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# Exploring the Relationship between Energy Usage Segregation and Environmental Degradation in N-11 Countries

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## Abstract

Numerous studies regarding the economic growth-environmental pollution link have struggled to determine the effects of various forms of energy consumption on environmental degradation, particularly in the context of emerging economies. This study examines the environmental Kuznets curve (EKC) for CO<sub>2</sub> emissions in N-11 countries during 1990-2014 by segregating three forms of energy consumption (renewable, biomass and non-renewable). Urbanization and trade openness are additional explanatory variables that are used in the empirical framework. Using the Generalized Moments Method (GMM), the empirical evidence confirms the presence of an N-shaped relationship between economic growth and environmental degradation for N-11 countries. This study analyzed the interaction effects among trade openness, biomass consumption and economic growth; these interactions had a negative impact on CO<sub>2</sub> emissions levels of N-11 countries. Suitable policy recommendations have been provided based on the detailed results.

**Keywords:** Environmental Kuznets Curve; Biomass Energy; Trade openness; Renewable energy

## 1. Introduction

Energy consumption is an extremely crucial factor for enabling economic growth of every nation. Energy is consumed in various forms and one of the leading forms of global energy consumption is fossil-fuel based energy. Nevertheless, over time, the continuous consumption of energy in the form of fossil fuels has resulted in two major predicaments for emerging economies: the rapid exhaustion of non-renewable natural resources and an increase in the emission of greenhouse gasses such as carbon dioxide (CO<sub>2</sub>). Because of these mounting environmental problems, nations must develop clean technology and energy solutions, and in that pursuit, these nations must shift from non-renewable to renewable energy sources, including solar, wind, tidal, waste, and others forms. Nations around the world are progressively recognizing the prospects and implications of new sources of energy, and consequently, the share of renewable energy consumption in total energy consumption is increasing. By the end of 2015, more than 60 nations issued biofuel directives at a national or provincial level (REN21, 2016).

It is not hard to believe that the nexus between renewable energy consumption and environmental degradation may be a critical factor for sustainable development of emerging economies. Because the cross-border diffusion of technological progress is increasing, countries gradually shift from less developed or developing stages to the emerging stage. This group of eleven countries is referred to as the “Next 11” or N-11 economies (Eghbal, 2008)<sup>1</sup>. According to the World Bank (2015), these countries represent approximately 8% of the global gross domestic product (GDP), which justifies the growth potential of these nations. In addition, the U.S. Energy Information Administration reported that N-11 countries generate nearly 10% of the global CO<sub>2</sub> emissions (EIA, 2015), which explains the unsustainable nature of economic growth.

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<sup>1</sup> These countries include Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, the Philippines, Turkey, and Vietnam.

A graphical representation of this growth has been provided in Figure-1. These countries are on a high economic growth trajectory, and consequently, these nations' demand for energy is very high, which raises concerns regarding environmental degradation without conciliating economic growth.

<Insert Figure 1 here>

During the past few decades, industrialization and population growth led to a rapid increase in global energy demand (Jegannathan and Nielsen, 2013; Lorek and Fuchs, 2013; UNFCC, 2015; UN, 2015). Currently, awareness of climate change and its repercussions are being widely discussed by the researchers (Meng et al., 2016; Wang et al., 2016b; Zeng et al., 2017 a, b). In the early 1990s, ambient pollution problems began to be more frequently described in studies regarding energy economics (Grossman and Krueger, 1991). Stern (2007) described this phenomenon and reported that environmental degradation processes could generate a global economic recession. This trend has also been observed in recent years in developing countries. Therefore, determining energy consumption patterns that occur during the course of economic growth is one of the most essential methods to achieve sustainable development.

Numerous theoretical frameworks have been used to consider the effect of economic growth patterns on environmental degradation, and the Environmental Kuznets curve (EKC) hypothesis is one of the most frequently used frameworks. The theoretical framework of the EKC hypothesis establishes the existence of a relationship between economic growth and environmental quality. In addition, this model allows the incorporation of additional explanatory variables, which help clarify the evolution of environmental degradation process. In this study, we use the EKC framework and incorporate a set of explanatory variables to explore the impact of economic growth on CO<sub>2</sub> emissions for N-11 economies during 1990-2014. This study

explores the impact of income, renewable energy consumption, biomass energy consumption, non-renewable energy consumption, trade openness, and urbanization on CO<sub>2</sub> emissions. Prior studies have investigated the (a) impacts of renewable energy sources on CO<sub>2</sub> emissions and (b) differential impacts of renewable and non-renewable energy sources on CO<sub>2</sub> emissions. Bilgili et al. (2016) analyze the impact of renewable energy consumption on CO<sub>2</sub> emissions for 17 OECD countries during 1977-2010 and determine that renewable energy consumption has a negative impact on CO<sub>2</sub> emissions. Dogan and Seker (2016a) examine the association between CO<sub>2</sub> emissions, renewable and nonrenewable energy, real income and trade openness for European Union nations during 1980-2012. Their empirical results demonstrate that renewable energy consumption has a negative impact on CO<sub>2</sub> emissions. Álvarez-Herranz et al. (2017a) probe the impact of energy innovation and renewable energy consumption on CO<sub>2</sub> emissions for 17 OECD countries during 1990-2012. They find that renewable energy consumption has a negative impact on CO<sub>2</sub> emissions. Riti et al. (2017) investigated the association between CO<sub>2</sub> emissions, fossil fuel energy consumption, and real income for China during 1970-2015. Their empirical results demonstrate that energy consumption has a positive impact on CO<sub>2</sub> emissions.

The results from prior studies indicate that certain research gaps exist. For example, we have not found a study that has considered the impact of biomass energy consumption on CO<sub>2</sub> emissions. Prior studies generally segregate renewable and non-renewable energy sources; further segregation of the components of renewable energy consumption has largely been ignored. Trade volume and energy consumption patterns are highly linked with economic growth, and therefore, the interactions between these variables may impact CO<sub>2</sub> emissions. This study contributes to existing literature regarding energy economics in five ways. (i) This study uses the EKC framework to investigate the associations among income, renewable energy

consumption, biomass energy consumption, non-renewable energy consumption, trade openness, urbanization, and CO<sub>2</sub> emissions for a panel of N-11 countries. (ii) We applied the generalized method of moments (GMM) to estimate the relationship between these variables. (iii) Our research introduces interaction effects between trade openness and biomass energy consumption with income, and these interaction variables have a dampening effect on CO<sub>2</sub> emissions in N-11 countries. (iv) We segregated the use of renewable energy and biomass energy consumptions to determine the possible impact of these energy sources on CO<sub>2</sub> emissions. (v) We also consider three subpanels that are constructed based on World Bank (2016) classifications (developed, industrialized, and emerging countries). Our results demonstrate that an N-shaped environmental Kuznets curve exists for N-11 countries and for the three subpanels.

The remainder of this paper is organized as follows: Section-2 provides a review of relevant literature, Section-3 provides the theoretical framework of the EKC hypothesis, Section-4 summarizes the present energy policies of N-11 countries, Section-5 describes the empirical model and data, Section-6 details the results and analysis, and Section-7 concludes the paper with policy implications.

## **2. Literature review**

Over the past few decades, numerous studies have explored the link between economic growth, energy consumption, and CO<sub>2</sub> emissions (Ozcan, 2013; Dogan and Seker, 2016a, Meng et al., 2016, Zeng et al., 2017 a, b, among others). Our study hypothesizes the existence of a relationship between economic growth and environmental degradation in N-11 emerging economies. Below, we review prior studies regarding the growth-emissions nexus, the trade-

emissions nexus and the urbanization-emissions nexus. Then, we discuss these relationships in the subsequent subsections.

## **2.1. Economic Growth and CO<sub>2</sub> Emissions**

There is an extensive volume of literature regarding Energy and Environmental Economics and the association between economic growth and CO<sub>2</sub> emissions. During the earliest stage of economic growth, nations primarily depend on fossil fuels for fulfilling their energy demands. Burning those fossil fuels subsequently generates CO<sub>2</sub> emissions in the ambient atmosphere; an increase in the consumption of fossil fuels gradually increases the level of CO<sub>2</sub> emissions. Therefore, to a degree, patterns of economic growth exert negative pressures on environmental quality. Once economic growth reaches a certain level, increasing levels of pollution and environmental awareness among citizens force policymakers and industries to shift towards cleaner technologies and green energy resources, and economic growth pattern leads to a reduction in atmospheric CO<sub>2</sub> emissions. This implies that the relationship between CO<sub>2</sub> emissions and economic growth is an inverted U-shaped, and this entire phenomenon is referred as the Environmental Kuznets curve (EKC) hypothesis.

Grossman and Krueger (1991) proposed the famous EKC hypothesis by assessing the impact of the North American Free Trade Agreement (NAFTA) on environmental quality of Mexico City. These scholars discovered a new dimension in evaluating the emissions levels in the context of economic growth. Over the years, researchers have estimated the EKCs for a wide range of pollutants and various forms of the EKC have been discovered, e.g., inverted U-shaped, U-shaped, N-shaped, inverted N-shaped, M-shaped, and linear.

The situation may be similar in the case of CO<sub>2</sub> emissions. One of the earliest studies regarding EKC framework estimation for CO<sub>2</sub> emissions was conducted by Shafik and Bandyopadhyay (1992). These scholars analyzed 149 countries during 1960-1990 and could not determine EKC hypothesis. As for a single-country context, the seminal study was conducted by Carson et al. (1997). They analyze 50 states in the US during 1988-1994 and discover an inverted U-shaped EKC pattern, with the turnaround point at \$62,700 per capita. Following the path of these studies, over the last three decades, researchers have attempted to estimate EKCs for CO<sub>2</sub> emissions for various nations, and recently with a special focus on emerging countries. Abdou and Atya (2013) investigate the EKC of Egypt during 1961-2008 and find the evidence of an inverted U-shaped EKC. Within the EKC framework, Rabbi et al. (2015) analyze the association between per capita CO<sub>2</sub> emissions, energy use, per capita real GDP, and trade openness for Bangladesh during 1972-2012. Using a cointegration model, they note the evidence of an inverted U-shaped EKC. Saboori et al. (2012) conduct the first EKC estimation study of Indonesia and analyze the associations among CO<sub>2</sub> emissions, economic growth, energy consumption, and foreign trade during 1971-2007. In alignment with the Auto-Regressive Distributed Lag (ARDL) approach, they determine that an EKC does not exist for Indonesia. Sugiawan and Managi (2016) estimate the EKC for Indonesia during 1971-2010 but present contradictory empirical evidences. Few EKC estimation studies have been conducted in the Korean context, and one of the earliest studies is conducted by Kim and Jung (2014). They analyze the impact of GDP on CO<sub>2</sub> emissions for 15 local government regions in Korea during 1990-2010. Using a panel Generalized Least Square (GLS) model, they find the evidence of an inverted U-shaped EKC. Most of the studies conducted in Mexico largely focus on pollutants other than CO<sub>2</sub>, and Gallagher's (2005) study is one of only a few studies that did focus on CO<sub>2</sub>



emissions. Gallagher focused on the impact of economic integration on CO<sub>2</sub> emissions in Mexico during 1985-2000 and found evidence of several turnaround points of an inverted U-shaped EKC at various levels of economic integration. Bello and Abimbola (2010) estimate the EKC for CO<sub>2</sub> emissions in Nigeria during 1980-2008. In alignment with the GMM approach, they are unable to find evidence of an EKC in Nigeria. In a subsequent study by Chuku (2011), the EKC is tested during 1960-2008, and the turnaround points of inverted U-shaped EKCs are found in the range of \$237.23-\$280.84 per capita. One of the earliest and comprehensive EKC estimation studies for Pakistan was conducted by Shahbaz et al. (2011). This study has analyzed the relationship between CO<sub>2</sub> emissions, energy consumption, economic growth, and trade openness during 1971-2009 and by applying the bounds test for the cointegration approach. They find the evidence of an inverted U-shaped EKC<sup>2</sup>. Serião (2014) conducts the only EKC estimation study for the Philippines and attempted to estimate the impact of household consumption on CO<sub>2</sub> emissions during 2005-2006. The results demonstrate that an inverted U-shaped EKC exists for the Philippines. Halicioglu (2009) estimates the EKC for Turkey and analyzed CO<sub>2</sub> emissions, energy consumption, income, and foreign trade during 1960-2005. Using the ARDL and ECM approaches, Halicioglu determines that an inverted U-shaped EKC exists for Turkey<sup>3</sup>. Finally, Tang and Tan (2015) conduct an EKC estimation study for Vietnam to analyze the association between CO<sub>2</sub> emissions, energy consumption, income, and foreign trade during 1976-2009. Using the cointegration approach, they find evidence of an inverted U-shaped EKC in Vietnam. However, in a subsequent study that has conducted by Al-Mulali et al. (2015a), the results did not provide evidence to support the EKC hypothesis.

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<sup>2</sup> Similar results were obtained in subsequent studies that were conducted by Shahbaz et al. (2012) and Shahbaz (2013); these studies also provided evidence of inverted U-shaped EKCs in Pakistan.

<sup>3</sup>Shahbaz et al. (2013b) estimated the EKC for Turkey during 1970-2010 and analyzed CO<sub>2</sub> emissions, energy intensity, economic growth, and globalization. Using the ARDL and ECM approaches, the researchers found evidence of an inverted U-shaped EKC in Turkey.

A recent study that has conducted by Shahbaz et al. (2016b) to estimate the EKC for CO<sub>2</sub> emissions in N-11 countries by considering CO<sub>2</sub> emissions, energy consumption, and economic growth within the EKC framework. They find the evidence of an inverted U-shaped EKC for all N-11 countries. All of these studies, including the single country and cross-country analyses, are inconclusive in terms of suggesting the shape of the EKC for N-11 countries. Furthermore, none of these studies segregated the effects of renewable and non-renewable energy consumptions and analyzed their effects on CO<sub>2</sub> emissions. This is one of the primary contributions of this study to extant literature. In addition, prior studies estimated the EKCs by using the square of income, but this study considers the cubed-term of income and thus provides a scope for the N-shaped EKC of N-11 countries.

## **2.2. Trade Openness and CO<sub>2</sub> Emissions**

Trade openness may impact CO<sub>2</sub> emissions via various channels, and the impact can either be positive or negative. For an industrialized or developed nation, trade openness results in a technique effect on the economy by introducing technologies that pollute less during production processes. Therefore, the production processes become more environmentally sustainable by decreasing ambient pollution levels. Conversely, if the economy is in a nascent phase of development, to boost growth, policymakers of developing nations insist on procuring low cost and polluting technologies from developed nations. In this scenario, economic growth via technology, trade occurs at the cost of environment. Therefore, in this case, trade causes production process to become environmentally unsustainable by increasing ambient pollution levels.

Numerous studies that explore the EKC relationship incorporate trade openness as a significant variable (Grossman and Krueger, 1991; Wyckoff and Roop, 1994; Suri and Chapman, 1998; Nahman and Antrobus, 2005; Feridun et al., 2006; Halicioglu, 2009; Baek and Kim, 2011; Jayanthakumaran et al., 2012). These studies conclude that increases in trade result in higher global environmental pollution levels. Conversely, this intuition has been invalidated empirically for local pollutants (such as SO<sub>2</sub> and NO<sub>2</sub>); however, the relationship is mostly positive for global pollutants such as CO<sub>2</sub> emissions (Frankel and Rose, 2005). Feridun et al. (2006) demonstrate that pollution is positively related to trade openness in Nigeria during 1980-2000. Halicioglu (2009) examines the relationship between CO<sub>2</sub> emissions, energy consumption, income and foreign trade for Turkey during 1960-2005 and concludes that increases in trade inflows resulted in increases in CO<sub>2</sub> emissions. Furthermore, Baek and Kim (2011) determine that trade openness and income growth positively and significantly affect environmental quality for developed countries, but environmental degradation increased because of trade openness and economic growth in developing countries. In addition, they note that an adverse relationship existed between energy consumption and environmental quality. Conversely, Jayanthakumaran et al. (2012) determined that trade openness has a similar impact on CO<sub>2</sub> emissions in China and India. Shahbaz et al. (2014) analyze the association between electricity consumption, industrial value-added activities, domestic credits to the private sector, trade openness, and CO<sub>2</sub> emissions for Bangladesh during 1975-2010 and determine that trade openness leads to an increase in CO<sub>2</sub> emissions.

Certain studies have broadened the analysis of the association between trade openness and CO<sub>2</sub> emissions by considering multivariate frameworks and including financial development, HDI, and institutional quality (e.g., Ibrahim and Law, 2015; Shahbaz et al., 2015;

Al-Mulali et al., 2016; Sinha and Sen, 2016, and many others). The results of these studies have been inconclusive regarding the impact of trade openness on CO<sub>2</sub> emissions. These studies describe the impact as both positive and negative depending on the context, choice of other explanatory variables, and methodological adaptations.

### **2.3. Urbanization and CO<sub>2</sub> emissions**

Urbanization plays a significant role in influencing environmental quality via various channels. When industrialization sets a pace in an economy, newly built factories and plants must hire employees. Because these companies require several operational and logistical facilities, factories are built near the cities, and occasionally, several small towns are formed around these production units. To increase their income and pursue a better lifestyle, individuals move away from villages and rural areas and seek employment opportunities at these production units. Because of this process, population in urban areas increases. The migrated populace adds to population of the cities and towns, and demand for energy increases within a short span of time. Fossil fuel consumption increases to meet this elevated demand for energy, which subsequently increases CO<sub>2</sub> emissions levels in the tropospheric atmosphere. In addition to this particular channel, urbanization can cause environmental degradation in several other ways. Numerous researchers have determined that the degree of transportation, vehicular congestion, energy waste, and space heating are possible consequences of urbanization (Sinha, 2015; Sinha and Bhattacharya, 2016, 2017). Therefore, it is imperative to consider urbanization in the empirical framework when analyzing the carbon emissions in developing nations.

Cole and Neumayer (2004) conduct one of the earliest studies considering urbanization within the EKC framework. They analyze the relationship between CO<sub>2</sub> emissions, growth in

manufacturing industries, age structure of the population, per capita GDP, energy intensity, and urbanization for 86 countries during 1975-1998. Their study applied a panel regression model and determined that urbanization leads to an increase in CO<sub>2</sub> emissions. Martínez-Zarzoso and Maruotti (2011) investigate the relationship between per capita income, population, urbanization, energy efficiency and industrial activity on CO<sub>2</sub> emissions and conclude that urbanization leads to an increase in CO<sub>2</sub> emissions, irrespective of the stage of development of the 88 countries. Wang et al. (2012) analyze the association between urbanization, GDP, industrial growth, tertiary industry proportion, energy intensity, R&D output, and CO<sub>2</sub> emissions for Beijing during 1997-2010. Using the partial least square approach, they determine that urbanization is the primary driver for an increase in emissions. Chen and Huang (2013) examine the association between energy use, electric consumption, FDI, GDP, urban population, and CO<sub>2</sub> emissions for N-11 countries during 1981-2009 using the panel cointegration and causality approach. They find that urbanization increases electric power consumption and carbon emission.

Hassan and Salim (2015), Shahbaz et al. (2015), Al-Mulali et al. (2016), Ali et al. (2016), Destek et al. (2016), Kang et al. (2016), Wang et al. (2016a, b), He et al. (2017) and several other studies extend the urbanization-emissions nexus to include diverse aspects. They have used multivariate frameworks to consider dimensions such as spatial dispersion, dynamics of nations, income inequality, and land use patterns, but the results were inconclusive.

### **3. Theoretical framework of EKC analysis**

According to the EKC hypothesis, during the early stages of economic development, increase in income will increase pollution until it reaches to a certain point because this relationship is an inverted-U scheme, and then relationship between income and pollution

becomes negative. It implies that the EKC hypothesis theoretically demonstrates a country's transition from developing to developed via economic growth (Grossman and Krueger, 1991). To clarify, the relationship between economic growth and environmental quality implies that environmental degradation is an increasing function of economic activity to a point; beyond this point, higher income levels lead to improve environmental quality (Grossman and Krueger, 1991, 1995; Halkos, 2003; Balsalobre and Alvarez, 2016). This argument can be analyzed by considering three channels through which economic growth affects the environment: scale effect, composition effect, and technique effect (Figure-2).

<Insert Figure 2 here>

Figure-2 illustrates how the scale effect is associated with the sectoral structure of an economic system. During the pre-industrial stage, limited consumption of natural resources and a restricted production of biodegradable wastes keep the level of environmental degradation low. As the speed of economic growth increases because of agriculture, the use of forest resources and the extraction of natural resources begin to surpass regeneration rates. A gradual increase in industrialization increases the quantity and toxicity of non-degradable waste. During the developing stage of economic development, an increase in income levels will not only increase output but will also deteriorate environmental quality. The scale effect implies that the margin of new improvements generates increasing returns in terms of reducing pollution (Torras and Boyce, 1998). Over time, economic development generates a growth in knowledge intensive industries and a refinement of production processes; these two scenarios describe the composition and technique effects, respectively (Figure-2). The composition effect exerts a positive impact on environment when an economy transitions from an agriculture and heavy manufacturing sector to knowledge intensive sector. The sectoral transition that is caused by

the composition effect reduces intensive energy consumption and toxic emissions, thereby decreasing emissions and reversing the slope of the EKC (Hettige et al., 2000; Halkos, 2003). Finally, the technical effect catalyzes improvements in productivity and the adaptation of cleaner technologies, which leads to an increase in environmental quality. Andreoni and Levinson (2001) concluded that economic growth corrects environmental contamination levels via technical factors and reduces the slope of the EKC to a greater extent. In addition, the emergence of knowledge intensive industries and growing environmental concerns may lead to more stringent environmental regulations, the introduction of cleaner technologies, the replacement of obsolete and polluting technologies, and additional environmental investments. This period is followed by a stabilization and gradual decrease in environmental degradation. Technical innovation is the primary driver of this process (Andreoni and Levinson, 2001). Therefore, it can be inferred that when technical innovation reinforces the endogenous aspect of the EKC hypothesis (Gradus and Smulders, 1993; van den Bergh and Nijkamp, 1994), the technical effect conditions the income-emissions association via improving energy technologies, replacing obsolete and polluting technologies with cleaner technologies and introducing more efficient production processes (Verdier, 1993; Bovenberg and Smulders, 1995).

In addition, an N-shaped EKC pattern describes the relationship between income per capita and the level of environmental pollution in accordance with the EKC (Figure-3). Although pollution decreases with an increase in income levels, after the scale effect exceeds the technical effect and technical obsolescence occurs, the level of ambient pollution begins growing again (Balsalobre and Álvarez, 2016; Álvarez et al., 2017a, b).

<Insert Figure 3 here>

During the first stage of economic growth, economies remain in a developing stage that is characterized by policies that create distortions, subsidize energy consumption, and result in market failures (De Bruyn et al., 1998). During the second stage, distortions disappear and market failures are corrected. During the subsequent development stage, strict environmental policies are applied, and environmental awareness increases. Institutional changes during this stage explain the behavioral patterns that are described by the EKC hypothesis (Jones and Manuelli, 1995). Finally, the relationship between income and environmental pollution is N-shaped; when technical advances no longer have increasing returns, a second stage occurs and decreasing technical returns force economies to return to a state of increasing environmental destruction (Balslaobre and Álvarez, 2016).

#### 4. Empirical model and data

This study tests the validity of the EKC hypothesis on the relationship between economic growth and carbon emissions based on the following three simultaneous equations:

$$Y_{it} = a_0 + a_1R_{it} + a_2B_{it} + a_3N_{it} + a_4L_{it} + a_5H_{it} + a_6T_{it} + a_7W_{it} + a_8K_{it} + \varepsilon_{it}$$

(1)

$$C_{it} = b_0 + b_1Y_{it} + b_2Y_{it}^2 + b_3Y_{it}^3 + b_4R_{it} + b_5B_{it} + b_6N_{it} + b_7T_{it} + b_8B_{it} * Y_{it} + b_9U_{it} + \varepsilon_{it}$$

(2)

$$C_{it} = c_0 + c_1Y_{it} + c_2Y_{it}^2 + c_3Y_{it}^3 + c_4R_{it} + c_5B_{it} + c_6N_{it} + c_7T_{it} + c_8T_{it} * Y_{it} + c_9U_{it} + \varepsilon_{it}$$

(3)

In these equations,  $i = 1 \dots N$  denotes the sample countries,  $t = 1 \dots T$  refers to the study period, and  $\varepsilon$  represents the error term. Eq. (1) is an extended form of the Cobb-Douglas production function. In this model, per capita GDP is presented in current US dollars ( $Y$ ) and is dependent on per



capita renewable energy consumption ( $R$ ),<sup>4</sup> per capita biomass energy consumption ( $B$ ), per capita fossil fuel energy consumption ( $N$ ), labor force ( $L$ ), a human development indicator ( $H$ ), trade openness ( $T$ ), per capita combustible renewable energy waste ( $W$ ), and per capita gross capital formation ( $K$ ). Eq. (2) demonstrates that per capita CO<sub>2</sub> emissions ( $C$ ) can be influenced by per capita GDP ( $Y$ ), squared per capita GDP ( $Y^2$ ), cubed per capita GDP ( $Y^3$ ), per capita renewable energy consumption ( $R$ ), per capita biomass energy consumption ( $B$ ), per capita fossil fuel energy consumption ( $N$ ), trade openness ( $T$ ), urbanization ( $U$ ), and the interaction between per capita biomass energy consumption and per capita GDP ( $B*Y$ ). Eq. (3) is similar to Eq. (2) with the exception of the interaction factor; in Eq. (3), per capita CO<sub>2</sub> emissions ( $C$ ) is hypothesized to be influenced by the interaction between trade openness and per capita GDP ( $T*Y$ ).

In this model, we estimated the association between CO<sub>2</sub> emissions, economic growth, energy consumption (renewable biomass and non-renewable), energy efficiency, trade openness, HDI, labor force, and the rate of urbanization. It is evident from Eq. (2) and Eq. (3) that our study focuses on investigating whether the association between economic growth and carbon emissions is either an N-shaped or inverted N-shaped EKC (see Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1995; Torras and Boyce, 1998; Balsalobre et al., 2015; Sinha and Bhattacharya, 2016, 2017; Álvarez-Herranz et al., 2017 a, b, and others)<sup>5</sup>. The N-shaped pattern allows us to focus on issues that are related to scale effect and the long-term effects of energy

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<sup>4</sup> Renewable energy consumption data does not include biomass energy consumption.

<sup>5</sup>The EKC demonstrates a repeated phenomenon that results in a positive association between economic activity and pollution levels up to a certain level of critical income; a higher level of income is associated with progressively greater levels of environmental quality followed by a U-inverted pattern (Grossman and Krueger, 1991). In the short term, environmental degradation increases with economic growth but when a certain level of income is reached, continued increases are associated with improved environmental quality. Meanwhile, certain studies (Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1995) provide evidence of a N-shaped pattern for the EKC. Meanwhile, Moomaw and Unruh (1997) suggest that an N-shaped EKC in developed countries is justified by the structural transition from developing to the developed stage.

efficiency. This characteristic allows us to analyze the potential return to increasing emissions once economies have managed to reduce pollution rates and an environmental technical obsolescence may occur. Conversely, the inverted N-shaped pattern demonstrates that it is not essential for a nation to have a low level of environmental degradation once it has fallen to a certain level. It may be possible that because of changes in socio-economic scenario, environmental degradation may begin increasing for a second time. However, during advanced stages of economic growth, technical effect can reduce the level of environmental degradation.

In Figure-4, the turning point of an N-shaped EKC is illustrated. We compare this with the models that are represented by Eq. (2) and Eq. (3). The coefficients  $b_1, c_1 > 0$ ,  $b_2, c_2 < 0$ , and  $b_3, c_3 > 0$  indicate a cubic polynomial in an N-shaped EKC. The coefficients  $b_1, b_2, b_3, c_1, c_2$ , and  $c_3$  also allow us to calculate the turning points in the cubic EKC model:  $X(1)$  and  $X(2)$ .<sup>6</sup>

This study employed annual data for the period of 1990-2014 to examine an N-shaped linkage between economic growth and environmental degradation for N-11 countries and included additional determinants of carbon emissions. In addition, this study uses the EKC framework and includes the interaction between economic growth and biomass energy and between economic growth and trade openness to explore the moderation. Economic growth is expected to transition economic systems from the developing stage to the developed stage, and during this process carbon emissions might be reduced. The impact on biomass energy is expected to be similar to the impact on CO<sub>2</sub> emissions.

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<sup>6</sup>The estimation of the turning points for the cubic model used the following formulation (Diao et al., 2009):

$$X(j) = \frac{-b_2 \pm \sqrt{b_2^2 - 3b_1b_3}}{3b_3}, \forall j = 1,2$$

For estimating the turning points, it is necessary to make a change in the coefficient  $b_1$ , since the breaking point where the function reaches the maximum and minimum values depends on  $X$ . When  $X$  appears in the moderate model  $GDP_{pc}$ , this will affect the coefficient of the first grade. Therefore, the coefficient  $b_1 = (b_1 + b_3 * X)$  and  $X$  assumes its median value, which is justified by the asymmetric distribution of that variable.

<Insert Figure 4 here>

Equations (1), (2), and (3) were simultaneously estimated using the generalized method of moments (GMM). GMM analyzes the linkages between variables within a panel data setting and provides reliable results. During this analytical process, there are possibilities of endogenous and heteroscedastic issues, which can be addressed by the instrumental variables that are used within a GMM framework (Arellano and Bover, 1995; Blundell and Bond, 1998; Halkos et al., 2003). The Hansen-J test has been used to examine over-identification issues and to determine the validity of the instruments that are used within the framework<sup>7</sup>. The Durbin-Wu-Hausman test is used to check for possible endogeneity in the model<sup>8</sup>.

The data used in this study are for N-11 countries during 1990–2014. We collected the annual data for per capita CO<sub>2</sub> emissions (in kt), per capita GDP (constant 2010 US\$), per capita Renewable Energy Consumption (in kt), per capita Fossil Fuel Energy Consumption (in kt), Labor Force, Trade Openness (as a % of GDP), per capita gross capital formation (constant 2010 US\$), per capita combustible renewable and waste (in kt), and urbanization from World Bank Indicators, per capita biomass energy consumption (in t) from the Global Material Flows Database of Vienna University, and the Human Development Indicator from the Human Development database of United Nations Development Programme.

To add more information to the analysis, the dataset of N-11 countries was segregated into three categories, which include the developed category (South Korea), the newly industrialized category (Indonesia, Mexico, Iran, Philippines, and Turkey), and the emerging

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<sup>7</sup>The null hypothesis of this test indicates that the instruments are valid, and therefore, the results of this test should be insignificant to ensure that the null hypothesis can be accepted.

<sup>8</sup>The null hypothesis of this test indicates that the model is exogenous, and therefore, results of this test should be significant to ensure that the null hypothesis can be rejected.

category (Bangladesh, Egypt, Nigeria, Pakistan, and Vietnam). This classification has been provided by the World Bank (2016). The empirical model is shown in Figure-5.

## 5. Empirical Results and Discussion

We began the process by testing the unit root properties of the variables because it is important to know the order of integration of the variables. To check the order of integration, we applied unit root tests, including the Levin-Lin-Chu (LLC) test (Levin et al. 2002), Breitung (2002), Im-Pesaran-Shin (Im et al. 2003) and the Fisher-type augmented Dickey-Fuller test (Maddala and Wu, 1999). The applicability of these tests was confirmed by the results of the cross-section dependence test (Pesaran, 2007), and the results are provided in Table-1. Clearly, the cross sections are independent up to 4 lags, and this provides evidence regarding the applicability of the first-generation unit root tests. The results of the unit root tests are provided in Table-2 and indicate that the variables do not demonstrate the presence of unit root problems after their first differences. Therefore, it can be concluded that the variables are integrated to order one, i.e.,  $I(1)$ .

<Insert Table 1 here>

<Insert Table 2 here>

<Insert Table 3 here>

<Insert Table 4 here>

<Insert Table 5 here>

<Insert Figure 5 here>

The results that are estimated by GMM for Eq. 1 are provided in Table-5 and demonstrate that, as a whole, renewable energy consumption has a positive impact on economic growth for

developed and industrialized countries and a negative impact on emerging countries and N-11 countries. This scenario can be explained in terms of the cost aspects of renewable energy generation. If the individual countries of the N-11 panel are considered, then the countries in the developed and industrialized categories can afford the cost of renewable energy implementation without dampening economic growth. Conversely, the immediate impact of renewable energy consumption is noted in the case of the emerging countries because they undertook this initiative at a later stage. Therefore, the impact of this initiative is negative on their economic growth pattern. The overall impact of renewable energy consumption is negative on economic growth of N-11 countries. In contrast, the impact of non-renewable fossil fuel consumption is positive on the economic growth pattern for all panels. The results indicate that non-renewable fossil fuel consumption continues to be the major player in the energy mix and economic growth is driven by energy sources. Therefore, it is not surprising that this impact is positive. Various prior studies noted that non-renewable energy consumption has a positive impact on economic growth and this segment of our result aligns with these studies (for more details, see Ozturk, 2010).

One of the significant findings of this study concerns the impact of biomass energy consumption on economic growth. Because the percentage of this particular form of energy is gradually increasing in the energy mix, the cost of this energy is comparatively lower when compared to renewable energy. Therefore, biomass energy consumption is significantly contributing to economic growth. This result is similar to Bildirici (2013). However, a lack of energy efficiency harms economic growth; this is demonstrated by the negative coefficient of renewable energy waste. Although the impact is not significant for the developed and emerging categories, the impact is negative and significant for industrialized economies and N-11 countries as a whole. This result aligns with Sinha (2015). The waste of renewable energy

demonstrates a lack of energy efficiency, and it is this wasted amount of energy that does not contribute to economic growth. This waste generally includes solid biomass, liquid biomass, and biogas. Because this lack of energy efficiency, as measured by renewable energy waste, negatively impacts economic growth, policy level interventions are required to enhance energy efficiency by reducing energy waste.

These nations are still largely dependent on non-renewable fossil fuel consumption, and these energy consumption patterns subsequently deteriorate environmental quality by creating ambient air pollution, of which the majority is tropospheric CO<sub>2</sub> emissions. These CO<sub>2</sub> emissions gradually create respiratory problems for the labor force that subsequently deteriorate their hygienic state; consequently, economic growth is adversely affected. The negative impact of CO<sub>2</sub> emissions on economic growth bears this evidence. This aspect has been supported by numerous prior studies (e.g., Sebri and Ben-Salha, 2014; Zeb et al., 2014; Shahbaz et al., 2015; Kang et al., 2016; Sinha and Sen, 2016; Wang et al., 2016, and many others). Conversely, the technical effect that is exerted by trade openness impacts economic growth positively and significantly. The coefficient of trade openness for all four cases is positive and significant, which implies that trade openness has a positive impact on economic growth in N-11 economies. This result aligns with the results for Turkey (Ozturk and Acaravci, 2013), newly industrialized countries (Hossain, 2011), BRICS countries (Sinha and Sen, 2016), and several other contexts.

An empirical analysis of the carbon emissions function verifies the existence of an N-shaped relationship between income and CO<sub>2</sub> emissions (Tables 4 and 5). The coefficients  $Y$ ,  $Y^2$ , and  $Y^3$  are positive, negative and positive, respectively, and are all statistically significant. This result validates the existence of N-shaped EKC for all categories. This relationship considers that CO<sub>2</sub> emissions will increase with economic growth to a certain turning point, after which,

emissions will decline with a sustainable level of economic growth; finally, CO<sub>2</sub> emissions will increase again. This N-shaped form of EKC is similar to the results reported by Friedl and Getzner (2003), Martínez-Zarzoso and Bengochea-Morancho (2004), Galeotti et al. (2006), Egli and Steger (2007), Chuku (2011) and numerous other scholars in regard to EKC estimation for CO<sub>2</sub> emissions.

The results reported in Tables 4 and 5 demonstrate that biomass energy consumption exerts a negative and significant effect on environmental quality. This indicates that biomass energy consumption first causes an increase in carbon emissions and then deteriorates environmental quality. Numerous studies support the negative environmental impact of biomass energy consumption (Panayotou, 1993; Foster et al., 2000; Barbier and Burgess, 2001; Victor and Victor, 2002; Ma and Stern, 2008), and our results related to this issue are in agreement with these studies. However, this study examines the effect of the interaction between biomass energy consumption and GDP per capita on CO<sub>2</sub> emissions and confirms that biomass energy consumption leads to a decline in CO<sub>2</sub> emissions when it is associated with increasing economic growth. This result is consistent with Foster et al. (2000) and Victor and Victor (2002). When we consider the N-11 countries, we note that rural electrification is a critical problem for the majority of these countries (Muhammad-Sukki et al., 2012; Fathurrahman, 2016). Most of the rural areas of these nations use forest resources as biofuel. Burning these resources increases the level of CO<sub>2</sub> emissions. Agrawal and Malik (2008) analyzed this issue in the Indian context. To address this problem, technologically improved biomass energy solutions that are ecologically sustainable are introduced, including biogas and bioelectricity. Our results demonstrate that although biomass energy consumption increases CO<sub>2</sub> emissions, when it is coupled with technological innovation, it significantly facilitates a reduction in CO<sub>2</sub> emissions.

In addition, the results of this study demonstrate that trade openness has a negative and significant impact on CO<sub>2</sub> emissions. This result aligns with Jayanthakumaran et al. (2012), Shahbaz et al. (2013a), Al-Mulali et al. (2015b), and Sinha and Sen (2016) and can be justified by considering that trade openness improves environmental quality because the technique effect dominates the scale effect (Ferrantino, 1997; Shahbaz et al., 2012, 2013 a, b). To corroborate this hypothesis, we employ an interaction between trade openness and GDP to analyze the effect that income exerts over trade openness and determine how it affects carbon emissions. This empirical finding confirms that income amplifies the positive effect that trade openness exerts on CO<sub>2</sub> emissions (see Figure-6).

<Insert Figure 6 here>

Figure-7 illustrates the effects of the interaction between income and biomass energy consumption and between income and trade openness on CO<sub>2</sub> emissions. The empirical results reveal that when there is an interaction between income and biomass energy consumption and between income and trade openness, CO<sub>2</sub> emissions are reduced. To clarify, when economies increase their income levels, the negative impact of the scale effect is reduced by reducing CO<sub>2</sub> emissions. Theoretically, when economies increase their income levels, there is an upward economic transition from the developing stage, and this is when the scale effect overcomes the technique and composition effects. Once the economy reaches a certain income level, the composition and technical effects overcome the scale effect and emissions decline with ascending income levels (Torras and Boyce, 1998; Balsalobre et al., 2015). This result indicates the existence of a transition between the developing stage and the developed stage of economic development, where the scale effect on trade liberalization increases exports and subsequently enhances economic growth. To clarify, the composition effect changes the industrial structure of



an economy through trade liberalization and the technique effect boosts economies to use more efficient and cleaner technologies. Consequently, a reduction in CO<sub>2</sub> emissions occurs because of comparative advancements in technologies and improvements in energy efficiency (Shahbaz et al., 2013; Balsalobre and Álvarez, 2016).

This study confirms that renewable energy helps in reducing CO<sub>2</sub> emissions and is evidenced by the negative and significant coefficients of renewable energy consumption in Tables 4 and 5. In addition, we note a positive and significant impact of non-renewable fossil fuel consumption on CO<sub>2</sub> emissions. Therefore, renewable energy consumption ensures environmental protection by reducing carbon emissions, and concurrently, non-renewable fossil fuel consumption endangers the environmental quality by increasing carbon emissions. Considering evidence that has been documented in prior studies, the results of this study are consistent in regards to renewable energy consumption (Bölük and Mert, 2014, 2015; Bilgili et al., 2016; Dogan and Seker, 2016 a, b; Jebli et al., 2016) and non-renewable fossil fuel energy consumption (Halicioglu, 2009; Kasman and Duman, 2015; Ali et al., 2016; Dogan and Seker, 2016b; Magazzino, 2016).

The effect of urbanization on CO<sub>2</sub> emissions is positive and significant and implies that the process of urbanization deteriorates environmental quality by increasing carbon emissions. This result aligns with Lin et al. (2009), Liddle (2013), Iwata and Okada (2014), Huo et al. (2015) and Shahbaz et al. (2016a). Lin et al. (2009) concluded that population is the primary factor that influences CO<sub>2</sub> emissions and that the level of urbanization plays a significant role. Conversely, Liddle (2013) concluded that population size and urban density are the determining factors that affect environmental quality. In a recent study, Shahbaz et al. (2016a) determined

that urbanization initially resulted in low carbon emissions, and after a certain level, decreased environmental quality.

Generally, the results obtained from this study can be summarized based on the individual models. First, biomass energy consumption has a negative impact on environment, and when it is coupled with economic growth, the resultant technique effect has a positive impact on the environment. Second, income-emissions associations in all three categories of nations and in N-11 countries as a whole provide evidence for N-shaped EKC. Third, the impact of renewable energy consumption is negative on the economic growth pattern of N-11 countries. The impact of the technique effect on environmental quality is also verified by the impact of the interaction between trade openness and economic growth on carbon emissions.

## **6. Conclusions and Policy Implications**

This study examines the validity of the environmental Kuznets curve hypothesis in N-11 countries and analyzes renewable and non-renewable energy consumption, biomass energy consumption, trade openness and other additional explanatory variables. The empirical results that were obtained by using the Generalized Method of Moments (GMM) confirm the existence of N-shaped EKC in N-11 countries.

Our results demonstrated that renewable energy has a negative impact on economic growth, but the impact of non-renewable energy positive and significant is positive. This result is consistent with the sub-panel of emerging countries. It is evident that N-11 nations remain dependent on non-renewable energy consumption, and because of the costs of implementing renewable energy systems, renewable energy negatively affects economic growth. However, when we analyze the sub-panels for the developed and industrialized countries, we note that

renewable energy consumption has a positive impact on economic growth. This result implies that countries that began renewable energy generation processes at an earlier stage reaped the benefits. Therefore, policymakers of the emerging countries should focus on the long-term benefits of renewable energy generation and retain both renewable and non-renewable energy sources in the economic system. These countries should also emphasize technology diffusion via a trade route because it has a significant positive impact on economic growth. However, N-11 countries should place more emphasis on renewable energy generation processes because they not only provide long-term benefits on economic growth but also help these countries achieve sustainable development goals. Implementation of this energy generation process can have a significant impact on environmental quality by reducing CO<sub>2</sub> emissions, which have a significant negative impact on economic growth. This ecological problem is more severe in emerging countries; compared to the other two sub-panels, these countries are faced with energy poverty issues. Successful nationwide implementation of renewable energy generation solves problems related to energy poverty in these nations and can directly impact the social and ecological situations in these nations by enhancing income growth. Therefore, policymakers should overlook short-run economic losses that result from renewable energy generation processes and should consider this situation from a long-term perspective.

This impact is more noticeable when we compare the EKC's generated in this study. Our results demonstrate that the EKC's are N-shaped for all three sub-panels and for the N-11 countries. These results imply that the present economic growth pattern may not be ecologically sustainable because the level of emissions increases as income increases until it reaches the first turnaround point. If we consider the individual components of this model, it is clear that renewable energy consumption has a negative impact on CO<sub>2</sub> emissions, and both non-renewable

and biomass energy consumption cause an increase in CO<sub>2</sub> emissions. In reference to the discussion regarding energy poverty in the previous paragraph, it can be stated that the unsustainable use of biomass energy sources in rural areas increases the ambient air pollution, and its effect is similar to the effect of non-renewable energy consumption. However, when biomass energy consumption interacts with economic growth, the interaction effect reduces CO<sub>2</sub> emissions. This result implies that the quality of biomass energy sources should be enhanced along the course of economic growth, and this is only possible by using an inclusive growth approach. Following this approach, policymakers can reduce the usage of ecologically unsustainable biomass energy sources in rural areas, and using technology diffusion can make high end biomass energy sources available to rural populations. In addition, the existing biomass energy sources can be replaced with new sources in a phase-wise manner; therefore, it will also be easier to complete the entire initiative without harming economic growth. It might also be possible for policymakers to replace non-renewable energy sources using the same phase-wise manner to ensure that the shift from non-renewable to renewable energy sources does not harm their economic growth patterns. Clearly, new biomass energy sources should be provided to households, and renewable energy solutions should be provided to industries because the cost of renewable energy implementation is greater than for biomass energy implementation. Although countries may incur certain short-run economic losses, they may be able to receive rent from the renewable and technologically improved biomass energy sources that are provided to households and industries. These rents can add to economic growth through interest income. Governments can invest this excess income from the economic rents and use it to expand existing renewable energy generation processes. Through this process, governments may possibly achieve their renewable energy goals that were set at national levels within specified periods.

It should be noted that increasing rates of urbanization in these nations are exerting pressure on environmental quality. Therefore, the phase-wise shift from non-renewable to renewable energy sources may be beneficial to address increasing pressures on urban infrastructure. This phase-wise transition should have a next step where urban households are provided opportunities to procure renewable energy sources at a pro rata rate from the government. The government may impose interest based on the capacity of the renewable energy source, and the interest income that is received from the urban households may help the government subsidize the price of the improved biomass energy sources in rural areas. In this manner, (a) the energy poverty issue may be effectively addressed, (b) problems related to increasing CO<sub>2</sub> emissions can be addressed, (c) economic growth will not be harmed by importing costly renewable energy based technologies, and (d) households and industries will be motivated to embrace the shift.

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