Renewable Energy Policies and Contradictions in Causality: A case of Next 11 Countries

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Abstract

Numerous studies on the causal relationship between economic growth, energy consumption and carbon dioxide (CO_2) emissions have shown divergence in policy recommendations, which arises mainly due to the choice of methodology and the period of study. This inconclusiveness in policy prescriptions might turn out to be critical, when the renewable energy policies of the developing nations are considered. Our study analyses the causal relationship between economic growth, carbon emissions, fossil fuel and renewable energy consumption in Next 11 countries during the period of 1990-2016. Along with conducting parametric and non-parametric causality tests together, introducing the Geweke (1982) causality test in the literature of energy economics, we attempt to establish a wholesome aspect of policy design, by comparing and complementing results of different causality analysis, and how the causality directions should comply with the context setting. Our empirical evidence confirms that robust renewable energy policy can be designed by complementing the various causality test results, rather than focusing on one particular causality test.

Keywords: Renewable Energy Policy; CO_2 Emissions; Geweke Causality; Next 11 Countries

1. Introduction

Energy consumption is one of the most important drivers of economic growth in any nation, and this energy is consumed predominantly in the form of fossil fuel consumption. However, it cannot be ignored that continuous consumption of fossil fuel energy over years has resulted in several ecological issues, majorly in the forms of rapid exhaustion of natural resource pool and increase in carbon emissions in the ambient atmosphere. Nations are gradually recognizing this intensifying environmental issue, and consequently, they have started developing clean technology solutions in pursuit of the gradual transformation from non-renewable energy sources to renewable energy sources. Under such circumstances, an increase in the share of renewable energy use in the total energy mix can be observed in recent years (see, Yang et al., 2016; Kung et al., 2017; Paramati et al., 2017; Zhang et al., 2017; Shahbaz et al., 2017; Sinha et al., 2017; Sinha and Shahbaz, 2018).

From this discussion, it is assumed that the trilateral association between economic growth, energy consumption, and environmental degradation may appear to be significant from the perception of sustainable development, which is largely dependent on managing the energy challenges. From the perspective of emerging economies, this energy challenge can be observed in a dual form in these countries (Lin and Moubarak, 2014; Shahbaz et al. 2015, 2016). First, these nations are being faced with the problem of energy security and energy poverty. Second, these nations are in the transition phase to implement nationwide clean or low carbon energy systems, without compromising on economic growth. The "Next-11" or N-11 countries are characterized by these two phenomena.[1] These countries approximately represent 7.94% of the global GDP (World Bank, 2016a) and generate nearly 11.2% of global CO_2 emissions (EIA, 2015). These two reported statistics explain the growing environmental concerns caused by the present pattern of economic growth in N-11 countries, and these

[1] These countries include Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, the Philippines, Turkey, and Vietnam (Eghbal, 2008).

problems reflect the *Limits to Growth* problem identified by the economists from *Club of Rome* (Meadows et al., 1972). Given the conflicting objectives prevailing in these countries, a renewable energy system can provide a profitable and sustainable solution for both industrialization and rural electrification, and thereby, can provide an opportunity for these nations to be less dependent on fossil fuel.

The extant literature on the relationship between economic growth, CO_2 emissions, and energy consumption from renewable and non-renewable sources has shown conflicting results for any given context. These conflicting results have occurred due to the use of different methodologies on the same data sets (Ocal and Aslan, 2013; Dogan, 2015), or using different time periods (Alam et al., 2012, Amin et al., 2012). Therefore, researchers and policymakers cannot make any unified conclusion regarding policy implications, following the results of the studies on any region(s). If the dataset is kept same, then the nexus among economic growth, CO_2 emissions, and energy consumption varies based on the assumption of associative linearity among the variables. Based on this argument, it can be said that, parametric and non-parametric causality tests on the same dataset might provide conflicting results, and this conflict can be seen in subsequent policy implications. Therefore, in order to suggest sound policy implications about the renewable energy policy in any nation(s), the causal associations between the aforementioned three variables must be robust, and there lies the objective of the present study. Researchers have identified that traditional parametric and non-parametric causality tests might not provide expected results in case of low frequency data, which is mostly used in the form of annual data (Bahmani-Oskooee, 1993; Pan et al., 2007; Fernandez-Perez et al., 2016). For a low frequency dataset, the causality test should address the contemporaneous correlation, which parametric (e.g., Granger, 1969) and non-parametric causality tests (e.g., Diks and Panchenko, 2006) cannot address. There comes the role of Geweke (1982) causality test, which can complement the results of traditional parametric and non-parametric causality tests by addressing the issue of contemporaneous correlation. In this study, we have analysed the nexus between economic growth, CO_2 emissions, fossil fuel consumption, and renewable energy consumption for N-11 countries over the period of 1990-2016. In doing so, we have chosen Granger (1969) causality test, Diks and Panchenko (2006) causality test, and Geweke (1982) causality test. Subsequent to this, we have compared the results of Geweke (1982) causality test with Granger (1969) causality test and Diks and Panchenko (2006) causality test. This comparison of results demonstrated how the inconsistencies in the policy implications derived from parametric and non-parametric causality tests are addressed by Geweke (1982) causality test results.

According to the findings of the earlier studies, there are certain research gaps. For instance, we have not come across any study that compares and complements the results of different causality tests from a policy prescription perspective, in keeping with the contextual setting. Moreover, results of studies focusing at renewable energy policies are inconclusive in terms of their policy prescriptions, and we have not also come across any study, which addresses this void in the literature. Complementing the results of one causality test with another can be crucial for designing a holistic renewable energy policy, given the context of emerging economies. This study has four contributions to existing literature of energy economics. (i) This study applies parametric and non-parametric approaches to examine the causal relationship between economic growth, carbon emission, fossil fuel and renewable energy consumption for N-11 countries, which demonstrates the discrepancies in empirical results, followed by differing policy implications. (ii) This study introduces Geweke (1982) causality test in the literature of energy economics. (iii) This study puts forth the comparative analysis in terms of policy implications, and demonstrates how the results of different causality tests are complemented by each other. (iv) We have also considered three subpanels in accordance with World Bank (2016a) classifications (developed, newly industrialized, and emerging countries). (v) Our results show how robust renewable energy policies can be designed by means of complementing the results of causality tests, which has by far not been addressed in existing literature.

The remaining paper is organized in the following manner. Section-2 presents the literature review on the nexus among fossil fuels, renewable energy, carbon emissions, and economic growth in N11 countries, Section-3 gives an overview of the existing renewable energy policies and initiatives in N11 countries, Section-4 explains the empirical model and gives a brief description of the data, Section-5 presents the analysis of the results, Section-6 describes the theoretical and practical implications of the study, and Section-7 concludes the paper by highlighting the key contributions in terms of methodological adaptations and the policy implications.

2. Literature Review

The causal association between economic growth, energy consumption and carbon emissions have been extensively studied over last few decades (see, Ozcan, 2013; Farhani and Shahbaz, 2014; Alper and Onur, 2016; Sinha et al., 2017; Sinha and Shahbaz, 2018, among others). Our study attempts to revisit the relationship among economic growth, carbon emissions, fossil fuel, and renewable energy consumption to highlight the divergence in policies reported in various studies, which might occur due to the different methodological adaptations and/or choice of different time periods. The studies reviewed in this section are the ones, which have analyzed the nexus among economic growth, carbon emissions, and energy consumption for N-11 countries. This review has been carried out by classifying N-11 countries as developed, newly industrialized, and emerging countries (World Bank, 2016a), and this classification will help to retain the objective of the study and identify the research gap.

Let us begin with the developed category. In South Korea, using the Markov switching model, Park and Hong (2013) reported that carbon emissions do not have any impact on economic growth, and unidirectional causality is found running from energy consumption to carbon emissions, during the period 1991-2011. They further suggest that there is a need to control CO_2 emissions either by decreasing energy consumption or through use of alternative sources of energy. On the contrary, using the panel causality tests, Pao et al. (2014) conducted the study over the period 1990–2010 and found that renewable energy causes economic growth and bidirectional causality exists between economic growth and fossil fuel consumption. Grounded on the obtained results, the authors suggested the promotion of renewable and nuclear energy use to tackle the problem of climatic shift and energy security. We can observe that the studies have used different time periods and methodologies, and the policy implications emerging out of these studies diverge in terms of proposing a common framework for policy makers in South Korea. Though the policy implications complement each other, but when they are observed individually, the issues addressed by them differ, as the policy targets differ by the obtained results.

Now, we will move towards the newly industrialized category of N-11 member countries. In Indonesia, conflicting results can be found, even though similar methodologies were adapted. Arifin and Syahruddin (2011) proposed that increase in consumption of renewable energy would have increased GDP of Indonesia during period of 1971-2008 and could reduce the dependence on non-renewable energy sources. This policy was inferred based on the evidence of growth hypothesis between renewable energy and economic growth and neutrality hypothesis between fossil fuel consumption and economic growth. However, a conflicting policy directive is reported from the results obtained by Lean and Smyth (2010). They found that energy consumption and carbon emissions have direct causal impacts on economic growth for the period of 1980-2006. Their empirical analysis suggested that

Indonesia should promote energy consumption to foster economic growth without providing any directive on energy security or climate change issues. Such contrast in policy implications can be observed for the context of Mexico also. Pao et al. (2014) stressed on the need for developing renewable energy solutions for tackling climatic shift and energy security issues. In another study, conducted during the period of 1971-2007 and using Granger causality test, Lee and Yoo (2016) found that carbon emissions cause economic growth, economic growth causes energy consumption, and bidirectional causality exists between energy consumption and carbon emissions. They propose energy conservation policies to ensure energy security and to address carbon emission issues. Though the policy targets are same, these two studies conducted in Mexico show divergence in the implementation of policies. A similar kind of situation can be seen in the case of Iran. Using the Toda-Yamamoto procedure, Lotfalipour et al. (2010) concluded that during 1967-2007, carbon emissions and fossil fuel consumption have no causal impacts on economic growth. Considering energy not to be an agent of economic growth, the researchers opined for conservative energy policies, along with replacement of traditional fossil fuel energy sources with alternate cleaner energy sources. In another study, following the same methodological approach, Mahmoodi and Mahmoodi (2011) found no causal impact of renewable energy consumption on economic growth during the period of 1985-2007. It is difficult to comment on energy policies of Iran with respect to renewable energy sources, as the finding of the second study indicates renewable energy consumption not as an catalyst of economic growth, and thereby, leaving equal probabilistic choices for Iran to adapt either a conservative energy policy or an aggressive renewable energy policy. Now, we will look into the context of Philippines. Apergis and Payne (2011), using the panel Granger causality approach, showed that renewable energy and fossil fuel consumption had bidirectional causal relationships with economic growth, during the period of 1990-2007. The policies suggested by the authors indicate that energy security can be achieved by focussing on renewable and non-renewable sources of energy, while the interdependence between sources of energy requires multilateral approaches to achieve energy efficiency. In another study conducted over the period of 1956-2012, Lim et al. (2014) suggested that reduction in CO_2 emissions could be achieved through energy efficiency, without considering the scope of renewable energy sources. The empirical results indicate that there lies a dichotomy in terms of achieving energy efficiency, and consequently, policy implications recommended by these two studies differ. A similar kind of divergence in policymaking can be observed in case of Turkey. Soytas and Sari (2009) analysed the nexus between economic growth, CO_2 emissions, and energy consumption in Turkey during the period 1960-2000, using Toda-Yamamoto causality approach. They argued that the only way of meeting carbon emissions targets is to reduce fossil fuel consumption, as the vital source of electricity supply is coal fired power plants. In a different study conducted during the period 1990-2011. Using the ARDL approach for the same variables, Dogan (2015) proposed that for ensuring long-lasting economic growth, policy makers of Turkish government should enforce the reduction of electricity consumption from renewable sources and promote use of electricity produced from non-renewable sources. These studies show the dichotomy regarding the usage pattern for fossil fuel for fostering economic growth.

Similar kind of results can be seen for the emerging N-11 member countries. In case of Bangladesh, Apergis and Payne (2011) analysed the association between energy consumption and economic growth for the period of 1990-2007 using Granger causality test. They focussed on ensuring energy security by proposing that both renewable and non-renewable sources of energy should be promoted to ensure economic growth. However, the study conducted by Alam et al. (2012) during 1972-2006, indicated the policymakers to focus solely on alternative sources of energy to meet energy demand. These two studies demonstrate the divergence in energy policies recommended for Bangladesh. Now, we will look into the case of Pakistan. Apergis and Payne (2011) mentioned the importance of interdependence of fossil fuels and renewable energy for Pakistan, thus having a major focus on energy security. This finding has been contradicted in several studies. Using different set of variables, methodological adaptations, and different study periods, the studies by Ali et al. (2015) and Shahbaz et al. (2015) show the policy implications in terms of focusing on renewable sources of energy to ensure economic growth, as well as, to tackle issues of climatic shift. The policies show an apparent divergence in either the policy target or the implementation of the policies. A nearly similar kind of scenario can be seen in the case of Vietnam. Tang and Tan (2015) focused on the implementation of clean technologies and strengthening of environmental regulations, while analyzing the causal association between income, energy consumption, CO_2 emissions, and foreign direct investment (FDI) for the duration of 1976-2009. An earlier study by Dinh and Shih-Mo (2014) conducted during 1980-2010 found that bidirectional causal association exists between carbon emissions and income, and energy consumption and income, respectively. They have opined that policymakers should focus on investment in energy infrastructure, so that energy efficiency can be achieved via reduction of energy waste. For Nigerian economy, Akpan and Akpan (2012) analysed the causal association between electricity consumption, carbon emissions, and economic growth for the period 1970-2008 using error correction approach. Based on the empirical findings, authors suggested to invest on cleaner technologies by replacing old polluting technologies, to address energy efficiency and climatic shift issues. Rafindadi (2016) analysed the causal association between economic growth, energy consumption, financial development, trade openness, and CO_2 emissions for the period of 1971-2011 using Granger causality approach. The empirical results suggested the use of green energy technologies in production process for enhancing energy efficiency. Lastly, we will observe the divergence in policies for the case of Egypt. Mensah (2014) analysed the causal association between energy use, real GDP and CO_2 emissions for the period of 1971-2009, and the author prescribed investing into energy efficient and clean technologies to engender green growth. Recently, Ibrahiem (2016) analysed the causal association among CO_2 emissions, economic growth, energy consumption, trade openness, and population density for the period 1980-2010, and the researcher proposed that energy growth will not be influenced by energy conservation policies, and it can reduce carbon emissions, as well. So, the divergence can be seen in this context also.

Through this review of the literature on the causal analysis of association between income, energy consumption, and CO_2 emissions, we have observed that the policy recommendations given by the authors differ largely by the choice of methodology, and choice of study period. During the course of this review of literature, we have not come across a study, where the complementary nature of multiple causality analysis methodologies is considered, so that a complete picture coming out of the results can give a comprehensive policy recommendation. We also haven't come across any study, which discusses the divergence in the policies coming out the inconclusive results of causality analysis.

3. Overview of N-11 Countries

The growth in economic activities in N-11 countries is majorly driven by the rise in industrial activities, and it creates a demand for energy in these nations. As the consumption of electricity is enabling growth in every sector, the demand of energy is rising in these nations is rising along with economic growth (Figure-1). In 2016, CO_2 emissions in N-11 countries account for 12.41 per cent of the worldwide CO_2 emissions, while they account for more than 10 per cent of worldwide income generation (EIA, 2015; World Bank, 2016b).

<Insert Figure 1 here>

South Korea's energy policy aims to produce 6.1% of energy from renewable sources by 2020, and the government is planning to twice this share by 2030 (Shin, 2015).

Furthermore, it is predicted that South Korea has wind power potential of 186.5 TWh per year, and the tidal power has potential of generating 552 million kWh per year (Chanal and Meisen, 2012). The present energy policy also includes investing in the international alternate energy market and implementing energy efficient building for sinking energy wastage.

For Mexico, hydropower consitutes the main share of renewable energy, with installed capacity of 11,603 MW, followed by geothermal power capacity of 958 MW. Presently, Mexico is ranked 4th in the world in terms of using geothermal energy. Apart from that, Mexico has wind energy potential of 71,000 MW, even though only 1.7% of this potential is currently in use (Huenteler et al., 2016). Presently, Mexico is the third country in the world in terms of potential invest destination in photovoltaic power projects, after China and Singapore (Alemán-Nava et al., 2014).

As the economy of Turkey has been reliant more on natural gas, renewable energy policy of Turkey is targeted at increasing the share of renewable energy in total energy production by more than 25 percent over next five years. Under this scheme, most emphasis has been given on the unexplored sources of hydropower, windmill installations, and geothermal power (Yagcitekin et al., 2015). Moreover, Turkish Energy Regulatory Agency (EMRA) has highlighted how biofuels can significantly add value to the existing energy mix. As per the new renewable energy policy of Bangladesh, the share of renewable energy is expected to reach a double digit percentage of the national energy mix by next three years (Baul et al., 2018). This progress has been formalized by formation of Directorate of Renewable Energy and Research & Development.

Vietnam is expecting an increase of nearly 1000 per cent in electricity demand by end of next decade, which is nearly three times higher than the projected energy demand. This steep rise in the demand of electricity might be attributed to the problems of poor rural coverage in the national electrification programme, as well as, continued reliance on the fossil fuel as the primary source of energy. While responding to these problems, the government of Vietnam is looking forward to increase the share of renewable energy in energy mix by more than 30 per cent by the end of next decade (Ahmed et al., 2017), as this solution is expected to address both the energy-related predicaments being faced by Vietnam. This issue of energy shortage can also be seen in case of Iran. In order to combat this situation, Iran is putting special emphasis on hydroelectricity projects and solar panels. The potential of renewable energy generation in Iran has been attracting European investors, and this is giving the renewable energy sector a new boost (Dudley, 2017).

The issues of rural electrification with high demand for electricity are present in case of Indonesia, as well. By the end of next decade, the Indonesian government is targeting at raising the share of energy from alternate sources by at least 125 per cent in the existing energy portfolio (Liu et al., 2017). This characteristically similar problem has been encountered in case of Egypt, and in order to tackle this problem, the government is channelizing the monetary and physical resources in the discovery of alternate energy resources. This initiative by government is being targeted at increasing the pie of renewable energy to be at least one-fifth in energy portfolio by 2022 (Abdulrahman and Huisingh, 2018), and this step has turned Egypt to be a profitable investment destination for the European renewable energy firms (Dudley, 2017).

Unlike other nations, Nigeria has already started facing the problem of rapid natural depletion, leading towards the problem of energy security, which the other nations are still expecting to face. In order to handle this issue, the government of Nigeria has introduced *Vision 20*, which is specifically designed for providing boost to renewable energy generation sector (Akuru et al., 2017). By the end of next decade, the Nigerian government is expecting renewable energy to attain at least one-fifth of the energy portfolio.

A boost in the renewable energy generation inititive can also be seen in case of Philippines, where the government is targeting to increase the share of renewable energy in the energy mix by two-fold, by the end of next decade (Lee et al., 2017). In order to make this solution socially sustainable, government has started to welcome people-private-public partnerships, so that the awareness regarding the advantages of renewable energy can be increased, and the organizations are persuaded to implement the usage of renewable energy sources for their respective production processes.

Finally, for combating the energy security and rural electrification issue, the government of Pakistan is relying more on hydroelectricity sources, which can be expanded up to 60 GW (Zafar et al., 2018). With an expectation of possible reduction in communal disparities, the government of Pakistan is emphasizing on the discovery of alternative energy sources, which might also decrease the reliance of Pakistani economy on fossil fuel consumption. In a nutshell, it is evident that N-11 countries need renewable energy as a solution for sustainable growth, and public infrastructure is complementing these initiatives. It can be expected that moving along this trajectory, N-11 countries might be able to move from non-renewable energy to renewable energy resources, and thereby, dipping carbon emissions and ensuring sustainable development.

4. Empirical Model and Data

In this study, our objective is to compare the results of three different causality tests, and the policy implications coming out of the results of those tests. In order to achieve this, we have selected the parametric and non-parametric causality tests, along with the Geweke (1982) causality test. The parametric and non-parametric causality tests are chosen in order to explain the linear and non-linear associations between the variables under consideration.

4.1. Granger (1969) Causality Test

Under the parametric causality test with the assumption of linear relationship, we apply the Granger causality test (Granger, 1969). This test has been chosen owing to its applicability to large and small sized sample sizes. The estimation model can be explained as per the following:

$$\begin{bmatrix} \Delta Y_{i,t} \\ \Delta C_{i,t} \\ \Delta F_{i,t} \\ \Delta R_{i,t} \end{bmatrix} = \sum_i \sum_t \left(\begin{bmatrix} \alpha_{i,t} \\ \alpha_{i,t} \\ \alpha_{i,t} \\ \alpha_{i,t} \end{bmatrix} + \begin{bmatrix} \beta_{11\,i,t} & \cdots & \beta_{14\,i,t} \\ \vdots & \ddots & \vdots \\ \beta_{41\,i,t} & \cdots & \beta_{44\,i,t} \end{bmatrix} \begin{bmatrix} \Delta Y_{i,t-1} \\ \Delta C_{i,t-1} \\ \Delta F_{i,t-1} \\ \Delta R_{i,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{i,t} \\ \varepsilon_{i,t} \\ \varepsilon_{i,t} \\ \varepsilon_{i,t} \end{bmatrix} \right) \quad \ldots (1)$$

where, Y is GDP, C is CO_2 emissions, F is fossil fuel consumption, R is renewable energy consumption, ε is the white noise error term, i is the countries ($i = 1, 2, \ldots, N$) and t is the years ($t = 1, 2, \ldots, T$). In this system of equations, the null hypothesis of no Granger causality can be expressed by $\beta_{i,t} = 0$, and it can be validated by the joint significance of coefficients, derived from Wald statistics.

4.2. Diks and Panchenko (2006) Causality Test

As the Granger causality test fails to accommodate the possible non-linear associations among the variables, non-parametric causality tests are required. First generation non-parametric causality tests were derived by Baek and Brock (1992) and Hiemstra and Jones (1994). However, these tests suffer from various shortcomings. The Baek and Brock (1992) test assumes the time series to be having no endogeneity issues and uniformly distributed across the cross-sections. Though this problem was addressed in the test designed by Hiemstra and Jones (1994), it disregards the potential deviations in restricted distributions. This issue was identified by Diks and Panchenko (2005), and was addressed in Diks and Panchenko (2006).

Taking a bivariate case, the null hypothesis of the Granger causality between series X_t and series Y_t can be specified as:

$$H_0 : \; Y_{t+1} \big| \left(X_t^{lx}; Y_t^{ly} \right) \sim Y_{t+1} \big| Y_t^{ly} \quad \ldots (2)$$

where, *lx* and *ly* respectively denote the lagged observations of *X* and *Y*. Now, if we assume $Z_t = Y_{t+1}$, and equation-2 is made time independent, then equation-2 takes the form with respect to the joint distributions that the joint probability density function $f_{X,Y,Z}(x, y, z)$ and its partial differentials must fulfil the following condition, which unequivocally reveals that *X* and *Z* are independent conditionally on $Y = y$ for each fixed value of y.

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \cdot \frac{f_{Y,Z}(y,z)}{f_y(y)} \qquad \ldots (3)$$

Given the condition, the null hypothesis of no Granger causality can be specified as per following:

$$\theta \equiv E\left[f_{X,Y,Z}(X,Y,Z)f_Y(Y) - f_{X,Y}(X,Y)f_{Y,Z}(Y,Z)\right] = 0 \qquad \ldots (4)$$

where, $\hat{f}_C(C_i)$ is a restricted density estimator of a d_C-variate random vector *C* at *Ci* denoted by $\hat{f}_C(C_i) = (2\varepsilon_n)^{-d_C}(n-1)^{-1}\sum_{j j\neq i} I_{ij}^C$ that $I_{ij}^C = I\left(\left\|C_i - C_j\right\| < \varepsilon_n\right)$ with indicator function $I(.)$, bandwidth ε_n, and the sample size as *n*. Based on these estimators, equation-4 can be written as per the following:

$$T_n(\varepsilon_n) = \frac{n-1}{n(n-2)}\sum_i\left[\hat{f}_{X,Y,Z}(X_i,Y_i,Z_i)\hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i,Y_i)\hat{f}_{Y,Z}(Y_i,Z_i)\right] \qquad \ldots (5)$$

If $\varepsilon_n = Cn^{-\beta}$, given $C > 0$, $1/4 < \beta < 1/3$, and single lag specification, equation-5 takes the following form:

$$\sqrt{n}\frac{(T_n(\varepsilon_n) - \theta)}{S_n} \xrightarrow{con} N(0,1) \qquad \ldots (6)$$

where, $\xrightarrow{con}$ signifies the convergence in the distribution, and S_n is indicative asymptotic variance of $T_n(.)$. Consequently, it can be observed that if Diks and Panchenko (2006) test statistic measured in equation-6 is greater than 1.28, the null hypothesis of no causality can be rejected at 10 per cent level.

4.3. Geweke (1982) Causality Test

Let us assume that there are two series, i.e. *X* and *Y*. Assuming the stationarity of both the series and presence of cointegrating association between them, Geweke (1982) suggested the following forms of causal association between the two series:

$$X_{i,t} = \alpha + \sum_t \sum_i \beta_{i,t} X_{i,t-1} + \varepsilon_{1_{i,t}}, Var\left(\varepsilon_{1_{i,t}}\right) = \sigma^2_{1\,i,t} \quad \dots (7)$$

$$X_{i,t} = \alpha + \sum_t \sum_i \beta_{i,t} X_{i,t-1} + \sum_i \sum_{t=1}^{T} \gamma_{i,t} Y_{i,t-1} + \varepsilon_{2_{i,t}}, Var\left(\varepsilon_{2_{i,t}}\right) = \sigma^2_{2\,i,t} \quad \dots (8)$$

$$X_{i,t} = \alpha + \sum_t \sum_i \beta_{i,t} X_{i,t-1} + \sum_i \sum_{t=0}^{T} \gamma_{i,t} Y_{i,t-1} + \varepsilon_{3_{i,t}}, Var\left(\varepsilon_{3_{i,t}}\right) = \sigma^2_{3\,i,t} \quad \dots (9)$$

$$X_{i,t} = \alpha + \sum_t \sum_i \beta_{i,t} X_{i,t-1} + \sum_i \sum_{t=-m}^{T} \gamma_{i,t} Y_{i,t-1} + \varepsilon_{4_{i,t}}, Var\left(\varepsilon_{4_{i,t}}\right) = \sigma^2_{4\,i,t} \quad \dots (10)$$

Now, all of these associations follow asymptotic Chi-square distribution. Assuming the degree of freedom as *d*, the maximum likelihood procedures of determining the causality are as per the following:

$$\text{Instantaneous causality: } \ln\left(\sigma^2_{2\,i,t} / \sigma^2_{3\,i,t}\right) * n \sim \chi^2(1) \quad \dots (11)$$

$$\text{Total causality: } \ln\left(\sigma^2_{1\,i,t} / \sigma^2_{4\,i,t}\right) * n \sim \chi^2(2d+1) \quad \dots (12)$$

In equation-11 and 12, it can be seen that Geweke causality test considers the instantaneous and total causality. While considering any dataset of low frequency, instantaneous correlation between variables can be missed, and this issue is present in Granger (1969) causality test and Diks and Panchenko (2006) causality test. Using the residuals of Granger (1969) causality tests, Geweke causality test can capture the instantaneous feedback. This causality approach takes care of the non-linear association between variables, as well. Owing to these reasons, Geweke causality test complements the problems of Granger (1969) and Diks and Panchenko (2006) causality tests.

4.4. Data

For empirical analysis, we consider the data for N-11 countries from 1990 to 2016. The per capita annual data for CO_2 emissions (in kt), GDP (constant 2010 US$), renewable energy consumption (in kt), and fossil fuel energy consumption (in kt) were collected from

World Bank Indicators[2]. For bringing more insights, we segregated the dataset of N-11 countries under three categories. These categories are the developed countries (South Korea), the newly industrialized countries (Indonesia, Mexico, Iran, Philippines, and Turkey), and the emerging countries (Bangladesh, Egypt, Nigeria, Pakistan, and Vietnam). World Bank (2016a) provided this classification.

5. Results and their Discussions

The analysis of the dataset starts with checking of cross-sectional dependence, and in order to achieve this, we have employed the cross-sectional dependence (CD) test devised by Pesaran (2006). The null hypothesis of Pesaran (2006) CD test is that there is no dependence among the cross sectional units, and it is calculated by the mean of bilateral correlation coefficients of ADF regression residuals for every cross-section. The results of this test are presented in Table-1, and the results show rejection of the null hypothesis. The strength of the cross-sectional dependence is further checked by Chudik and Pesaran (2015) test, with the null hypothesis of weak cross-sectional dependence. The empirical results in Table-1 depict that the cross-sections of the panel are strongly dependent on each other, and therefore, we can employ second generation unit root test.

<*Insert Table 1 here*>

For examining the integration order among the variables, cross-sectional Im-Pesaran-Shin (CIPS) and cross-sectionally augmented Dickey-Fuller (CADF) unit root test devised by Pesaran (2007) are utilized. These tests are second generation unit root tests, which are based on the assumption that in a panel dataset, there is cross-sectional dependence. The CIPS unit root test is an extension of Im-Pesaran-Shin (IPS) (2003) with single factor having heterogeneous loading across cross-section. It is a cross-sectionally augmented IPS Dickey Fuller type test, which takes account of cross-sectional means of undifferentiated and lagged-

[2] World Bank, 2017. World Bank Indicators CD-ROM.

differentiated IPS-type regression residuals. In this test, the p-value of Breusch-Godfrey Lagrange multiplier test of each specific regression is reported. On one hand, the null hypothesis of homogeneous non-stationary is examined in contrast to the alternate hypothesis of heterogeneous alternatives. On the other, CADF test is derived from the mean of augmented Dickey-Fuller (ADF) t-statistic of every panel member. The null hypothesis of this test asserts that the series in the panel are non-stationary, which is contrary to alternate hypothesis, where only one part of the series is stationary.

Table-2 presents the results, and it is visible that the variables are free from unit roots after first differentiation. Hence, we can conclude that the order of integration among the variables is 1, i.e., the variables are I(1).

<*Insert Table 2 here*>

As the variables are I(1), it is possible that in the long-run, the variables might be cointegrated. This is scrutinized using the Westerlund (2007) test of cointegration. This test is based on structural dynamics, and therefore, it does not require the common factor restriction. The test statistics follow an asymptotical normal distribution and have good small-sample properties. Besides, this particular test is capable of accommodating heterogeneity and cross-sectional dependence by using the bootstrap.

Table-3 presents the results of the Westerlund (2007) cointegration test (details of the test is provided in Appendix-1). The test statistics indicate that the variables are cointegrated at 1% significance level, i.e., these variables are associated for long run.

<*Insert Table 3 here*>

As we have already found the cointegrating association between the variables across the samples, we can now proceed towards the causality analysis.

5.1. Comparison of Parametric and Geweke Causality Analysis

We will start analyzing the results of causality analysis by comparing the results of Granger (1969) causality test and Geweke (1982) causality test. Table-4 presents the results of Granger (1969) causality test, and the comparative results of both the tests are given in Table-6. We will now observe how the policy implications, when the results of both the tests are compared.

<Insert Table 4 here>

For the developed countries, the results of parametric causality test show that the rise in fossil fuel consumption directly affects CO_2 emissions, and the pattern of economic growth in these countries catalyzes renewable energy consumption. Moreover, rises in CO_2 emissions and fossil fuel consumption have their direct impacts on renewable energy consumption. This empirical finding is in similar lines with Shin (2015). However, this segment of findings gives no information about the impacts of CO_2 emissions and fossil fuel consumption on economic growth pattern, and vice versa. The results of Geweke (1982) causality test give the answer to these voids. The results of this test reveal significant bidirectional causal associations between CO_2 emissions, fossil fuel consumption, and economic growth. Though the results of Granger causality analysis show that fossil fuel consumption negatively affects ambient air quality, it is silent about its effect on economic growth, which is revealed by the results of Geweke (1982) causality analysis. It divulges the trilateral association between CO_2 emissions, fossil fuel consumption, and economic growth. These bidirectional associations reveal the ecologically unsustainable nature of economic growth. This phenomenon has already been indicated by Park and Hong (2013). The percentage of renewable energy generation is insignificant in energy mix under this category, it might be too optimistic to expect the effect of renewable energy consumption on CO_2 emissions. However, it cannot be denied the economic growth pattern resulted in energy security and carbon emissions issues, which demanded the rise in renewable energy consumption, and therefore, we can expect that it directly and positively affects economic growth. This expected impact of clean energy policy for these nations are analogous to empirical findings of Park et al. (2013).

Now, let us move towards the newly industrialized countries. The results of parametric causality test show the bidirectional causal associations between CO_2 emissions and fossil fuel consumption, and CO_2 emissions and economic growth. These associations indicate the effect of economic growth pattern and fossil fuel consumption on ambient air quality, and the effect of CO_2 emissions on economic growth pattern. This segment of results is similar to the findings of Geweke (1982) causality analysis. However, the unidirectional causal association between fossil fuel consumption and economic growth signifies that economic growth being achieved by these nations is majorly driven by the consumption of fossil fuel. This evidence seems to be inconclusive, as a rise in economic growth should call for more energy, and the rising demand for fossil fuel based energy might lead to energy security and energy poverty related issues. This logical inconsistency is tackled by the bidirectional causal association between fossil fuel consumption and economic growth, which is divulged by empirical results of Geweke (1982) causality analysis. This segment of results provides the rationale behind the emergence of renewable energy generation in these nations, as indicated by Yıldırım et al. (2014) and Shahbaz et al. (2016). In order to address energy security, energy poverty, and environmental degradation related issues, and that too without harming economic growth pattern, renewable energy is increasingly becoming a sustainable alternative for fossil fuel consumption in these nations.

Now, we will move towards the emerging countries. The results of parametric causality test show that fossil fuel consumption directly affects CO_2 emissions and economic growth, whereas CO_2 emissions also directly affect economic growth. It is quite evident from this segment of the results that the driver of economic growth is actually instigating damage to the growth pattern. This segment of results is similar to empirical findings of Alam et al. (2012), Shahbaz et al. (2012), Tang and Tan (2015), Esso and Keho (2016), and several others. However, the effect of renewable energy consumption is still not much significant in these countries, and therefore, it will be too optimistic to expect that renewable energy consumption will directly affect economic growth. The same goes for the bidirectional causal association between renewable energy consumption and CO_2 emissions, which has been divulged by parametric causality test. These nations are majorly characterized by the rural electrification and energy poverty related issues, as identified by Paramati et al. (2017), and owing to this reason, the municipal government in these countries is turning out to be aggressive in implementation of renewable energy solutions, as a replacement of fossil fuel energy. Simultaneously, renewable energy solutions are also expected to reduce carbon emission-related issues. In view of this evidence, a bidirectional causal association between renewable energy consumption and fossil fuel consumption can be expected, and the results of Geweke (1982) causality analysis reveal the same. Along with this significant segment of finding, the results also reveal the trilateral association between fossil fuel consumption, CO_2 emissions, and economic growth, which the parametric causality test failed to address. This association describes that economic growth in this category of countries is unsustainable.

Lastly, we will move towards the full panel results. The results of parametric causality test show that bidirectional causal associations are possible between (i) renewable energy consumption and CO_2 emissions, (ii) fossil fuel consumption and CO_2 emissions, and (iii) renewable energy consumption and economic growth. Apart from that, it can also be seen that fossil fuel consumption is having direct impacts on economic growth and renewable energy consumption, whereas CO_2 emissions directly affect economic growth. Scrutinizing this segment of evidences, we can say that economic growth pattern achieved by N-11 countries is unsustainable, owing to fossil fuel consumption and consequent CO_2 emissions. In order to bring forth sustainability in economic growth pattern, fossil fuel should be replaced by renewable energy resources, and renewable energy consumption will have a direct impact on economic growth. It is true that, driven by energy security and energy poverty related issues, N-11 countries have started the renewable energy initiatives, but it will be too early to assume the impacts of these initiatives on economic growth or carbon emissions. So, the bidirectional causal association between renewable energy consumption and CO_2 emissions, and between renewable energy consumption and economic growth might not be considered as valid. Now, we can compare this segment of results with the results of Geweke (1982) causality test. Results of this test demonstrate the trilateral causal association between CO_2 emissions, fossil fuel consumption, and economic growth, and thereby, showing the unsustainable nature of economic growth pattern in these nations. The bidirectional causal association between fossil fuel and renewable energy consumption show that environmental degradation caused by fossil fuel consumption is being compensated by renewable energy consumption, and its rising share in energy mix is also forcing the policymakers to enforce regulations regarding fossil fuel consumption.

5.2. Comparison of Non-Parametric and Geweke Causality Analysis

By far, we have analyzed the results of Granger (1969) parametric causality test results, and compared them with the results of Geweke (1982) causality test. Now, we will look into the results of Diks and Panchenko (2006) non-parametric causality test and Geweke (1982) causality test. The results of Diks and Panchenko (2006) non-parametric causality test are presented in Table-5, and the comparative results of tests are recorded in Table-6. We will now observe the policy implications comparing the results of both the tests. The results of non-parametric causality test for developed countries depict that increase in renewable energy consumption directly affects fossil fuel consumption, and economic growth pattern of these countries catalyzes renewable energy consumption. This empirical finding is similar with Shin (2015). However, this segment of findings gives no information about the impact of CO_2 emissions on fossil fuel consumption, renewable energy consumption, and economic growth, and vice versa. The empirical findings of Geweke (1982) causality test answer these voids. The results of this test reveal significant bidirectional nexus among CO_2 emissions, fossil fuel consumption, and economic growth. The pattern of economic growth prevailing in these nations was majorly driven by fossil fuel consumption, and this resulted in rise in ambient CO_2 emissions. However, this rise in CO_2 emissions might have negative impact on hygienic state of labor force, and therefore, on economic growth. So, the rise in CO_2 emissions forced government in these nations to reduce fossil fuel consumption, and to find a cleaner source of energy. The bidirectional casual association between renewable energy consumption and economic growth reveals the demand of renewable energy consumption driven by economic growth pattern, and how renewable energy consumption can add to economic growth. This piece of evidence provides us with the rationale behind the recommendations put forth by Shin (2015). Renewable energy is still to gain prominence in energy mix, and so it does not have any significant impact on either fossil fuel consumption or CO_2 emissions. This is divulged by no causal associations between renewable energy consumption and fossil fuel consumption or CO_2 emissions.

For the newly industrialized countries, the results of non-parametric causality test depict that the pattern of economic growth directly affects CO_2 emissions, whereas renewable energy consumption directly affects economic growth. However, in these nations, renewable energy consumption has not yet gained sufficient prominence, as indicated by Fronda (2015), Mahapatra (2016), Wheeler and Desai (2016), and others. Therefore, in this context, it will be too early to comment on overall impact of renewable energy consumption. Most of these nations are suffering from environmental degradation, rural electrification, and energy security issues (Gallagher, 2005; Seriño, 2014; Sugiawan and Managi, 2016, and several others). These issues are addressed by the bidirectional causal associations found by Geweke (1982) causality test. The bidirectional causal associations between CO_2 emissions and fossil fuel consumption, as well as between CO_2 emissions and economic growth, indicate the influences of economic growth pattern and fossil fuel consumption on ambient air quality, as well as the effect of CO_2 emissions on economic growth pattern. These causal associations indicate the need of a clean energy solution in this category of countries, as the rise in CO_2 emissions negatively influences economic growth, which forces the government to look for a cleaner alternative of fossil fuel, without harming economic growth. The bidirectional causal association between economic growth and fossil fuel consumption substantiates this statement, by demonstrating the direct impact of economic growth on fossil fuel consumption. This signifies that economic growth calls for more fossil fuel consumption, while on the other hand the consumption of the same is deteriorating the ambient air quality by increasing CO_2 emissions.

The results of non-parametric causality test for the emerging countries depict that renewable energy consumption directly affects CO_2 emissions, whereas fossil fuel consumption and CO_2 emissions directly affect economic growth. These countries are having energy poverty and rural electrification issues. Therefore, to boost economic growth, government is trying to bring more villages under electrification schemes, relegate the pollution levels of ambient air, and introduce renewable energy solutions as a replacement of fossil fuel. Hence, the unidirectional causality running from renewable energy consumption to CO_2 emissions does not hold true due to low share of renewable energy in energy portfolio. For this reason, it might be too optimistic to expect any significant impact on CO_2 emissions. This issue has already been identified by Awan (2015), Burger (2015), Noi (2016), and several others. Though this situation is nearly similar to that of the newly industrialized countries, governments in emerging economies are more aggressive in terms of implementation of renewable energy solutions, as the existing fossil fuel-based infrastructure might be inadequate to cater to energy demand. This issue is addressed by the bidirectional causal associations found by Geweke (1982) causality test. The bidirectional nexus among CO_2 emissions, fossil fuel consumption, and economic growth can be explained in the similar lines with the newly industrialized countries, whereas the difference lies in case of bidirectional causal association between renewable energy consumption and fossil fuel consumption. This association indicates the inadequacy of fossil fuel-based energy sources to cater to energy demand, as well as its negative ecological impact, and thereby the emergence of renewable energy sources as a replacement of fossil fuel-based energy sources.

Finally, we will move towards analyzing the results for full sample. The results of non-parametric causality test depict that CO_2 emissions directly affect renewable energy consumption, whereas fossil fuel and renewable energy consumption directly influence economic growth. The bidirectional causal associations can be found between CO_2 emissions and fossil fuel consumption, as well as between CO_2 emissions and economic growth. Going by this piece of evidence, it can be stated that rising ambient air pollution issues caused by rising CO_2 emissions, and to ensure energy security, N-11 countries are trying to adopt renewable energy solutions, alongside the fossil fuel-based energy sources. This initiative was also compelled by the harmful effect of CO_2 emissions on economic growth pattern. However, it will be too early to envisage the effect of renewable energy consumption on economic growth, because N-11 member countries from the emerging and newly industrialized categories have started promoting the clean energy initiatives mainly during early 90s, as it has been discussed in the COP21 summit. Researchers have identified this issue (Paramati et al., 2017; Sinha et al., 2017), and therefore, the unidirectional causality from CO_2 emissions to renewable energy consumption as well as from renewable energy consumption to economic growth might not be considered as valid. This issue is addressed by the bidirectional causal association found by Geweke (1982) causality test. The bidirectional causal association between renewable and fossil fuel energy consumption proves the demand for renewable energy consumption in ensuring the energy security issues in N-11 countries, in addition to the gradual shift of energy sources from fossil fuel to renewable energy sources. This finding is similar to the findings in existing literature of energy economics.

<Insert Table 5 here>

<Insert Table 6 here>

6. Implications for Theory and Practice

Designing renewable energy policy for any nation is a critical aspect, as most of the clean energy policies are bidirectional in nature (Lu et al., 2014; Bot et al., 2015). The nature of the designed policies should also comply with the setting of the context. While assessing the growth-emission-energy causal association, the causality directions divulged by the results should be verified along the line of the context setting. This verification might prove to be critical for implementing renewable energy policies, as a renewable energy policy not only brings forth a transformation in energy mix, but also it helps a nation to achieve the sustainable development goals both directly and indirectly. Therefore, the unidirectional causal association should be verified with the context setting, before recommending any policy design, and this is the scenario with most of the studies, which recommend policies based on causality assessment (e.g., Khan et al., 2016; Qureshi et al., 2016; Wang et al., 2016; Fan et al., 2017). While carrying out the meta-analysis of energy-growth causal relationship, Kalimeris et al. (2014) have stated the significance of causality direction in recommending policy prescriptions, where lie the theoretical and practical implications of the present study.

Let us begin with the theoretical implication of the study. Whenever we look into the causal association among variables and derive policy implications, we necessarily look into the causality direction, which are derived from the assumed linear or non-linear association among the variables. Therefore, results obtained from linear and non-linear causality tests might be different, so as the policy implications. This study has demonstrated how the results of linear and non-linear causality tests are compared and complemented, and how the robustness of empirical results can be checked using Geweke (1982) causality test. By far, in the literature, most of the studies on renewable energy-growth-emission nexus have used the results of causality tests without validating the direction of causality, and this study has shown the way of validating the causality directions by (i) comparing and complementing the results of linear and non-linear causality tests, and (ii) validating the results by Geweke (1982) causality test. This validation of causality directions might help in designing the sustainable energy framework, as indicated by Kalimeris et al. (2014).

Coming to the implication in terms of practice, the present throws light on how the results of causality tests can be validated using contextual settings. Any policy implication should consider the causality direction obtained from the causality tests, along with the context setting. This consideration becomes critical, when renewable energy policies are considered. Now, if a particular renewable energy policy is aimed at reducing CO_2 emissions and fossil fuel consumption, then it should also be remembered that this policy will also have short term and long term impacts on economic growth pattern. Therefore, relying on the results of one causality test might not bring out the true picture, and any unidirectional causal association should be treated with utmost care, as bidirectional nature of renewable energy policies ensure the nature of sustainable development in any economy (Lu et al., 2014; Bot et al., 2015). This study has shown the way to design renewable energy policies by assessing (i) the unidirectional causal association obtained from linear and non-linear causality tests, (ii) complementing the results of both the tests, and (iii) triangulating the results by Geweke (1982) causality analysis. By following these three steps, this study has shown a practical way of designing a renewable energy policy, which can not only address the issues of emissions, but also can ensure a sustainable economic growth. Therefore, by and large, this study has demonstrated a way to address the following sustainable development goals (SDGs): (a) SDG 7 – affordable and clean energy, (b) SDG 8 – decent work and economic growth, and (c) SDG 13 – climate action (UNDP, 2017).

Presently, sustainable development of any nation is discussed around the frameworks of SDGs. If these goals are analyzed, then it can be seen that implementation of renewable energy sources might play a significant role in ensuring economic growth to be sustainable by reducing carbon emissions, and by making energy to be affordable. In this pursuit, when nations try to implement renewable energy sources, they will have to implement cleaner production processes, so that nations can achieve green growth. This is where the role of a sound renewable energy policy comes into picture to enhance cleaner production by firms, for the sake of enriching environmental quality. At the very outset, investment in renewable energy projects might slow down economic growth, and with passage of time, renewable energy will help in boosting economic growth, not only by making it ecologically sustainable, but also by creating several job opportunities. Then growth trajectory itself might call for higher share of renewable energy sources in energy portfolio. Like any economic policy, this inherent bi-directionality is the characteristic of any sound renewable energy policy, and the present study addresses the robustness of this characteristic by comparing and complementing the results of linear and non-linear causality analysis (Stern et al., 1996; Kane, 2013). This study might prove to be relevant and significant for emerging economies, which are striving to implement renewable energy sources, and thereby, sustaining economic growth. This will not only help those nations in implementing cleaner production processes, but also help them to achieve the SDGs.

7. Conclusion

This study examines the causal association between economic growth, CO_2 emissions, fossil fuel consumption, and renewable energy consumption for N-11 countries over the period of 1990-2016, and in order to assess this association, we have used Granger (1969) causality test, Diks and Panchenko (2006) causality test, and Geweke (1982) causality test. We have identified the contradictions arising out of the results of these tests, how empirical results complement each other, and how the shortcomings of parametric and non-parametric causality tests can be overcome by using Geweke (1982) causality test. These results also demonstrate the importance of causality direction, while suggesting a policy decision, and it has also demonstrated how the causality direction should be considered in order to address the policy gaps.

While assessing the growth-energy-emission nexus, policy implications are suggested based on the causality direction. This can prove to be very crucial, as for any given context, the established causality direction must adhere to the setting of context, and thereby, the causality direction can provide a significant policy directive. This also needs to be remembered that given the present climatic condition across the globe, nations are striving to come up with effective renewable energy policies. Inclusion of renewable energy consumption in the model of growth-energy-emissions nexus not only signifies an energy use segregation, but also inclusion of an additional variable, which might bring forth alterations in the direction of causal association. Therefore, the methodology to analyse causality needs to be robust enough to accommodate the changes in period of the study. Now, from the contextual perspective, the direction of causality and policies derived out of the direction are important in case of developing economies because economic structure of N-11 countries are undergoing an industrial transformation, and they are trying to implement clean energy solutions as a replacement of traditional fossil fuel energy sources. This scenario is visible for case of N-11 countries, and therefore, we have kept our focus on designing sound renewable energy policies for N-11 countries, which comply with the setting of those countries. These policies are largely based on the combined result of the causality tests, and thereby, making these results more robust compared to the findings.

Saying this, we also need to discuss the way a robust renewable energy policy should be designed by complementing the results of causality tests. As we have already seen in this study, relying on the results of one causality test might bring out an incomplete scenario, as the causality tests vary according to the assumed relationship among policy variables. Therefore, when the results of multiple causality tests are obtained, the causality direction should be validated by the characteristics of chosen context. If parametric and non-parametric causality tests result contradict in the causality direction, then those contradictions have to be validated by using Geweke (1982) causality test, as this test will complement the issues of contemporaneous correlation absent in these tests. If the parametric and non-parametric causality tests demonstrate the presence of unidirectional causal association, then those results need to be validated by using Geweke (1982) causality test, as bidirectionality is a likely character of any economic policy involving income and drivers of economic growth (Pontusson, 1995). And while considering renewable energy policies, consideration of this aspect can turn out to be significant, because these policies can have direct and long term impacts on economic growth and carbon emissions. Therefore, in a nutshell, in order to design a robust renewable energy policy, one should complement and validate the traditional causality test results using Geweke (1982) causality test, and match the causality direction with the context setting.

Finally, let us look at this study from a methodological perspective. As the volume of literature on estimating the feedback mechanism between economic growth and environmental degradation is rising, and annual data will be used in most of those studies, so this study may find its own relevance in terms of estimating the feedback mechanism in the most effective way. It is true that this technique has not been used much in the field of economics and it is mostly used in the field of medicine (Kamiński et al. 2001; Lin et al., 2009; Solo, 2016), there is a huge scope for researchers to implement this mechanism in their studies, where low frequency data will be used.

Appendix 1

Westerlund (2007) Cointegration Test

For testing the nature of cointegration among variables, we have employed Westerlund's (2007) panel cointegration test. It is based on structural dynamics, and therefore, does not require the common factor restriction. To examine whether cointegrating relationship exists between series $y_{i,t}$ and $x_{i,t}$, let us assume the following error-correction model:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i(y_{it-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{P_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{-q_i}^{P_i} \gamma_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad \text{(A-1)}$$

where d_t is the deterministic component which is assumed to be zero, one, or a vector of (1, t)′, and P_i and $q_i$qi are the lag and lead orders for unit *i*. The cointegration is expressed byy$y_{it-1} - \beta_i' x_{i,t-1} = 0$. The coefficient α_i measures the speed at which the system corrects back to long-run equilibrium of correction, and a negative value of α_i implies the presence of a cointegrating relationship, while α_i = 0 means no error correction and no cointegration. Westerlund (2007)'s approach is to test the null hypothesis of no cointegration that α_i = 0 for all i. Two alternative hypotheses are: First, the panel is cointegrated as a whole, i.e., $\alpha_i = \alpha <$ 0 for all *i*; and second, at least one cross-sectional unit is cointegrated, i.e., α_i<0 for at least one *i*. The test statistics proposed for the first alternative hypothesis are called panel test, which are:

$$P_T = \frac{\hat{\alpha}}{SE(\hat{\alpha})};\ P_\alpha = T_{\hat{\alpha}} \quad \text{(A-2)}$$

where $\hat{\alpha}$ is the estimate of the homogenous speed of error correction for all units and $SE(\hat{\alpha})$ is the standard error of $\hat{\alpha}$. The group-mean test statistics for the second alternative hypothesis are:

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \quad \text{(A-3)}$$

$$G_{\alpha} = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{A-4}$$

where $\hat{\alpha}_i$ is the parameter estimate for unit $i, SE(\hat{\alpha}_i)$ is the associated standard error, and $\hat{\alpha}_i(1) = 1 - \sum_{j=1}^{P_i}\hat{\alpha}_{ij}$. It is shown that these test statistics are normally distributed asymptotically and have good small-sample properties. Furthermore, these tests are able to accommodate heterogeneity and cross-sectional dependence by using the bootstrap.

Table 1: Results of Cross Section dependence tests

Variables	Pesaran (2006)		Chudik and Pesaran (2015)
	Test statistics	*ρ*	*Test statistics*
Y	33.41[a]	0.901	6.44[a]
C	28.05[a]	0.756	4.54[a]
F	33.64[a]	0.907	1.79[b]
R	23.74[a]	0.650	-1.67[c]

a significant at 1% level

b significant at 5% level

c significant at 10% level

Table 2: Results of second generation unit root tests

	CIPS	CADF	CIPS	CADF
	Developed countries		*Newly Industrialized countries*	
Level				
Y	-2.673	-1.934	-2.732	-1.758
C	-2.755	-2.312	-2.791	-2.532
F	-2.611	-2.212	-2.160	-1.654
R	-2.224	-2.762	-1.591	-1.643
First Difference				
Y	-4.168[a]	-3.156[a]	-4.177[a]	-3.059[a]
C	-4.163[a]	-3.869[a]	-4.973[a]	-2.906[c]
F	-4.442[a]	-4.505[a]	-5.053[a]	-3.151[b]
R	-4.821[a]	-4.312[a]	-4.704[a]	-3.166[b]
	Emerging countries		*Full sample*	
Level				
Y	-2.718	-1.997	-2.886	-1.111
C	-2.220	-2.181	-2.389	-2.497
F	-1.724	-1.858	-2.175	-2.163
R	-2.020	-2.215	-2.247	-2.157
First Difference				
Y	-5.159[a]	-2.626[b]	-4.878[a]	-2.876[a]
C	-4.117[a]	-3.394[a]	-4.676[a]	-3.081[a]
F	-4.087[a]	-2.567[b]	-4.183[a]	-3.089[a]
R	-4.585[a]	-3.518[a]	-4.594[a]	-3.421[a]

a significant at 1% level

b significant at 5% level

c significant at 10% level

Table 3: Results of Westerlund (2007) cointegration test

	G_t			G_a		
	Statistics	*p-value*	*Robust p-value*	*Statistics*	*p-value*	*Robust p-value*
Developed countries	-0.768	0.821	0.000	-0.837	0.868	0.000
Newly industrialized countries	-1.753	0.462	0.000	-5.480	0.798	0.000
Emerging countries	-2.421	0.060	0.000	-9.195	0.310	0.000
Full sample	-1.967	0.202	0.000	-6.747	0.714	0.000
	P_t			P_a		
	Statistics	*p-value*	*Robust p-value*	*Statistics*	*p-value*	*Robust p-value*
Developed countries	-0.768	0.662	0.000	-0.837	0.707	0.000
Newly industrialized countries	-3.393	0.366	0.000	-4.409	0.480	0.000
Emerging countries	-5.029	0.056	0.000	-6.710	0.194	0.000
Full sample	-6.558	0.047	0.000	-6.558	0.217	0.000

Note: robust p-values are obtained after bootstrapping

Table 4: Results of Granger (1969) causality test

Independent variables	*Dependent variables*			
	C	*Y*	*R*	*F*
Developed countries				
C	-	0.0421	6.8751[a]	1.5031
Y	0.8646	-	9.2181[a]	0.3026
R	0.8009	2.1458	-	0.0590
F	3.5239[c]	1.9468	4.1386[a]	-
Newly industrialized countries				
C	-	6.9799[a]	-0.4656	2.1675[b]
Y	1.7936[c]	-	-0.6469	-0.3474
R	1.2885	0.8585	-	-0.7826
F	5.5931[a]	8.3941[a]	0.9429	-
Emerging countries				
C	-	6.8842[a]	5.9168[a]	0.6634
Y	0.3436	-	0.6103	-0.1097
R	3.1784[b]	5.9602[a]	-	-0.0741
F	14.6191[a]	6.5107[a]	1.4244	-
Full Sample				
C	-	9.1408[a]	8.7136[a]	1.9882[b]
Y	0.9779	-	3.5172[a]	-0.4635
R	2.9556[b]	4.8019[a]	-	-0.7813
F	14.1013[a]	10.2146[a]	8.0527[a]	-

a significant at 1% level

b significant at 5% level

c significant at 10% level

Table 5: Results of Diks and Panchenko (2006) causality test

Independent variables	*Dependent variables*			
	C	*Y*	*R*	*F*
Developed countries				
C	-	1.045	1.170	-0.646
Y	-0.002	-	1.344[c]	-0.201
R	0.805	-0.533	-	1.502[c]
F	0.933	0.772	1.121	-
Newly industrialized countries				
C	-	1.081	0.440	1.206
Y	1.909[b]	-	0.063	1.174
R	1.192	1.347[c]	-	0.670
F	0.363	0.639	0.001	-
Emerging countries				
C	-	1.813[b]	-0.748	1.002
Y	-0.374	-	-0.916	0.199
R	1.586[c]	1.195	-	1.636
F	1.230	1.519[c]	-1.675	-
Full Sample				
C	-	2.372[a]	1.285[c]	2.581[a]
Y	1.691[b]	-	1.269	1.238
R	0.845	1.805[b]	-	1.038
F	1.443[c]	1.437[c]	1.179	-

a significant at 1% level

b significant at 5% level

c significant at 10% level

Table 6: Comparison of the results of causality tests

Associative variables	*Parametric Causality test*	*Non-parametric Causality test*	*Geweke Causality test*	
	Verdicts	*Verdicts*	*Chi-square values*	*Verdicts*
Developed countries				
C and R	C → R	C --- R	0.4277	C --- R
C and F	C ← F	C --- F	37.0727[a]	C ↔ F
C and Y	C --- Y	C --- Y	16.9014[a]	C ↔ Y
R and F	R ← F	R → F	0.8770	R --- F
R and Y	R ← Y	R ← Y	3.2328[c]	R ↔ Y
F and Y	F --- Y	F --- Y	13.2901[a]	F ↔ Y
Newly industrialized countries				
C and R	C --- R	C --- R	1.0275	C --- R
C and F	C ↔ F	C --- F	19.7048[a]	C ↔ F
C and Y	C ↔ Y	C ← Y	23.2613[a]	C ↔ Y
R and F	R --- F	R --- F	0.6612	R --- F
R and Y	R --- Y	R → Y	0.2483	R --- Y
F and Y	F → Y	F --- Y	15.4718[a]	F ↔ Y
Emerging countries				
C and R	C ↔ R	C ← R	0.8084	C --- R
C and F	C ← F	C --- F	22.2576[a]	C ↔ F
C and Y	C → Y	C → Y	6.8500[a]	C ↔ Y
R and F	R --- F	R --- F	78.7935[a]	R ↔ F
R and Y	R → Y	R --- Y	1.1875	R --- Y
F and Y	F → Y	F → Y	10.5610[a]	F ↔ Y
Full Sample				
C and R	C ↔ R	C → R	0.014	C --- R
C and F	C ↔ F	C ↔ F	55.065[a]	C ↔ F
C and Y	C → Y	C ↔ Y	27.830[a]	C ↔ Y
R and F	R ← F	R --- F	20.845[a]	R ↔ F
R and Y	R ↔ Y	R → Y	0.0128	R --- Y
F and Y	F → Y	F → Y	23.740[a]	F ↔ Y

a significant at 1% level

c significant at 10% level

--- signifies no causality

←/→/↔ signify directions of causality

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