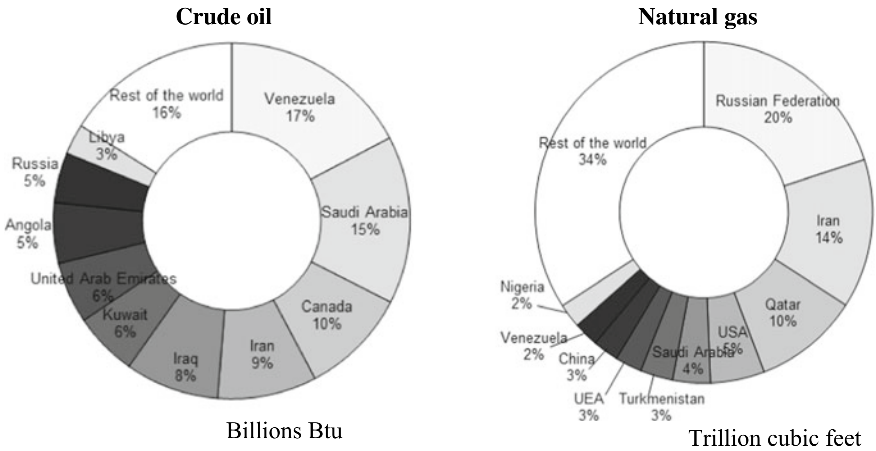

Fig. 9.7 Oil and gas proven reserves (2018). *Source* Own production based on EIA data

relying on them to satisfy their internal demand needs. The long-term implications of being dependent on monopolist, single-supply routes, and oil or natural gas as dominant energy forms can be detrimental to a country's welfare and independent policymaking.

9.2.3 Global Climate Crisis

The world is currently facing a global climate crisis. There has been an increase of 2 degrees Fahrenheit during the twentieth century ratified by the NASA which has led to global environmental change, "Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice, accelerated sea-level rise and longer, more intense heat waves". The Intergovernmental Panel on Climate Change (IPCC) states that *"the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time"*. In response to climate change, the United Nations Conference on Climate Change (COP21) in Paris in 2015 resulted in 195 countries approving the first universal, legally binding global climate deal on greenhouse gas emissions, known as the Paris Agreement. The Paris Agreement aims to keep the increase in global average temperature to well below 2 °C above pre-industrial levels and has been ratified by 187 countries till date and representing over 87.75% of emissions. Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to greenhouse gases produced by human activities. The world currently emits 35 billion tonnes of energy-related CO_2 each year. The IEA has calculated that energy-related CO_2 emissions need to fall to around 18 billion tonnes a year by 2040 to limit the rise in global temperature to 2 °C.

Fossil fuels produce large quantities of carbon dioxide when burned. Carbon emissions trap heat in the atmosphere and lead to climate change. The Intergovernmental Panel on Energy Studies' paper "Global warming of 1.5 °C" describes the impacts of global warming of 1.5 °C above pre-industrial levels and emphasizes the negative role played by fossil fuels and their contribution to global net CO_2 emissions. Looking at individual performances, India is expected to show the greatest increase in its CO_2 emission levels with a 161% jump in emissions from 2018 to 2050, followed by Africa with an increase of 96%. On the contrary, Japan is expected to improve the most, decreasing its emissions by 21% from 2018 to 2050, followed by the European Union, expected to reduce its emissions by 12% by 2050.

The EU has put in place legislation to reduce emissions by at least 40% by 2030—as part of the EU's 2030 climate and energy framework and contribution to the Paris Agreement. This includes revising the EU emissions trading system (EU ETS) national emissions targets for sectors outside the EU ETS. Japan, which is the world's fifth-biggest carbon emitter, is committed to reducing its greenhouse gas emissions by 80% by 2050. China is planning on implementing the ETS project. Figure 9.8 displays the forecasted evolution of CO_2 emissions by region.

Energy crises have a multiplicative effect over the economy since all industrial processes rely upon the energy factor and have proven that countries should rely upon more than just a few suppliers to cope with their demand needs to mitigate disruption risks and dependency issues. The reliance on polluting fossil fuels needs to be reduced to fulfill Paris Agreement requirements on the one hand and to reduce dependency on external producers on the other.

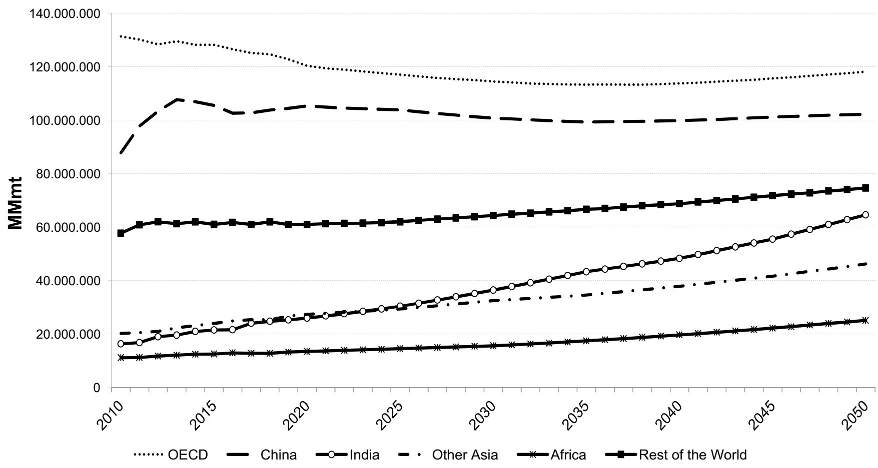

Fig. 9.8 Evolution of CO_2 emissions (2010–2050). *Source* Own production based on EIA data

9.2.4 Green Energy

At present, when energy security of supply is fundamental and climate change is at a crucial stage, it is of great importance to rethink how to deal with forecasted increasing demand a more sustainable manner. As strategies to secure energy supply while facing environmental challenges, there are two best-practice options, one from the supply side and the other from the demand side. From the supply side, it relates to renewable energy sources and from the demand side to energy efficiency and conservation.

9.2.5 Energy Efficiency and Conservation

Energy efficiency implies a reduction in the amount of energy consumed per produced unit of output. Energy intensity is a measure of the energy efficiency of an economy. It is calculated as units of energy per unit of GDP; low energy intensity indicates a lower price or cost of converting energy into GDP. Therefore, energy intensity and energy efficiency demonstrate an inverse relationship, with a decrease in energy intensity, resulting in an increase in the energy efficiency. To comply with United Nations Sustainable Development Goal 7 (SDG 7), energy intensity needs to undergo huge reductions. For this, many countries have issued national policies regarding energy efficiency and energy intensity. At a European level, Directive 2012/27/EU on energy efficiency establishes a common framework of measures for the promotion of energy efficiency within the European Union to achieve the headline target of a 20% reduction in primary energy consumption by 2020 (EC reference).

Worldwide energy intensity is expected to be reduced by 42% before 2050, taking as a base case 2018 scenario as presented in Fig. 9.9.

China is expected to improve the most in energy efficiency terms, reducing its energy intensity by 57% from 2018 to 2050. China has already started developing its economy toward the achievement of an energy intensity reduction, achieving a 24% improvement from 2010 to 2018. Other Asian countries are expected to improve by 46%, followed by Africa which will improve by 39%. Improvements in energy efficiency simultaneously address energy security, affordability, and environmental concerns, contributing to CO_2 reduction. Measures could be taken at a household and non-household level. At a household level, efficiency plays a major role in transport, house cooling, cooking systems, among others. In transport, road passenger vehicles should use almost 50% less fuel per kilometer traveled in 2040 compared with today to comply with environmental agreements, supported by strengthened fuel economy standards and larger uptake of electric vehicles, avoiding 20 Mtoe of fuel consumption in road transport. In the infrastructure sector, energy efficiency measures bring additional savings. This reflects more stringent Minimum Efficiency Performance Standards for appliances and particularly for cooling equipment. To

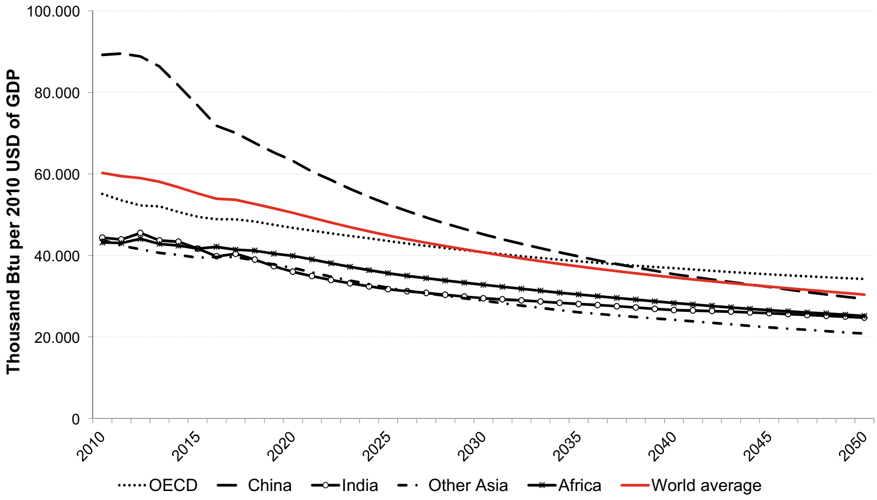

Fig. 9.9 Energy intensity evolution (2010–2050). *Source* Own production based on EIA data

comply with Paris agreement requirements by 2040, the industrial sector's average energy intensity may decrease by 50% from present levels, largely due to increases in recycling rates and equipment efficiency.

9.2.6 Clean Energy Sources

Despite the importance of energy efficiency measures, these will not be enough to cope with increasing energy demand needs. To grow more sustainably, cleaner energy sources need to grow in detriment of pollutant energy sources. Figure 9.10 presents Pounds CO_2 per MBtu per fossil fuel, showing the importance of eliminating coal and other pollutant fuels in the process of energy production. All types of coal and fuels are highly pollutant, as per Fig. 9.10. Natural gas produces the lowest dioxide emissions among fossil fuels, due to which it may emerge as an essential transition fuel to combat global climate change, along with renewable energies.

Out of all energy sources, renewables have proved to be the cleanest, safest, and most reliable for electricity production. Electricity production from RES is possible at low or even zero carbon emission levels, because of which they are gaining importance relative to oil and coal. Further, RES are attractive for the supply chain due to their benefits; moving away from fossils fuels removes the risk of price fluctuations and regulatory changes, they also attract customers interested in corporate and environmental responsibility. Nowadays, RES are also more affordable and accessible than ever, as the cost per kWh of the energy they produce continues to fall.

Solar energy and wind energy are the world's biggest sources of renewable energy and grow in popularity each year. Other notable sources of energy for the future

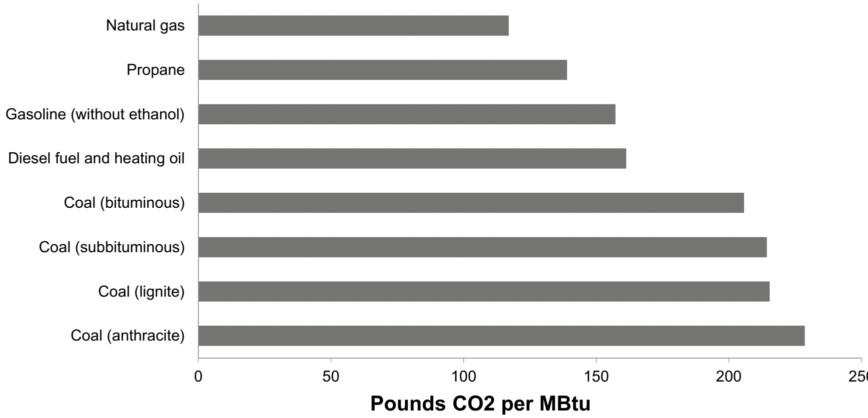

Fig. 9.10 Carbon dioxide emissions coefficients by fuel. *Source* Own construction based on EIA data

are nuclear power and geothermal energy. Nuclear power has its share of concerns; however, as technology develops, it may become a viable replacement for centralized fossil fuel power stations. Geothermal energy is another option, although it is more limited.

Many countries are adopting RES for electricity production. One of them is Iceland, the country generated the cleanest electricity per capita in the world, with almost 100% of RES production, and its generation mix is based on geothermal and hydroelectric power plants. Another example is Costa Rica, Costa Rica can meet a large part of its energy needs from hydroelectric, geothermal, solar, and wind sources, and it is committed to be completely carbon neutral by 2021. In Uruguay, owing to a supportive regulatory environment and a strong partnership between the public and private sectors, the country has invested heavily in wind and solar power, without using subsidies or increasing consumer costs. Thus, as an outcome of Uruguay's efforts, in less than ten years, 95% of its electricity production comes from renewables.

At a global level, the total installed capacity of renewable energy sources is expected to quadruple in following 30 years, from 2,340 quads Btu in 2018 to reach approximately 8,126 quads Btu by 2050. The growth in renewable energy is dominated by the developing world, with China, India, and other Asian countries accounting for nearly half of the growth in global renewable power generation, as noted by BP in their yearly Outlook. For example, in India, total RES installed capacity is expected to increase over tenfold, from 112 quads Btu in 2018 to 1478 quads Btu in 2050. In 2018, OECD countries account for 44% of total RES installed capacity, followed by China (30% of global share). By 2050, China is expected to have the biggest installed capacity share (34%), followed by OECD countries (33%). At present, China is the world's largest polluter; however, it is also the biggest investor in renewable energy in the world, incentivizing its cities to reduce fossil fuel consumption and heavily investing in RES (Fig. 9.11).

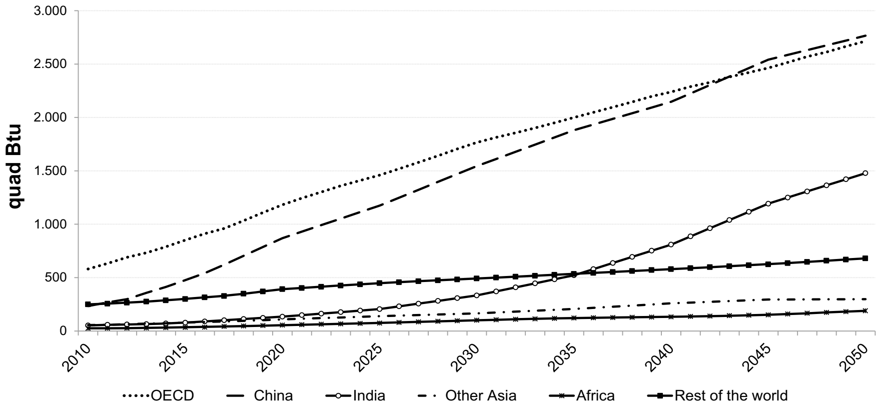

Fig. 9.11 RES installed capacity (2010–2050). *Source* Own construction based on EIA data

While discussing clean energy sources and the many advantages they offer, it also important to mention some of the concerns that require attention. The primary issue with renewable energies is that they rely on weather conditions; hence, they face intermittency problems, alternating periods of high production with periods of low production.

Cost-efficient energy storage systems are fundamental to ensuring that excess energy generated in peak periods can be used to shore up the gaps when generation is lower. Along with storage systems, well-interconnected systems help to tackle intermittency problems in a more efficient way. At the European Union level, a strong and fast-growing interconnection of the grid on an EU level has been already achieved as a tool to deal with national consumption peaks.

Despite the existence of storage facilities and efficiently interconnected markets in some areas, there is still a demand gap to be hedged via other energy sources. Natural gas is viewed as a complementary energy source for wind and solar energies, enabling its greater adoption.

RES and natural gas will be fundamental energy sources in the future, although oil will also continue playing a central role. Figure 9.12 displays the evolution of the future worldwide energy mix. Between 2018 and 2040, renewable energy is the fastest-growing source of energy, contributing half of the growth in global energy supplies and becoming the largest source of power by 2040. Renewable energies are expected to grow by (+64%) from 2018, followed by natural gas (+40%) and nuclear energy (+36%). The demand for liquid fuels grows for the first part of the period before gradually plateauing. On the contrary, coal's share is forecasted to decrease by 0.2% mainly due to the general aim to reduce CO_2 emissions. The largest source of energy will continue being liquids. Natural gas grows more rapidly than both oil and coal, overtaking coal to be the second-largest source of global energy. Coal consumption will decline to its lowest level since before the industrial revolution. The fall in coal consumption can be attributed Chinese policies against the usage of

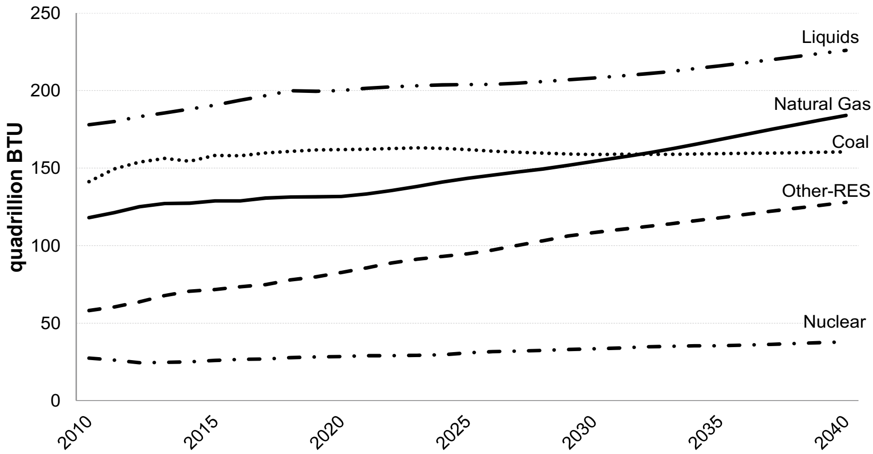

Fig. 9.12 World energy consumption by energy source (2010–2040). *Source* Own construction based on EIA data

coal, partly balanced with consumption increases in other Asian countries, such as India.

Cleaner energy sources, natural gas, nuclear, and renewable energies will account for 47% of total energy demand in 2040, while they account for 39% presently. Taking a look at liquids, they currently account for 33% of the total energy consumption, a trend that is expected to change, accounting for just 13% in 2040 as displayed.

The rest of this study is structured as: Sect. 9.2 provides a brief of the related literature while data and method are offered in Sect. 9.3. Section 9.3.2 presents the empirical discussion. Finally, Sect. 9.4 provides the concluding remark.

9.3 Methodological Procedure

9.3.1 Data Source

The present study relies on the Diebold and Yilmaz (DY, hereafter) to evaluate the interconnectedness between the variables: crude oil (Brent), world Texas intermediate (WTI) oil prices, liquefied natural gas prices and Henry Hub (Platt's) prices for daily realized data from January 1, 2009 to October 31, 2019. The data were sources from the Federal Reserve Bank of St. Louis (FRED) database (https://fred.stlouisfed.org/). In Table 9.1, further description of the data series containing the unit representation and code is presented.

In addition, the descriptive statistics and the correlation matrix of the employed data are presented in Table 9.2. From the information in Table 9.2, it is observed that the Brent crude oil (Brent) price exhibits the highest volatility considering the

Table 9.1 Indicators and unit of measurement

Variables	Code unit of measurement	Source
Brent crude oil	Brent price US dollars	FRED
World texas intermediate	WTI price US dollars	FRED
Liquefied natural gas prices	NGLC price US dollars	FRED
Henry hub (Platt's)	HH price US dollars	FRED

Source Authors' compilation
Note The data from Fred Louis database is available in https://fred.stlouisfed.org/

Table 9.2 The descriptive statistics

Variables	WTI price	Brent price	HH price	NGLC price
Mean	71.7256	78.3126	3.379721	8.871054
Median	70.645	74.43773	3.23	9.06
Maximum	113.39	124.9286	8.15	15.88
Minimum	26.19	30.80333	1.49	3.69
Std. Dev.	21.61529	25.68288	0.882746	3.200221
Skewness	0.065804	0.177234	0.742494	0.415471
Kurtosis	1.694211	1.652177	4.188278	2.334166
Jarque-Bera	195.4932*	220.4482*	410.5516*	128.686*
Correlation matrix				
	WTI price	Brent price	HH price	NGLC price
WTI price	1			
Brent price	0.969753*	1		
	(207.2814)	–		
HH price	0.462443*	0.386749*	1	
	(27.21139)	(21.88037)	–	
NGLC price	0.817689*	0.814634*	0.551916*	1
	(74.10807)	(73.28196)	(34.53055)	–

Note The WTI, BRENT, HH, and NGLC are, respectively, the West Texas Intermediate crude oil prices, Brent crude oil prices, Henry Hub natural gas spot price, and US Natural Gas Liquid Composite price. Also, the * is the statistical significant level at 1% and () is the test statistic

maximum and minimum values as well as the standard deviation. This is illustratively followed by the World Texas Intermediate (WTI) price, the liquefied natural gas (NGLC) price, and the Henry Hub (Platt's) prices. Similarly, the evidence of correlation among the each pair of the variables is statistically significant as evidently shown in Table 9.2. However, the correlation evidence between WTI and Brent crude oil prices, NGLC and Brent prices, and Brent crude oil and NGLC prices is all statistically significant especially with a correlation coefficient of more than 0.80.

Table 9.3 Spillover Index

Variables	WTI price	Brent price	HH price	NGLC price	From others
WTI price	**97**	3	0	0	3
Brent price	7.5	**92.5**	0	0	7.5
HH price	1.1	0	**98.7**	0.2	1.3
NGLC price	4.4	38.4	0.4	**56.8**	43.2
Contribution to others	12.9	41.4	0.5	0.2	**55**
Contribution including own	110	133.9	99.2	57	13.80%

Note The WTI, BRENT, HH, and NGLC are, respectively, the West Texas Intermediate crude oil prices, Brent crude oil prices, Henry Hub natural gas spot price, and US Natural Gas Liquid Composite price

9.3.2 Empirical Method

This study applies DY to evaluate the interconnectedness between the outlined variables under review. In the application of the DY approach, the order of selection of the variables is not important just as the techniques do not significantly suffer from other econometric problems such as the serial correlation and heteroskedasticity. The DY techniques are novel on the premise of its less rigorous computational requirements that aid the characterization that reflects diverse events and episodes. The DY procedure is built on the vector autoregressive (VAR) and variance decomposition setting. Diebold and Yilmaz (2009) is structured in the VAR framework that is sensitive to the order orientation of the variables after the Cholesky factorization. However, the extended version of the Diebold and Yilmaz (2012) ameliorate for the shortcomings of the 2009 version that does not take into account the order orientation (Koop et al. 1996; Pesaran and Shin 1998).

The Diebold–Yilmaz index highlights four spillovers indices, namely directional spillovers pairwise spillover, net spillover, and total spillovers. The DY setup is based on a covariance stationary VAR:

$$y_t = \Phi_0 + \sum_{i=1}^{n} \Phi_i y_{t-i} + \varepsilon_t$$

Here, $y_t = (y_{1t}, y_{2t}, \ldots, y_{nt})'$ is a vector of covariance stationary series Φ_i, $i = 0, 1, 2, \ldots, p$, denotes $(n \times n)$ matrix of parameters ε_t is a $(n \times 1)$ vector of zero mean errors required to be independent and identically (*iid*) distributed with covariance matrix Σ, $\varepsilon_t \sim iid(0, \Sigma)$.[3]

However, the estimates of the DY result are presented in Table 9.3 in addition with the spillover rolling window in Fig. 9.1. Accordingly, the pairwise result indicates

[3]For the want of space, interested reader on the DY indices see the Studies of Diebold and Yilmaz (2009, 2012, 2014).

that the spillover effect from Brent price to NGLC price is the highest (38.4), thus indicating that there is higher possibility for the contagion of shock (resulting from volatility and other forms of uncertainty) from the event surrounding the dynamics of Brent crude oil price to the liquefied natural gas price. This evidence was earlier investigated in the study of Panagiotidis and Rutledge (2007) that found a significant evidence of cointegration between the United Kingdom (UK) gas and the oil prices. Similarly, the study of Geng et al. (2016) found a significant evidence of multi-scale impact of oil price shock on gas markets especially in the pre- and post-revolution. While the study also found a significant linkage between oil price and shale gas revolution, the effect of oil price on Henry Hub price is found to be significant but weaker. Similarly, the spillover effect caused by shock in the World Texas Intermediate (WTI) price to the Brent price, NGLC price, and HH price are respectively 7.5, 4.4, and 1.1.

Furthermore, the impact of the contribution to and from others is observed to yield a significant total spillover effect of 13.80% as illustrated in Table 9.3. The spillover effect (caused by shock) from the combined series is observed to be higher in the order of NGLC (43.2), Brent price (7.5), the WTI price (3), and HH price (1.3). The implication is that the liquefied natural gas is more impact whenever there is shock among the estimated markets of oil and gas prices. Similarly, the spillover effect contribution from Brent price to other estimated market commodities is highest (41.4) and followed by the spillover effect from the WTI price to other market commodities (12.9). Intuitively, it is not a surprise that the contribution from Brent price to other market commodities is highest considering the significant of Brent crude oil globally. The reason is because the Brent and WTI are the two dominant oil reference prices globally while the Brent crude oil most preferred because it relative advantages (Álvarez-Díaz 2019; Caporin et al. 2019; Caro et al. 2020) (Fig. 9.13).

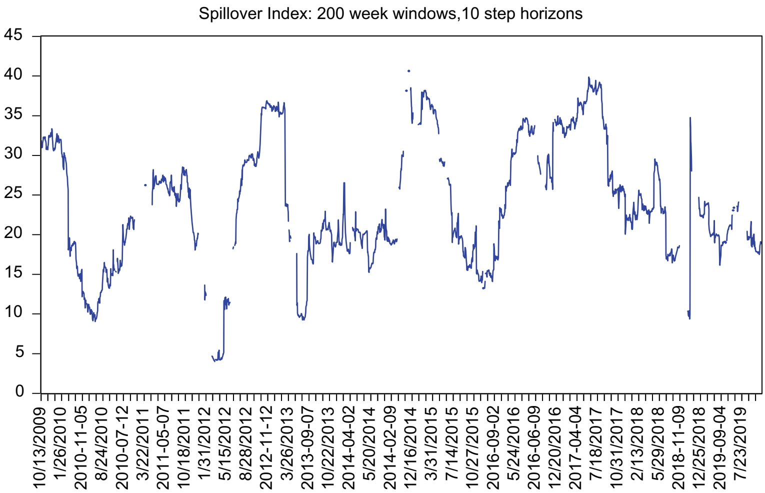

Fig. 9.13 The spillover rolling window

9.4 Concluding Remark and Policy Direction

In all oil and natural gas markets, supply and demand forces play the main role in price formation despite price-setting differences. Demand for primary energy is ever-growing, with the developing world increasing its role as the main consumer. Total energy consumption is expected to grow by 46% between 2018 and 2050 driven by an increase in worldwide population and purchasing power from developing countries (headed by China and India). At the same time, the world is currently facing a climate crisis. Fossil fuels are the most polluting energy sources and their production is located in only a few countries, leading to dependency risk. Hence, it is necessary to rethink how to deal with forecasted increasing demand in a more sustainable way.

As strategies to secure energy supply while facing the environmental challenge, the two best options are the promotion of energy efficiency and greater investments in renewable energy domestic production. On the one hand, global energy efficiency is expected to improve by 42% between 2018 and 2050. While on the other hand, renewable installed capacity is expected to increase in all areas. Renewable energy sources are expected to be the fastest-growing energy source followed by natural gas which will help RES to cope with intermittency issues.

To understand the current energy mix paradigm, it is necessary to look deeper into the most relevant components, which currently are oil (and other liquids), coal and natural gas, all of which are fossil fuels. Thus, the present study seeks to investigate the nature of interconnectedness between a cocktail of energy prices, natural gas, and crude oil prices. The investigation is conducted with the novel and recent methodology advanced by Diebold and Yilmaz (2012); the DY approach is robust and provides both secular and cyclical movement that distinct from previous volatility estimators. Empirical findings were based on daily realized data from January 2009 to October 31, 2019, to validate the hypothesized argument. Accordingly, the current examination from a total spillover effect of 13.80% such that the contribution of shock from others is highest for liquefied natural gas (NGLC) price (43.2). The contribution of shocks to Brent price (7.5) and WTI price (3.0) was also received from others. Interestingly, the Brent price is observed to contribute the highest shock to others (41.4) considering the global adoption of the Brent crude oil as against the WTI which also contributes a shock of 12.9 to others.

This study is not without policy directives and recommendation. Considering the importance of both the Brent crude oil (Brent) and the world Texas intermediate (WTI) in the global commodity markets, a more diversification of the global markets is essential. In adopting more economic diversification, the impact of oil shocks on other commodity markets, thus minimizing or avoiding any potential economic and financial crisis. During the implementation of similar study in the future, additional commodities that capture other commodities and financial markets could be incorporated in the study.

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Chapter 10
Comparison of Wave Energy and Offshore Wind

Laura Castro-Santos and Félix Puime Guillén

Abstract The aim of this chapter is to compare wave energy and offshore wind energy in economic terms. The future of energy and electricity production will be at ocean. In this sense, offshore wind and wave energy are the two main important offshore renewable energies. However, it is important to compare them in economic terms to calculate their feasibility in order to take strategic decisions. In this context, aspects such as the LCOE are calculated to provide an economic comparison of these two technologies. The methodology will be carried out for a particular case of study. The location selected for this purpose has the offshore wind resource, and the wave energy resource is very good: It is the region of Galicia (located in the northwest of Spain). Results indicate the best ocean renewable energy in economic terms. This comparison is useful for future considerations in order to select the best location for an offshore renewable energy farm.

Keywords Wave energy · Offshore wind · Feasibility · Ocean energy · Renewable energy

10.1 Introduction

When talking about renewable energy, it is important to point out that in addition to the important advantages that these have over other types of energy, such as that they do not generate polluting gases, or waste, their use is infinite and that they generate by investment many more jobs than other alternative sources. However, it is important to bear in mind that they may also have disadvantages for their development since in their initial phase, the one corresponding to the investment, the profitability for

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the investors may be lower than that of other alternative projects, these perceiving a high cost of opportunity in financial terms.

Even so, it is important to highlight that in Spain, the implementation of these energy sources has been very important since 40% of the electricity generated has come from this type of energy in 2018. Although Spain currently has a huge dependence regarding fossil fuels, especially if we compare it with other European Union countries, thanks to renewable energy, this gap is decreasing (Asociación de Empresas de Energías Renovables 2019).

Within the different systems already available to obtain energy from nature in a renewable way, those obtained in the sea have a great projection of the future; these include those that take advantage of the sea wind, the force of the waves and the changes in the tides.

Specifically, we can define offshore wind energy as that source of clean and renewable energy that is produced through the wind that comes from the sea and especially those areas where it reaches its highest rate of speed and power. This type of renewable energy, in addition to inexhaustible and non-polluting, takes advantage of a much more abundant type of resource than the terrestrial wind.

In fact, wind energy is the most important of renewable energies and a fundamental piece for sustainable energy development in the EU. In this sense, the European Wind Association foresees that investments in parks in Europe will reach 124 billion dollars between 2013 and 2020 (Gatzert and Kosub n.d.).

Marine wind energy, taking advantage of what has already developed in terrestrial wind in recent years has had a strong momentum, is 100 years later than terrestrial and in recent times has developed quite a lot. With the installation of offshore wind farms, it is used that the wind speed on the high seas is much higher than the terrestrial, thus producing a greater amount of energy and supplying the coastal areas where a very important part of the population resides.

However, these wind farms are associated with a series of problems that must be solved so that their implementation is massive, since on the one hand, their installation can be very expensive and it is still studying how it can affect the fauna and flora of some environments

Recently, the World Bank has said that offshore wind energy will produce investments of 500,000 million dollars over a period of ten years, and that it has increased up to 500% in the last decade (Roca 2019).

For its part, the EU is trying to make this type of energy production between 230 and 450 GW in 2050. In fact, in its 2018 Wind Energy Report, it cites that an installed capacity of 189 GW has already been reached, becoming this type of energy in the second most important of the continent (Wind Europe et al. 2018).

In the case of Spain, it is expected to become a world power of offshore wind power as early as 2025, and the Norwegian energy company Equinor has expressed interest in investing more than 800 million in the construction of a huge offshore wind farm in the Canarian archipelago, and this project is expected to start operating in 5 years, generating numerous jobs.

With regard to the energy coming from the waves, it can be said that it is one of the most promising renewable energies, on a planet where the oceans cover approximately 70% of the earth's surface.

Today, its development is still very incipient, and this type of installation only produces no more than 1–10 MW at a time, although it would be enough to power a city. Therefore, these technologies are at an early stage of development, although they have progressed significantly in recent years (Astariz and Iglesias 2015).

The EU, in its goal of transforming Europe into a high energy efficiency economy, reducing energy consumption by 20% and trying to reach the goal of total energy consumption from renewable sources, expects marine energy I can contribute to 17 TW h/year (Tinsley et al. 2019).

In addition, the energy of the waves has the advantages that the energy density is generally between 30 and 40 per meter of wave along the coast and that the energy of the waves generates electricity because the waves are braking while moving, so that in an area of less than one square mile, enough energy could be achieved to satisfy 20,000 homes (Tinsley et al. 2019).

On the other hand, today, it has disadvantages such as machines can produce noise in their operation which would affect the life of the oceanic ecosystem and can lead to environmental damage such as a change in local biodiversity.

Also, today, its cost of implementation is very high in economic terms, but it is expected that this will be reduced in the near future since companies are making heavy investments in research.

In Spain, there is a specific case of this type of generation, specifically in the Basque Country with the Mutriku wave plant that can produce about 250,000 kWh per year from the waves, this plant being one of the most important in Europe (Fischer 2019).

Therefore, we can guarantee that renewable energy on the high seas has enormous potential, and the plan is that by 2050, the capacity will be 188 GW and 460 GW for ocean and wind energy, respectively.

Today, offshore wind energy is already a profitable energy; around 35,000 people work in this sector in Europe, and the capacity of this energy is around 3.8 GW.

Finally, to say that the most favorable wind areas are in mid-high latitudes since the wind is influenced by local atmospheric impacts and also that the wind energy industry is trying to reduce operating costs and working on the development of turbines cheaper (Pérez-Collazo et al. 2015).

The objective of this chapter is to compare wave energy and offshore wind energy in economic terms. The future of energy and electricity production will be at ocean. In this sense, offshore wind and wave energy are the two main important offshore renewable energies. However, it is important to compare them in economic terms to calculate their feasibility in order to take strategic decisions. In this context, aspects such as the LCOE or NPV are calculated to provide an economic comparison of these two technologies. The methodology will be carried out for a particular case of study. The location selected for this purpose has the offshore wind resource, and the wave energy resource is very good: It is the region of Galicia (located in the northwest of Spain). Results indicate the best ocean renewable energy in economic terms. This comparison is useful for future considerations in order to select the best location for an offshore renewable energy farm.

10.2 Methodology

The method considered for the calculation of the life cycle cost (LCS) of the floating offshore wind farm or the wave energy farm has been previously described following Eq. (1) (Castro-Santos et al. 2016; Castro-Santos and Diaz-Casas 2014), where C1 is the cost of conception and definition of the farm, C2 is the design and development cost, C3 is the manufacturing cost, C4 is the installation cost of the farm, C5 is the exploitation cost of the farm and C6 is the dismantling cost of the farm.

$$\mathrm{LCS} = \mathrm{C1} + \mathrm{C2} + \mathrm{C3} + \mathrm{C4} + \mathrm{C5} + \mathrm{C6} \tag{1}$$

Obviously, all these costs are different depending on the type of offshore renewable energy because the manufacturing, installation, exploitation and dismantling are different for a floating offshore wind farm and for a wave energy farm. In addition, the logistics for a wave energy farm is different of an offshore wind farm because the size of the energy platforms, in this case the wave energy converters (WECs), in general, is smaller than the offshore wind platforms.

On the other hand, the levelized cost of energy (LCOE) is calculated using Eq. (2) (Castro-Santos and Diaz-Casas 2015), where LCS_t is the cost of the farm in the year t in euros, E_t is the energy produced by the offshore renewable energy farm in MWh/year,N_{farm} is the life cycle of the project in years and k is the capital cost.

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{N_{\mathrm{farm}}} \frac{\mathrm{LCS_t}}{(1+k)^t}}{\sum_{t=0}^{N_{\mathrm{farm}}} \frac{E_{\mathrm{t}}}{(1+k)^t}} \tag{2}$$

Finally, net present value (NPV) represents the present net value of the cash flows of the offshore renewable energy farm (wind or waves), and its equation is (3) (Short et al. 1995; Castro-Santos et al. 2016), being G_0 the initial investment (C1, C2, C3 and C4 during the years of constructing the farm and C6 in the year N_{farm}) and CF_t the cash flow of the farm in the year t.

$$\mathrm{NPV} = -G_0 + \sum_{t=1}^{N_{\mathrm{farm}}} \frac{\mathrm{CF}_t}{(1+k)^t} \tag{3}$$

The project will be economically feasible if its net present value has positive values, and it will be not feasible if the net present value is negative. In addition, investors want a LCOE as smaller as possible.

10.3 Case of Study

The location selected for this study is the Galicia region, located in the northwest of Spain (see Fig. 10.1) (Google 2019).

The floating platform considered for floating offshore wind is the WindFloat platform (Myhr et al. 2014; Principle Power 2012; Maciel 2010) and for the wave energy farm is the AquaBuoy (Castro-Santos et al. 2018; Weinstein et al. 2003). Their main characteristics are shown in Table 10.1.

Two different electric tariffs have been considered (100 and 200 €/MWh) due to the fact that there is not a specific floating offshore wind or wave energy tariff in Spain.

Fig. 10.1 Location selected

Table 10.1 Characteristics of the platforms considered

Characteristic	WindFloat	AquaBuoy	Units
Power	5.075	0.250	MW
Height of the tower	90	–	m
Draft	10	30	m
Number of mooring lines	6	3	Lines/platform

10.4 Results

Regarding the total cost of the life cycle, the floating offshore wind farm considered has a value from 1333.3 to 2812.2 M€ and from 2167.0 to 3944.2 M€ for the wave energy farm. Figure 10.1 shows how the total cost depends on the distance from farm to shore.

Regarding the levelized cost of energy (LCOE), the floating offshore wind farm considered has a value from 93.70 to 782.61 €/MWh and from 719.86 to 10,180 €/MWh for the wave energy farm (see Fig. 10.2). Therefore, the floating offshore wind technology will be more economically suitable than the wave energy technology because its LCOE is less (Fig. 10.3b).

Regarding the net present value (NPV) and the electric tariff of 100 €/MWh, the floating offshore wind farm considered has a value from −1156.20 to 113.91 M€ and from −2698.50 to −1210.90 M€ for the wave energy farm (see Fig. 10.2). Therefore, the floating offshore wind technology will be more economically suitable than the wave energy technology because its NPV is higher. In fact, negative values of NPV determine that the project is not economically feasible, and positive values of NPV (such as the offshore wind) determine that the project will be feasible considering an electric tariff of 100 €/MWh (Fig. 10.4).

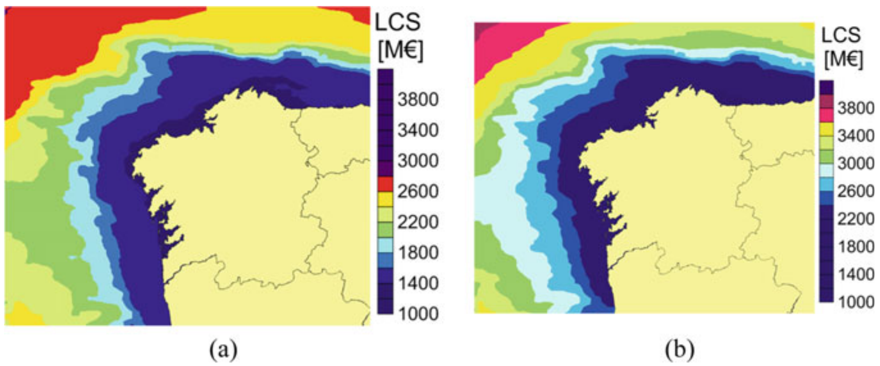


Fig. 10.2 Life cycle cost of a floating offshore wind farm (**a**) and a wave energy farm (**b**)

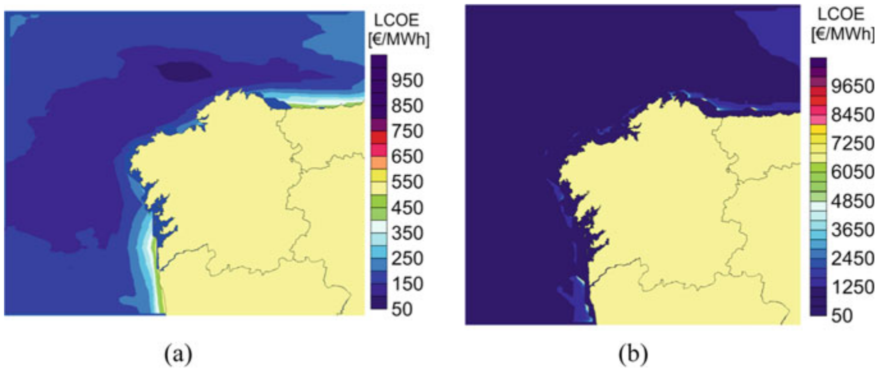


Fig. 10.3 LCOE of a floating offshore wind farm (**a**) and a wave energy farm (**b**)

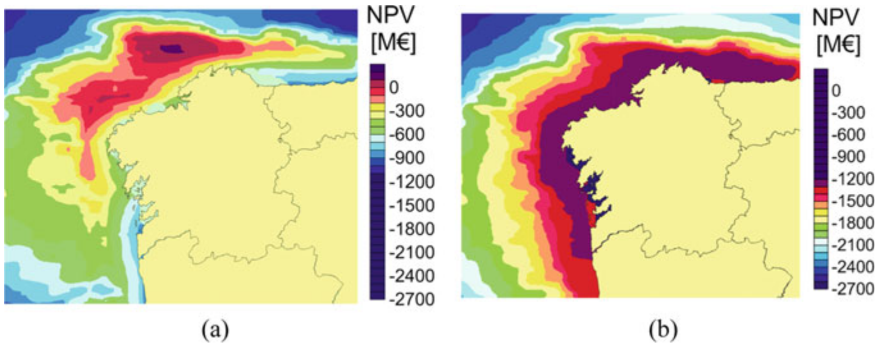
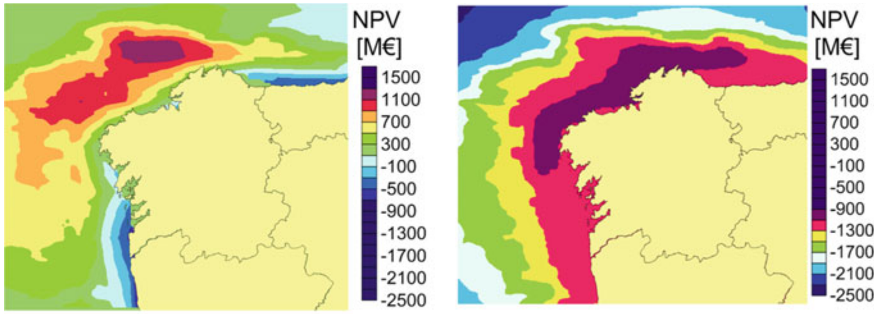


Fig. 10.4 NPV of a floating offshore wind farm (**a**) and a wave energy farm (**b**) considering an electric tariff of 100 €/MWh

Regarding the net present value (NPV) and the electric tariff of 200 €/MWh, the floating offshore wind farm considered has a value from −847.02 to 1220.5 M€ and from −2468.90 to −1039.4 M€ for the wave energy farm (see Fig. 10.2). Therefore, the floating offshore wind technology will be more economically suitable than the wave energy technology because its NPV is higher. The project is not feasible for wave energy considering an electric tariff of 200 €/MWh. However, the project is more economically feasible for the offshore wind considering the 200 €/MWh than the 100 €/MWh, which is obvious because the incomes of production are higher (Fig. 10.5).



(a) (b)

Fig. 10.5 NPV of a floating offshore wind farm (**a**) and a wave energy farm (**b**) considering an electric tariff of 200 €/MWh

10.5 Conclusions

The objective of this chapter has been to compare wave energy and offshore wind energy in economic terms. The future of energy and electricity production will be at ocean. In this sense, offshore wind and wave energy are the two main important offshore renewable energies.

However, it is important to compare them in economic terms to calculate their feasibility in order to take strategic decisions. In this context, aspects such as the levelized cost of energy and net present value have been calculated to provide an economic comparison of these two technologies.

The methodology has been developed for a particular case of study. The location selected for this purpose has the offshore wind resource, and the wave energy resource is very good: It is the region of Galicia (located in the northwest of Spain). In addition, the floating offshore renewable energy platforms considered for the study have been the WindFloat, which is a semisubmersible floating offshore wind platform and the AquaBuoy, which is a wave energy converter.

Results indicate that the best technology in terms of LCOE and NPV is the floating offshore wind, because it has values of LCOE smaller than the wave energy and values of NPV positive for the case of 100 €/MWh and for the case of 200 €/MWh of electric tariff. However, the wave energy industry should increase the development of its technology in order to reduce the costs of manufacturing and installation. Its future goes through increasing the unitary power of each wave energy converter to be more competitive regarding the other floating offshore renewable energy technologies.

Moreover, the governments should establish a specific electric tariff for these types of floating offshore renewable energy technologies, because they stay in an early stage of their development.

The comparison established in this chapter is useful for future considerations in order to select the best floating offshore renewable energy technology and where will be its best location.

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Chapter 11
Fresh Insight into the EKC Hypothesis in Nigeria: Accounting for Total Natural Resources Rent

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Abstract The present study revisits the trade-off between economic growth and pollutant emission popularly known as the EKC hypothesis. This study distinct from the bulk of study in the literature by circumventing for omitted variable bias by the addition of total natural resources rent. Empirical investigation is conducted on an annual frequency data from 1971 to 2015. Conventional unit root test of Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) unit root to establish stationarity properties. For long run (equilibrium) analysis the Pesaran's ARDL bounds test traces equilibrium relationship between the outlined variables. The ARDL regression suggest that 1% increase in real income increases pollutant emission by 79.33% and 117.18% in short run and long run, respectively, while the electricity consumption positively increases pollutant emission in Nigeria. Interestingly, FDI inflow improves the quality of the environment by dampening emission. The current study validates the EKC hypothesis of the case of Nigeria. This suggests that the country is still at her scale stage of her economic growth trajectory where emphasis is placed on economic growth relative to quality of the environment. These outcomes are indicative to government administrators and environmental economists to be cautious on strategies to disentangle economic expansion from pollutant emissions there by necessitating the need for a paradigm shift to clean energy mix like renewable energy sources, which are globally recommended and environmental friendly.

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Keywords Electricity consumption · CO_2 emissions · Climate change · Foreign direct investment

11.1 Introduction

The development of all sectors within an economy requires a stable and reliable energy source. For any country, the direct and indirect effect of electricity utilization cannot be over emphasized as it is closely linked to economic growth (Balcilar et al. 2019). The United States Energy Information Administration (EIA 2018) established that there is a close link between a country's economic growth and energy use. Electricity use is positively correlated with economic growth for both developed and developing economies, a great length of studies have focused on the relationship between economic growth and energy consumption. In the literature, some studies concluded that electricity (energy consumption) plays a vital role in economic growth (Masih and Masih 1998; Ferguson et al. 2000), some argued that there exist a conservative hypothesis because causality runs from economic growth to energy consumption (Jumbe 2004; Wolde-Rufael 2005) while others revealed that there is no causality or relationship between economic growth and energy consumption (Akinlo 2008; Akpan and Akpan 2012; Tsaurai 2013).

The 2019 world energy outlook reports that about 850 million people globally still do not have access to electricity (IEA 2019), this is a huge improvement when compared to the 2010 report which estimated that 1.4 billion people over 20% global population do not have access to electricity (IEA 2010). This global improvement is due to expansion of electricity generation from wind and solar PV resulting in an overtake of coal by renewable electricity generation source in the power generation mix. Despite the global outlook, about 600 million people within Sub-Sahara Africa still do not have access to electricity and this number is expected to decline just slightly to 530 million by year 2030 as expansion of electricity generation is not sufficient to lead to sustainable and affordable electricity within this region.

For Nigeria, in 2018, about 20 million households do not have access to electricity, although the government already privatize the power sector to decrease this number by increasing the generation capacity to 12,522 MW (thermal generation capacity: 10,142 MW and hydro-generation capacity: 2380 MW) yet the country only generates about 4000 MW per day which results in epileptic power supply. The country's electricity market is mainly supplied by the Power Holding Company of Nigeria (PHCN) which was divided into separate entities in 2013 called the Local Electric Distribution Companies (LDC) in which each company or entity is responsible for handling the distribution of electricity in each state or region. Yet these companies have not been able to provide minimum required international standard electricity across the nation. Nigeria being the giant of Africa, the statistical evidence from 2018 world bank database revealed that the country's population is almost 200 million, with average growth rate of 6.67% in 2013, 6.3% in 2014, just 1.94% and 2.1% in 2018 and 2019, respectively. Despite the positive growth rate, the supply of electricity has remained inconsistent and irregular; this has led households and industries to seeking alternative source of power that mainly required fossil fuels and increase in carbon dioxide emission level. To make up for the power shortage, industries and households continuously make use of power generating sets; NDC (2016) reports that an estimated 60 million Nigerians owns electricity power generating sets and spend almost \$13.35 million to fuel these equipment's annually. Shuaibu and Oyinlola (2013) reported that the total CO_2 emissions from combustion fuels is 41.2%, from electricity and heat generated is 8.2%, from manufacturing and construction sectors is 3.1%, from energy industry is 4.5%, from transport sector is 24% while from other sectors is 2%.

The inter-relationship between energy consumption, economic growth, and carbon dioxide (CO_2) emission has been researched extensively in the literature over the past decades. Nevertheless, there has been mixed results regarding the flow of causality among these variables ranging from bi-directional causality, to unidirectional and no causality at all. This mixed results might be attributed to difference in methodology, difference in period of study, and difference in countries studied as well. Furthermore, this study advances the frontiers of knowledge by underpinning the determinant of greenhouse gas emission (GHG), especially in Nigeria where there is huge energy intensification. Thus, the present study augment the traditional EKC framework by the addition of total natural resources rent to a carbon-income regression function. This hypothesized model comes pertinent on the premise to determine the environmental cost implication of extraction of the total natural resources from the primary stage to its final rent stage. Studies of this sort are not only timely but also essential for policymakers and environmental practitioners, given the global consciousness for cleaner and ecosystem energy consumption.

Table 11.1 provides an overview of empirical works that examined the relationships between energy consumption, economic growth and CO_2 emission within Africa. Similarly, Table 11.2 provides an overview of energy consumption growth nexus for African country studies. But there is not any study on Nigeria that examined the impacts of natural resource rent, foreign direct investment alongside with electricity consumption and economic growth on CO_2 emission. Therefore, this study aims to fill this gap by contributing to existing literature. Most studies as summarized in both Tables 11.1 and 11.2 confirmed a unidirectional causality between economic growth and CO_2 emission, electricity consumption and CO_2 emission, on the other hand, a few of the studies posits causality flowing from CO_2 to economic growth.

The remaining part of this study is structured as follows: Sect. 11.2 presents a brief review of empirical literature, Sect. 11.3 presents the data and methodology used, and Sect. 11.4 presents result discussion while Sect. 11.5 concludes and offer policy implication based on the findings.

Table 11.1 Overview of empirical studies on energy consumption, economic growth, and CO_2 emission in Africa

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
1	Odhiambo, N. M	1970–2007	2011	South Africa	Co-integration	Economic growth→
					ARDL bounds and Granger causality test	CO2 emission,
						Energy consumption → economic growth, Energy consumption → CO_2 emission
2	Nnaji C. E, Chukwu J.O, and Nnaji M.	1971–2009	2013	Nigeria	Co-integration	Electricity supply ≠ Economic growth, electricity supply → CO_2 emission, Economic growth → CO_2
					ARDL bounds and Granger causality test	
3	Hlalefang Khobai and Pierre Le Roux	1971–2013	2017	South Africa	Johansen co-integration technique and VECM	CO_2 emission → Economic growth
						Energy consumption ↔ Economic growth
4	Marcel Kohler	1960–2009	2013	South Africa	Co-integration	Per capita Energy use ↔ CO_2 emission, Economic growth → CO_2
					ARDL bounds and Granger causality test	
5	Albiman M.M, Suleiman N.N., and Baka H.O.	1975–2013	2015	Tanzania	Toda and Yamamoto's non-causality test	Economic growth → CO_2
						Energy consumption → CO_2

(continued)

Table 11.1 (continued)

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
6	Alage P.O, Adeniran O.S., and Ogundipe A. A.	1970–2013	2016	Nigeria	Johansen maximum likelihood co-integration and VECM	Electric power $\neq$ CO_2 emission,
						Fossil fuel $\rightarrow$ CO_2 emission, fossil fuel $\rightarrow$ GDP per capita

Notes $\rightarrow$, $\leftrightarrow$, $\neq$ denote unidirectional causality, bi-directional causality, and neutrality (no causality), respectively

Table 11.2 Overview of energy consumption growth nexus in Africa

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
1	Akinlo	1980–2006	2009	Nigeria	Johansen–Juselius; co-integration; VEC; co-feature analysis	Electricity consumption → Economic growth
2	Akinlo	1980–2003	2008	11 African Countries (Gambia, Ghana, Sudan, Zimbabwe, Congo, Senegal, Cameroon, Cote d'Ivoire, Nigeria, Kenya, Togo)	Autoregressive distributed lag (ARDL) bounds test	Economic growth → Electricity consumption(Gambia, Ghana, Sudan, Zimbabwe, Congo, Senegal) Economic growth ≠ EC (Cameroon, Cote d'Ivoire, Nigeria, Kenya, Togo)
3	Odhiambo	1971–2006	2009a	Tanzania	ARDL bounds testing approach	Electricity consumption → Economic growth
4	Odhiambo	1971–2006	2009b	South Africa	Granger causality	Electricity consumption ↔ Economic growth
5	Belloumi	1971–2004	2009	Tunisia	Granger causality, VECM	Electricity consumption ↔ Economic growth in the long run but → in the short run
6	Akpan and Akpan	1970–2008	2012	Nigeria	Multivariate VECM	Electricity consumption ≠ Economic growth
7	Tsaurai	1980–2011	2013	Zimbabwe	Bi-variate time series framework	Electricity consumption ≠ economic growth

(continued)

Table 11.2 (continued)

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
8	Akomolafe Kehinde John	1981–2014	2019	Nigeria	VECM	Electricity consumption ↔ economic growth in the short run
9	Akinwale Y., Jesuleye O., and Siyanbola, W	1970–2005	2013	Nigeria	VAR and ECM	Economic growth → Electricity consumption
10	Bah and Azam	1971–2012	2017	South Africa	ARDL bounds test, Toda and Yamamoto augmented Granger causality test	Electricity consumption ≠ Economic growth
11	Dlamini J., Balcilar M. and Gupta R	1971–2009	2015	South Africa	Bootstrap rolling window approach	Electricity consumption → Economic growth
12	Solarin and Shahbaz	1971–2009	2013	Angola	ARDL bounds test and the VECM Granger causality test	Electricity consumption ↔ Economic growth in both short and long run
13	Jumbe	1970–1999	2004	Malawi	Granger causality and Error-correction model	Electricity consumption ↔ Economic growth (Granger causality approach) Economic growth → Electricity consumption (Error correction model)

(continued)

Table 11.2 (continued)

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
14	Wolde-Rufael	1971–2001	2005	19 African countries (Algeria, Congo DR, Egypt, Ghana, Ivory Coast, Cameroon, Morocco, Nigeria, Gabon, Zambia, Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunusia, Zimbabwe)	Toda–Yamamoto's and Granger causality	Economic growth $\rightarrow$ Electricity consumption (Algeria, Congo DR, Egypt, Ghana, Ivory Coast) Electricity consumption $\rightarrow$ Economic growth (Cameroon, Morocco, Nigeria) Electricity consumption $\leftrightarrow$ Economic growth (Gabon, Zambia) Electricity $\neq$ Economic growth (Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunusia, Zimbabwe)
15	Samu R., Bekun F. V., and Fahrioglu M.	1971–2014	2019	Zimbabwe	Toda-Yamamoto, Maki Causality test and	Electricity consumption $\rightarrow$ Economic growth

(continued)

Table 11.2 (continued)

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
16	Eyup Dogan	1971–2011	2014	Four low income countries in Sub-Saharan Africa (Kenya, Zimbabwe, Congo and Benin Republic)	Johnson Cointegration, Granger causality test	Using Johnson Cointegration test Electricity consumption $\neq$ economic growth (Kenya and Zimbabwe), Granger causality test indicate Electricity consumption $\rightarrow$ Economic growth for Kenya and Electricity consumption $\neq$ economic growth (Zimbabwe, Benin, and Congo)
17	Yris D. Fondja Wandji	1971–2009	2013	Cameroon	Granger causality, cointegration test and Error Correction Model,	Electricity consumption $\neq$ economic growth
18	Onakoya A.B, Onakoya A.O, Jimi-Salami O.A. and Odedairo B.O.	1975–2010	2013	Nigeria	Co-integration and Ordinary least square	Electricity consumption $\rightarrow$ economic growth
19	Dantama Y.U., Umar Y., Abdullahi Y.Z. and Nasiru I.	1980–2010	2012	Nigeria	ARDL	Petroleum consumption and electricity consumption $\rightarrow$ economic growth

(continued)

Table 11.2 (continued)

S. No.	Author(s)	Period	Year of publication	Country	Methodology	Conclusion
20	Esso L.J.	1970–2007	2010	Seven African countries(Nigeria, Ghana, Cameroon, Cote d'Ivoire, South Africa, Congo)	Gregory Hansen Co-integration approach	Economic growth → Electricity consumption(Cameroon, Ghana, Cote d'Ivoire and South Africa) before 1988 but become negative after then for Ghana and South Africa

Notes →, ↔, ≠ denote unidirectional causality, bi-directional causality, and neutrality (no causality), respectively

11.2 Literature Review

The literature review will be in twofolds, the first aspect will focus on economic growth and energy/electricity consumption while the second aspect will focus on economic growth, energy consumption, and carbon dioxide emission. Starting with the first focus, the literature is flooded with studies on economic growth and energy/electricity consumption. The premier study of seminal paper presented by Kraft and Kraft (1978) investigate the causal relationship between economic growth and energy consumption, for USA for the period 1947–1974 and the findings of the paper postulated a causal relationship that runs from economic growth to energy. The same result emerge from the work of Yu and Choi (1985) for the Philippines, similar result for Taiwan was reported by Cheng and Lai (1997) using Hsiao's version of co-integration and granger causality test on data for periods 1955–1993. Furthermore, Aqeel and Butt (2001) revealed for Pakistan that causality runs from economic growth to energy consumption. Mehrara (2007) also investigated the causal link between per capita GDP and per capita energy consumption for 11 selected oil exporting countries using panel unit root tests and panel co-integration analysis; the result revealed a strong unidirectional causality flow from economic growth to energy consumption.

Akinlo (2008) studied the relationship between energy consumption and economic growth for eleven Sub-Saharan African countries using autoregressive distributed lag (ARDL) bounds test, granger causality test based on vector error correction model (VECM); the result revealed causality flowing from economic growth to energy consumption for Sudan and Zimbabwe, bi-directional flow for Senegal, Gambia and Ghana. For Cote d'Ivoire, Kenya, Nigeria, Cameroon and Togo, the result confirmed a no causal directional flow.

Many studies have tried to examined the causal link and direction of causal flow between economic growth and energy/electricity consumption just to mention a few: Soytas and Sari (2003), Shui and Lam (2004), Wolde-Rufael (2005), Ang (2008), Esso (2010), Bekun and Agboola (2019), Balcilar et al. (2019). For Nigeria, studies posit a positive relationship between economic growth and energy consumption the works of Adeniran (2009), Odularu and Okonkwo (2009), Omotor (2008), Omisakin (2008) and Onakoya et al. (2013), are case in point.

The second aspect of the review examined the relationship between economic growth, energy consumption and CO_2 emission. Several empirical studies with the use of different methodologies and divers sample sizes investigated energy-economic-environment nexus. Ang (2007) for France examined this relationship using co-integration and vector error-correction modeling techniques on data for periods 1960–2000 and the result revealed a support for the argument that causality flows from economic growth to energy use and pollution in the long run. Similarly, Soytas et al. (2007) for USA using granger causality approach and found that in the long run income does not granger causes carbon dioxide emission but energy use does.

Also, for selected 19 European countries Acaravci and Ozturk (2010) using autoregressive distributed lag (ARDL) approach and error-correction granger causality test on data covering periods 1960–2005 found long run relationship with unidirectional causality between the three variables for Greece, Portugal, Germany, Switzerland, Denmark, Iceland, and Italy. Apergis and Payne (2009) for a group of Commonwealth independent states found that causality flows from economic growth and energy consumption to carbon emission in the short run but a bi-directional flow between energy consumption and CO_2 emission in the long run. For South Africa, Menyah and Wolde-Rufael (2010) examined the causality flow between the energy consumption, economic growth, and pollutants using ARDL approach bound test on data for period 1995–2006, their finds revealed a long run unidirectional relationship flowing from energy consumption and pollutant emissions to economic growth and from energy consumption to pollutant emissions.

For India, Alam et al. (2011) reported a long run bi-directional causality flow between carbon dioxide emission and energy consumption; no causality between energy consumption and economic growth and between CO_2 emission and economic growth as well. For the same country, Ohlan (2015) using ARDL approach on data period 1970–2013 examined the impact of energy consumption, trade openness, economic growth, and population density on carbon dioxide emission. The study revealed both short and long run positive relationships between the variables of interest and CO_2 emission while the main contributor to this emission is population. For Iran, Lotfalipour et al. (2010) examined the causality flow between fossil fuel, economic growth, and carbon dioxide emission. Using Toda-Yamamoto causality test, the study concluded that a causality flows from energy consumption and GDP to carbon emission and that carbon dioxide emission and energy consumption does not lead to economic growth. Sulaiman and Abdul-Rahim (2014), applying ARDL method examined the causality link between economic growth, CO_2 emission and energy consumption for Malaysia using data for the period 1975–2015 and their findings also state that economic growth is not influenced by energy consumption or carbon dioxide emissions. For 12 selected MENA countries, Arouri et al. (2012) examined the relationship between economic growth, CO_2 emission and energy consumption for the period 1981–2005 using bootstrap panel method with result revealing CO_2 emission positively impacted by energy consumption.

Many studies have tried to examine the causal link and direction of causal flow between economic growth, energy/electricity consumption and carbon dioxide emission just to mention a few: Zhang and Cheng (2009), Odhiambo (2009a), Ogundipe and Apata (2013), Shahbaz et al. (2013), Apergis and Ozturk (2015), Al-Mulali et al. (2015). Olarinde et al. (2014), Vadyarthi (2013), Albiman et al. (2015) Manu and Sulaiman (2017). For Nigeria, Akpan and Akpan (2012) revealed that economic growth leads to increase carbon dioxide emission and are further increased by electricity consumption. Also, Chukwu and Nnaji (2013) also support the claim that economic growth lead to an increase in carbon emission and similar submission emerges from the study of Chindo et al. (2015). Chindo and Abdul-Rahim (2018) revealed that in the long run economic growth is the only determining variable while in the short run all variables economic growth, energy consumption, and population growth are significant variables.

11.3 Data and Methodology Sequence

The present study made use of secondary time series frequency data comprising foreign direct investment (net inflow), economic growth (constant 2010$), electricity consumption (energy power consumption in Kw/h), total natural resources rent (%GDP), and carbon dioxide emissions (Kilotons) as proxy for environmental degradation. All data were retrieved from the World Development Indicators between[1] the periods of 1971–2015. The empirical sequence of the present study follows four paths, namely first, investigation of unit root properties to ascertain the stationarity status of the outlined variables. This is pertinent to avoid variables integrated of order 2 ~ I(2) and misleading inferences. Second, test for equilibrium relationship (co-integration) relationship between choice variables. Third, ARDL regression and finally, detection of causality test to detect the direction of causality flow for proper policy implications.[2]

11.4 Empirical Results and Discussion

This section focuses on the discussion of study empirical simulations. First, preliminary analysis of visual plot of all variables under consideration and subsequently basic summary statistics and then correlation matrix analysis. Figure 11.1 shows the graphical plot of the variables under review with energy consumption (electricity consumption) and economic growth (GDP) showing a positive correlated trend over the sampled period. Foreign direct investment (FDI) and total natural resources rent also exhibited positive relationship over sampled period. Furthermore, Table 11.3 highlights the basic summary statistics with economic growth having the highest average with highest maximum and minimum, while economic growth and FDI are positive skewedness relative to total natural resources rent pollutant emission and electricity consumption were negatively skewed over investigated period. Subsequently, Table 11.4 presents the Pearson correlation matrix analysis of the outlined variables shows the linear relationship between the variables that shows positive significant relationship between pollutant emission and economic growth over considered period. These outcomes suggest that growth in Nigeria is pollution driven. Similar trend is reveal between FDI and pollutant emission. However, total natural resources rent shows negative relationship with pollutant emission. The need for more analysis is pertinent to substantiate the position of the correlation analysis.

The need for stationarity analysis is essential in time series modeling to circumvent for spurious outcomes. The present study adopted the use of conventional unit root test of ADF and PP to investigate the unit root properties as revealed in Table 11.5.

[1]https://data.worldbank.org/.

[2]For brevity, equations of estimation test are available on lead papers given they well established in the literature for interested readers.

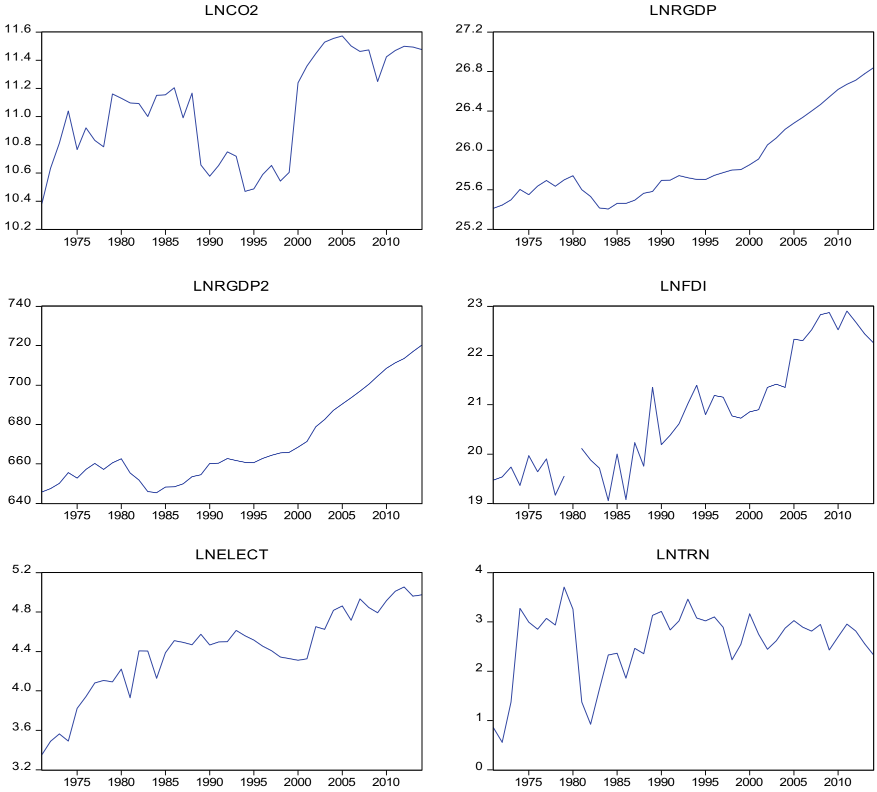

Fig. 11.1 Visual display of considered variables

Table 11.3 Summary statistics

	LNCO2	LNRGDP	LNRGDP2	LNFDI	LNELECT	LNTRN
Mean	11.03783	25.88088	669.9985	20.82092	4.412099	2.576355
Median	11.09137	25.70477	660.7353	20.77332	4.467510	2.815866
Maximum	11.57184	26.83758	720.2556	22.90268	5.054953	3.707911
Minimum	10.38222	25.40412	645.3694	19.05813	3.352373	0.557321
Std. dev.	0.369134	0.427205	22.27987	1.179312	0.428387	0.700426
Skewness	−0.079094	0.922868	0.939482	0.332158	−0.751164	−1.294211
Kurtosis	1.627544	2.535952	2.566091	1.909317	3.079973	4.197009
Jarque-Bera	3.419681	6.489567	6.662814	2.922038	4.055235	14.57119
Probability	0.180895	0.038977	0.035743	0.232000	0.131649	0.000685
Sum	474.6266	1112.878	28809.93	895.2994	189.7202	110.7832
Sum Sq. dev.	5.722906	7.665190	20848.49	58.41259	7.707660	20.60507
Observations	43	43	43	43	43	43

Table 11.4 Correlation coefficient matrix analysis

Observations	CO_2	RGDP	RGDP2	FDI	ELECT	TRN
CO_2	1.000					
RGDP	0.719***	1.000				
RGDP2	0.674***	0.987***	1.000			
FDI	0.631***	0.891***	0.849***	1.000		
ELECT	0.668***	0.839***	0.803***	0.816***	1.000	
TRN	−0.025	0.035	−0.019	0.039	0.110	1.000

Note Series are in their level form
*, **, ***Indicates 1%, 5%, and 10% significant level respectively

Table 11.5 ADF and PP and tests of unit root

Statistics (level)	LNCO2	LNRGDP	LNRGDP2	LNFDI	LNELECT	LNTRN
τ_T (ADF)	−2.1451	−1.1080	−0.9088	−4.9925***	−3.2546*	−5.1745***
τ_μ (ADF)	−1.9751	1.3308	1.3997	−1.3254	−2.1604	−5.3725**
τ (ADF)	0.8551	2.3727	2.4034	0.5659	2.1740	−0.1794
τ_T (KPSS)	0.1143	0.2006**	0.2012**	0.1276*	0.1251*	0.0794
τ_μ (KPSS)	0.3910*	0.7135**	0.7122**	0.7706***	0.7447***	0.2945
Statistics (first difference)	LNCO2	LNRGDP	LNRGDP2	LNFDI	LNELECT	LNTRN
τ_T (ADF)	−6.775***	−4.336***	−4.297***	−12.387***	−6.449***	−6.527***
τ_μ (ADF)	−6.866***	−2.873*	−2.836*	−12.511***	−6.2917***	−6.443***
τ (ADF)	−6.862***	−2.268**	−2.225**	−12.324***	−8.313***	−6.506***
τ_T (KPSS)	0.0903	0.0789	0.0802	0.3913***	0.0934	0.2278***
τ_μ (KPSS)	0.0888	0.3750*	0.3892*	0.4168*	0.2090	0.4062*

Note significance at ***0.01 and **0.05

The test shows that all examined variables are integrated of mixed order. Subsequently, the co-integration analysis was conducted by the Pesaran Bunds test (see Appendix Table 11.8) that shows long run equilibrium relationship among the investigated series and the parsimonious optimum lag order (see Appendix Table 11.9). To conduct the magnitude of the co-integration analysis the long run regression in Table 11.6. The ARDL regression shows a high convergence speed with the contribution of economic growth, energy consumption, FDI, and total natural resources rent. Further analysis shows that a 1% in economic growth and the square of GDP show 79.33% and 117.18% in both short and long run, respectively. The results affirm the presence of the EKC hypothesis for the case of Nigeria. This implies that the growth in Nigeria is driven by pollutant emission. This suggest that the growth trajectory

Table 11.6 ARDL results

Variables	Coefficient	S.E	t-statistic	P-value
Short run				
LNRGDP(-1)	79.334*	17.041	4.655	0.000
LNRGDP2(-1)	−1.489*	0.323	−4.633	0.000
FDI	−0.239*	0.077	−3.097	0.007
ELECT	0.417	0.293	1.427	0.171
D(LNTRN(-1))	0.249*	0.080	3.115	0.006
ECT	−0.677*	0.112	−6.022	0.000
Long run				
RGDP	117.180*	39.048	3.001	0.008
RGDP2	−2.200*	0.736	−2.989	0.008
FDI	−0.756*	0.219	−3.456	0.003
ELECT	0.774*	0.249	3.113	0.006
TRN	−0.529*	0.153	−3.457	0.003
Diagnostic tests				
Tests	F-statistic	Prob. value		
χ^2 NORMAL	0.286	0.867		
χ^2 SERIAL	2.265	0.138	$F(2, 15)$	
χ^2 WHITE	1.055	0.460	$F(20, 17)$	
χ^2 RAMSEY	1.521	0.235	$F(1, 16)$	

Model: $CO_2 = f$(GDP, ELECT, TNR)
Note *, **, *** indicate 1%, 5%, and 10% level, respectively

in Nigeria is still at her scale stage of her growth path where emphasis is on higher income level rather than environmental degradation (Bekun et al. 2019a). Furthermore, energy consumption is seen to increase pollutant emission with an elasticity of 042 and 0.77% in both short and long run. Interestingly, total natural resources rent reveals positive effect in short run and negative impact in the long run, this implies that exploration of natural rent in the long run will enhance the quality of the environment. This is quit shocking know that most extraction process are primary and crude which has its cost implication. Similar trend with FDI, the effect of FDI dampens the quality of the environment. This implies that the FDI inflow helps to improve the environment. This suggests that FDI attraction in Nigeria is environmentally friendly thought not energy (electricity) consumption over the investigated period. The outcomes of energy-induce pollutant emission are insightful given the need for paradigm shift for more renewable energy source consumption that are reputed to more ecosystem friendly and cleaner. Furthermore, Table 11.7 reports the modified Wald test of causality and validates the energy-induced growth hypothesis. As a one-way directional causality is running from energy (electricity consumption) to GDP. This outcome resonates with the study of Emir and Bekun (2019) in Romanian

Table 11.7 Granger causality analysis

Excluded	Chi-square	d*f*	Prob.
Dependent variable: LNCO2			
LNRGDP	0.062	1	0.803
LNRGDP2	0.061	1	0.805
LNFDI	1.890	1	0.169
LNELECT	1.169	1	0.279
LNTRN	1.674	1	0.195
All	6.569	5	0.254
Dependent variable: LNGDP			
LNCO2	0.903	1	0.342
LNRGDP2	2.472	1	0.115
LNFDI	7.249***	1	0.007
LNELECT	2.864**	1	0.090
LNTRN	9.962***	1	0.001
All	25.335***	5	0.000
Dependent variable: LNFDI			
LNCO2	2.048	1	0.152
LNRGDP	0.278	1	0.598
LNRGDP2	0.289	1	0.590
LNELECT	1.239	1	0.265
LNTRN	0.056	1	0.812
All	11.027**	5	0.050
Dependent variable: LNELECT			
LNCO2	0.003	1	0.954
LNRGDP	0.032	1	0.857
LNRGDP2	0.031	1	0.859
LNFDI	0.047	1	0.828
LNTRN	0.134	1	0.713
All	0.769	5	0.978
Dependent variable: TRN			
LNCO2	7.150	1	0.993
LNRGDP	0.409	1	0.522
LNRGDP2	0.387	1	0.533
LNFDI	1.568	1	0.210
LNELECT	0.876	1	0.349
All	17.499***	5	0.003

Note significance at ***0.01 and **0.05

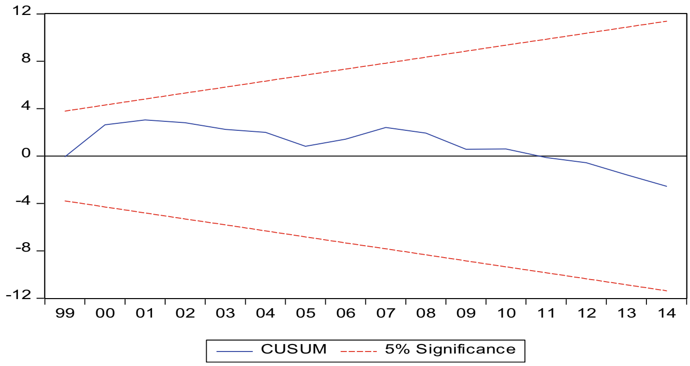

Fig. 11.2 Diagnostic stability test of CUSUM

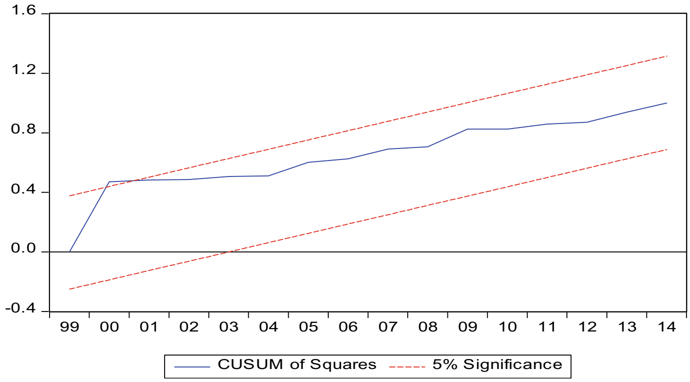

Fig. 11.3 Diagnostic stability test of CUSUMsq

economy. This implies that the energy conservative policy cannot be implemented for the case of Nigeria. Similar trend of unidirectional causality is observed for the case of FDI inflow and total national resources rent (Bekun et al. 2019b). These outcomes have inherent policy decision. The regression conducted were free from model specification bias, serial correlation issues and normally distributed and suitable for policy direction. The model stability test carried by CUSUM and CUSUMsq test are presented in Figs. 11.2 and 11.3, respectively.

11.5 Conclusion

The consistent pressure by human activities has impact on the environment and biocapacity of the ecosystem. These consequences on the environment have been of great concerns among energy practitioners, environmentalist, and government administrators who formulate energy framework and strategies. This topical debate is still on-going since the pioneering study of Kraft and Kraft (1978) for the USA, and several other studies have been documented in the related literature. However, there been no consensus in the energy economics literature, especially, for the case of Nigeria, which has received little documentation. It is on this premise, the present study explores the interaction between real income, square of real income, pollutant emissions proxy by environmental degradation, and electricity consumption. This country specific study built on the already existing preposition of Simon Kuznets (1955) on the trade-off between the nexus inequality and economic growth. This concept over the years has metamorphosed in the energy literature to conceptualize the EKC. The EKC ideology explains the trade-off between economic growth and pollutant emission, which was made popular by Grossman and Krueger (1991). Over the years plethora of studies have emerge validating the EKC hypothesis.

Empirical findings trace a long run equilibrium relationship between the outlined variables over the study framework. The study structure was investigated in a carbon-income function with the incorporation of total natural resources rent and FDI inflow into the conventional EKC setting. Our study empirical finding suggests that energy (electricity) consumption in Nigeria is dirty and increase pollutant emission (CO_2). Although past studies have validated the pivotal role of energy consumption to economic growth. The present study joins strands of study that finds empirical support for energy-induced economic growth as revealed by the causality analysis. However, this outcome does not go without its environmental cost where the energy also drives pollution emission. Thus, from a policy standpoint from this study, there is the need to drift from energy from fossil fuel consumption to cleaner energy sources like photovoltaic, wind, biomass, hydro-energy among other renewable energy consumption. The need to tighten environmental commitment is key given global consciousness for cleaner ecosystem like the Kyoto protocol.

Appendix

See Appendix Tables 11.8 and 11.9.

Table 11.8 ARDL bounds test

Test stat.	Value	*K*
F-stat.	4.670	5
Critical value bounds		
Significance (%)	I(0) Bounds	I(1) Bounds
10	2.26	3.35
5	2.62	3.79
2.5	2.96	4.18
1	3.41	4.68

Source Author computation

Table 11.9 Lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−26.18628	NA	2.29e−07	1.739799	2.001029	1.831894
1	212.7243	387.4226*	4.07e−12*	−9.228341	−7.399732*	−8.583671*
2	250.3858	48.85816	4.36e−12	−9.318152	−5.922163	−8.120907
3	295.6567	44.04739	4.19e−12	−9.819283*	−4.855914	−8.069463

*, **, ***Indicates 1%, 5%, and 10% significant level respectively

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Chapter 12
The Importance of Meta-Analysis in the Energy-Growth Nexus; Guidelines for a Complete Implementation

Angeliki N. Menegaki

Abstract This chapter hopes to urge energy-growth nexus researchers toward meta-analyses. The field suffers from the lack of a global relationship that would also provide the theoretical foundations that are so much needed in the energy-growth nexus. The chapter also shows the importance of meta-analysis in the energy-growth nexus and provides useful guidelines that must be followed for it to become verbose and successful. The energy-growth nexus is a topic with contradictory results that vary depending on the country, group of countries, period in which it is applied, and the employed method. A meta-analysis could contribute to making these studies more helpful and reliable as far as policy making is concerned. The chapter will demonstrate how data are collected in a meta-analysis, how they are screened and analyzed in a meta-regression model, as well as how they are interpreted, hoping to set the base for a continuous meta-analysis in the field. To this end, the chapter includes best case examples from the very few meta-analyses that have been implemented so far.

Keywords Meta-analysis · Energy-growth nexus · Meta-regression

12.1 Introduction

Sometimes specific academic fields are seething with research which, however, cannot speak for itself. Conclusions are contradictory, and this makes the academic field of little use, unless one stops for a while and measures what has been done so far and derives macro-conclusions. This means that one has to leave the tree picture for a while (i.e., individual studies) and look at the forest picture. What does it look like? This is the case in the energy-growth nexus field currently. Forty-two years after the

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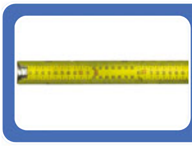
seminal paper of Kraft and Kraft (1978), still no concrete results have been specified in the macro-picture, no theory has been established, and individual studies keep sprawling toward every direction: Time, number of variables, combinations of countries, and econometric methods are giving birth to a chaotic combination of studies that cannot be compared with each other directly, because they do not fall under the same category.

Based on the four parameters provided in Table 12.1, one can identify at least 2*2*4 = 16 categories of different energy-growth energy studies, and this means that comparisons among them are far from easy and straightforward. Note: The aforementioned number, namely 16 is generated as follows: 2 stands for the types of data encountered (times series or panel), 2 stands for the option between a single country and group of countries, 4 is the number of steps in the econometric analysis (unit root testing, cointegration, and causality, all proceeded with cross-sectional dependence, if panel data is the case). This number is 3 in time series, because cross-sectional analysis is not considered.

The situation described renders the meta-analysis a useful and necessary tool in the energy-growth nexus in order to enable the overview of what has been measured so far, what are we doing right now, and where we should be going to. The main advantage of the meta-analysis is that it can combine small individual studies that cannot be generalized for larger samples and groups of countries and render these individual studies combinable. As a study of studies that it is, the meta-analysis

Table 12.1 Building blocks of energy-growth nexus studies

	**Type of data** •Time series •Panel data
	**Data span** •Data spans keep growing year by year •Data spans depend on the variable of interest (e.g. newly developed and sophisticated variables are available for short data spans)
	**Geographical area** •Country •Group of countries (either economic or geopgraphical group)
	**Econometric method (differs in:)** • Cross-sectional dependence (if panel data) • Unit root testing • Cointegration analysis • Causality analysis

Source The author's compilation

requires a homogeneous body of literature (Russo 2007). All possible studies on energy-growth nexus are gathered, and then, these studies contribute observations in a new study, which is the meta-analysis that aims to develop a single conclusion and a global relationship with great statistical power. Legitimately, one may claim that an extensive and systematic literature review can enable the visualization of the global relationship we are seeking, but this is quite different from the meta-analysis. The selection and treatment of studies in literature reviews may be arbitrary and subjective. In a meta-analysis, however, the treatment of studies is more objective and straightforward, and with sufficient guidelines, it can also be replicable.

12.2 Why Is Meta-Analysis Attractive for Energy-Growth Researchers?

The most important aim and objective in the energy-growth nexus is the investigation of the four known hypotheses: Growth, Conservation, Feedback, and Neutrality. Furthermore, the studies aim at estimating the elasticities of energy consumption with respect to income changes. As a side piece in these studies, elasticities are also estimated for capital, labor, and other covariates of the energy-growth equation. Next, Table 12.2 provides all the reasons for which a meta-analysis is attractive in the energy-growth nexus.

After having explained the attractiveness of the meta-analysis, it would be beneficial for readers to provide the steps that one should take in order to produce a complete meta-analysis (Table 12.3). While the meta-analysis regression may seem to follow the general steps of a multivariate regression, attention must be paid to specific steps such as the literature search in Step 2 and the data abstraction in Step 4 for which I devote a separate graph (Table 12.3) to isolate and emphasize the particular steps that need to be taken.

Step 4 in Table 12.3 encloses the steps that should be tabulated in a spreadsheet and be filled in for every study. This information is the gist of the meta-analysis and will provide the data for the estimation of the meta-analytic regression. The detailed information is shown in Fig. 12.1 below. Each of the steps in Fig. 12.1 should be placed in a different column. If the step encloses many dummy variables, then additional columns should be provided in the spreadsheet and would correspond to a specific sub-step in Fig. 12.1.

12.3 Presentation of Meta-Analysis Case Studies in the Energy-Growth Nexus

This section provides summary results of two case studies in the energy-growth nexus, one by Menegaki (2014) and Kalimeris et al. (2014). Readers can get examples of data selection and set up from the first meta-analysis studies in the field. Two more studies

Table 12.2 Explaining the attractiveness of meta-analyses in the energy-growth nexus

Ref.	Reason of attractiveness	Explanation
1	Results are generated from pooling from a larger population	If the study is a single country, it can produce a single observation. If the study is a multi-country one, it can produce as many observations as the countries participating in the study or the different types of energy source in each study
2	The statistical power of the estimated results is improved	Each individual study can generate many variables. Increasing the sample size rectifies this problem and gives more statistical power to the estimated results and hence of increased validity
3	Disagreement across individual studies can be highlighted and its sources be sought	Meta-analyses will lead authors to better and more transparent writing of their energy-growth nexus papers. Energy-growth analysts will fill in information that is not evident on first sight for each study. Since methods, data, and countries are heterogeneous, the presentation of each paper is different in its details
4	Reliable hypothesis testing can be implemented	Higher statistical power of the estimated meta-coefficients entails reliable hypothesis testing
5	Research on publication bias should be investigated	Publishing negative results is not very appealing to editors, and this may produce a wrong picture of reality since it does give all publications an equal opportunity of being published
6	They can play a key role in planning new studies	Some funding bodies require meta-analyses to take place before any funding takes place for new projects (Biostat Inc 2019)

Source The author's compilation

have been identified but are not reported here because of space considerations in the chapter. The interested reader, however, could refer directly in them: these studies are by Sebri (2015) and deals with renewable energy sources only and Hajko (2017).

12.3.1 Case Study 1: The Meta-Analysis on the Energy-Growth Nexus by Menegaki (2014)

In 2014, the first meta-analysis in the energy-growth nexus field was produced by Menegaki (2014). It consisted of 51 studies of twenty years previous the publication

Table 12.3 Steps for a meta-analysis in the energy-growth nexus

1. Formulation of the research question (calculation of elasticities and verification of the hypotheses)

↓

2. Literature search (Keywords, databases, language limitations e.g. English, inclusion and exclusion criteria for a study)

↓

3. Set the yardstick of the selection of studies (keywords, phrases etc). The yardstick must be an explicit and objective criterion and the selected study is assigned a quality score. Later in the sensitivity analysis, low scores studies can be dropped and the meta-analytic regression can be re-calculated

↓

4. Data abstraction: Which dependent and independent variables are to be selected for inclusion in the meta-analytic regression? The selection entails a highly structured format. This step encompasses more steps that are shown in Table 3)

↓

5. Select means to standardize the collected data (about the number of observations contributed by each study)

↓

6. Detailed declaration of data manipulation (e.g. data exclusion or inclusion, data imputation)

↓

7. Select the meta-analysis regression model (e.g. multivariate regression or other non-parametric method etc.)

↓

8. Heterogeneity between studies. This test investigates whether studies have been similar in order to combine them

↓

(continued)

Table 12.3 (continued)

9. Study the robustness of the estimated model (stability, heteroskedasticity, heterogeneity etc.) ⬇
10. Design a systematic review with continuous updates of new data (state the keywords and search formulae and combinations in the databases the studies are searched) ⬇
11. Sensitivity analysis (e.g. ad-hoc methods such as investigating the effect on the estimated regression when leaving out specific studies or through a Chow test etc.) ⬇
12. Applicability of results (e.g. the energy-growth nexus can generate a global relationship and strengthen the theory etc.)

Source The author's compilation

of the study. The study found that results were not independent of the statistical method employed, the data type, and the inclusion of certain variables such as capital.

The study had not made separate meta-analyses for production function and demand function types, but it had included dummy variables for the demand function type elements. This separate codification, however, did not contribute sufficient observations for a separate model estimation that would focus only on the production function or the demand function. Moreover, a dummy had been used for the environmental Kuznets curve modeling. Namely, this meta-analysis had introduced a dummy for those studies that dealt with the environmental Kuznets curve, but the observations were insufficient to produce a separate meta-regression. Therefore, the perspective of this first study stayed rather limited.

Table 12.4 shows the included studies in the first meta-analysis by Menegaki (2014). It contains the year of publication and the number of meta-analytic observations that each study contributed to the meta-analysis. Note that, the number of observations is generated by the different models applicable in different countries and groups of countries as well as their results.

Table 12.5 describes the variables selected in the first meta-analysis and their basic descriptive statistics. The selection of variables is only indicative but not exclusive, because it depends on what the surveyed studies can offer in a collective way. Namely, a meta-analytic list of variables could not contain a variable encountered only once

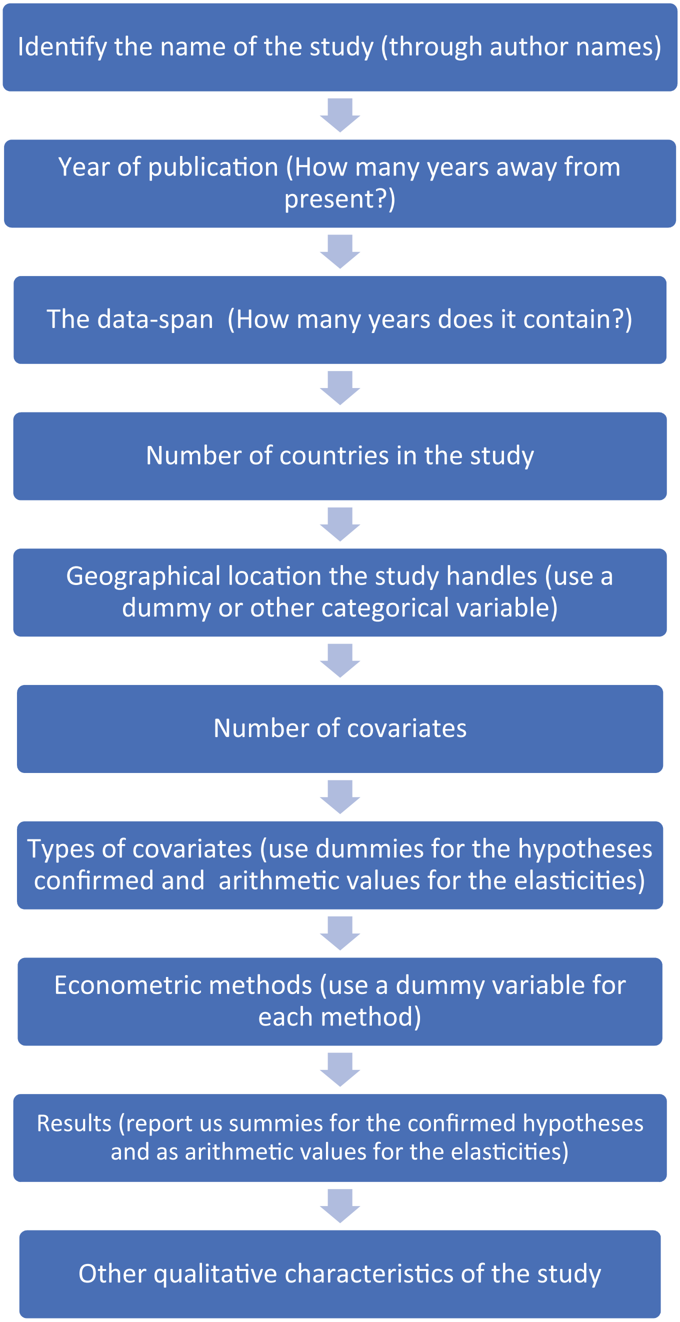


Fig. 12.1 Additional internal steps for data abstraction (step 4) in the meta-analysis given in Table 12.2. *Source* The author's compilation

Table 12.4 Author, publication year, and number of observations (Menegaki 2014)

Authors	Year of publication	Observations
Acaravci and Özturk	2010	12
Akinlo	2008	7
Al-Iriani	2006	6
Altinay and Karagol	2004	1
Altinay and Karagol	2005	1
Ang	2007	1
Ang	2008	1
Apergis and Payne	2009a	4
Apergis and Payne	2009b	6
Apergis and Payne	2010	9
Asafu-Adjaye	2000	4
Balcilar et al.	2010	7
Bartleet and Gounder	2010	2
Belloumi	2009	1
Bowden and Payne	2009	5
Chiou-Wei et al.	2008	9
Eggoh, Bangake and Rault	2011	10
Erdal et al.	2008	1
Esso	2010	7
Friedl and Getzner	2003	1
Fuinhas and Marques	2012	5
Ghali and El-Sakka	2004	1
Glasure and Lee	1998	2
Gosh	2002	1
Halicioglu	2009	1
Hamit-Hagar	2012	1
Ho and Siu	2007	1
Hondroyiannis et al.	2002	2
Jalil and Mahmud	2009	1
Lean and Smyth	2010	5
Lee	2005	17
Lee and Chang	2008	16
Lee and Chien	2010	7
Lise and Montford	2007	1
Mahadevan and Asafu-Adjaye	2007	20

(continued)

Table 12.4 (continued)

Authors	Year of publication	Observations
Masih and Masih	1996	6
Mozumder and Marathe	2007	1
Narayan and Prasad	2008	30
Odhiambo	2010	3
Odhiambo	2009	1
Oh and Lee	2004	2
Özturk and Acaravci	2010	1
Özturk et al.	2010	3
Paul and Bhattacharya	2004	1
Shiu and Lam	2004	1
Squalli	2007	11
Tsani	2010	4
Wang et al.	2011	1
Yuan et al.	2008	4
Zhang and Cheng	2009	1
Zhixin and Xin	2011	1

Source Menegaki (2014)

in a study. This cannot generate any information, only in exceptional cases where one individual study contributes many observations.

As observed, Table 12.5 is divided into five parts. One is the general study characteristics with elements such as year of publication, whether stability examination with breaks is present, and the type of the data, the time span, and the start year of the time span. Second is the method of analysis which contains the most frequently met method. If some methods appear only once or in another rare frequency, researchers could create another category termed as "other." Third in this table appears the geographical allocation of the studies. It would be advisable to separate them based on the continent or some major countries such as the USA could be placed alone in separate categories. Another division could be made based on the economic development performance of the country as provided by World Bank. In this part, it also includes another variable that contains the number of countries in the study, so that the reader can be aware not only of the geographical location of the study but also of the number of countries' studies in each continent or geographical location.

The third part of variables contains the variables selected in the long-run relationship, while the fourth part deals with the description of causality. The variable inclusion can be as rich as the studies allow and as imaginative as the researcher can reach.

Table 12.6 contains the meta-analytic results of the first study. Apparently, the researcher has provided several model estimations to show that heteroskedasticity

Table 12.5 Description of variables in the meta-analysis by Menegaki (2014)

Variable name	Explanation	Mean	Standard deviation
i. General study characteristics			
YEAR	Year of publication	2007.67	2.364
STAB	Stability examined with breaks; 1: yes, 0: no	0.07	0.259
TIPA	Type of data; 1: time series, 0: panel data	0.54	0.498
NYEA	Number of years (time span) in each study	34.50	8.49
STYEA	Start year of the time span	1967.92	8.09
ii. Method of analysis			
ARDL	Method for cointegration; 1:ARDL bounds test, 0: otherwise	0.88	0.28
PEDR	Method for cointegration;1: Pedroni, 0: otherwise	0.21	0.41
JOHA	Method for cointegration; 1: Johansen, 0: otherwise	0.05	0.22
TODA	Method for cointegration; 1: Toda-Yamamoto, 0: otherwise	0.07	0.25
COIN	Method for cointegration; 1: General analysis, 0: otherwise	0.52	0.49
iii. Countries in the study			
EURO	1: Europe, 0: otherwise	0.36	0.48
AMER	1: America, 0: otherwise	0.14	0.35
AFRI	1: Africa, 0: otherwise	0.12	0.33
ASIA	1: Asia, 0: otherwise	0.31	0.46
AUST	1: Australia, 0: otherwise	0.03	0.16
NCOU	Number of initial countries included in the analysis	18.04	9.66
iv. Variables included in the long-run relationship			
ELEC	Electricity included in total energy consumption; 1: If electricity is included, 0: not included	0.34	0.47
ECEL	Energy consumption elasticity	0.54	0.39
PRDU	Prices of goods; 1: if P exists in the equation, 0: if it does not	0.06	0.23
EKCD	1: if EKC is examined in the equation, 0: if it does not	0.06	0.23
CAPI	Elasticity of capital	0.27	0.20
CO2D	CO_2 emissions; 1: if CO_2 exists in the equation, 0: if it does not.	0.01	0.10
LABD	1: if labor exists in the equation, 0: if it does not	0.20	0.39

(continued)

Table 12.5 (continued)

Variable name	Explanation	Mean	Standard deviation
v. Causality			
BIDI	Bidirectional causality between EC and GDP; 1:yes, 0:no	0.22	0.41

Source Adapted from Menegaki (2014)

was not a problem and supports the robustness of the estimated model. The weighted least squares (WLS) is generally estimated using the weights from the inverse standard errors of effect sizes or a monotonic transformation of the primary study sample size.

12.3.2 Case Study 2: The Meta-Analysis on Energy-Growth Nexus by Kalimeris et al. (2014)

In the same year, 2014, Kalimeris et al. (2014) have published the second meta-analysis which is based on a much larger sample of 158 studies and a very comprehensive analysis. Nevertheless, they could support neither a macro-dimension nor a neutrality hypothesis between the energy and growth relationship. This study used a different classification of variables, which reveals that the spectrum of variable representation is vast. Thus, for example, the year of publication is a dummy variable with groups termed based on the decade the publication was issued, e.g., 1970s, 1980s, etc. While Menegaki (2014) uses a continuous variable to count the year of publication from the present time, this study offers a different idea on how to represent the publication year, and this reveals the vast horizons open to variable definition and codification.

Therefore, the study by Kalimeris et al. (2014) uses a dummy for the data size, between the groups of 10–19, 20–29, 30–39, etc. Furthermore, instead of a pure geographical description of the countries in the sample, the authors use a description of their economic development and status, e.g., G7 countries, OECD countries, etc. They also use seven econometric methodologies and nine energy types. They also underline the importance of the energy measurement. Many studies are not clear of this definition, but Kalimeris et al. (2014) note nine distinct types of energy measurement such as Btu's and oil equivalent. Instead of generating many observations from one study, they have used a dummy variable to separate their sample into single countries and more than one countries' studies. Causality was represented with one variable for every hypothesis: Conservation, Growth, Neutrality, and Feedback (Table 12.7).

Kalimeris et al. (2010) carried out their analysis with a rough set data analysis method to create rules inserted in functional relationships for the whole dataset. However, the method failed to provide concrete and effective results about the direction

Table 12.6 Meta-regression results (Models 1, 2, 3 and 4)

	Model 1: OLS		Model 2: Heteroskedasticity robust covariance model		Model 3: Heterogeneity robust model		Model 4: Weighted heteroskedasticity robust model	
	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*
Constant	−2949.95 (10916.06)	0.787	−2949.95(10051.60)	0.769	−2949.95 (12045.49)	0.806	−4679.77 (6818.90)	0.493
Type of data	138.97 (71.30)	0.052*	138.97 (74.36)	0.062**	138.97 (95.24)	0.145	72.98 (73.22)	0.319
Electricity	−211.91 (67.98)	0.002*	−211.91 (72.90)	0.004*	−211.91 (93.15)	0.023*	−72.17 (69.17)	0.297
ARDL method	457.07 (64.30)	<0.001*	457.07 (110.58)	<0.001*	457.07 (103.23)	<0.001*	383.97 (171.46)	0.026*
Pedroni cointegration	308.33 (91.49)	<0.001*	308.33 (138.36)	0.026*	308.33 (108.88)	0.005*	414.63 (204.41)	0.043*
Other cointegration	18.62 (65.78)	0.777	18.62 (68.58)	0.786	18.62 (63.12)	0.768	38.11 (59.57)	0.523
Number of countries	4.44 (2.79)	0.113	4.44 (4.83)	0.358	4.44 (5.59)	0.427	−0.88 (4.05)	0.826
Number of years	−2.94 (5.29)	0.578	−2.94 (4.57)	0.520	−2.94 (6.47)	0.649	2.00 (3.16)	0.527
Start year of the time span	1.40 (5.45)	0.796	1.40 (5.01)	0.778	1.40 (5.96)	0.813	2.17 (3.40)	0.524
Prices of goods	−290.60 (79.18)	<0.001*	−290.60 (64.38)	<0.001*	−290.60 (71.15)	<0.001*	−163.53 (69.53)	0.019*
Environmental Kuznets curve	436.89 (81.67)	<0.001*	436.89 (137.18)	0.001*	436.89 (134.51)	0.001*	400.39 (159.39)	0.012*

(continued)

Table 12.6 (continued)

	Model 1: OLS		Model 2: Heteroskedasticity robust covariance model		Model 3: Heterogeneity robust model		Model 4: Weighted heteroskedasticity robust model	
	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*	Coefficient (Standard error)	*p*
Capital formation	0.72 (0.12)	<0.001*	0.72 (0.18)	<0.001*	0.72 (0.13)	<0.001*	0.66 (0.21)	0.001*
Carbon emissions	−180.48 (97.86)	0.066**	−180.48 (126.52)	0.155	−180.48 (88.21)	0.041*	−293.94 (131.58)	0.026*
Labor	135.55 (117.66)	0.250	135.55 (168.51)	0.422	135.55 (137.76)	0.326	298.80 (197.98)	0.132
Bidirectional causality	0.07 (0.05)	0.152	0.07 (0.04)	0.101	0.07 (0.04)	0.099**	0.014 (0.02)	0.615
Stability	−130.64 (89.02)	0.143	−130.64 (117.62)	0.267	−130.64 (99.15)	0.188	−227.27 (205.14)	0.269
Adjusted R^2	0.68		0.68		0.70		0.79	
F	37.08		37.08		37.08		63.39	
Br./Pagan LM $\chi^2(15)$			311.27				718.99	
VIF	<10							
CUSUM	40%							
Number of clusters					17			
Observations	247		247		247		247	

Note *5% significance, **10% significance. *Source* Menegaki (2014)

Table 12.7 Variables and frequencies in the meta-analysis by Kalimeris et al. (2014)

Variable	Description	Frequency (N = 686)
Length of study period in years	<10	5
	10–19	8
	20–29	191
	30–39	353
	40+	127
Economic development of the country	G7	121
	Other OECD	163
	Non-OECD high development	148
	Other non-OECD	245
	region of Country	9
One or more countries	Single country	637
	Group of countries	49
Econometric methodology	Sims–Engle–Granger	207
	Johansen–Juselius	189
	Toda–Yamamoto	116
	Pedroni	52
	ARDL bounds test	52
	Other	70
Energy input source	Energy per capita	272
	Total energy	214
	Electricity	139
	Coal	22
	Oil	14
	Gas	13
	Other (nuclear, renewables, total fossil fuels)	12
Energy measurement method	Oil equivalent	357
	Electricity	168
	Btu	49
	Coal equivalent	25
	Crude quantity	12
	Other (Devisia index, Joule, exergy)	8
	Undefined	67

Adapted from Kalimeris et al. (2014)

of causality, and this entailed that the direction of causality could not be described by a theoretically testable argument. The authors in this study continued with a multinomial logistic regression with dependent variables being the causality categories identified minus one. They concluded that the direction of causality is probably sensitive to the econometric method, and there is no general macro-rule among the attributes of the study that leads to a certain hypothesis. Thus, for example, the only weak indication that the Johansen–Juselius methodology with oil-equivalent energy measurement leads to the support of the conservation hypothesis that could not be of much use, since it is not based on robust findings (Table 12.8).

Table 12.8 Multinomial logistic results: rate ratios with 95% confidence intervals (Kalimeris et al. 2014)

Attribute	Categories	Rate ratio and 95% CI versus E $\neq$ GDP		
		E $\rightarrow$ GDP	GDP $\rightarrow$ E	E $\leftrightarrow$ GDP
Econometric methodology	Sims–Engle–Granger	1.14 (0.53–2.43)	1.12 (0.51–2.44)	2.46 (1.01–5.98)
	Johansen–Juselius	4.34 (1.90–9.94)	2.39 (1.00–5.72)	8.80 (6.40–22.8)
	Toda–Yamamoto	0.99 (0.44-2.22)	1.55 (0.70–3.43)	0.53 (0.17–1.60)
	Pedroni	35.5 (4.29–293)	14.0 (1.60–123)	33.0 (3.69–295)
	ARDL	1.95 (0.66–5.78)	3.14 (1.13–8.75)	4.70 (1.46–15.1)
	Others (this is the reference category)	1	1	1
Energy measurement	Btu	0.18 (0.06–0.58)	1.28 (0.45–3.61)	0.13 (0.04–0.47)
	Oil equivalent	0.96 (0.45–2.05)	1.74 (0.73–4.16)	1.00 (0.46–0.47)
	Electricity	0.87 (0.38–2.00)	1.60 (0.63–4.03)	0.52 (0.21–1.27)
	Others	0.39 (0.12–1.27)	1.16 (0.34–4.01)	0.47 (0.15–1.49)
	Undefined	1	1	1

Source Kalimeris et al. (2014)

12.4 Concluding Remarks

This chapter has provided the main steps in an energy-growth meta-analysis with guidelines so designed in order to avoid the main criticisms against meta-analysis. The main part of the chapter had dealt with the presentation of the most important points and the results of two meta-analyses that have taken place in the energy-growth nexus field. Both of them have found that the different econometric methods used are one of the reasons for the contradictory results. One has employed a traditional regression analysis and the other a multinomial regression analysis. Both the meta-analyses are inconclusive, and they somehow confirm the dead-end this research field has ended into. Two additional case studies are referred to but are not analyzed, and the interested reader is advised to refer to them if one needs additional guidance and examples.

The fact that the two meta-analyses underline much the importance of the econometric method paves the way to discussion about the future of this field. Unless research becomes coordinated by a central planner (that may be a journal, a conference or other form of energy-growth researcher coordination), it will be quite difficult for the energy-growth studies to be compared with each other and find the ways that energy conservation measures affect economic growth differently across countries. Robust meta-analysis is one way out the deadlock, wherein the energy-growth nexus literature has led itself into. This will also contribute to the formation and testing of a theoretical relationship which is still missing from the field.

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Chapter 13
Renewable Energy—Economic Growth Nexus: Addressing Potential Issues of Endogeneity and the Precision of the Long-Run Relationship

Adwoba Manyekyi Bentil and Philip Kofi Adom

Abstract In the face of the global energy challenges and the associated climate issues, the transition to renewable energy sources continues to gain grounds. Proponents of renewable energy transition argue that renewable energy supply promotes economic growth. However, the concerns of variability in renewable energy supply cast doubt on the growth-driven argument. Thus, whether renewable energy supply will promote economic growth or not is an empirical question. This chapter examined the nexus between renewable energy supply and economic growth. As a contribution, this paper addressed potential problems of endogeneity and the precision of the long-run estimates. The result showed that renewable energy supply causes economic growth in the short run while economic growth causes renewable energy supply in the long run. Cointegrating estimates revealed positive effects of renewable energy supply on economic growth in the short run but negative effects on economic growth in the long run. The interdependency between renewable energy supply and economic growth implies that investment in renewable energy supply could stimulate economic growth but only in the short run.

Keywords Renewable energy · Economic growth · Endogeneity · Precision of long-run parameters

13.1 Introduction

The importance of energy to economic growth is a long-established fact in the literature. Bayar and Özel (2014) noted that the consumption of electrical power, no matter the fuelling sources could drive economic activity and the production of goods and services. Voser (2012) opined that the "oxygen" of the economy and the "life-giving

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blood" for economic growth is energy. Phat (2012) states that energy has become progressively crucial to the basics and fundamentals of any industrial and manufacturing objectives. Thus, without the supply of energy, industrialisation becomes impossibility. Moreover, with the global concerns of green economic growth, environmental sustainability and economic sustainability, the use of cleaner energy types, such as renewable energy, has become crucial.

Hydropower energy constitutes the major renewable energy source for electricity generation globally. Hydropower energy supplied 71% of all renewable electricity consumption at the end of the year 2015 (World Energy Council 2016). Approximately, 15.9% of the world's global power consumption in 2017 was from hydropower (World Energy Council 2016). The world has seen a major increase in the development of hydropower over the years. Across the world, this growth has come from new and emerging economies mostly in Asia, Latin America and Africa. Factors, such as lower energy price (Adom et al. 2017, 2018a; International Renewable Energy Agency 2012), energy security (Adom et al. 2019) and economic growth, drive the development of hydropower renewable energy. Opoku et al. (2017) revealed that factors, such as high demand for electricity and energy storage, pliability in the generation, the management of freshwater, mitigation on the negative impacts of change in climate and consideration for fauna and flora adaptations, are the driving forces behind the development of hydropower technology.

For many years, Ghana has been dependent on hydropower for its electricity. Until the 1990s, hydropower energy was the major generating source. However, due to the generation difficulties experienced in 2002/2003 and 2015/2016, there has been a shift in the structure of electricity generation. From 100% share in total electricity generation, the share of hydropower energy has fallen to 40% or less since 2016/2017. The country has added more thermal plants to complement power generation. Adom et al. (2017) described the current electricity sector as the "thermalisation age". On the other hand, Ghana has only added Kpong and Bui dams, making it three hydropower generation sources.

Africa countries, including Ghana, continue to make significant progress in economic growth but this economic achievement is at a significant risk due to the energy (electricity) supply constraints faced by these economies. Van der Wat (2013) asserts that the African economy is growing at an impressive pace yet its potential may not be fully realised due to the challenge of the supply of electrical power. In Ghana, for more than two decades now, there have been serious concerns about electrical power supply, which has cost the economy greatly. Kumi (2017) estimated that the cost of power losses to the formal and informal sectors averaged at US $2.1 million daily. In 2015/2016, when there were severe power blackouts throughout the economy for an extended period, economic growth fell from 3.92% in 2015 to 3.58% in 2016. The industrial sector, which is highly energy-driven, experienced a negative growth rate of 0.5 in 2016 (Ghana Statistical Service 2018; Adom et al. 2015). Consequently, many industries small and big recorded negative balance sheets, which lead to high labour retrenchment in the industry.

Several factors have underpinned the power crisis problem in Ghana. They include the significant fall in the water levels of hydro-dams (particularly in Akosombo Dam), shortage of light crude oil and gas to power gas and light crude oil thermal plants, and other technical challenges. However, the significant falls in the water levels of hydro-dams have often plunged the country into very serious power problems in the country. For example, the sub-optimal generation from Akosombo in 2015/2016 and 2002/2003 due to the fall in the water levels was the chief cause of the power challenges experienced during these periods. This provides a counterproductive argument against the growth effects of developing hydropower energy technology. Thus, while the technology may provide growth benefits due to its lower cost implications and positive impacts on the environment, the erratic or unpredictability nature of supply due to weather variation or climate change can prove counterproductive in the long term. That is, the growth effects of hydropower renewable energy technology on the growth of an economy might be different between the short term and long term. The aim of this chapter is to examine the short- and long-run effects of hydropower renewable energy supply on economic growth as well as the causal relationship in Ghana.

The literature on the link between renewable energy consumption and economic growth presents ambiguous results. Studies have found positive, negative and no effects of renewable energy consumption on economic growth. Largely, panel-based studies report evidence in support of the positive effects of renewable energy consumption on economic growth. Tugcu et al. (2012) examined the relationship between renewable and non-renewable energy and economic growth for G7 countries. The authors found that renewable energy consumption matters for economic growth. Apergis and Danuletie (2014) also reported a significant positive effect of renewable energy consumption on economic growth for 80 countries. Inglesi-Lotz (2016) tested the renewable energy consumption and economic growth nexus for OECD countries and found a significant positive effect of renewable energy consumption on economic growth. Bhattacharya et al. (2016) examined a similar relationship for 38 top renewable energy-consuming countries. The result confirmed the positive effect of renewable energy consumption on economic growth in these economies. Kocak and Sarkgunesi (2017) for Black Sea and Ballan countries have also reported evidence in support of the positive effects of renewable energy consumption on economic growth. More recent studies such as Zafar et al. (2019) for Asia-Pacific Economic Cooperation countries, Adams et al. (2018) for sub-Saharan Africa, Ntanos et al. (2018) for European countries and Ahmed and Shimada (2019) for emerging and developing economies (consisted of African countries) reported of a significant long-run relationship between renewable energy consumption and economic growth. However, other panel-based studies reported opposite evidence. Ventkatraja (2019) found that decreasing the share of renewable energy consumption in total energy mix contributed to positive economic growth in BRICS countries. Menegaki (2011) reported a weak relationship between renewable energy consumption and economic growth in Europe, while Ozcan and Ozturk (2019) found no causality from renewable energy consumption to economic growth. Maji et al. (2019) found that, in West Africa, renewable energy consumption slows down economic growth, which contrasts the findings of Adams et al. (2018).

The evidence based on time series technique rather remains highly uncertain, with reported evidence of differentiated effects. Alper and Oguz (2010) revealed that renewable energy consumption positively impacts on economic growth in Bulgaria, Estonia, Poland and Slovenia. Fan and Hao (2020) found significant long-run relationship between renewable energy consumption and economic growth taking into account the effects of foreign direct investment in China. Wang et al. (2018) examined the link between renewable energy consumption, human development index and economic growth in Pakistan. The result showed that renewable energy consumption discouraged the human development index. Marinas et al. (2018) using data from central and eastern European countries revealed that, in the long run, renewable energy consumption does not cause economic growth in Czech Republic, Hungary and Romania but does cause economic growth in the other countries.

The review above highlights some important gaps that require attention. First, in contrast to the previous literature, this study used hydro-renewable energy supply instead of renewable energy consumption data. From production perspective, renewable energy supply properly capture input than renewable energy consumption. Second is the issue of endogeneity, which could result from reverse causality and omitted variable bias. In the case of the former, there are reported evidences of bidirectional causality between renewable energy consumption and supply and economic growth (Inglesi-Lotz 2016; Kocak and Sarkgunesi 2017; Lin and Moubarak 2014; Apergis and Payne 2010). This creates potential endogeneity problem. Wang et al. (2018) addressed this potential endogeneity problem by using simultaneous equation model. Nonetheless, the use of actual data, which consists of short-term cyclicality, apart from causing reverse causality problem provides estimates that are not a true reflection of the true long-run parameters (Adom et al. 2018b). In the case of the former, Fan and Hao (2020) and Zafar et al. (2019) controlled for the importance of foreign direct investment and trade openness. This is because renewable energy technologies correlate with foreign direct investment and the technology absorptive capacity of the host country (measured here as trade openness). Therefore, excluding it from the model will create identification issues. However, including these variables independently may not be enough due to the Bhagwati hypothesis (Bhagwati 1973), which emphasises the point that trade liberalisation can influence foreign direct investment and foreign direct investment can influence trade liberalisation (see Sakyi et al. 2015). Thus, omitting the interaction of foreign direct investment and trade liberalisation could cause potential endogeneity problem. Lastly, the ambiguous nature of the relationship between renewable energy consumption and economic growth in the literature suggests possible differentiated effects between the short run and long run.

This study contributes to the literature in the following ways. First, on the issue of endogeneity, this paper used two approaches. For the issue of reverse causality, the paper used potential GDP per capita instead of actual GDP per capita. The use of potential GDP per capita provides two advantages. It helps solve the reverse causality problem by taking out the short-term cyclicality component of the data. Second, taking out the short-term cyclicality makes the data more long-term oriented and hence improves the precision of the long-run parameters (Adom et al. 2018b). Moreover, smoothening the data to remove the short-run cyclicality can remove potential structural break problems with the data. On the issue of omitted variable bias, this paper included the effects of foreign direct investment and trade liberalisation as well as their interaction as suggested by the Bhagwati hypothesis. Lastly, this work contributes to the literature by distinguishing between the short- and long-run effects of hydro-renewable energy supply on economic growth. By delineating between the short- and long-run effects, this work reveals the heterogeneous growth effects of the technology, which could inform renewable energy policies and energy policies in general. In other words, establishing the short- and long-run heterogeneous effects provides information concerning the growth effects as well as the risk factors associated with the hydropower renewable energy technology. This could inform policymakers to put in place contingency measures to minimise the risk factors associated with the technology. Section 13.2 reviews the state of renewable energy technology in Ghana. Section 13.3 presents the method and data. Section 13.4 discusses the results, and Sects. 13.5 and 13.6 conclude with policy recommendations.

13.2 Hydro-generation Sources in Ghana

Ghana has three main dam sites, viz. Akosombo Dam, the Bui Dam and the Kpong Dam. The Akosombo Dam (situated at south-eastern Ghana on the Volta River) provides a larger share of total electricity generation from hydropower sources. In 2017, the Akosombo Dam generated 4,282 GWh, which was 16.3% higher than the projected value. Due to the forecasted challenges in gas supply and maintenance works carried on thermal units at Aboadze in the first quarter in 2017, the recommended plan was to run all six generating plants during the peak period. The result was a decline in the elevation to 240.09 ft, which was 0.09 ft above the estimated level (Energy Commission Ghana 2018). The lake elevation was 253.40 feet at the end of the inflow season (Energy Commission Ghana 2018).

The second largest dam is the Bui hydro-plant, commissioned in 2013 on the Black Volta River. In 2017, the Bui Dam generated 581.79 GWh, which was lower than the target of 840 GWh. The primary reason was the overdrafting of the dam in the first quarter of the year. The Bui Dam begun in the year with an elevation of about 175.87 masl (metres above sea level) but fell to 169.61 masl (metres above sea level) in June 2017 only to rise to 175.92 masl (metres above sea level) in December 2017 (Energy Commission Ghana 2018). The Kpong Dam is located on the lower Volta River at Akuse, with a capacity of 160 megawatts. The Kpong Dam complements power supply from Akosombo Dam to Volta Aluminium Company Limited in Tema for the smelting of aluminium.

Table 13.1 shows the installed capacity and generation types. According to the table, until the year 2016, a larger proportion of total electricity generation originated from renewable hydropower sources. The high dependency on renewable

Table 13.1 Ghana total energy generated and installed capacity (2000–2017)

Year	Installed capacity (MW)	Total energy generated (GWh)	Hydro (GWh)	Thermal (GWh)	Other renewable (GWh)
2000	1418	7296	6610	687	0
2001	1551	7859	6609	1250	0
2002	1578	7273	5036	2237	0
2003	1582	5900	3885	2015	0
2004	1730	6038	5280	758	0
2005	1730	6788	5629	1159	0
2006	1935	8429	5619	2810	0
2007	1981	7004	3727	3277	0
2008	1981	8324	6195	2129	0
2009	1970	8958	6877	2081	0
2010	2165	10,167	6996	3171	0
2011	2170	11,200	7561	3639	0
2012	2280	12,024	8071	3953	0
2013	2831	12,871	8233	4635	3
2014	2831	12,963	8387	4572	4
2015	3656	11,492	5845	5644	3
2016	3795	13,022	5561	7435	26
2017	4398	14,086	5616	8442	28

Source Authors' own construction with data from Ghana GRID Company Limited

hydropower became problematic during periods of drought. The consequence was prolonged blackouts and load shedding, which affected economic activities negatively. In 2015, total electricity generation dropped from 12,963 GWh in 2014 to 11,492 GWh, which represented a fall of 1471 GWh fall. The chief factor was the decline power generation from hydro of 8387 GWh in 2014 to 5845 GWh in 2015. During that same period generation from thermal sources rose from 4572 GWh in 2014 to 5845 GWh in 2015 to partly compensate for the shortage in hydro-generation.

The shortfall noted in gross supply of electricity caused severe energy supply crises in Ghana. The supply of power was very erratic. The bulk energy-consuming sectors experienced much of the negative effect of the power supply crises. The Institute of Statistical, Social and Economic Research (ISSER), in a recent report, showed that Ghana lost about one billion dollars in the year 2014 because of power crises (ISSER 2015). The crisis damaged electronic equipment, refrigerated food, etc. The health sectors also suffered adversely. Adom et al. (2015) discovered that the power supply challenges had undesirable impacts on most of the industries.

Electricity produced from water sources reduced in 2017 as well as 2016, but the total generation of electricity sprung up again in 2017 and 2016 due to the rise in the generation of electricity from thermal plants. Generation from other renewable energy sources remains small, emphasising the point of low development of other renewable energy sources in Ghana.

13.3 Method and Data

This section discusses the approach taken to undertake the entire study and the technique used to analyse the data. It further elaborates on the type of data collected and sources of the data.

13.3.1 Data Type and Sources

This study used secondary time series data that cover the period 1975–2017. The specific variables that data were collected on include hydropower energy supply, GDP per capita, trade openness, foreign direct inflows and gross domestic investment. Hydropower energy supply is the share of hydropower energy in total electricity generation. GDP per capita (used here as an indicator of the size of the economy) is measured in real terms of US dollars. Trade openness, a measure of globalisation or trade liberalisation, is the sum of export and import as a per cent of GDP. Foreign direct inflows are the net inflow of FDI as per cent of GDP. Gross domestic investment is the gross fixed capital formation as a per cent of GDP. All data came from the World Bank Development Indicators.

13.3.2 Theoretical Framework

The theoretical basis of our empirical model originates from the Solow growth model. The Solow growth model hypothesises a functional relationship between production and factor inputs. Equation 13.1 shows the mathematic relationship, where A is a measure of the total factor productivity and K and L are capital and labour inputs.

$$Y = Af(K, L) \tag{13.1}$$

Based on the recommendations of Howarth (1997) and Brookes (1990), we augmented the output model to include energy input (see Eq. 13.2). Assuming that labour is identical to the total population, we divided through 13.2 by labour to obtain Eq. 13.3, where $y = Y/L$, $k = K/L$, and $e = E/L$. Equation 13.4 is the simplified version of Eq. 13.3.

$$Y = Af(K, L, E) \tag{13.2}$$

$$\frac{Y}{L} = Af\left(\frac{K}{L}, \frac{L}{L}, \frac{E}{L}\right) = Af\left(\frac{K}{L}, 1, \frac{E}{L}\right) \tag{13.3}$$

$$y = Af(k, e) \tag{13.4}$$

Next, total factor productivity depends on the size of foreign investment and trade liberalisation policies. The literature hypothesises a positive relationship between total factor productivity and foreign direct investment (Arisoy 2012; Wooster and Diebel 2010). The reason is that FDI induces technological diffusion and spillovers, which tend to promote efficiency and productivity in an economy. In addition, openness of trade positively affects total factor productivity. Edwards (1998) and Miller and Upadhyay (2000) found that total factor productivity is higher for outward-oriented countries. Based on this assertion, we hypothesised a relationship between total factor productivity; trade openness and FDI (see Eq. 13.5).

$$A = \mathrm{e}^{c+\beta_{\mathrm{tp}}\mathrm{TOP}+\beta_{\mathrm{fd}}\mathrm{FDI}} \tag{13.5}$$

Next, we inserted Eq. 13.5 into Eq. 13.4 to produce Eq. 13.6. Further, we hypothesised a Cobb–Douglas production function, which imposes the constant returns to scale assumption on factor inputs (see Eq. 13.7). Inserting Eq. 13.7 into Eq. 13.6 produces Eq. 13.8. Finally, we performed a log-transformation of Eq. 13.8, and this produces Eq. 13.9, where output per capita is a linear function of trade openness, FDI, capital investment and energy input.

$$y = \mathrm{e}^{c+\beta_{\mathrm{tp}}\mathrm{TOP}+\beta_{\mathrm{fd}}\mathrm{FDI}} f(k, e) \tag{13.6}$$

$$f(k, e) = k^{\beta_k} \mathrm{e}^{\beta_e} \tag{13.7}$$

$$y = \mathrm{e}^{c+\beta_{\mathrm{tp}}\mathrm{TOP}+\beta_{\mathrm{fd}}\mathrm{FDI}} k^{\beta_k} \mathrm{e}^{\beta_e} \tag{13.8}$$

$$\ln y = c + \beta_{\mathrm{tp}}\mathrm{TOP} + \beta_{\mathrm{fd}}\mathrm{FDI} + \beta_k \ln k + \beta_e \ln e \tag{13.9}$$

13.3.3 Empirical Framework

The empirical specification in this study originates from Eq. 13.9. Since Eq. 13.9 is more deterministic or exact, we included a stochastic term to account for the unobserved factors that can affect output per capita. The stochastic term (ε) follows a white noise process.

$$\ln y_t = c + \beta_{\mathrm{tp}}\mathrm{TOP}_t + \beta_{\mathrm{fd}}\mathrm{FDI}_t + \beta_k \ln k_t + \beta_e \ln e_t + \varepsilon_t \quad (13.10)$$

We operationalised output per capita as the real GDP per capita (GDPpc). Energy input is captured here as the share of renewable hydroelectric power energy in total electricity generation (SHYDRO). Renewable energies are cost-effective since they reduce the price of the energy input (Adom et al. 2018a; IRENA 2012). Moreover, it is environmentally friendlier; therefore, it could promote productivity level without any ramifications on the environment. Thus, as an economy switch to a renewable energy technology, in this case, hydropower energy, there are likely to be some growth benefits in the short term. However, there could be downward compensation, especially in the long term, due to the erratic or volatile nature of the renewable energy supply, all things being equal. The erratic or volatile nature of the technology can induce some unsustainability in power supply as well as increase the variance and levels of electricity prices (Adom et al. 2017, 2018a). By implication, the effect of increasing the share of hydro in total electricity generation might have differentiated effects between the short run and long run.

Trade openness captures the extent of economic openness of the country. Though the theoretical predictions of the effect of trade openness on total factor productivity and hence output per capita growth are positive, this could be more realistic in the short run since, in the long run, such openness may subject the domestic economy to an intense international competition, all things being equal. This could create import-substituted industries locally, which could affect economic growth and output negatively in the long run. Thus, the effect of trade openness on economic growth may be different between the short run and long run.

Similarly, though FDI induces technological spillover to the recipient economy, which improves productivity and efficiency in the local economy, this is less likely to be so in the short term for an economy that has lower absorptive capacity. Moreover, weaker environmental regulations may only trigger technological diffusion that can harm the environment (i.e. the pollution haven hypothesis). Thus, the positive effects of FDI are postponed to the long term when the country has developed stronger absorptive capacity and implemented stricter environmental regulation. This also suggests that the impact of FDI on economic output or growth may be different between the short and long run. FDI captures foreign investment.

Gross fixed capital formation captures domestic capital stock or investment. Since there are time lags in investment decisions, the growth effects of domestic investment may be more realistic in the long run than in the short run. Based on the above discussion, we reformulated Eq. 13.10 as Eq. 13.11.

$$\ln \mathrm{GDPpc}_t = c + \beta_{\mathrm{tp}}\mathrm{TOP}_t + \beta_{\mathrm{fd}}\mathrm{FDI}_t + \beta_k \ln \mathrm{GCF}_t + \beta_e \mathrm{SHYDRO}_t + \varepsilon_t \quad (13.11)$$

13.3.4 Econometric Technique

This section discusses the estimation techniques employed to obtain the parameter estimates in this study. The section has the following subdivisions: Bounds cointegrating test, Engle–Granger causality and ARDL technique.

13.3.4.1 Bounds Cointegrating Test

The Bounds cointegrating test is a test proposed by Pesaran et al. (2001). In contrast to other cointegrating tests, the Bounds cointegrating test does not impose strict I(1) restrictions on the variables involved. The test applies to series that are I(1) or I(0) or mutually cointegrated. However, the approach requires that the dependent variable be I(1) while the order of integration for the independent variables does not exceed I(1). To perform the test, we estimated an unrestricted error correction model of Eq. 13.12.

$$\begin{aligned}\Delta \ln \mathrm{GDPpc}_t &= c + \sum_{l=1}^{k} \gamma_l \Delta \ln \mathrm{GDPpc}_{t-l} + \sum_{l=1}^{k} \beta_{\mathrm{tpl}} \Delta \mathrm{TOP}_{t-l} + \sum_{l=1}^{k} \beta_{\mathrm{fdl}} \Delta \mathrm{FDI}_{t-l} \\ &\quad + \sum_{l=1}^{k} \beta_{\mathrm{kl}} \Delta \ln \mathrm{GCF}_{t-l} + \sum_{l=1}^{k} \beta_{\mathrm{el}} \Delta \mathrm{SHYDRO}_{t-l} + \gamma \ln \mathrm{GDPpc}_{t-1} \\ &\quad + \beta_{\mathrm{tp}} \mathrm{TOP}_{t-1} + \beta_{\mathrm{fd}} \mathrm{FDI}_{t-1} + \beta_k \ln \mathrm{GCF}_{t-1} + \beta_e \mathrm{SHYDRO}_{t-1} + \varepsilon_t\end{aligned} \tag{13.12}$$

The null hypothesis for the Bounds cointegrating test is that the coefficient of the lag level variables is restricted to zero against the alternative that the coefficient of the lag level variables is different from zero.

$$H_o : \gamma = \beta_{\mathrm{tp}} = \beta_{\mathrm{fd}} = \beta_k = \beta_e = 0 \quad \text{(Null hypothesis)}$$
$$H_A : \gamma = \beta_{\mathrm{tp}} = \beta_{\mathrm{fd}} = \beta_k = \beta_e \neq 0 \quad \text{(Alternative hypothesis)}$$

The Bounds test generates two critical values at any significance level. These two critical values provide a bound that defines all the possible classification of the regressors into purely I(0), purely I(1) or mutually cointegrated. The following decisions can emerge based on the test:

1. If the calculated *F*-statistics exceed the upper bound *F*-critical value, we reject the null in favour of the alternative hypothesis. Thus, there is cointegration.
2. If the calculated *F*-statistics is lower than the lower bound *F*-critical value, we fail to reject the null hypothesis. Thus, there is no cointegration.
3. If the calculated *F*-statistics falls between lower and upper bound *F*-critical values, there is indecision. In this case, as recommended by Kremers et al. (1992), one can use the significance of the error correction term to make an inference.

13.3.4.2 Engle–Granger Causality Test

The existence of cointegration implies long-run causality at least in one direction (Adom 2017). This study applied the two-stage error correction Granger causality test. Even though the method is sensitive to the values of nuisance parameters especially in finite samples (Toda and Yamamoto 1995; Rambaldi and Doran 1996), it is able to distinguish between short- and long-run causality. In addition, unlike the VAR block Granger causality, this method considers cointegration. The method involves two steps. First, we estimate the long-run Eq. (13.11) and then retrieve the residuals from the equation.

In the second stage, we estimate an error correction model, where the one-year lag of the residual component from the estimated long-run equation appears as an additional regressor. To test for short-run causal relationship, we restrict the coefficients of all lags of the independent variables to zero. Rejection of the null will imply the existence of short-run causality from the independent variable to the dependent variable. On the other hand, the test of long-run causal relationship restricts the coefficient of the lag error term, which is the measure of the error correction term, to zero. Rejection of the null implies long-run causality from the independent variables to the dependent variable. Equation 13.13 is the regression approach for the Engle and Granger causality test.

$$\begin{aligned}\Delta \ln \mathrm{GDPpc}_t = {} & + \sum_{l=1}^{k} \gamma_l \Delta \ln \mathrm{GDPpc}_{t-l} + \sum_{l=0}^{k} \beta_{\mathrm{tpl}} \Delta \mathrm{TOP}_{t-l} + \sum_{l=0}^{k} \beta_{\mathrm{fdl}} \Delta \mathrm{FDI}_{t-l} \\ & + \sum_{l=0}^{k} \beta_{\mathrm{kl}} \Delta \ln \mathrm{GCF}_{t-l} + \sum_{l=0}^{k} \beta_e \Delta \mathrm{SHYDRO_t} + \mathrm{ERT}_{t-1} + \varepsilon_t \end{aligned} \tag{13.13}$$

13.3.4.3 Autoregressive Distributed Lag Cointegration Method

The estimation of the autoregressive distributed lag cointegration method depends on the evidence of cointegration. Based on the existence of cointegration, the ARDL derives the long-run coefficients based on Eq. (13.14), where "*X*" is a vector of explanatory variables and "*D*" is the drift term.

$$\emptyset(L, P) \ln \mathrm{GDPpc}_t = \sum_{i=1}^{k} \delta(L, P) X_t + \vartheta D_t + \varepsilon_t \tag{13.14}$$

Equation (13.15) is the corresponding short-run coefficients, where τ_j^* and π_j^* measure the short-run dynamics of the convergence of the model to equilibrium; π is the vector of short-run parameters, and EC_{t-1} is the error correction term. In this study, we used the Akaike information criteria to select the optimal lag length to include. This is because we did not want to risk under-fitting the model, as is the case with the Schwartz Bayesian Criteria.

$$\Delta \ln \mathrm{GDPpc}_t = \theta(1, P)\mathrm{EC}_{t-1} + \sum_{i=1}^{k} \pi \, \Delta X_t + \vartheta \, \Delta D_t \sum_{j=1}^{p-1} \tau_j^* \Delta \ln \mathrm{GDPpc}_{t-j} - \sum_{i=1}^{k} * \sum_{j=1}^{q-1} \pi_j^* \, \Delta X_{t-j} + \varepsilon_t \quad (13.15)$$

13.3.5 Robustness Checks

This thesis performed some robustness check on the results. First, the ARDL method assumes that the independent variables are weakly exogenous, which is a stronger assumption. Moreover, the method is not robust to the problem of serial correlation in the error term. Therefore, as the first robustness strategy, we applied the fully modified ordinary least squares (FMOLS) and the canonical cointegrating regression (CCR) developed by Phillip and Hansen (1990) and Park (1992), respectively, to obtain the long-run coefficients. The FMOLS and CCR are instrument-based estimators that correct for both the problems of endogeneity and serial correlation.

Second, FDI and trade openness could complement each other, according to Bhagwati hypothesis (Bhagwati 1973). A recent study by Sakyi et al. (2015), for example, has found the existence of the Bhagwati hypothesis in Ghana. Thus, Eq. 13.11 could suffer from omitted variable bias, which could overstate the true effect of hydropower energy supply on GDP per capita. As a further robustness check, we included the interaction of FDI and trade openness as additional regressors (see Eq. 13.16 [1]). The Bhagwati hypothesis suggests $\beta_{\mathrm{tpfd}} > 0$. "$\beta_{\mathrm{tp}}$" measures the direct effect of trade openness on GDP when FDI is equal to zero. "β_{fd}" measures the direct of FDI on GDP when trade openness is equal to zero. This does not make sense especially when the FDI and trade openness data do not have zeros. To solve this problem, we demeaned the independent variables: $\mathrm{TOP}_t^* = \mathrm{TOP}_t - \overline{\mathrm{TOP}}$, $\mathrm{FDI}_t^* = \mathrm{FDI}_t - \overline{\mathrm{FDI}}$, $\ln \mathrm{GCF}_t^* = \ln \mathrm{GCF}_t - \overline{\ln \mathrm{GCF}}$, and $\mathrm{SHYDRO}_t^* = \mathrm{SHYDRO}_t - \overline{\mathrm{SHYDRO}}$. In Eq. (13.17), β_{fd} measures the direct effect of FDI on GDP per capita at the mean of trade openness, while β_{tp} measures the direct effect of openness of trade on per capita GDP at the mean of FDI.

$$\ln \mathrm{GDPpc}_t = c + \beta_{\mathrm{tp}}\mathrm{TOP}_t + \beta_{\mathrm{fd}}\mathrm{FDI}_t + \beta_{\mathrm{tpfd}}\mathrm{TOP}_t * \mathrm{FDI}_t + \beta_k \ln \mathrm{GCF}_t + \beta_e \mathrm{SHYDRO}_t + \varepsilon_t \quad (13.16)$$

[1] Note: This equation is estimated using the FMOLS and CCR.

$$\ln \text{GDPpc}_t = c + \beta_{\text{tp}}\text{TOP}_t^* + \beta_{\text{fd}}\text{FDI}_t^* + \beta_{\text{tpfd}}\text{TOP}_t^* * \text{FDI}_t^* + \beta_k \ln \text{GCF}_t^* + \beta_e\text{SHYDRO}_t^* + \varepsilon_t \quad (13.17)$$

The final robustness check follows a recent study by Adom et al. (2018b). In this study, the authors argue that the use of actual data, which “includes the short-term cyclicality, poses two main problems: reverse causality problem and misrepresentation of the true long-run effects. They argued that the use of potential data, which is devoid of the short-term cyclicality”, instead of actual data improves model efficiency as well as provide precise estimate of the true long-run effects. In this thesis, we applied the Hodrick–Prescott filter (Prescott 1998) to obtain the potential per capita GDP and then used it as the dependent variable.

13.4 Results and Discussions

This section presents the main findings of the study. It has the following subsections: Preliminary analyses of the data, a test of short-run and long-run causality, long-run and short-run effect of hydroelectric power on economic growth, robustness check and diagnostic tests.

13.4.1 Preliminary Analysis of Data

Figure 13.1 shows the time series plot of the variables. GDP per capita was generally low during the period before the eighties. However, the trend has reversed after the 1980s, showing a consistent rise. The structure of electricity generation has significantly changed afterwards 1990s. The share of renewable hydropower energy (formerly the chief generator of electricity) continues to show a decline. This obviously has an important implication on energy pricing as the country continues to move away from the cheapest source of generating power. FDI has also seen a significant increase in 2000, albeit it fell in 2010, possibly triggered by the advent of the global financial and economic crisis in 2007/2008. Trade openness has also experienced a consistent rise in the trend, an indication of intense economic openness. After 2000, the degree of economic openness slowed down but picked up after 2010. Gross domestic investment has seen a consistent rise in the trend but with some degree of volatility in the trend.

We used Elliot–Rothenburg GLS unit root test to test for persistence in the data. The null hypothesis is that the variables have unit root or carry memory of their past. The unit root test shows that, in levels, all the variables do have unit root (see Table 13.2). In other words, they carry memory of their past. However, after

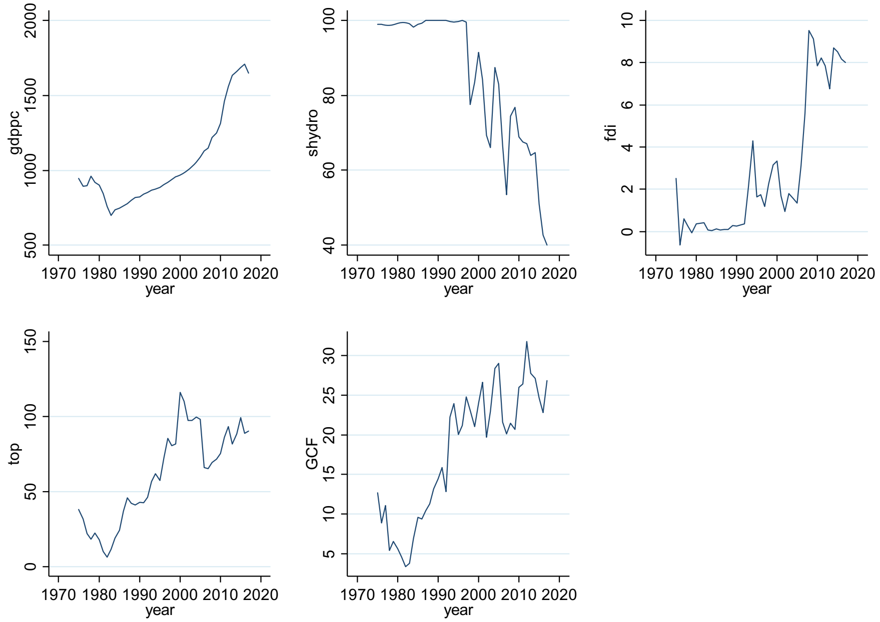


Fig. 13.1 Time series plot of variables

Table 13.2 Unit root test

Variables	Constant	Constant and trend
ln GDPpc	−0.4850	−1.3955
Δ ln GDPpc	−2.6411**	−3.7418**
SHYDRO	1.2793	−1.2287
ΔSHYDRO	−6.3731***	−7.6976***
FDI	−0.7998	−2.3026
ΔFDI	−3.3372***	−5.0814***
GCF	−1.0806	−2.3026
ΔGCF	−6.1893***	−6.7800***
TOP	−0.7649	−1.9723
ΔTOP	−2.5252**	−5.8242***

Null hypothesis: the series has unit root
***, ** and * denote 1%, 5% and 10% significance levels, respectively

first differencing the series, the variables become stationary. Thus, the variables are I(1), which satisfies the requirements of the ARDL and provides a ground for cointegration analysis.

Table 13.3 Bounds co-integrating test

	1% critical value		5% critical value		10% critical value	
Statistic	LB	UB	LB	UB	LB	UB
F-stat = 5.5499	3.29	4.37	2.56	3.49	2.2	3.09

Note there is cointegration if the calculated F-statistics exceeds the upper bound critical value. There is no cointegration if the calculated F-statistics is lower than the lower bound critical value. The decision is inconclusive if the F-statistics falls between the lower and upper bound critical values

13.4.2 Testing for Cointegration

Table 13.3 shows the Bounds cointegrating test. The null hypothesis is that, there is no level relationship. The calculated F-statistics of 5.5499 is greater than the upper bound critical values at all significance levels. Thus, there is enough statistical basis to reject the null hypothesis of no level relationship. In other words, the variables, share of hydro, gross domestic investment, trade openness and foreign direct investment can be treated as the "the long-run forcing variables" explaining the changes in GDP per capita. The existence of cointegration also implies causality in at least one direction. Therefore, in the section that follows, we tested for the causal relationships, especially between GDP per capita and hydropower energy supply.

13.4.3 Testing for Causality

We first applied the block Granger causality test to test the direction of causality between GDP per capita and hydropower energy supply. The optimal lag length selected is one. We subjected the vector autoregressive (VAR) to some model diagnostics in Table 13.4, which are normality of the errors, heteroscedasticity and stability of the roots (see Fig. 13.2 in appendix). The estimated VAR model passed the normality, heteroscedasticity and stability tests.

Table 13.5 shows the block Granger causality test. First, the test shows that hydropower energy Granger causes GDP per capita. Thus, reductions in hydropower

Table 13.4 Diagnostic test for the VAR

Diagnosis	Test	Statistics	Null hypothesis	Conclusion
Normality	Jarque-Berra	16.3398	Errors are normally distributed	Accept
Heteroskedasticity	White	330.8364	Errors are homoscedastic	Accept
Stability	AR roots	–	The roots are stable	Accept

Table 13.5 Block Granger causality

Null hypothesis	Wald statistics	*P*-value	Decision
SHYDRO does not cause ln GDPpc	5.1733^{*}	0.0753	Reject
ln GDPpc does not cause SHYDRO	7.6394^{**}	0.0219	Reject

Note ** $p < 0.05$, * $p < 0.1$

energy supply will hamper economic progress. The causality from hydropower energy supply to economic progress has two explanations. First, hydropower energy supply is less carbon-intensive and environmentally friendly. The environmentally friendly nature of hydropower could affect productivity positively and hence economic growth. This implies that economic growth supplied through renewable hydropower is likely to be green in nature with no negative attended effects on the environment. Second, supplying energy through hydropower is cost-effective. A recent study by Adom et al. (2018a) showed that hydropower energy supply reduces the price of electricity in Ghana. Thus, hydropower can reduce the cost of production and thereby promote productivity increase.

Second, we failed to accept the null hypothesis that GDP per capita does not Granger cause hydropower energy supply. The causality from GDP per capita to hydropower energy supply implies that disruptions in economic growth can harm the progress and development of hydropower energy sources. The block Granger causality concluded of a bidirectional causality between economic growth and hydropower energy supply. Similar studies such as Lin and Moubarak (2014), Apergies and Payne (2010) and Kocak and Sarkgunesi (2017) found similar result. The bidirectional causality between GDP per capita and hydropower energy supply suggests that the economy and the energy sectors are interdependent in nature. Therefore, economic policies and energy policies should be well-integrated.

However, the block Granger causality does not distinguish between short- and long-run causality. This is very crucial considering the importance of policy lags and potential sluggishness in the adjustment process in the energy supply–economic growth nexus. For this reason, the study proceeded, using the Engle–Granger causality test, to test for short- and long-run causality. Table 13.6 shows the causality test based on the Engle–Granger causality test. First, the test shows that renewable hydropower Granger causes economic growth only in the short run and not in the

Table 13.6 Engle–Granger causality

Hypothesis	Short run	Decision	Long run	Decision
ΔSHYDRO does not cause Δ ln GDPpc	3.7096^{*}	Reject	1.9656	Accept
Δ ln GDPpc does not cause ΔSHYDRO	0.0578	Accept	4.0855^{**}	Reject

Note ***, ** and * denote 1%, 5% and 10% significance level, respectively. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 13.7 Engle–Granger causality

Diagnostic test for ARDL Model			
Diagnostics	Test	Statistics	Decision
Heteroskedasticity	Breusch-Pagan-Godfrey	1.8673	No Heteroskedasticity
Serial correlation	Breusch-Godfrey	2.9006	No Serial correlation
Stability test	CUSUM and CUSUMSQ		Stable

long run. The lack of a causal relationship in the long run from hydropower energy supply to economic growth, in the case of Ghana, could be due to the changes in electricity supply structure away from hydropower to other sources, such as thermal energy. In Ghana, hydropower remained the mainstay power source for supplying electricity. However, due to the impact of the weather on the dams, which destabilises hydropower supply, the country has increased the share of thermal plants to stabilise the power system. Currently, thermal plants contribute to the greater share (about 60%) of total electricity in Ghana. This age of thermalisation as noted in Adom et al. (2018a) implies that, in the long run, the causal relationship from hydropower to economic growth would weaken. Moreover, other renewable sources such as solar, wind and biogas are on the lower side.

On the other hand, economic growth Granger causes hydropower energy supply only in the long run. This result is intuitive since renewable energy sources are costly investments that are more likely to materialise in the long run than in the short run. Economic growth in the long term can lead to structural transformations such as industrialisation and urbanisation, which increases the energy demand requirement and hence put pressure on the national energy system. Thus, for sustainability purposes, economic growth can trigger the switch to more sustainable energy sources, such as renewable energies. Moreover, economic growth can trigger the emergence of urban green settlements, which places premium on green energy.

Lastly, change is a gradual process and given that renewable energy sources are not very popular among the masses (especially in developing economies where primary energy sources constitute the highest share of total energy), and it may take time for people to adopt and use the technology on a larger scale. For example, in Ghana, the use of renewable energies is on a lower scale since many are not sure of the technology in terms of the risk it poses and the benefit it professes. However, in the long term, when this information has become available and the technology has been tried and tested, economic growth can trigger a move towards renewable energy sources.

13.4.4 Long-Run and Short-Run Effects of Hydropower Energy Supply

This section presents the results based on the ARDL method. Table 13.7 shows the model diagnostic tests. The results passed the test of heteroscedasticity, serial correlation and stability tests (see Figs. 13.3 and 13.4 for the plot of cumulate squares and cumulative sum of squares in the appendix). The stability of the model rules out the possible effects of structural breaks on the constancy nature of the parameter estimates.

Tables 13.8 and 13.9 contains the long- and short-run cointegrating estimates, respectively. The share of hydropower supply has a significant negative effect on economic growth in the long run (see Table 13.9). According to the result, an increase in the share of hydropower supply by 10 percentage points will decrease economic growth by 1.33%. Given the mean share of hydropower supply of 85.24212%, this translates to an elasticity estimate of 1.1337 (computed as the product of the mean of hydropower and the coefficient of hydropower), which is greater than unitary. Thus, a 1% increase in the share of hydropower energy supply will lead to 1.1337% decrease in GDP per capita in the long run. The negative effect of hydropower on economic growth in the long term could emanate from the uncertainty that is associated with renewable energy sources. The increased uncertainty in renewable energy supply can affect electricity supply and electricity price alike, which could have negative implications on economic growth. For example, Adom et al. (2019) found that, in Ghana, disturbances in the water-energy equilibrium distort electricity supply in the long run. On the relationship between electricity price and hydropower supply, Adom et al. (2017) found that the concentration of hydropower in Ghana

Table 13.8 Long-run coefficients

Method: ARDL cointegrating approach
Dependent variable: ln $GDPpc_t$
Time period: 1975–2017

Variable	Coefficient Std. Error	*t*-Statistic	Prob.
$SHYDRO_t$	−0.013264 (0.003532)	−3.755465	0.0012
FDI_t	0.013646 (0.016091)	0.848071	0.4060
GCF_t	0.019301 (0.008366)	2.306932	0.0313
TOP_t	−0.003195 (0.002132)	−1.498252	0.1489
Constant	7.896391 (0.350538)	22.526518	0.0000

Note Figures in ( ) denote the standard errors of the estimates

Table 13.9 Short-run coefficients

Method: ARDL cointegrating approach
Dependent variable: $\Delta \ln \text{GDPpc}_t$
Time Period: 1975–2017

Variable	Coefficient	Std. Error	*t*-Statistic	Prob
$\Delta \ln \text{GDPpc}_{t-1}$	0.273100	0.110427	2.47313	0.0220
$\Delta \ln \text{GDPpc}_{t-2}$	0.192812	0.109152	1.766444	0.0919
ΔSHYDRO	0.000465	0.000555	0.838699	0.4111
$\Delta \text{SHYDRO}_{t-1}$	0.002670	0.000835	3.199994	0.0043
$\Delta \text{SHYDROc}_{t-2}$	0.001745	0.000632	2.762400	0.0117
$\Delta \text{SHYDRO}_{(t-3)}$	0.002605	0.000809	3.219276	0.0041
ΔFDI	0.003956	0.003398	1.163997	0.2575
ΔFDI_{t-1}	−0.007841	0.003593	−2.182003	0.0406
ΔGCF	0.001174	0.001378	0.852466	0.4036
ΔGCF_{t-1}	−0.002556	0.001640	−1.558040	0.1342
ΔTOP	−0.000331	0.000525	−0.630913	0.5349
ΔTOP_{t-1}	0.002304	0.000586	3.933465	0.0008
CointEq_{t-1}	-0.287411	0.044762	−6.420863	0.0000

increases the uncertainty in electricity prices in the long term. Also, Adom et al. (2018a) showed that, in the short run, increased variability in hydropower sources increases the price of electricity in Ghana.

However, in the short run, the results show that hydropower supply has a significant positive effect on economic growth (see Table 13.9). The coefficient suggests that an increase in the share of hydropower energy supply by 10 percentage points will cause GDP to increase by 0.7485%. This translates to an elasticity estimate of 0.63804, which suggests that increasing hydropower energy supply by 1% in the short run will cause GDP per capita to increase by 0.63804%. The positive effect of hydropower energy supply is an indication that, in Ghana, the growth benefits associated with hydropower renewable energy supply may be limited to the short run. An explanation of this could stem from the uncertainties in the water-energy equilibrium associated with hydropower energy supply in the country. This is not to suggest that hydropower energy supply may not produce any long-term growth benefits. In fact, it could be possible if the uncertainties associated with the technology are minimised.

The effect of foreign direct investment on GDP is positive but statistically insignificant in the long run. In the short run, FDI has an immediate positive effect on GDP but the effect becomes significantly negative after one year. This indicates some nonlinearity in the relationship between FDI and GDP. The inflow of FDI from the onset may trigger technological boom, which could be beneficial to economic growth. However, where there exists laxity in environmental regulations in the recipient economy, these technological inflows may not meet the minimum environmental requirement, which could affect the environment negatively and economic growth. The environmental economics literature describes this phenomenon as the pollution haven hypothesis. As shown in the table, the overall effect of FDI on GDP per capita is negative (i.e. −0.011797), a possible indication that a pollution haven hypothesis may be prevalent in Ghana. However, the position of the literature on the existence of a pollution haven hypothesis, especially in developing economies where environmental regulations are not strict, is not unanimous. While Solarin et al. (2017) confirmed the existence of a pollution haven hypothesis for Ghana, Amuakwa-Mensah and Adom (2017), Adom and Amuakwa-Mensah (2016) and Aboagye and Kwakwa (2014) found the opposite result for sub-Saharan Africa (included Ghana).

Gross domestic investment has a positive effect on GDP per capita only in the long run. The short-run coefficient shows no statistical power. According to the long-run estimate, increasing gross domestic investment by 10 percentage points will cause GDP per capita to increase by 1.9%, which translates to an elasticity estimate of 0.3456 (evaluated at the mean of gross domestic investment). Thus, a 1% increase in gross domestic investment will increase GDP per capita by 0.3456%. The result that gross domestic investment promotes economic growth only in the long run can be explained from the angle that there are time lags in investment decisions. The positive effect of gross domestic investment is consistent with the findings of Sakyi and Egyir (2017) and Sakyi et al. (2015).

The effect of trade openness has a significant impact on GDP only in the short run. The short-run coefficients show that the effect of trade openness on GDP is negative and insignificant but becomes positive and statistically significant after a one-year period. This shows a nonlinear effect of trade openness on GDP. However, the overall effect is positive in the short run. Trade liberalisation can initially dampen domestic economic activities due to the preliminary intense competition that local industries might face. However, with time, local industries may develop their technologies to stay competitive as well as imitate best practices, which could affect economic growth positively. Sakyi (2011) also found the impact of trade openness on economic growth to be positive.

Lastly, the error correction term is negative and statistically significant. This confirms the cointegration result that shocks in economic growth are temporal in Ghana. According to the coefficient, if there is a 1% error shock in economic growth, about 29% of this shock is corrected in the first year.

13.4.5 Further Robustness Checks

The ARDL model assumes weak exogeneity, which is very restrictive. Therefore, first, we subjected the above results (especially the long-run results) to some model diagnostics. We applied the fully modified ordinary least squares (FMOLS) and the canonical cointegrating regression (CCR) as the long-run estimation techniques. Models 1 in Table 13.10 show the long-run effects of hydropower energy supply. The result shows a significant negative effect of hydropower supply on GDP per capita in the long run. Models 2 show that the effect is still negative and statistically

Table 13.10 Long-run effects of hydropower supply

Dependent variable: In $GDPpc_t$								
	Fully modified OLS				Canonical cointegration regression			
	M1	M2	M3	M4	M1	M2	M3	M4
$SHYDRO_t$	−0.0136*** (0.0017)	−0.0071*** (0.0010)	−0.0054*** (0.0008)	−0.0056*** (0.0004)	−0.0137*** (0.0018)	−0.0086*** (0.0016)	−0.0062*** (0.0013)	−0.0069*** (0.0006)
GCF_t		0.0105*** (0.0038)	0.0138*** (0.0030)	0.0080*** (0.0014)		0.0136*** (0.0080)	0.0148*** (0.0035)	0.0108*** (0.0016)
FDI_t		0.0350*** (0.0059)	0.0215*** (0.0054)	0.0186*** (0.0026)		0.0274*** (0.0076)	0.0201*** (0.0059)	0.0182*** (0.0030)
TOP_t		−0.0023** (0.0010)	−0.0008 (0.0007)	0.0002 (0.0004)		−0.0032** (0.0013)	−0.0013 (0.0010)	−0.0006 (0.0005)
$FDI_t * TOP_t$ Constant	8.0590*** (0.1487)	7.386*** (0.1087)	0.0008*** (0.0002) 6.8749*** (0.0129)	0.0003*** (8.55E−05) 6.898*** (0.0062)	8.0655*** (0.1565)	7.5258*** (0.1584)	0.0007*** (0.0002) 6.8793*** (0.0146)	0.0007*** (0.0001) 6.8745*** (0.0069)
Adj. R-square	0.771	0.868	0.906	0.913	0.771	0.863	0.904	0.946
Long-run var	0.0398	0.0042	0.0023	0.0005	0.0398	0.0042	0.0023	0.0005

Note ***, ** and * denote 1%, 5% and 10% statistical significance levels. Figures in () are the standard errors significant, when we controlled for the effects of gross domestic investment, FDI and trade openness. Gross domestic investment and FDI have significant positive effects on GDP in the long run. However, the effect of trade openness on GDP is significantly negative.

Second, foreign direct investment (FDI) and trade openness may not move in parallel path as implied by the Bhagwati hypothesis. Trade liberalisation may facilitate the inflow of FDI while the inflow of FDI can also facilitate trade. Thus, trade liberalisation and FDI may complement each other to promote economic growth. If this is true, in the case of Ghana (as found by Sakyi et al. 2015), the estimated model may suffer from an important omitted variable bias, which could bias our long-run results. Therefore, as a further robustness check, we included the interaction of FDI and trade openness. Here, we demeaned the independent variables so that we can interpret the unconditional effect of trade openness at mean of FDI. The same applies to the unconditional effect of FDI. Models 3 in Table 13.10 contain the results. The share of hydropower in total electricity generation still maintains its robust negative effect on GDP per capita.

The interaction of FDI and trade openness has a significant positive effect on long-run GDP per capita. This confirms the existence of the Bhagwati hypothesis. Thus, in Ghana, trade liberalisation and FDI complement each other to promote GDP per capita, which is also consistent with the findings of Sakyi et al. (2015). Gross domestic investment maintains its significant positive long-run effects on GDP per capita.

Lastly, the causality results showed evidence of bidirectional causality. This implies that our estimated model may suffer from the reverse causality problem and identification problem. Moreover, the use of actual GDP per capita, which is not devoid of the short-term cyclicality, instead of potential GDP per capita, affects the precision of the long-run estimates. We applied the data transformation suggested by Adom et al. (2018b). Adom et al. (2018b) argued that the use of actual data, which includes short-term cyclicality, could be a potential source of reverse causality and imprecise estimate of the true long-run relationship. We applied the Hodrick–Prescott filter as used in Adom et al. (2018b) to remove the short-term cyclical variation from the actual GDP per capita to get the potential GDP per capita. Model 4 contains the results. The first impression from these results is that, compared to Model 3, the standard errors are lower in Model 4, which implies an improvement in the efficiency of the long-run parameters. The share of hydropower energy supply still maintains its robust significant negative effect on GDP per capita in the long run. Further, results confirm the Bhagwati hypothesis as well as the positive effect of gross domestic investment on GDP per capita.

13.5 Conclusion

This paper examined the short- and long-run causality and effects between economic growth and renewable energy supply, using a time series technique and data covering the period from 1975 to 2017. This study highlighted three major contributions: (1) addressing potential endogeneity problem, (2) improving the precision of the long-run coefficients and (3) distinguishing between the short- and long-run effects. The following conclusions emerged from the study.

First, hydropower energy supply Granger causes GDP per capita in the short run while GDP per capita Granger causes hydropower energy supply in the long run. This suggests a bidirectional causal relationship between hydropower energy supply and GDP per capita but differentiated by time. In other words, while hydropower energy supply can be a limiting factor for economic growth in the short run, in the long run, economic growth can be a limiting factor for hydropower renewable energy supply expansion.

The long-run and short-run cointegrating estimates revealed that while hydropower energy supply has a positive effect on GDP per capita in the short run, it exerts a significant negative effect on GDP per capita in the long run. Further, robustness check on the result revealed that hydropower energy supply exerts a significant negative effect on GDP per capita in the long run. Thus, the growth effects of renewable hydropower energy supply, according to the results, are limited to the short run.

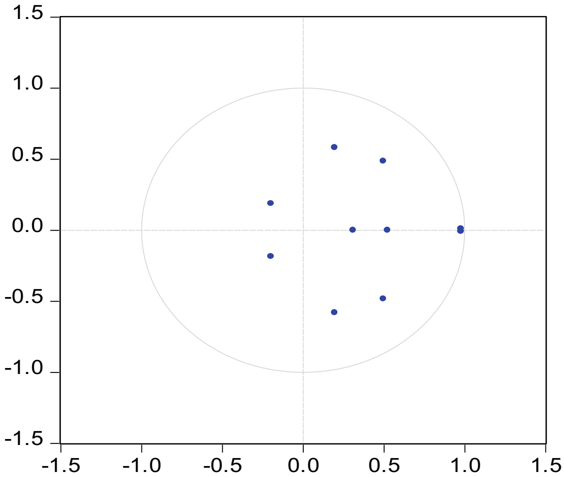
The interdependency between renewable hydropower energy supply and GDP per capita suggests that macroeconomic policies and energy policies in the country should be integrated in nature. The positive short-term growth effects of renewable hydropower energy supply imply that the government makes significant investment in the technology. This could proceed along the public–private partnership initiative due to the hefty investment involved. However, as shown in this paper, in the long-term, the erratic nature and unpredictability of supply of the technology may introduce disturbances into the economic system, which can affect economic growth negatively. In order to ensure all year-round supply of energy from the technology, it may be essential for the government to invest in hydro-storage facility. Moreover, at the moment, the country has only three major hydroplants at Akosombo, Kpong and Bui. Complementing these with other mini hydroplants could also help the situation.

This study adopted a macro-approach to the problem. Given the heterogeneity in energy requirement for the different sectors, the hydropower energy technology may exert differential effects on sectoral output. This is very crucial to design sector-specific energy policies. Future, research could be carried on the sectoral effects of hydropower energy supply. Moreover, it will be interesting to investigate the effects of different generating technologies on economic growth.

Appendix

See Appendix Figs. 13.2, 13.3 and 13.4.

Fig. 13.2 Inverse roots of AR characteristic polynomial. *Source* Author



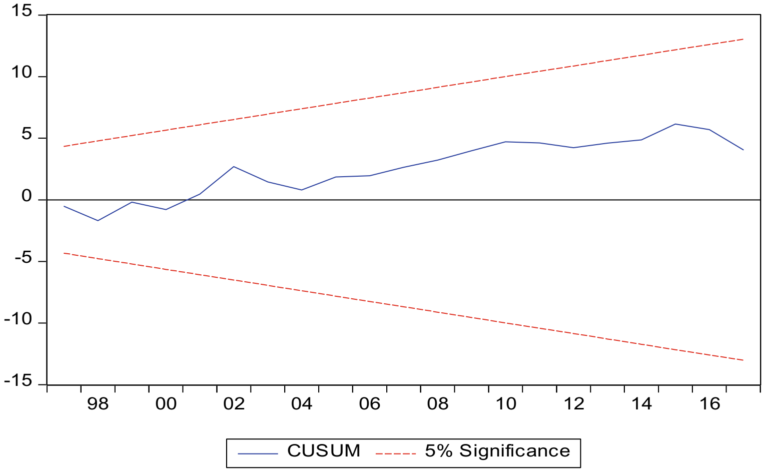


Fig. 13.3 Results of cumulative sum (CUSUM). *Source* Author

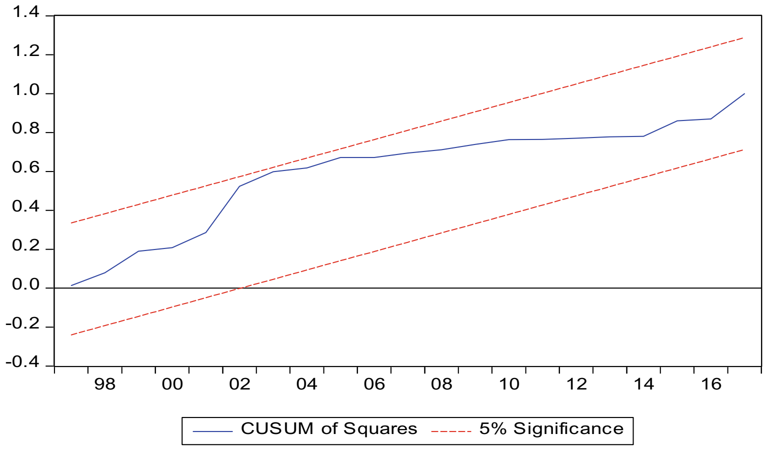


Fig. 13.4 Results of cumulative sum of squared (CUSUMSQ). *Source* Author

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Chapter 14
How Does Environmental Degradation React to Stock Market Development in Developing Countries?

Mert Topcu, Can Tansel Tugcu, and Oguz Ocal

Abstract As capital markets develop, the issue of whether this development improves the environmental quality rises very rapidly. Although not very documented, the literature has reached a consensus on the positive role of stock market development on carbon emissions in developing countries. Previous studies, however, do not include great number of countries to reach a broad consensus and assume that the effect does not change over time. Given these motivations, this study examines the impact of stock market development on carbon emissions in a panel of 60 developing countries over the period 1990–2014. Findings reveal that stock market development decreases environmental degradation in the short-run, whereas further development leads to environmental degradation in the long-run. Policy implications depending on these results are also discussed.

Keywords Stock market development · Environmental degradation · Developing counties

JEL Classification O16 · P28

14.1 Introduction

Over the last decade, energy economics literature has provided augmented energy demand functions, which add a set of socio-economic variables onto the basic energy model. Financial development is one of the promising ones, which has been built

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by referring to the finance-growth theory. Even though the literature has not yet as expanded as energy-growth literature, the number of these studies has been steadily increasing.

Theoretical settings of finance-energy literature have basically inspired from finance-led growth hypothesis. Therefore, previous literature has addressed that financial development can affect energy demand via three channels according to the previous literature. Direct effect channel implies that consumers can find easier and cheaper borrowing opportunity as financial system develops in order to purchase durable goods which consume energy a lot. Business effect channel implies that business sector can also find opportunity to borrow easily and less costly as financial markets improve which in turn affect energy demand via investment and production decisions. Finally, wealth effect channel implies that increasing financial activities can affect economic agents' confidence by creating a wealth effect which can promote economic activity and demand for energy. However, Sadorsky (2010) argues that energy demand might be irresponsive to financial development given the validity of growth-led finance hypothesis, and this relationship can only be resolved through empirical analyses.

Most of the previous studies looking into the impact of financial development on energy consumption have measured financial development using bank-related variables and as a matter of fact, indeed, investigated the impact of banking sector development (see, for example: Tang and Tan 2014; Zeren and Koc 2014; Aslan et al. 2014; Altay and Topcu 2015; among others). However, relatively little research has been done with the stock market variables on the impact that financial development has on energy consumption (see: Sadorsky 2011; Coban and Topcu 2013; Topcu and Altay 2017; Topcu and Payne 2017; Altay and Topcu 2017).

Unlike finance-energy literature, the number of studies in finance-environment literature is relatively limited (see, for example: Tamazian and Rao 2010; Jalil and Feridun 2011; Al-mulali and Sab 2012a, b; Lee 2013; Omri 2013; Ozturk and Acaravci 2013; Shahbaz 2013; Shahbaz et al. 2013a, b, c, d, 2016; Boutabba 2014; Al-mulali et al. 2015a, b; Mugableh 2015; Salahuddin et al. 2015; Ziaei 2015; Dogan and Seker 2016; Dogan and Turkekul 2016; Farhani and Ozturk 2015; Rafindadi 2016). Specifically, the impact of stock market on environment is an area which is almost untouched. To best of our knowledge, the literature includes only a few number of studies. For instance, Paramati et al. (2018) stock market indicators have a positive impact on carbon emissions in a panel of 20 developing countries, whereas the impact turns out negative in a panel of 23 developed countries. Likewise, Paramati et al. (2017)'s stock market development has a negative impact on emissions in developed G20 nations, whereas it has a positive impact in developing G20 nations. Lanoie et al. (1998) report for two developed nations (the US and Canada) that efficient capital markets spur environmental quality. Dasgupta et al. (2001) find for a four number of developing countries (Argentina, Chile, Mexico, and the Phillipines) that stock market development improves environmental performance. Tamazian et al. (2009) report that stock market development decreases carbon emissions in BRIC countries. Zhang (2011) finds for China that the stock market is not yet well-developed to significantly decrease carbon emissions. Abbasi and Riaz (2016) report that stock market development dramatically increases emissions in Pakistan. In the case Malaysia, Iatridis (2013) finds that carbon emissions increase with the stock market development.

Overall, the aforementioned literature roughly suggests that stock market development increases carbon emissions and deteriorates the environment. However, this evidence is not very robust as previous attempts include limited number of developing countries. Therefore, the aim of this study is to extend the analysis with the inclusion of more developing countries to provide better insights for policy makers. Given this motivation, this study intends to be the encompassing one in the literature. Unlike previous attempts, in addition, this study not only investigates the long-run relationship, but also provides short-run evidences.

Rest of the study is structured as follows: Sect. 14.2 describes model and data, Sect. 14.3 presents empirical approaches and findings, and finally, Sect. 14.4 discusses policy implications and gives concluding remarks.

14.2 Model and Data

As a proxy of environmental degradation, per capita carbon emissions (CO_2) are described as a function of per capita energy consumption (e), per capita income (y), its squared term ($y$sq), and stock market development (s). The analysis includes 60 developing countries and is based on annual observations spanning from 1990 to 2014. Table 14.1 lists these countries.

Environmental degradation is represented by carbon emissions measured by metric tons per capita, energy consumption is represented by energy use kg of oil equivalent per capita, income is represented by GDP per capita measured using constant 2010 US$, and stock market development is represented by stock market capitalization measured as a share of GDP. All data are sourced from World Bank World Development Indicators Database (2018), with the exception of the stock market data which is sourced from World Bank Global Financial Development Database (2018). To interpret the results in terms of elasticities, all variables are transformed into natural logarithms.

Table 14.2 presents the descriptive statistics of the data. When we review the mean values of the variables, carbon emissions are 14.72, energy consumption is quite closer to 7, income is 8.38, and stock market indicator is slightly less than 3. Notice that, the variable that has the highest standard derivation is the stock market development proxy, which is closely followed by carbon emissions.

Table 14.1 Sample of countries

South-East Asia	Middle East and North Africa	Europe and Central Asia	Central and South America	Sub-Saharan Africa
Bangladesh	Egypt	Bulgaria	Argentina	Botswana
China	Iran	Croatia	Bolivia	Cote d'Ivoire
Fiji	Jordan	Cyprus	Brazil	Ghana
India	Morocco	Czech Rep.	Chile	Kenya
Indonesia	Oman	Greece	Colombia	Mauritius
Korea	Saudi Arabia	Hungary	Costa Rica	Namibia
Malaysia	Tunisia	Iceland	Ecuador	Nigeria
Mongolia		Kazakhstan	El Salvador	South Africa
Nepal		Malta	Jamaica	Swaziland
Pakistan		Moldova	Mexico	Tanzania
Philippines		Poland	Paraguay	Uganda
Sri Lanka		Russian Fed.	Peru	
Thailand		Serbia	Trinidad and Tobago	
		Slovak Rep.	Uruguay	
		Turkey		

Table 14.2 Descriptive statistics

	ln CO_2	ln e	ln y	ln s
Mean	14.72509	7.033550	8.383148	2.979693
Median	14.85355	6.943061	8.471089	3.092500
Maximum	17.40161	9.623058	10.39366	5.581856
Minimum	11.46288	4.812745	5.999065	−4.655306
Std. dev.	1.151492	0.846511	0.990997	1.245914
Observations	1138	1138	1138	1138

14.3 Methods and Findings

14.3.1 Unit Root Testing

Necessary precondition for implementing an Engle-Granger-based panel cointegration analysis is to provide that the variables in consideration are integrated of order one. Besides, prior to a panel ARDL estimation, it is necessary to ensure that the variables in interest are level or first-difference stationary. In this context, panel unit root

Table 14.3 Unit root results

Variables	Level	First difference
ln CO_2	−0.176 (0.43)	−28.400 (0.00)
ln e	1.353 (0.91)	−24.608 (0.00)
ln y	9.796 (1.00)	−18.342 (0.00)
ln s	−7.057 (0.00)	−14.909 (0.00)

[a]Numbers in parentheses are p-values
[b]Tests include only constant
[c]Maximum lag length is determined considering SIC

tests developed by Im et al. (2003, IPS) were utilized, and findings were reported in Table 14.3. Accordingly, there seems no restriction for conducting the related analyses.

14.3.2 Cointegration

Since the variables in consideration are integrated of order one, this study employs an Engle-Granger-based panel cointegration analysis which was recently developed by Pedroni (1999, 2004) for the investigation of a possible cointegration relationship.

Within dimension tests		
1.	Panel-ν stat:	$Z_\nu = T^2 N^{3/2}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1}$
2.	Panel-rho stat:	$Z_\rho = T\sqrt{N}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i)$
3.	Panel-pp stat:	$Z_t = \left(\tilde{\sigma}_{N,T}^{2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i)$
4.	Panel-adf stat:	$Z_t^{*} = \left(\tilde{s}_{N,T}^{*2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{*2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}^{*}\Delta\hat{e}_{i,t}^{*})$
Between dimension tests		
5.	Group-rho stat:	$\tilde{Z}_\rho = TN^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{t=1}^{T}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i)$
6.	Group-pp stat:	$\tilde{Z}_t = N^{-1/2}\sum_{i=1}^{N}\left(\hat{\sigma}_i^{2}\sum_{t=1}^{T}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{t=1}^{T}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i)$
7.	Group-adf stat:	$\tilde{Z}_t^{*} = N^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{s}_i^{*2}\hat{e}_{i,t-1}^{*2}\right)^{-1/2}\sum_{t=1}^{T}\hat{e}_{i,t-1}^{*}\Delta\hat{e}_{i,t}^{*}$

Table 14.4 Cointegration results

Tests	Stat
Panel-v	−1.441(0.92)
Panel-rho	−1.828(0.03)
Panel-pp	−8.313(0.00)
Panel-adf	−7.390(0.00)
Group-rho	1.122(0.86)
Group-pp	−10.131(0.00)
Group-adf	−9.032(0.00)

[a]Numbers in parentheses are *p*-values

Pedroni (1999, 2004) has proposed seven test statistics, which are shown above. These statistics assume that the variables are not level-stationary, and the cointegration vector is heterogeneous across the cross-section units. In this sense, the null of no cointegration was tested against the alternative hypothesis of cointegration by using the tests, four of which are termed as "panel statistics" and the others as "group statistics". Findings presented in Table 14.4 support the cointegration relationship.

14.3.3 Estimation

The present study employs a panel ARDL model for investigating the impact of financial development on environmental degradation. Our model incorporates with the pooled mean group estimator (PMG) that was developed by Pesaran et al. (1999). The considered model is formulated in the following manner:

$$\ln \mathrm{CO2}_{it} = \alpha_i + \sum_{j=1}^{ki} \beta_{ij} \ln \mathrm{CO2}_{i,t-j} + \sum_{j=0}^{fi} \delta_{ij} \ln \mathrm{FD}_{i,t-j} + \sum_{j=0}^{hi} \phi_{ij} \ln \mathrm{EC}_{i,t-j} + \sum_{j=0}^{ri} \partial_{ij} \ln \mathrm{GDPPC}_{i,t-j} + \sum_{j=0}^{di} \tau_{ij} \ln \mathrm{GDPPC2}_{i,t-j} + \varepsilon_{it} \quad (14.1)$$

In order to see the separate effects (i.e., short and long) of financial development on environmental degradation, Eq. (14.1) can be parameterized as follows:

$$\Delta \ln CO_{2\,it} = \alpha_i + \varpi_i \ln CO_{2\,i,t-1} + \delta_i^* \ln FD_{it} + \phi_i^* \ln EC_{it} + \partial_i^* \ln GDPPC_{it} + \tau_i^* \ln GDPPC2_{it} + \sum_{j=1}^{ki-1} \beta_{ij}^{**} \Delta \ln CO_{2\,i,t-j} + \sum_{j=0}^{fi} \delta_{ij}^{**} \Delta \ln FD_{i,t-j} + \sum_{j=0}^{hi} \phi_{ij}^{**} \Delta \ln EC_{i,t-j} + \sum_{j=0}^{ri} \partial_{ij}^{**} \Delta \ln GDPPC_{i,t-j} + \sum_{j=0}^{di} \tau_{ij}^{**} \Delta \ln GDPPC2_{i,t-j} + \varepsilon_{it} \quad (14.2)$$

where ϖ represents error correction coefficient, the notations $\delta^*, \phi^*, \partial^*, \tau^*$ and $\delta^{**}, \phi^{**}, \partial^{**}, \tau^{**}$ illustrate the long- and short-run coefficients, respectively.

Pesaran et al. (1999) developed two estimators, namely the mean group (MG) and the pooled mean group (PMG) which both can be utilized to estimate Eq. (14.2). However, since the MG does not allow certain parameters to be distributed homogenously across cross-section units, this study utilizes the PMG for the estimation of Eq. (14.2).

As both pooling and averaging, the PMG estimator allows the intercepts, short-run coefficients, and error variances to differ freely across groups, but constraints the long-run coefficients to be the same (Pesaran et al. 1999). Because of initial conditions or some structural factors that have a possibility to influence all groups in a similar way, utilizing the PMG estimator seems to be appropriate for the considered purpose.

According to findings illustrated in Table 14.5, the model that we try to solve has a stable equilibrium. It is proved by negative and statistically significant error correction coefficient. Besides, estimates reveal that stock market development decreases environmental degradation in the short-run, while the impact turns to positive in the long-run. As expected, energy consumption is the major factor that raises carbon dioxide emissions either in the long or in the short-run. Finally, carbon dioxide emission is positively affected by per capita income in the long-run, whereas the link is statistically insignificant in the short-run. Despite of the desired signs, the environmental Kuznets curve hypothesis is not satisfied given the insignificant coefficients provided either from the short- or long-run estimations.

14.4 Conclusion

In recent years, the number of studies that investigate the impact of global warming and climate change on environmental quality has increased. A great number of these studies have employed urbanization, financial development, energy consumption, and trade into the function. The results of these studies, however, are volatile across the income level of related countries.

Table 14.5 Panel ARDL estimation results

Dependent variable: ln CO_2	
Long-run coefficients	
ln *e*	0.965 (0.00)
ln *y*	0.624 (0.06)
ln *y*sq	−0.024 (0.18)
ln *s*	0.009 (0.00)
Error correction parameter	−0.538 (0.00)
Short-run coefficients	
ln *e*	0.567 (0.00)
ln *y*	−0.899 (0.88)
ln *y*sq	0.089 (0.82)
ln *s*	−0.018 (0.03)

[a]Numbers in parentheses are *p*-values

Unlike previous studies in the area, this study considers the simultaneous use of energy consumption, income, and stock market development in order to estimate the separate impact of each (i.e., short and long) variable on environmental degradation. For this purpose, panel ARDL model is utilized for 60 developing countries over the period 1990–2014. Due to the production structure of developing countries, the relationship between economic activity and environmental degradation could be nonlinear, which has been called the environmental Kuznets hypothesis. The environmental Kuznets curve hypothesis argues that in the initial stages of development, environmental degradation raises and then it decreases as incomes increase.

The results of this study show that stock market development decreases environmental degradation in the short-run; however, environmental degradation rises with stock market development in the long-run. As discussed earlier, the existing literature documents that stock market development positively affects carbon emissions in developing countries. This is very consistent with the long-run results of this study. However, the short-run results of this study show that stock market development is not harmful to the environment in the short-run. This split reveals that the impact of stock market development on environment can vary over time. This is probably due to the underdeveloped capital market structure of developing countries. Because developing countries are not better able to transform stock market development into the production, this development does not strictly lead to an environmental degradation in the short-run.

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Chapter 15
Determination of Asymmetries and Market Integration in the Electricity and Crude Oil Markets

Berenga Serwaa Jantuah and Philip Kofi Adom

Abstract The aim of this thesis is to examine the asymmetric market behaviour in the supply-side and demand-side of the electricity market and the implications it has on government subsidy programme and electricity consumption/access. The study applied the nonlinear versions of the fully modified OLS, dynamic OLS and canonical cointegrating regression as a further robustness check. The study used annual data from 1976 to 2017. The results showed the integration of electricity and crude oil markets, with a significant long-run pass-through effect from crude oil price (i.e. input price) to the price of electricity (i.e. output price). There is a significant asymmetry in the response of electricity price to crude oil price changes, with suppliers of electricity absorbing more of lower crude oil price vis-a-vis higher crude oil price. This clearly shows that there exist market imperfections in the electricity sector. Lastly, consumers of electricity are more responsive to lower electricity price than higher electricity price. However, the existence of market imperfections could impede the government subsidy programme aimed at improving electricity access. Introducing competition and diversifying generating source in the sector to include renewable energy could prove very useful. In the short-term, however, subsidy programme aimed at improving electricity access can be effective if it targets the final price of electricity instead of the price of the critical input (i.e. oil).

Keywords Market integration · Electricity price · Crude oil price · Price asymmetries

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15.1 Introduction

Lower access to electricity plunges both residential and industrial electricity consumers into a lower equilibrium trap. This impact negatively on the welfare of the citizenry and the economy at large. Government intervention such as a subsidy programme to improve electricity access or consumption is critical to achieve sustainable development. The aim of this thesis is to examine the asymmetric market behaviour in the supply-side and demand-side of the electricity market and the implications it has on government subsidy programme and electricity consumption. Specifically, we test (1) whether the electricity and crude oil markets in Ghana are segmented/integrated, (2) for asymmetry in the response of electricity price to crude oil prices and (3) for asymmetry in the response of electricity consumption to changes in electricity price. The asymmetries in the response of electricity price to oil price and electricity consumption to electricity price are critical requirements for the effectiveness of the government subsidy programme aimed at improving access to electricity consumption. The study adopted the nonlinear autoregressive distributed lag (NARDL) method by Shin et al. (2011). In addition, the study employed the nonlinear versions of dynamic OLS (*DOLS*), canonical cointegration regression (*CCR*) and the fully modified OLS (*FMOLS*) as a further robustness check of the long-run results.

Electricity markets in most economies have been vertically integrated and state-owned. The vertical integration of the electricity market is necessary for promoting the coordination and efficiency of wholesale power supply. Moreover, this structure, according to proponents, guards consumers against exploitation as the government set fixed rates above the cost. However, especially in developing economies, the performance of most of these state-owned and vertically integrated monopoly power sectors have been very poor. The fixation of utility charges by the government weakened the balance sheet of these utility companies. Consequently, this affected investment in additional generation, causing frequent power outages (Adom et al. 2018a). In addition, the dominance of the state in the power sector also influenced most managerial decisions that were not very consistent with the goals of the utility companies (Adom 2011). These reasons and more necessitated a reform of the power sector. The rationale for the deregulation of the power sector is to promote market efficiency and competition in the sector (Mohammadi 2009). Moreover, the deregulation of the sector implies that the forces of demand and supply and not regulators drive the determination of price. What this suggests is that market participants in the electricity sector are likely to be more responsive to changes in the price of the critical input (Mjelde and Bessler 2009).

In Ghana, the power sector was highly integrated, with the Volta River Authority (VRA) responsible for the generation, transmission and distribution of power. The functions of distribution were later unbundled from VRA and given to the Electricity Company of Ghana (ECG) and National Energy Department (NED). Subsequently, the functions of generation and transmission were unbundled, with VRA incharge of generation while Ghana GRID Company took charge of the transmission of power in the country in 2006. Later, Ghana established the Energy Commission of Ghana

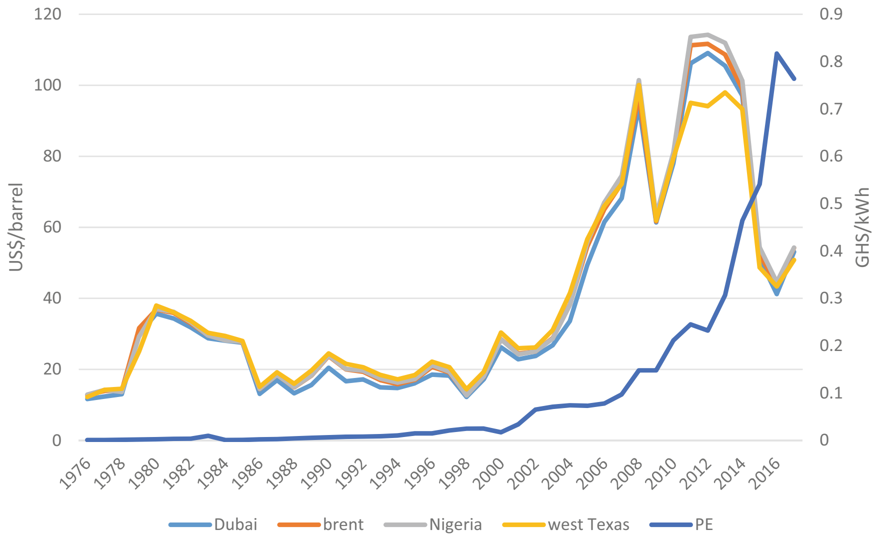

Fig. 15.1 Time series plot electricity and crude oil prices

to issue licenses and monitor the performance standards of the utility companies in the nineties.

Despite these initial reforms, the regulator fixed the price of electricity (mostly below the marginal cost of producing electricity), and this weakened the balance sheet of the utility companies[1] and the link of the electricity sector with its critical input sources. Adom (2017) and Adom et al. (2018a) both realised that electricity prices remained relatively stable in the greater parts of the period preceding 1994. However, the trend has changed drastically after the establishment of the Public Utility Regulatory Commission (PURC) in 1994. Figure 15.1 shows the plot of electricity price and crude oil prices. It is clear from the figure that the correlation between these two prices seems weaker or absent before 1994 but became stronger after 1994. This implies that the prices of electricity and crude oil may exhibit a common stochastic trend in the long term. The 'thermalization' of power generation in Ghana (Adom et al. 2017) further heightens the tendency for a common stochastic trend between electricity and crude oil prices. Thermal has overtaken hydro as the major power-generating source since 2016. In 2016, electricity generated from thermal constituted about 57% of total power generation. This increased to 60% in 2017 (Adom et al. 2017). Until recently, most of these thermal plants run on light crude oil. This is an indication that the cost of crude oil is a critical input in the build-up of electricity prices in Ghana.

[1]The debt levels especially in the distribution sector reached unsustainable levels. The Power Distribution Service (PDS) has now taken the role of distributing power from ECG in 2019. The quasi-privatization of the distribution sector is part of the ongoing reform to improve efficiency in the operations of the sector.

While the above facts point to the fact that the electricity and crude oil market may exhibit a common stochastic trend in Ghana, empirical studies testing this claim in Ghana is sparse (Adom et al. 2017, 2018a). The existence of a common stochastic trend between electricity price and crude oil price has an important implication for the integration of both markets. Thus, market participants cannot benefit from arbitrage (Bernal et al. 2019). Since electricity and crude oil are critical inputs in most sectors of the economy, especially the financial sector, the existence of common energy markets has important implications for financial derivatives decision-making, portfolio risk management and optimal hedging issues. As found by Adom (2019), energy indices pose as critical risk factors in the financial sector in Ghana. Adom et al. (2017) examined the link between the variability in electricity price and renewable energy supply in Ghana taking into account the role of crude oil price. They found that a level relationship exists between the price of electricity and the set of independent variables that included crude oil price. Further result showed that crude oil prices increase the volatility in electricity prices in both the short run and long run. Adom et al. (2018a) instead examined the effect of hydro energy supply on the levels of electricity price in Ghana taking into account the price of crude oil. The result showed evidence of cointegration. Crude oil price has a positive impact on the levels of electricity both in the short run and long run but the effect is greater in the latter.

Elsewhere, other studies have also considered the integration of energy markets (Lahiani et al. 2017; Batten et al. 2017; Ederington et al. 2019, inter alia) but few have investigated integration of the electricity market with other energy markets. Asche et al. (2006) considered the integration of natural gas, electricity and crude oil markets in the UK. Bencivenga et al. (2010) and Bosco et al. (2010) considered the integration of the same markets for the European Union market. Mjelde and Bessler (2009) and Nakajima and Hamori (2013) examined the situation in the US energy markets while Nakajima and Hamori (2012) examined the integration of electricity and crude oil markets in Japan. Bernal et al. (2019) examined the link between the electricity and fossil fuel markets in Mexico. Moutinho et al. (2011) examined the long-run relationship between energy prices in the Spanish energy market. These studies found mixed results regarding the integration of the electricity and crude oil markets. One limitation that pertains to the above studies is that they all assumed that the responses of electricity prices to crude oil prices are symmetric, which is a very restrictive assumption. Different explanations have been provided for the asymmetric price responses, such as menu cost, production and inventory cost of adjustment, market power (Loy et al. 2016; Borenstein and Shepard 2002; Peltzman 2000), price volatility and search cost (Radchenko 2005; Loy et al. 2016).

A more important policy question is whether there are asymmetries in the price responses. In other words, do electricity prices respond the same way to increases and decreases in crude oil price? This is a critical policy issue for the government's tax and subsidy policy on critical inputs in the power sector. Improving access to electricity is one of the important Sustainable Development Goals. Lowering/subsidising the price of electricity by the government can improve electricity access especially for the poor, all things being equal. The government can achieve this by subsidising the cost of critical inputs in power generation or remove taxes on the critical inputs. The existence of asymmetry in the electricity price response to crude oil price changes, on one hand, and asymmetry in electricity consumption response to electricity price, on the other hand, are mandatory requirements in the market for the government subsidisation or tax programme to achieve the desirable outcomes. If, for example, sellers of crude oil refuse to pass on price reductions to electricity suppliers, consumers of electricity may suffer some welfare loss (Bonnet et al. 2013). In the same vein, where crude oil sellers do pass on price reductions to electricity suppliers, but electricity suppliers refuse to pass on the lower electricity price to consumers, consumers of electricity may again suffer some welfare losses. Thus, for a consumer of electricity to enjoy a government tax reduction or subsidy programme, there should be asymmetry in price responses in the electricity and crude oil market as well as asymmetry in electricity consumption to changes in electricity price.

Though there is a plethora of studies that examine the asymmetries in energy prices (Apergis and Vouzavalis 2018; Atil et al. 2014; Borenstein and Shepard 2002; Kaufmann and Laskowski 2004; Peltzman 2000, inter alia), most of these studies are concentrated in well-developed markets in the developed economies of Asia, Europe and America. This leaves an important literature gap for energy markets in Africa. Moreover, few of these studies have considered the asymmetry in the price responses between the electricity and crude oil markets. One notable exception is the study by Mohammadi (2009). Mohammadi (2009) examined how asymmetric is electricity prices in the USA to adjustment from equilibrium.

The current study makes the following contributions to the literature on the integration of energy markets. First, it provides evidence from a developing Africa country perspective. In the case of Ghana, it provides the first attempt in terms of analysing the asymmetries (long run and short run) in the price responses between electricity and crude oil markets. Second, it complements the scarce literature on the integration of electricity and crude oil markets and the asymmetries in their price responses. In addition, this paper examined the asymmetries in the response of electricity consumption to changes in electricity price. The dual asymmetries between electricity price and oil price and between electricity consumption and electricity price are necessary to achieve desirable outcomes of a government subsidy programme to improve access to electricity consumption. Section 15.2 describes the method and data. Section 15.3 presents and discusses the study's findings. Section 15.4 concludes the paper with policy implications.

15.2 Method and Data

This section discusses the empirical model and the econometric technique as well as the data type and sources.

15.2.1 Model Specification

The empirical model of this paper is motivated by Apergis and Vouzavalis (2018), Atil et al. (2014), Borenstein and Shepard (2002), Kaufman and Laskowski (2004), Jonhson (2002), and Peltzman (2000). This study applied the nonlinear autoregressive distributed lag (NARDL) technique developed by Shin et al. (2011). We applied the heteroskedastic autocorrelation consistent (HAC) standard errors in estimating NARDL. In contrast to the autoregressive distributed lag (ARDL) technique developed by Pesaran et al. (2001), the NARDL technique accounts for asymmetric responses of the dependent variable to changes in the independent variables. The approach by Shin et al., first, decomposes the independent variable assumed to exhibit asymmetry into negative and positive partial sums of decreases and increases. Applying this to the current paper, the decomposition of crude oil prices (cop) into positive and negative partial sums of increases and decreases are derived using Eqs. 15.1 and 15.2, respectively.[2]

$$\ln \text{cop}_t^{+\text{ve}} = \sum_{j=1}^{t} \ln \text{cop}_t^{+\text{ve}} = \sum_{j=1}^{t} \max(\Delta \ln \text{cop}, 0) \tag{15.1}$$

$$\ln \text{cop}_t^{-\text{ve}} = \sum_{j=1}^{t} \ln \text{cop}_t^{-\text{ve}} = \sum_{j=1}^{t} \min(\Delta \ln \text{cop}, 0) \tag{15.2}$$

Equations 15.1 and 15.2 are then introduced in the error correction model of Eq. 15.3, where q and p denote the optimal lags of the dependent and independent variables selected based on the Akaike information criterion (AIC), $-$ve and $+$ve denote the negative and positive partial sums decomposition, and 'pe' is the price of electricity.

$$\begin{aligned}\Delta \ln \text{pe}_t &= \alpha + \beta_1 \ln \text{pe}_{t-1} + \beta_2^{+\text{ve}} \ln \text{cop}_{t-1}^{+\text{ve}} + \beta_3^{-\text{ve}} \ln \text{cop}_{t-1}^{-\text{ve}} + \sum_{t=1}^{p-1} \alpha_i \Delta \ln \text{pe}_{t-i} \\ &\quad + \sum_{i=0}^{q-1} \left(\beta_{2i}^{+\text{ve}} \Delta \ln \text{cop}_{t-i}^{+ve} + \beta_{3i}^{-\text{ve}} \Delta \ln \text{cop}_{t-i}^{-\text{ve}}\right) + \varepsilon_t\end{aligned} \tag{15.3}$$

The hypotheses for the short-run and long-run asymmetry are stated as below:

H_0: $\beta_2^{+\text{ve}} = \beta_3^{-\text{ve}}$; testing for long-run asymmetry
H_0: $\beta_{2i}^{+\text{ve}} = \beta_{3i}^{-\text{ve}}$; testing for short-run asymmetry

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[2]This paper used four different spot oil prices, viz. the Nigeria Forcados, Dubai-Oman, Brent and the West Texas Intermediate. Light crude oil is most appropriate in the power sector. Therefore, the use of the US Brent and the West Texas Intermediate prices are appropriate for such an analysis. While conditions in the USA influence the WTI, the conditions in Europe, Africa and Asia influence the Brent spot price. The Dubai-Oman and Nigeria Forcados can cause market sentiments. Consequently, we have included them as additional price variables for crude oil price.

The long-run coefficients are computed as $\theta^{+\mathrm{ve}} = \beta_2^{+\mathrm{ve}} / \beta_1$ and $\theta^{+\mathrm{ve}} = \beta_{3i}^{-\mathrm{ve}} / \beta_1$. The '$\beta_{2i}^{+\mathrm{ve}}$' and '$\beta_{3i}^{-\mathrm{ve}}$' capture the adjustment of electricity prices to positive and negative shocks in crude oil prices in the short run. In the event of short- and long-run asymmetric responses, the corresponding short-run and long-run asymmetric ARDL model can be constructed as Eqs. 15.4 and 15.5, respectively.

$$\begin{aligned}\Delta \ln \mathrm{pe}_t &= \alpha + \beta_1 \ln \mathrm{pe}_{t-1} + \beta_2 \ln \mathrm{cop}_{t-1} + \sum_{t=1}^{p-1} \alpha_i \Delta \ln \mathrm{pe}_{t-i} \\ &\quad + \sum_{i=0}^{q-1} \left(\beta_{2i}^{+\mathrm{ve}} \Delta \ln \mathrm{cop}_{t-i}^{+ve} + \beta_{3i}^{-\mathrm{ve}} \Delta \ln \mathrm{cop}_{t-i}^{-\mathrm{ve}} \right) + \varepsilon_t \end{aligned} \tag{15.4}$$

$$\begin{aligned}\Delta \ln \mathrm{pe}_t &= \alpha + \beta_1 \ln \mathrm{pe}_{t-1} + \beta_2^{+\mathrm{ve}} \ln \mathrm{cop}_{t-1}^{+\mathrm{ve}} + \beta_3^{-\mathrm{ve}} \ln \mathrm{cop}_{t-1}^{-\mathrm{ve}} \\ &\quad + \sum_{t=1}^{p-1} \alpha_i \Delta \ln \mathrm{pe}_{t-i} + \sum_{i=0}^{q-1} \beta_i \Delta \ln \mathrm{cop}_{t-i} + \varepsilon_t \end{aligned} \tag{15.5}$$

The dynamic multipliers that correspond to $ln\mathrm{cop}_t^{+\mathrm{ve}}$ and $ln\mathrm{cop}_t^{-\mathrm{ve}}$ capture the asymmetric responses of electricity prices to the positive and negative shocks in crude oil prices. These dynamic multipliers are constructed as follows, where $n \to \infty$, $m_n^{+\mathrm{ve}} \to \theta^{+\mathrm{ve}}$ and $m_n^{-\mathrm{ve}} \to \theta^{-\mathrm{ve}}$:

$$m_n^{+\mathrm{ve}} = \sum_{j=0}^{n} \frac{\partial \ln \mathrm{pe}_{t+j}}{\partial \ln \mathrm{cop}_t^{+\mathrm{ve}}}$$

$$m_n^{-\mathrm{ve}} = \sum_{j=0}^{n} \frac{\partial \ln \mathrm{pe}_{t+j}}{\partial \ln \mathrm{cop}_t^{-\mathrm{ve}}}$$

15.2.2 Data Type and Source

This study used time series data that covered 1976–2017. The average end-use tariff of electricity captures the price of electricity. The data for electricity price come from the Electricity Company of Ghana (now the Power Distribution Services), the Energy Commission of Ghana, the Public Utility and Regulatory Commission, and the Volta River Authority, Ghana. Data on the four spot crude oil prices: the Nigeria Forcados, Dubai-Oman, Brent, Brent crude price and the West Texas Intermediate come from the BP Statistical Review of World Energy. Data on total electricity consumption, industrial electricity consumption and residential electricity consumption come from the International Energy Agency and the Energy Commission of Ghana. The real gross domestic product per capita captures the income effect (y). The data come from the World Bank Development Indicator database.

Table 15.1 shows the descriptive statistics, while Table 15.2 contains the results of the correlation analysis. All the crude oil price variables are significant and positively correlated with the price of electricity. The correlation coefficients are above 70%, which is very high. The positive correlation suggests that the price of electricity and crude oil price move together in the same direction. In addition, there is a significant positive correlation among the crude oil prices. The correlation coefficients approximate 100%.

15.3 Results and Discussion

This section presents the results of the study's findings. The section is subdivided as follows: test of unit root; test of cointegration; long-run and short-run asymmetries; robustness test for long-run asymmetries; and asymmetric response of electricity consumption to price changes.

15.3.1 Unit Root Test

This section applied the Phillips–Perron and Perron tests to test for unit root with and without a structural break. The results are contained in Table 15.3. Without accounting for a structural break, generally, all the series become stationary after first-differencing. A similar result is obtained when we control for the presence of structural break. These results provide a good ground to perform a cointegration analysis of the data. The next section shows the results of cointegration based on asymmetric ARDL technique.

15.3.2 Test of Long-Run Equilibrium

This section tested whether the price of electricity and the price of crude oil do have a common stochastic trend. The results are shown in Table 15.4. The upper part of the table contains the critical values for different sample sizes, while the bottom part of the table shows the calculated f-statistics using the different crude oil spot prices. Since our sample is 42, it is only appropriate to compare the calculated f-value with the critical values for the small sample sizes. It is obvious from the table that the calculated f-value exceeds the upper bound critical values at all significance levels. This implies that we reject the null hypothesis of no level relationship. In other words, the price of crude oil can be treated as the 'long-run forcing variable' explaining the changes in electricity price.

Table 15.1 Descriptive statistics of data

	ln lnec$_t$	ln iec$_t$	ln rec$_t$	ln pe$_t$	ln B$_t$	ln DO$_t$	ln WTI$_t$	ln NF$_t$	ln y$_t$
Mean	8.550	8.089	7.220	−3.912	3.450	3.383	3.466	3.459	6.920
Median	8.552	8.186	7.337	−4.146	3.355	3.302	3.356	3.342	6.835
Max	9.277	8.461	8.277	−0.202	4.716	4.692	4.606	4.738	7.471
Min	7.033	6.306	6.290	−7.308	2.543	2.453	2.504	2.536	6.553
Std.dev.	0.441	0.400	0.631	2.072	0.667	0.691	0.624	0.676	0.259
Skewness	−1.112	−2.635	−0.130	0.116	0.515	0.504	0.461	0.537	0.849
Kurtosis	5.284	11.180	1.733	1.917	2.093	2.059	2.039	2.104	2.616
Jarque–Bera	17.786	165.683	2.928	2.147	3.300	3.326	3.105	3.422	5.301
Prob	0.000	0.000	0.231	0.342	0.192	0.190	0.212	0.181	0.071
Obs	42	42	42	42	42	42	42	42	42

Table 15.2 Correlation analysis

Sample: 1976 2017					
	$\ln pe_t$	$\ln B_t$	$\ln DO_t$	$\ln NF_t$	$\ln WTI_t$
$\ln pe_t$	1.000000				
$\ln B_t$	0.735***	1.000000			
$\ln DO_t$	0.732***	0.999***	1.00000		
$\ln NF_t$	0.740***	0.9996***	0.998***	1.000000	
$\ln WTI_t$	0.752***	0.996***	0.994***	0.996***	1.00000

***$P < 0.01$, **$P < 0.05$, and *$p < 0.1$

Table 15.3 Test of unit root

	Phillip–Perron test		Perron test with structural break	
	Constant	Constant and trend	Constant	Constant and trend
$\ln pe_t$	0.165	−3.807**	−9.308***(1983)	−9.881***
$\Delta \ln pe_t$	−11.626***	–	–	–
$\ln NF_t$	−1.588	−1.958	−3.584(2003)	−3.199(2004)
$\Delta \ln NF_t$	−5.936***	−5.865***	−6.660***(1998)	−6.731***(1998)
$\ln WTI_t$	−1.725	−2.014	−3.606(2003)	−3.285(2003)
$\Delta \ln WTI_t$	−5.952***	−5.892***	−6.641***(1998)	−6.716***(1986)
$\ln B_t$	−1.601	−1.968	−3.566(2003)	−3.170(2004)
$\Delta \ln B_t$	−5.932***	−5.863***	−6.619***(1998)	−6.68***(1998)
$\ln DO_t$	−1.569	−1.934	−3.421(2003)	−3.102(2004)
$\Delta \ln DO_t$	−6.023***	−5.953***	−6.609***(1998)	−6.892***(1986)
$\ln ec_t$	−1.172	−2.408	−4.338(1983)	−5.027(1987)
$\Delta \ln ec_t$	−7.064***	−8.133***	−7.045***(1983)	−8.001***(1984)
$\ln iec_t$	−2.560	−2.616	−4.754(1983)	−5.440*(1983)
$\Delta \ln iec_t$	−9.189***	−9.405***	−7.229***(1983)	–
$\ln rec_t$	−0.195	−2.802	−3.756(1989)	−3.840(1988)
$\Delta \ln rec_t$	−6.785***	−6.699***	−7.471***(1995)	−7.421***(1995)
$\ln y_t$	1.239	−1.438	−2.797(2007)	−2.642(1998)
$\Delta \ln y_t$	−3.338**	−4.084**	−5.062*(1988)	−5.232(1991)

***$P < 0.01$, **$P < 0.05$, and *$p < 0.1$
Figures in () denote the chosen breakpoint in the data

The existence of a common stochastic trend between the prices of electricity and crude oil means that the electricity and crude oil markets are integrated in Ghana. Thus, the oil market presents a major source of risk for the electricity market in Ghana. This confirms the findings of other studies that also found the integration of the electricity and crude oil markets (Mjelde and Bessler 2009; Bencivenga et al.

Table 15.4 Bounds test of cointegration

	$N = 1000$			$N = 45$			$N = 41$		
	10%	5%	1%	10%	5%	1%	10%	5%	1%
Lower bound	2.63	3.1	4.15	2.79	3.37	4.8	2.84	3.44	4.77
Upper bound	3.35	3.87	5	3.54	4.2	5.725	3.585	4.26	5.855
Independent variable	F-stats								
Brent	6.3819								
Dubai-Oman	6.1401								
Nigeria Forcados	6.2449								
West Texas Intermediate	6.0247								

2010) but contrast the findings of other studies that found both markets to be segregated (Bernal et al. 2019; Moutinho et al. 2011; and Mohammadi 2009). In the case of Ghana, the integration of both markets could largely be driven by the shift in production structure away from hydro to thermal, which is largely powered by crude oil. Thus, without developing strong internal resilience towards shocks in crude oil prices (such as diversifying generation sources), changes in crude oil price will continue to pose difficulties for both consumers and suppliers of electricity alike especially given the current generation structure. Another important implication of the existence of market integration of electricity and crude oil markets is that imposing either taxes or subsidies in both markets would lead to double taxation or subsidisation. The former implies high tax burden on consumers of electricity, which could impact negatively on their welfare. The latter suggests huge government expenditure, which could suggest displacement in government expenditure away from more important welfare-enhancing projects.

Also, we tested for cointegration in the presence of structural break using the Gregory–Hansen cointegration technique. The null hypothesis is, there is no cointegration against the alternative hypothesis of cointegration with an unknown breakpoint. Table 15.5 shows the results. Generally, there is evidence of cointegration, with the likely breakpoint as 1982 as shown by ADF and *Z-t* statistics. This seems to confirm the earlier claim that the electricity and crude oil markets are well integrated, in the case of Ghana. The next section shows the asymmetric nature of the responses of electricity price to changes in crude oil spot prices.

15.3.3 Test of Long-Run and Short-Run Asymmetries

Table 15.6 contains the results on the short- and long-run asymmetries. Few things are worth nothing about this table. First, the error correction terms are negative and statistically significant. The speed of adjustment to long-run equilibrium is about 60% or more. This implies that for every one per cent error shock in the price of electricity, about 60% of this shock dies off in the first year. Second, the asymmetry in price responses is a long-run phenomenon. Third, electricity price responds asymmetrically to changes in crude oil prices. Positive changes in crude oil prices increase the price of electricity. On the other hand, negative price changes reduce the price of electricity.

However, suppliers of electricity transmit more of the positive changes in crude oil prices to consumers than they do for the negative changes in crude oil prices. As revealed by the long-run coefficients, a one per cent increase in crude oil price will increase the price of electricity by between 0.812 and 0.893%. This suggests that suppliers of electricity absorb between 0.1 and 0.19% of the crude oil price increase. On the other hand, a 1% decrease in crude oil price will reduce electricity price by between 0.6798 and 0.773%. Thus, suppliers of electricity retain 0.23–0.32% of the price decrease. Based on the results, suppliers of electricity are more willing to increase the price of electricity (the output) when the price of the critical input (oil)

Table 15.5 Gregory–Hansen cointegration with structural break

Indep. var	Statistics	Break type			
		Level	Level and trend	Δ in regime	Δ in regime and trend
ln B_t	ADF	−3.16 (1986)	−5.79*** (1982)	−3.43 (1990)	−6.73*** (1982)
	Z_t	−3.46 (1989)	−5.86*** (1982)	−3.44 (1989)	−6.81*** (1982)
	Z_a	−20.52 (1989)	−37.98 (1982)	−19.99 (1989)	−44.62 (1982)
ln WTI_t	ADF	−3.01 (1986)	−5.80*** (1982)	−2.88 (1989)	−6.71*** (1982)
	Z_t	−3.28 (1989)	−5.87*** (1982)	−3.28 (1989)	−6.80*** (1982)
	Z_a	−19.36 (1989)	−38.07 (1982)	−19.09 (1989)	−44.53 (1982)
ln NF_t	ADF	−3.11 (1986)	−5.79*** (1982)	−3.40 (1990)	−6.74*** (1982)
	Z_t	−3.43 (1989)	−5.86*** (1982)	−3.41 (1989)	−6.82*** (1982)
	Z_a	−20.32 (1989)	−37.97 (1982)	−19.80 (1989)	−44.68 (1982)
ln DO_t	ADF	−3.31 (1986)	−5.80*** (1984)	−3.46 (1990)	−6.73*** (1982)
	Z_t	−3.48 (1988)	−5.87*** (1984)	−3.44 (1989)	−6.81*** (1982)
	Z_a	−20.90 (1988)	−38.01 (1984)	−19.96 (1989)	−44.62 (1982)

***, ** and * denote 1, 5 and 10% statistical significance levels. Null hypothesis: there is no cointegration against the alternative of cointegration with an unknown breakpoint. The maximum lag was selected based on the Akaike information criterion. Figures in the parenthesis are the break point year

increases but are less willing to decrease the price of the output (electricity) if the price of the critical input decreases. This is a clear case of market imperfection in the electricity market in Ghana.

Figure 15.2 shows the long-run dynamic multipliers and the extent of asymmetry. The figure clearly shows that there exists significant asymmetry in the response of electricity prices to crude oil prices.

The tendency for suppliers of electricity to retain more of crude oil price decreases but less of crude oil price increase could be due to the following reasons. First, in Ghana, consumers of electricity do buy from one buyer (i.e. the Power Distribution Services, Electricity Company of Ghana and Northern Electricity Department). This monopoly in the distribution of electricity in Ghana makes the consumer vulnerable to market developments but gives the supplier more market power in terms of who

Table 15.6 Long-run and short-run asymmetries

Independent variables	Brent ARDL (1,0,0)	Dubai-Oman ARDL(1,0,0)	Nigeria Forcados ARDL(1,0,0)	West Texas Intermediate ARDL(1,0,0)
Long-run asymmetries				
ln cop_t_Pos	0.8371*** (0.1222)	0.8930*** (0.1196)	0.8120*** (0.1253)	0.8917*** (0.1402)
ln cop_t_Neg	−0.7292*** (0.0242)	−0.6798*** (0.2428)	−0.7399*** (0.2456)	−0.7733*** (0.2785)
constant	−7.0548*** (0.2954)	−7.1412*** (0.3160)	−7.0764*** (0.3032)	−7.1586*** (0.3154)
Adj. R-square	0.959	0.959	0.959	0.958
S.E.R	0.4093	0.413	0.441	0.414
Short-run asymmetries				
ln cop_t_Pos	–	–	–	–
ln cop_t_Neg	–	–	–	–
ECT_t	−0.6225*** (0.1185)	−0.6028*** (0.1170)	−0.6181*** (0.1190)	−0.5995*** (0.1175)
Adj. R-square	0.331	0.321	0.325	0.315
S.E.R Model stability	0.3936 Stable	0.3918 Stable	0.3954 Stable	0.3983 Stable

Note HAC standard errors & covariance (Bartlett Kernel, Newey-West fixed bandwidth) ***,** and * denote 1, 5 and 10% statistical significance. Model selection was automatic based on the Akaike information criterion. Figures in parenthesis are the standard errors

bears the burden of adverse changes in the market. Second, the Ghanaian market is proliferated with inefficient appliances and equipment, and this increases the demand for electricity and hence the price incidence on consumers. Third, electricity has become an integral part in the running of every aspect of the economy. This makes the product a critical input and makes its demand inelastic. Fourth, the indebtedness of the electricity sector could also make suppliers of electricity more willing to absorb more of the lower crude oil price to defray some of their debt. In Ghana, the debt stocks within the electricity sector have reached unstainable levels.

Lastly, the size of the long-run coefficients in Table 15.6 shows that there is a significant pass-through effect from crude oil prices to electricity prices in Ghana. While this suggests that Ghana has not done enough to build resilience (especially in the electricity sector) to shocks in the oil market, it further implies that the government subsidy programmes targeted at making electricity affordable can be effective. Figure 15.3 simulates the pass-through effect of a 5% change in crude oil price based on dynamic nonlinear ARDL model (Philips 2018).[3] The pass-through effect of the

[3]The conventional ARDL technique often produces complicated outcomes that are very difficult to interpret. Philips (2018) has proposed a much more flexible approach to ease the difficulty associated with interpreting the results from the conventional ARDL. The procedure by Philips

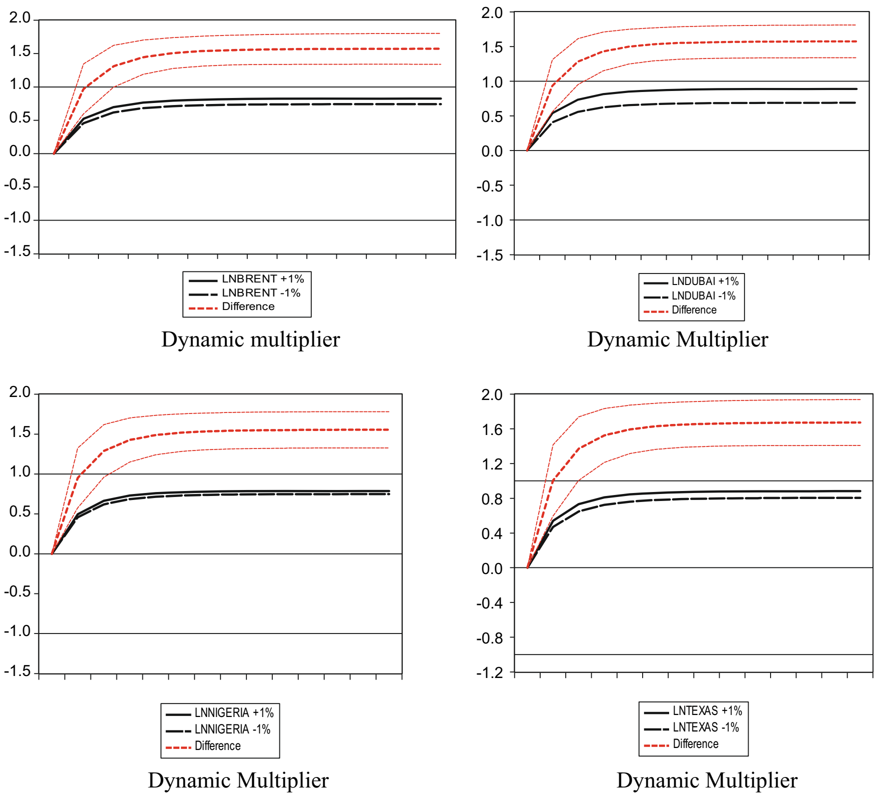

Fig. 15.2 Long-run dynamic multipliers

crude oil price change increases with time. As shown in Fig. 15.3, the change in electricity price due to a 5% increase in crude oil price is higher from the third period after the year of the shock. Section 15.3.4 presents further robustness check on the long-run asymmetries.

15.3.4 Robustness Check

The NARDL assumes weak exogeneity, which is a strong assumption. In this section, we applied the nonlinear versions of the linear long-run cointegrating models developed by Stock and Watson (1993), Park Joon (1992) and Phillips and

(2018) dynamically simulates the effects of a change in the weak exogenous regressor and how that change 'flows' through the dependent variable over time based on stochastic simulation technique.

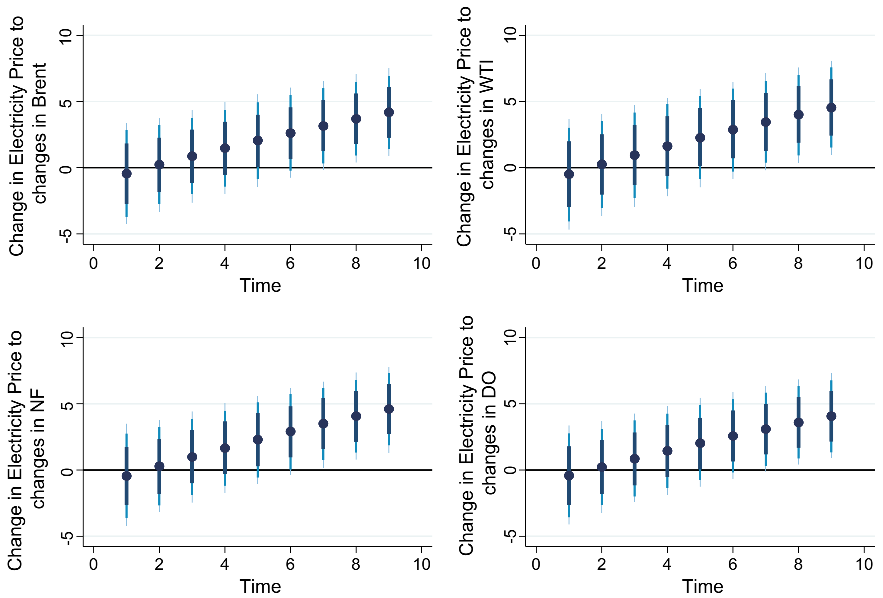

Fig. 15.3 Simulation of changes in electricity price to 5% change in crude oil price

Hansen (1990). These techniques are instrumental-based estimates that adopt different model correction mechanisms to deal with the problems of endogeneity and serial correlation.

Table 15.7 contains the results. The paper used the Wald test to test for the presence of long-run asymmetry. The results remain very robust. The Wald test rejects the null hypothesis of long-run symmetry in favour of the alternative hypothesis of long-run asymmetry. As shown in the table, positive changes in crude oil prices increase the price of electricity, while negative changes in crude oil prices decrease the price of electricity. Comparatively, the transmission for positive crude oil price changes is more than that for negative crude oil price changes. According to the estimates, an increase of 1% in crude oil price will cause electricity price to increase in the lower limit by 0.8676% and in the upper limit by 1.0208%. This implies that suppliers of electricity absorb almost zero to 0.122% of the initial increase in crude oil price. On the other hand, for a 1% decrease in the price of crude oil, suppliers of electricity absorb about 0.312–0.495% of the initial decrease. This result is consistent with the earlier claim that suppliers of electricity in Ghana are more willingly to retain more of negative crude oil prices but less of positive crude oil price changes. The size of the coefficients also supports the earlier result that there is significant pass-through of crude oil price changes to electricity prices in Ghana.

The output price (in this case electricity) can affect input prices (i.e. crude oil price). This could cause a potential reverse causality problem. Moreover, the use of

Table 15.7 Long-run asymmetries

Dependent variable: ln pe_t						
Independent	Brent			Dubai-Oman		
	FMOLS	CCR	DOLS	FMOLS	CCR	DOLS
ln cop_t_Pos	0.9109***	0.9035***	0.9526***	0.9773***	0.9707***	1.0196***
	−0.1654	−0.1648	−0.1873	−0.1574	−0.156	−0.1758
ln cop_t_Neg	−0.6338**	−0.6528**	−0.568*	−0.5795**	−0.5989**	−0.5046*
	−0.2385	−0.2417	−0.2846	−0.2294	−0.2305	−0.2692
Constant	−7.1497***	−7.1572***	−6.9816***	−7.2621***	−7.2691***	−7.0948***
	−0.1875	−0.1737	−0.2545	−0.193	−0.1782	−0.2541
Test of asymmetry	−14.298***	−14.584***	−11.810***	−14.565***	−14.462***	−11.942***
Adj. R-square	0.949	0.949	0.938	0.947	0.947	0.938
Long-run var	0.332	0.332	0.3085	0.338	0.338	0.472
Leads	–	–	1	–	–	1
Lags	–	–	1	–	–	1
Dependent variable: ln pe_t						
Independent	Nigeria Forcados			West Texas Intermediate		
	FMOLS	CCR	DOLS	FMOLS	CCR	DOLS
ln cop_t_Pos	0.9757***	0.9713***	1.0208***	0.8751***	0.8676***	0.9194***
	−0.1886	−0.1868	−0.2217	−0.1681	−0.247	−0.1935
ln cop_t_Neg	−0.6720**	−0.6875**	−0.5878*	−0.6634***	−0.6829***	−0.5890*
	−0.2729	−0.2755	−0.3344	−0.2441	−0.247	−0.295
Constant	−7.2910***	−7.2954***	−7.1767***	−7.1782***	−7.1849***	−7.0314***
	−0.2036	−0.1839	−0.2863	−0.1915	−0.1762	−0.2641
Test of asymmetry	−13.784***	−13.567***	−10.968***	−14.208***	−13.960***	−11.354***
Adj. R-square	0.947	0.946	0.934	0.949	0.948	0.936
Long-run var	0.357	0.357	0.351	0.345	0.345	0.329
Leads	–	–	1	–	–	1
Lags	–	–	1	–	–	1

***, ** and * denote 1, 5 and 10% statistical significance. Figures in parenthesis are the standard errors

actual electricity price, which includes the short-term cyclicality, creates two potential problems: (1) misrepresentation of the true long-run relationship and (2) reverse causality (Adom et al. 2018b). Following the approaches adopted in Adom (2019); Adom et al. (2018b, 2019a), we applied the Hodrick–Prescott filter to decompose the price of electricity into the cyclical component and the long-term component, and then used the long-term component, which is devoid of the short-term cyclicality as the dependent variable. Adom et al. (2018b) argue that this solves the problem of reverse causality and improves model efficiency and the accuracy of the long-run parameters. Moreover, removing the short-term cyclical part of the data and retaining only the long-term part removes potential structural break in the data, which is very likely in this paper.

Table 15.8 Long-run asymmetries

Dependent variable: lnpe$_t$_potential						
Independent	Brent			Dubai-Oman		
	FMOLS	CCR	DOLS	FMOLS	CCR	DOLS
ln cop$_t$_Pos	0.8448***	0.8451***	0.8637***	0.9251***	0.920***	0.9344***
	−0.0774	−0.0779	−0.0822	−0.0868	−0.0869	−0.0895
ln cop$_t$_Neg	−0.7605**	−0.7524**	−0.7223***	−0.6899***	−0.6875***	−0.6571***
	−0.1161	−0.1139	−0.125	−0.1265	−0.1274	−0.1371
Constant	−7.2823***	−7.2636***	−7.1798***	−7.4167***	−7.3926***	−7.3013***
	−0.0877	−0.0807	−0.1119	−0.1064	−0.098	−0.1294
Test of asymmetry	−32.288***	−31.423***	−28.053***	−27.404***	−27.114***	−24.485***
Adj. R-square	0.991	0.991	0.994	0.989	0.989	0.992
Long-run var	0.0727	0.0727	0.059	0.103	0.103	0.082
Leads	–	–	1	–	–	1
Lags	–	–	1	–	–	1
Dependent variable: lnpe$_t$_potential						
Independent	Nigeria Forcados			West Texas Intermediate		
	FMOLS	CCR	DOLS	FMOLS	CCR	DOLS
ln cop$_t$_Pos	0.8116***	0.8108***	0.8299***	0.9096***	0.9044***	0.9025***
	−0.0783	−0.0788	−0.0846	−0.0976	−0.0983	−0.1047
ln cop$_t$_Neg	−0.7871***	−0.7800**	−0.7472***	−0.8010**	−0.8065***	−0.7649***
	−0.1138	−0.1159	−0.129	−0.1412	−0.1444	−0.1579
Constant	−7.3151***	−7.2938***	−7.2093***	−7.4329***	−7.4051***	−7.3230***
	−0.0893	−0.0816	−0.1155	−0.1054	−0.0954	−0.1352
Test of asymmetry	−31.674***	−30.854***	−27.150***	−27.799***	−27.083***	−24.3795***
Adj. R-square	0.991	0.991	0.994	0.989	0.99	0.992
Long-run var	0.075	0.075	0.063	0.096	0.096	0.078
Leads	–	–	1	–	–	1
Lags	–	–	1	–	–	1

***, ** and * denote 1, 5 and 10% statistical significance
Figures in parenthesis are the standard errors

Table 15.8 contains the result when we used potential electricity price as the dependent variable. The standard errors in Table 15.8 compared with the standard errors in Table 15.7 have decreased significantly, which suggests model efficiency improvement. Second, the size of the long-run pass-through effects for positive and negative changes in crude oil prices have also changed. For a 1% increase in crude oil price, electricity price will change by 0.811% (in the lower limit case) and 0.934% (in the upper limit case). This implies that suppliers retain between 0.066 and 0.189% of the increase in crude oil price, which is relatively higher than the one obtained in Table 15.7. On the contrary, for a 1% decrease in electricity price, producers of electricity retain 0.193 and 0.343% of the decrease in crude oil price, which is lower than the previously reported value. Nonetheless, the findings are very consistent with the previous findings. Thus, suppliers of electricity are more likely to absorb more of the negative price changes in crude oil prices than the positive changes in crude oil prices, a situation that suggests the existence of market imperfection in the electricity market.

15.3.5 Asymmetry in Electricity Consumption to Price Changes

The success of a government subsidy programme to improve electricity access depends on the existence of (1) asymmetry in the response of electricity price to the critical input price (crude oil) and (2) asymmetry in the response of electricity consumption to changes in electricity price. The preceding section addressed the first part of asymmetries. This section investigates the second part. First, we tested for cointegration and then investigated the short- and long-run asymmetry in the response of electricity consumption to changes in electricity price.

15.3.5.1 Electricity Consumption Model

We modelled electricity consumption to have a Cobb–Douglas form (i.e. Equation 15.6a), where E_i^D refers to the electricity consumption of type i. The rationale is to be able to interpret the coefficients directly as elasticities. Three types of consumption categories are modelled: total electricity consumption, industrial electricity consumption and residential electricity consumption. We have decided to keep the model simple in this case. In order to ensure that there is no zero electricity consumption, we impose the restriction that the price of electricity, the constant and income to be nonzero (Adom 2017). The log transformation of Eq. (15.6a) yields Eq. (15.6b), where $\ln c = \sigma$ and 'i' refers to the consumption category type.

$$E_{it}^D = c\mathrm{pe}_t^{\beta} y_t^{\gamma} e^{\varepsilon_t} \tag{15.6a}$$

$$\ln E_{it}^D = \sigma + \beta \ln \mathrm{pe}_t + \gamma \ln y_t + \varepsilon_t \tag{15.6b}$$

The partial sums of increases and decreases in electricity price are derived using Eqs. (15.7a) and (15.7b).

$$\ln \mathrm{pe}_t^{+\mathrm{ve}} = \sum_{j=1}^{t} \ln \mathrm{pe}_t^{+\mathrm{ve}} = \sum_{j=1}^{t} \max(\Delta \ln \mathrm{pe}, 0) \tag{15.7a}$$

$$\ln \mathrm{pe}_t^{-\mathrm{ve}} = \sum_{j=1}^{t} \ln \mathrm{pe}_t^{-\mathrm{ve}} = \sum_{j=1}^{t} \min(\Delta \ln \mathrm{pe}, 0) \tag{15.7b}$$

Based on (15.7a) and (15.7b), we estimated the error correction equation in (15.8).

$$\Delta \ln E_{it}^{D} = \alpha + \beta_1 \ln E_{it-1}^{D} + \beta_2^{+\text{ve}} \ln \text{pe}_{t-1}^{+\text{ve}} + \beta_3^{-\text{ve}} \ln \text{pe}_{t-1}^{-\text{ve}} + \rho \ln y_{t-1} + \sum_{t=1}^{p-1} \alpha_i \Delta \ln E_{it-1}^{D} + \sum_{i=0}^{q-1} \left(\beta_{2i}^{+\text{ve}} \Delta \ln \text{pe}_{t-i}^{+\text{ve}} + \beta_{3i}^{-\text{ve}} \Delta \ln \text{pe}_{t-i}^{-\text{ve}}\right) + \sum_{i=0}^{q-1} \rho_i \Delta \ln y_{t-1} + \varepsilon_t \quad (15.8)$$

We then tested for cointegration using the bounds cointegrating approach by restricting the coefficients of the lag-level variables to zero. The results are shown in Table 15.9. There is strong evidence of cointegration as revealed by the values of the calculated f-statistic, which exceeds the upper critical f-values. This implies that the price of electricity and real income are the 'long-run forcing variables' explaining changes in electricity consumption in Ghana. This confirms the findings of previous studies on Ghana (Adom 2017). As a further check, we applied the Gregory–Hansen cointegration test with a structural break. Table 15.10 shows the result. Albeit, generally, there is evidence of cointegration with a structural break (considering the last column of the table), it is not very strong evidence.

The evidence of cointegration led the authors to test for short-run and long-run asymmetries based on Eq. 15.8. Equations (15.9a) and (15.9b) denote the short- and long-run asymmetric ARDL model.

H_0: $\beta_2^{+\text{ve}} = \beta_3^{-\text{ve}}$; testing for long-run asymmetry
H_0: $\beta_{2i}^{+\text{ve}} = \beta_{3i}^{-\text{ve}}$; testing for short-run asymmetry

$$\Delta \ln E_{it}^{D} = \alpha + \beta_1 \ln E_{it-1}^{D} + \beta_2 \ln \text{pe}_{t-1} + \rho \ln y_{t-1} + \sum_{t=1}^{p-1} \alpha_i \Delta \ln E_{it-1}^{D} + \sum_{i=0}^{q-1} (\beta_{2i} \Delta \ln \text{pe}_{t-i}^{+\text{ve}} + \beta_{3i} \Delta \ln \text{pe}_{t-i}^{-\text{ve}}) + \sum_{i=0}^{q-1} \rho_i \Delta \ln y_{t-i} + \varepsilon_t \quad (15.9a)$$

$$\Delta \ln E_{it}^{D} = \alpha + \beta_1 \ln E_{it-1}^{D} + \beta_2^{+ve} \ln \text{pe}_{t-1}^{+ve} + \beta_3^{-ve} \ln \text{pe}_{t-1}^{-ve} + \rho \ln y_{t-1} + \sum_{t=1}^{p-1} \alpha_i \Delta \ln E_{it-1}^{D} + \sum_{i=0}^{q-1} \beta_i \Delta \ln \text{pe}_{t-i} + \sum_{i=0}^{q-1} \rho_i \Delta \ln y_{t-i} + \varepsilon_t \quad (15.9b)$$

Table 15.11 shows the results for the long-run and short-run asymmetry in electricity consumption. We found evidence of only long-run asymmetry in the response of electricity consumption to price changes, which applies to total and industrial electricity consumption. The plot of the long-run dynamic multipliers (shown in Fig. 15.4)

Table 15.9 Bounds test of cointegration

	$N = 1000$			$N = 45$			$N = 40$		
	10%	5%	1%	10%	5%	1%	10%	5%	1%
Lower bound	2.37	2.79	3.65	2.56	3.078	4.27	2.592	3.1	4.31
Upper bound	3.2	3.67	4.66	3.428	4.022	5.412	3.454	4.088	5.544
Dependent variable		F-stats							
ln ec_t		6.3819							
ln rec_t		6.1401							
ln iec_t		6.2449							

Table 15.10 Gregory–Hansen cointegration with structural break

Indep. var	Statistics	Break type			
		Level	Level and trend	Δ in regime	Δ in regime and trend
ln ec_t	ADF	−4.49(1988)	−6.00***(1986)	−5.48*(1994)	−5.76*(1993)
	Z_t	−4.37(1986)	−5.22*(1986)	−5.47*(1986)	−5.52(1986)
	Z_a	−25.88(1986)	−32.77(1986)	−35.04(1986)	−35.41(1986)
ln iec_t	ADF	−6.18 ***(1987)	−6.04 ***(1987)	−6.25***(1986)	−5.42(1993)
	Z_t	−4.94**(1986)	−4.93(1986)	−5.09(1985)	−5.80*(1987)
	Z_a	−30.44(1986)	−30.33(1986)	−32.29(1985)	−36.17(1987)
ln rec_t	ADF	−4.32(1987)	−4.72(1989)	−4.91(1987)	−6.34**(1996)
	Z_t	−4.66(1988)	−4.92(1989)	−4.85(1988)	−5.82*(1996)
	Z_a	−28.81(1988)	−31.34(1989)	−30.18(1988)	−37.39(1996)

***, ** and * denote 1, 5 and 10% statistical significance levels. Null hypothesis: there is no cointegration against the alternative of cointegration with an unknown breakpoint. The maximum lag was selected based on the Akaike information criterion. The figures in the parenthesis are the breakpoints years

confirms the asymmetric response of consumption of electricity to changes in electricity price. Adeyemi and Hunt (2007), Fotis et al. (2017) and Gately and Huntington (2002) all found evidence of asymmetry in the response of electricity consumption to changes in electricity price. For residential electricity consumption, we did not find any significant asymmetry to changes in electricity price. Therefore, we discuss only the short- and long-run parameters associated with total and industrial electricity consumption.

According to Table 15.11, the effect of electricity price on electricity consumption is significantly negative, which confirms a priori expectation. Nonetheless, there is an asymmetry in response to electricity price. Overall, consumers of electricity are more responsive to downward movements in electricity prices than upward movements in electricity prices. According to the estimates, a one per cent positive increase in electricity price will cause consumers to reduce their consumption at the aggregate and industrial levels by 0.476% and 0.779%, respectively. On the other hand, a one per cent decrease in electricity price will cause consumers to increase their consumption by 1.073% and 1.536% at the aggregate and industrial levels, respectively.

The existence of asymmetry in the response of electricity price to changes in crude oil price, on one hand, and the asymmetry in the response of electricity consumption to changes in electricity price, on the other hand, imply that the government can adopt subsidy programmes by targeting the critical input in the electricity sector to enhance access to electricity consumption. However, the imperfections existing in the electricity market, which makes suppliers of electricity less willing to lower prices for consumers, could impede the success of the government subsidy programmes. Further, the results show that the effect of income is positive and statistically significant. Thus, the growth of the economy could trigger higher electricity consumption.

Table 15.11 Long-run and short-run estimates

Dependent variable: electricity consumption			
Independent variable	Total electricity consumption ARDL (1,0,1,1)	Industrial electricity consumption ARDL (1,0,0,0)	Residential electricity consumption ARDL (1,0,1,0)
Long-run asymmetries			
ln pe_t_pos	−0.4763* (0.2370)	−0.7788*** (0.2356)	0.1086 (0.0824)
ln pe_t_Neg	−1.0734** (0.4820)	−1.5363*** (0.4582)	−0.1683 (0.1554)
ln py_t	3.7778*** (1.3820)	4.8996*** (1.3694)	0.7390 (0.5135)
Constant	−16.8741* (9.1092)	−24.5234** (9.0295)	1.2027 (3.3392)
Adj R-square	0.904	0.764	0.967
S.E.R	0.1375	0.1967	0.1128
Short-run asymmetries			
ln pe_t_neg	0.0591 (0.0598)	–	0.0168 (0.0438)
ln py_t	−0.4425 (0.5939)	–	
ECT_t	−0.3313*** (0.0427)	−0.3436*** (0.0376)	−0.3313*** (0.0707)
Adj. R-Square	0.683	0.676	0.239
S.E.R Model stability	0.1300 Stable	0.1866 Stable	0.1069 Stable

Note HAC standard errors and covariance (Bartlett Kernel, Newey-West fixed bandwidth) ***, ** and * denote 1, 5 and 10% statistical significance. Model selection was automatic based on the Akaike information criterion. Figures in parenthesis are the standard errors

This is consistent with economic theory and the general findings in the empirical literature (Adom et al. 2019b; Adom and Kwakwa 2019; Adom 2017). The bottom part of the table shows that the error correction term is statistically significant and negative for all types of electricity consumption. This suggests a relatively stable system. Nonetheless, the value of the adjustment factor shows a slow adjustment to long-run equilibrium. The implication is that, albeit shocks in electricity consumption would be corrected in the near future, it would take relatively a longer time for the market to self-correct itself. In the instance of a negative shock in electricity consumption, which implies lack of access to electricity by many, allowing the market to self-correct itself may keep many of the people without access to electricity in a low equilibrium trap for a long time. Therefore, a short- to medium-term type of intervention from the government might be required to move people from the low equilibrium trap. For example, where the source of the problem of lack of access to

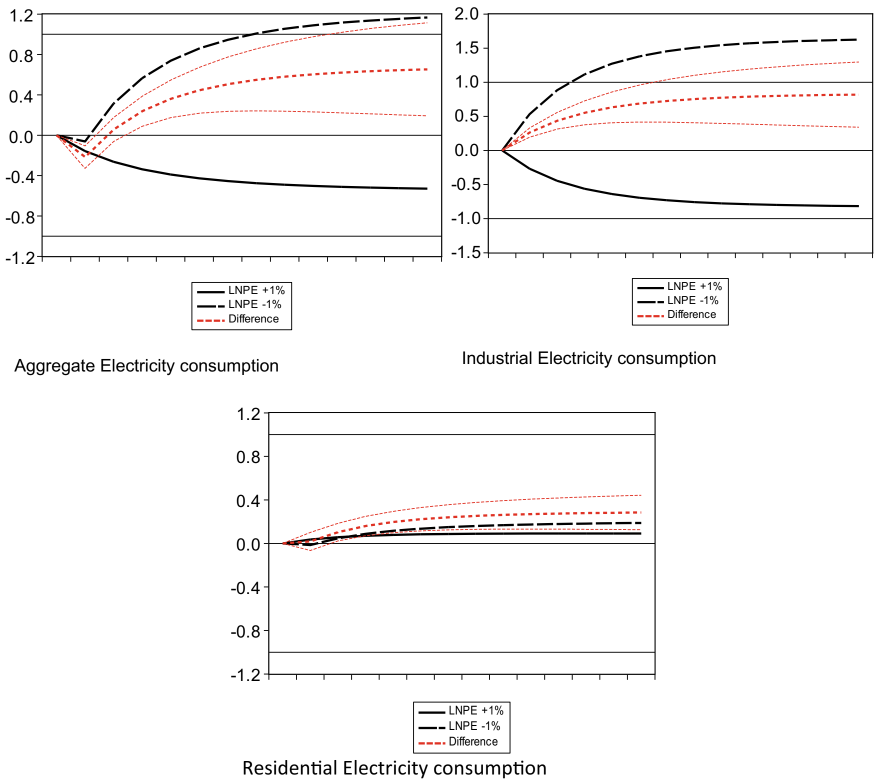

Fig. 15.4 Long-run dynamic multipliers

electricity has to do with affordability, a government subsidy programme on electricity could help pull many people from the low-equilibrium trap. On the other hand, where the source of the problem is due to lack of enough generation, investment in generation, transmission and distribution infrastructure both soft and hard would be critical to helping people escape the low-equilibrium trap.

15.3.5.2 Simulating the Impact of a Price Change on Electricity Consumption

In the second quarter of 2019, the price of electricity in Ghana increased by 11% and remained relatively stable throughout the year. Given the close connection between electricity consumption and electricity price, we simulated the impact of this change in price on aggregate and industrial electricity consumption. As shown in Fig. 15.5, simulation results for 11% increase in electricity price reveal the immediate significant negative impact on industrial electricity consumption, with the negative effect

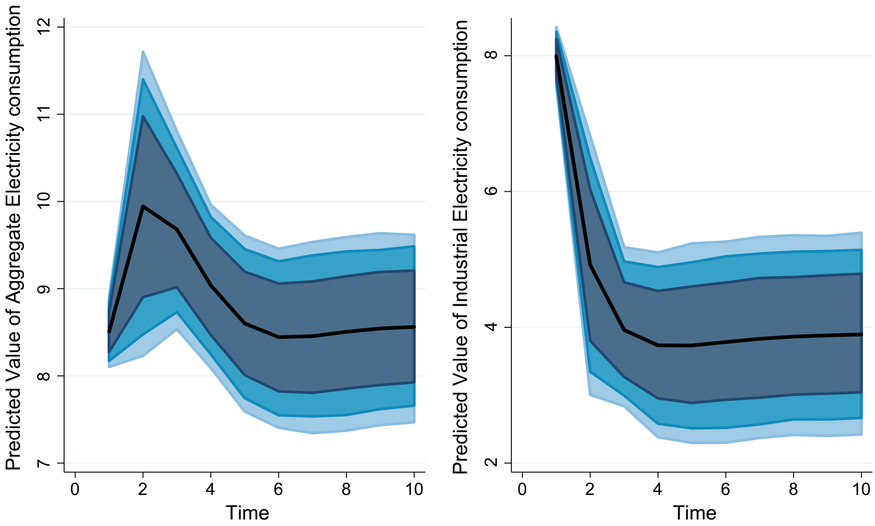

Fig. 15.5 Simulating 11% increase in electricity price

on aggregate electricity consumption more evident after the second period. From a demand-side management perspective, such a price-induced reduction in industrial electricity consumption could impact positively on the stability of the electricity system and the economy, especially, if driven by technological investment rather than the shutdown of plants and industries. However, where the latter effect dominates, a significant price cushion, such as a price subsidy programme, from the government may urgently be required in the industrial sector to prevent industrial collapse and its attendant negative implications on wealth creation and employment generation.

15.4 Conclusion and Policy Recommendation

This study tested for (1) the integration of the electricity and crude oil markets, (2) the long- and short-run asymmetry in the response of electricity prices to changes in crude oil price and (3) the long- and short-run asymmetry in the response of electricity consumption to changes in electricity price. The paper applied the nonlinear ARDL technique developed by Shin et al. The study also applied the nonlinear versions of the DOLS, FMOLS and CCR long-run cointegrating techniques. The study used time series data that covered 1976–2017. The following results emerged from the study.

The electricity and crude oil markets are well integrated in Ghana, which suggest the interdependency of the electricity and crude oil markets. Definitely, taxing or subsidising both products could amount to double taxation and subsidisation of both products. The long-run coefficients showed significant pass-through effect from crude oil prices to electricity prices. This has important implications on who bears the burden of the adverse changes in the crude oil market.

As shown, in this study, there is a significant asymmetry in the response of electricity (output) price to changes in crude oil price. Suppliers of electricity are more willing to absorb more of lower crude oil price than the higher crude oil price. Thus, there is a higher tendency on the part suppliers of electricity to pass on more of higher crude oil prices onto consumers as compared to lower crude oil price; this is a clear indication of the existence of market imperfections in the electricity sector in Ghana.

We also found significant asymmetry in the response of electricity consumption to changes in electricity price. Consumers of electricity are more responsive to lower electricity price than higher electricity price. This implies that a government programme that subsidises the critical input could increase electricity access and usage. However, the market imperfections that exist in the electricity sector could impede the government subsidy programme aimed at increasing access to electricity.

Removing the market imperfections in the electricity sector could prove useful for a government subsidy programme targeted at the critical input. In this regard, the government should introduce competition into the sector by opening up the sector for private sector participation. Apart from making government subsidy programme effective in achieving the desirable outcome, competition could improve operational efficiency and service delivery within the electricity sector. There might also be the need to unbundle the oil sector from the electricity sector by diversifying electricity sources to include other renewable energy sources. This could minimize the dependence on oil as the critical input and the risk that it poses to the participants in the electricity sector. In the short-term, however, subsidy programme aimed at improving electricity access can be effective if it targets the final price of electricity instead of the price of the critical input (i.e. oil).

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