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Sinha, Avik and Sengupta, Tuhin

Atria Institute of Technology, Bangalore, India, Indian Institute of Management Indore, India

2019

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Avik Sinha[1]
Economics and Business Policy,
School of Management and Entrepreneurship,
Atria Institute of Technology, Bangalore, India.
Email: f11aviks@iimidr.ac.in

Tuhin Sengupta
Department of Operations Management & Quantitative Techniques,
Indian Institute of Management Indore, India.
Email: f13tuhins@iimidr.ac.in

Abstract

There is a limited number of studies on the estimation of Environmental Kuznets Curve (EKC) hypothesis for Nitrous Oxide (N_2O) emissions, though it is one of the most harmful greenhouse gases (GHGs) present in ambient atmosphere. In the wake of industrialization, it is necessary to understand the impact of energy consumption pattern on N_2O emissions and revise the energy policies accordingly. In this study, we have analyzed the impact of renewable and fossil fuel energy consumptions on N_2O emissions for APEC countries over the period of 1990-2015, and the analysis has been carried out following the EKC hypothesis framework. The results obtained from the study indicate the efficacy of the renewable energy solutions in having positive impact on environmental quality by helping to reduce the level of N_2O emissions. The policy implications derived the results are designed keeping the objectives of Sustainable Development Goals (SDGs) in mind, so that the energy policies can bring forth sustainability in the economic systems in these nations.

Keywords: Renewable Energy; N_2O Emissions; APEC Countries; SDG; sustainability

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[1] Corresponding author

1. Introduction

Climate action is one of the most important needs in order to achieve sustainable development and reduce global warming, and it has prompted policymakers to delve deeper into the causes of climate deterioration (UNDP, 2017). It has been proven by several researchers that greenhouse gas (GHG) emissions are one of the prime factors affecting climate change, and it has steadily increased over the past few decades. This increase in the GHG emissions has increased global temperatures causing long lasting changes to our climate system. For instance, the Arctic ice extent is losing 1.07 million square kilometre of ice loss every decade (UNDP, 2017). Owing to such consequences, researchers across the globe have focused on understanding the determinants of GHG emissions. There are primarily four types of GHGs, namely, Carbon dioxide (76%), methane (16%), nitrous oxide (6%) and fluorinated gases (2%). Although the concentration of nitrous oxide (N_2O) is significantly lower than that of carbon dioxide, it claims to be an important GHG because of its equivalent mass basis (Del Grosso, 2012). It has 300 times the global warming potential of carbon dioxide (Solomon et al., 2007). Further, N_2O is the main ozone depleting substance in the stratosphere (Ravishankara et al., 2009). Primary sources of N_2O include agricultural activities and fossil fuel combustion (Sinha and Bhattacharya, 2016). Human activity has substantially tampered the nitrogen cycling process, primarily by increasing the amount of reactive nitrogen into the biosphere through the use of nitrogen induced fertilizers and cultivation of nitrogen fixing crops (Del Grosso, 2012). As a result, soil processes have been found to be responsible for more than two thirds of global nitrous oxide emissions (Thomson et al., 2012). However, in recent years, the rise in energy demand across the globe has increased the fossil fuel combustion, and in doing so, the number of thermal power plants is also on the rise. The high temperature in the furnace causes the oxidization of the molecular nitrogen, and thereby, generating oxides of nitrogen (Zeldovich, 1946; Glarborg et al., 2018). This phenomenon can be characterized as the rise in industrialization, and the shrinkage of agricultural lands (Fazal, 2000; van der Linden, 2018). This is in addition to the discourse that accumulation of various oxides of nitrogen, including N_2O, beyond a certain proportion leads to damages in lung tissues and causes emphysema, bronchitis etc (Miah et al., 2010).

It is very evident from the discussion above that increasing emissions coupled with the problem of climate change will affect both developing and developed countries. Therefore, it remains vital to understand how the problem of climate change will impact the economic growth and development of a region. This phenomenon can be theoretically explicated by Environmental Kuznets Curve (EKC) hypothesis, which explains the relationship between income and environmental degradation. The Kuznets curve, developed by Simon Kuznets (1955), established the relationship between economic growth and income inequality through an inverted U-shaped curve. Similar kind of relationship was later found between economic growth and environmental degradation by Grossman and Krueger (1991), which was later known as EKC. The hypothesis says that when income rises at the earliest stages of economic development, emissions rise and beyond a certain threshold level of income, the emissions start to decrease (Stern et al., 1996; Alam et al., 2016; Zaman et al., 2016; Balsalobre-Lorente et al., 2018). This is explained by the fact that initially environmental degradation occurs at the cost of high resource utilization to meet the increasing consumer demand. This is followed by a phase known as "the richer is greener", in which people with increasing income can now invest, afford and adopt clean technology thereby reducing environmental degradation (Tierney, 2009; Shahbaz et al., 2015a, b).

Since majority of GHG emissions source from carbon dioxide, majority of studies have looked into the EKC hypothesis analysis applying different models revolving around carbon emissions and economic growth (Dinda, 2004; Jalil and Mahmud, 2009; Zhang and Cheng, 2009; Ahmed et al., 2015, 2016; Ahmad et al., 2016; Dogan and Turkekul, 2016; Álvarez-Herránz et al., 2017 a, b; Ozatac et al., 2017; Gokmenoglu and Taspinar, 2018; Haseeb et al., 2018; Sarkodie, 2018; Shahbaz et al., 2016a, b, c, d, e, Shahbaz and Sinha, 2019), whereas little attention has been paid to other GHGs. There is a scant literature on EKC hypothesis analysis with respect to N_2O emissions. Apart from the importance of N_2O to climate change and greenhouse effect, it is extremely important to analyse the joint behaviour of N_2O emissions and economic growth to devise a structured energy policy (Narayan and Narayan, 2010). In this context, it is required to mention that the economic growth being achieved by developed and developing nations across the globe is majorly dependent on the fossil fuel-based energy solutions, and due to the rise in industrialization, the agricultural activities are shrunk (Fazal, 2000; van der Linden, 2018). As a consequence, the contribution of fossil fuel consumption in generating N_2O emissions is rising (Linak et al., 1990; Rout et al., 2005). Therefore, in order to have a control on the N_2O emissions, the policymakers need to design the energy policies accordingly.

Driven by this motive, we have chosen Asia Pacific Economic Cooperation (APEC) countries for our study.[2] In this study, we have analysed the impacts of economic growth, gross capital formation, research and development (R&D) expenditure, renewable energy consumption, fossil fuel energy consumption, trade openness, and population on N_2O emissions in APEC countries over a period of 1990-2015. In terms of energy, the demand for electricity in

[2] Australia, Canada, Chile, China, Indonesia, Japan, Korean Republic, Mexico, Malaysia, New Zealand, Peru, the Philippines, Russian Federation, Singapore, Thailand, and the United States

APEC countries is approximately 60% of the global demand (APEC, 2016). Further, the growth rate of energy demand for APEC countries (2.1%) is higher than the global energy demand growth rate (1.9%). APEC nations, representing more than 40% of the global population, have more than 80% (86% in 2013) energy supply coming from fossil fuels. Further, renewable energy source is increasing momentum with an annual growth rate of 2.5% (APEC, 2016). With respect to economy and trade, APEC countries represent 57% of the global real GDP and representing 47% of the total world trade. APEC strives to introduce new technologies that promote greener energy source in addition to improving food trade thereby strengthening the overall agricultural productivity and growth (APEC, 2016). Along with the technological progress and economic growth, APEC countries have registered a rise of 11.62 percent rise in N_2O emissions during 1990-2015, whereas the N_2O emissions across the world have shown an increase of 9.86 percent during this period (Figure 1). This has given us the opportunity to look into the possible causes of N_2O emissions in these countries, and thereby defining the scope of this study.

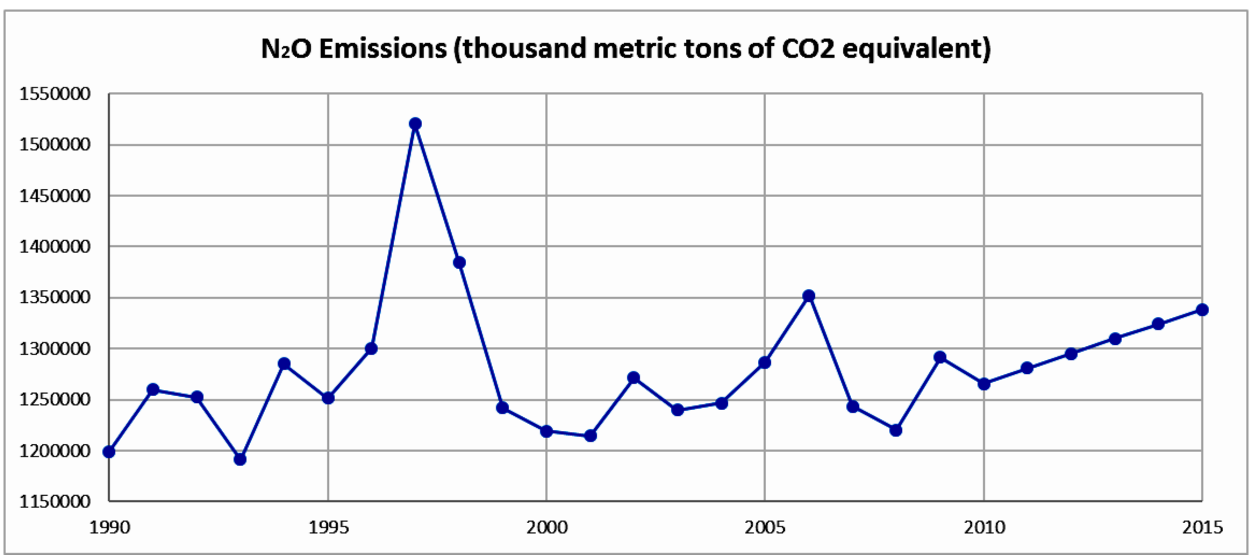

Figure 1: Pattern of N_2O emissions in APEC countries (1990-2015)

Due to the absence of comprehensive studies on EKC hypothesis concerning N_2O emissions, little can be inferred towards policy implications. For instance, Magnani (2001) show that the statistical significance of the polynomial terms of GDP per capita is lower in the regression analysis for high-income countries in comparison to low and middle-income countries. Cole et al. (1997) conducted the EKC analysis for 11 OECD countries using the generalized and ordinary least square fixed effect model and found the presence of inverted U-shape for nitrous oxide. On the contrary, Hill and Magnani (2002) found a straight line for a panel of 156 countries using the generalized least square model. Selden and Song (1994) analysed four models of EKC hypothesis i.e., quadratic random effect, quadratic fixed effect, cubic random effect and cubic fixed effect model and found the presence of inverted U-shaped behaviour for nitrous oxide in all these four models. Zambrano-Monserrate (2017) found a quadratic long run relationship between nitrous oxide emissions and economic growth in Germany, thus establishing EKC hypothesis for the same. Och (2017) found a contradictory result in the case of Mongolia by establishing a highly significant U-shaped relationship between nitrous oxide and income. The difference in behaviour in different papers is attributed to many factors such as differences in use of emission or concentration indicators, different model estimations, different data set in terms of different sets of countries and the time duration being selected, and the use of additional variables besides income (Bruyn, 2000). Studies have established that EKC hypotheses arise in many cases due to omission of other explanatory variables in the estimate (Roca et al., 2001; Shahbaz et al., 2017a, b, c, d). Also, the omitted variables in panel data estimates that are correlated with GDP may not be common to all countries considered in the sample thus resulting in biased estimate of the EKC in non-random samples of the estimated model (Stern and Common, 2001; Shahbaz et al., 2018b, c).

Most of the studies on N_2O have either not included additional variable in the model or the study is specific to a certain country. Our article is one of the first few attempts to comprehensively analyse EKC hypothesis (quadratic and cubic models) for the case of N_2O emissions in the APEC countries by considering other explanatory variables such as population of the member countries, trade openness, R&D expenditure, use of renewable energy and fossil fuels, and gross capital formation. This provides a comprehensive analysis in understanding the optimal energy policy mix a nation or a group of nations should have in order to minimize nitrous oxide emission. Our study attempts to contribute to the existing literature on the fact that nitrous oxide emissions can be minimized with simultaneous generation of renewable energy (Ming et al., 2016). Our study contributes to the literature of energy and environmental economics in several ways: (a) for the APEC countries, this is the first ever study to analyse the impact of economic growth parameters on N_2O emissions, (b) in this study, the impact assessment has been carried out following the N-shaped EKC framework, (c) we have used the renewable and non-renewable energy consumptions singularly and combinedly in the EKC models, so that their differential and mixed impacts on N_2O emissions can be seen, (d) analysing the EKC models assuming cross-sectional dependence has allowed us to incorporate the cross-country effects in the analysis, and (e) based on the results of the study, we have shown a way to achieve some of the objective of sustainable development goals (SDGs) within 2030.

The remainder of the paper is as follows: Section 2 highlights the data and methodology. Section 3 presents the empirical model along with results and analysis. Section 4 concludes the paper by highlighting the theoretical contribution and policy level implications for nitrous oxide emissions through the lens of EKC hypothesis.

2. Mathematical Model and Data

The present study aims at analyzing the impacts of renewable and nonrenewable energy consumption on N_2O emissions for the APEC countries. With a view to analyze these impacts, we have adapted the IPAT framework developed by Ehrlich and Holdren (1971). The empirical model to be tested in this study is designed in accordance with this framework. In keeping with standard EKC literature and IPAT framework, we have specified the following empirical specification for estimating the EKC:

$$N_2O = f(Y_{it}, Y_{it}^2, Y_{it}^3, GCF_{it}, RD_{it}, REN_{it}, FF_{it}, TR_{it}, POP_{it}) \quad (1)$$

Where, N_2O is the per capita N_2O emissions, Y is the per capita GDP, GCF is the gross capital formation, RD is the research and development expenditure, REN is the per capita renewable energy consumption, FF is the per capita fossil fuel energy consumption, TR is the trade openness, POP is the population, i is the cross sections (i = 1, …, N) and t is the time series (t = 1, …, T).

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

$$I = P \times A \times T \quad (2)$$

According to this framework, environmental degradation or pollution is impacted by population, the economic activities or the level and nature of energy consumption, and level of technological development. However, Dietz and Rosa (1994, 1997) suggested an empirically testable version of this model, and that version of the model is generally referred to as the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. The model shown in Eq. (1) is designed following this specification only, where N_2O is considered as the proxy of pollution, Y, GCF, REN, and FF are considered as the proxies of economic growth and affluence, TR, and RD are considered as the proxies of technological development, POP is the proxy of population. Taking a cue from this discussion, the empirical models to be tested in this study are as per the following:

$$N_2O_{it} = a_0 + a_1Y_{it} + a_2Y_{it}^2 + a_3Y_{it}^3 + a_4GCF_{it} + a_5RD_{it} + a_6TR_{it} + a_7POP_{it} + a_8REN_{it} + \epsilon_{it} \quad (3)$$

$$N_2O_{it} = b_0 + b_1Y_{it} + b_2Y_{it}^2 + b_3Y_{it}^3 + b_4GCF_{it} + b_5RD_{it} + b_6TR_{it} + b_7POP_{it} + b_8FF_{it} + \epsilon_{it} \quad (4)$$

$$N_2O_{it} = c_0 + c_1Y_{it} + c_2Y_{it}^2 + c_3Y_{it}^3 + c_4GCF_{it} + c_5RD_{it} + c_6TR_{it} + c_7POP_{it} + c_8REN_{it} + c_9FF_{it} + \epsilon_{it} \quad (5)$$

In the later sections of this study, Eq. (3) has been referred to as *Renewable Energy Model*, Eq. (4) has been referred to as *Fossil Fuel Model*, and Eq. (5) has been referred to as *Combined Model*. This segregation allows us to look into the individual impacts of renewable and nonrenewable energy consumption on N_2O emissions (for CO_2 emissions, see Sinha et al., 2018), and as well as their combined impact.

While carrying out the empirical analysis of the data, we started with checking the order of integration for the model variables, and this was carried out by employing second generation unit root tests developed by Breitung (2000) and Herwartz and Siedenburg (2008). Application of these tests was validated by the presence of cross-sectional dependence in the data, and it was tested by employing the cross-sectional dependence (CD) test by Chudik and Pesaran (2015). Subsequent to finding the order of integration, we have employed the Westerlund and Edgerton (2008) cointegration test, for checking the cointegration properties in the data, in the presence of cross-sectional dependence. Once the presence of cointegrating association is confirmed, we have employed the generalized method of moments (GMM) to estimate the Eq. (3) to (5). Along with estimation of the models specified for this study, we have also carried out the Dumitrescu and Hurlin (2012) heterogenous panel causality tests, in order to check the robustness of the results, along with discovering the possible causal associations among variables.

For this study, data has been collected for per capita N_2O emissions in thousand metric tons of CO_2 equivalent, per capita GDP in constant 2010 USD, gross capital formation in constant 2010 USD, research and development expenditure in constant 2010 USD, per capita renewable energy consumption in billion kWHs, per capita fossil fuel energy consumption in billion kWHs, trade openness in constant 2010 USD, and these data have been collected from the World bank indicators (World Bank, 2018), for 16 APEC countries over a period of 1990-2015. Before proceeding with the analysis, all the variables have been log-transformed, so as to smoothen the data, and for obtaining the elasticity terms, as well.

3. Results and Analysis

3.1. Order of integration

For checking the order of integration among the model parameters, we have employed Herwartz and Siedenburg (2008) and Breitung (2000) unit root tests. Usage of these tests have been validated by the results of Chudik and Pesaran (2015) weak cross-sectional dependence test (results are in Table 1), which show that the cross sections of the data are strongly interdependent, and thereby, allowing the application of the second-generation panel unit root tests. These unit root tests allow cross-sectional dependence in the data, and the results recorded in Table 2 show that the model variables are integrated to order one, i.e. I(1) in nature. Based on this result, we can proceed with the cointegration test.

Table 1: Results of Chudik and Pesaran (2015) weak cross-sectional dependence test

Variables	*Test statistic*	*p-value*	*Variables*	*Test statistic*	*p-value*

N_2O	13.472	0.000	RD	51.084	0.000
Y	55.835	0.000	REN	6.996	0.000
Y^2	55.773	0.000	FF	18.160	0.000
Y^3	55.676	0.000	TR	55.803	0.000
GCF	55.771	0.000	POP	55.856	0.000

Table 2: Results of Second Generation Unit Root Tests

Variables	*Herwartz and Siedenburg (2008)*		*Breitung (2000)*	
	Level	*First Diff.*	*Level*	*First Diff.*
N_2O	-0.4012	-2.3541[a]	-2.0358	-5.4113[a]
Y	1.9810	-1.6242[c]	5.1626	-4.8292[a]
Y^2	2.0290	-1.6617[b]	5.0663	-4.8174[a]
Y^3	2.0598	-1.6554[b]	4.8824	-4.7217[a]
GCF	0.8522	-1.8229[b]	2.6191	-4.6085[a]
RD	2.8442	-1.5582[c]	4.2925	-4.6672[a]
REN	1.8399	-2.3473[a]	3.1191	-2.2727[b]
FF	0.8561	-2.0520[b]	3.7359	-4.2842[a]
TR	1.1300	-1.7102[b]	1.6146	-4.5892[a]
POP	1.0718	-1.3410[c]	6.4216	-2.3186[b]

a significant value at 1%
b significant value at 5%
c significant value at 10%

3.2. Cointegration test

In the process of empirical analysis, second step is to assess the cointegrating association among the model variables. As we have already found that the cross-sections are interdependent, therefore we have used Westerlund and Edgerton (2008) cointegration test, which allows for cross-sectional dependence among the data. The test results are reported in Table 3, and the test statistics indicate the presence of cointegration association among the model variables. This cointegrating association have been found to be present across the three models tested in the present study.

Once we have confirmed the cointegrating association among the variables, we can now proceed with the estimation of long run coefficients.

Table 3: Results of Westerlund and Edgerton (2008) cointegration test

For Renewable Energy model						
	Test Statistic (1)	*p-value*	*Test Statistic (2)*	*p-value*	*Test Statistic (3)*	*p-value*
LM_τ	-2.750	0.003	-5.841	0.000	-3.080	0.001
LM_ϕ	-1.957	0.025	-1.857	0.032	-2.915	0.002
For Fossil Fuel model						
LM_τ	-1.743	0.041	-5.548	0.000	-6.579	0.000
LM_ϕ	-2.808	0.002	-1.642	0.050	-2.286	0.011
For Combined model						
LM_τ	-9.223	0.000	-11.263	0.000	-2.518	0.006
LM_ϕ	-5.992	0.000	-6.231	0.000	-1.815	0.035

Note:

Model (1): model with a maximum number of 5 factors and no shift

Model (2): model with a maximum number of 5 factors and level shift

Model (3): model with a maximum number of 5 factors and regime shift

3.3. Long run coefficients by GMM

After the cointegrating association among the model variables is found, we can proceed with the estimation of long run coefficients using the Generalized Method of Moments (GMM) approach. This method has been applied on three models, namely (a) Renewable Energy model, (b) Fossil Fuel model, and (c) Combined model. The results of GMM estimation across all the three models are reported in Table 4 and the estimated EKCs are shown in Figure 2. Now, we will discuss the results of all these three models one by one.

Table 4: Results of GMM tests for three models

Variables	*Renewable Energy model*	*Fossil Fuel model*	*Combined model*
Y	1.4510[c]	8.4997[a]	22.6837[a]
Y^2	-0.2763[c]	-1.0063[c]	-2.4829[a]
Y^3	0.0127[a]	0.0416[b]	0.0898[a]
GCF	0.9996[a]	0.0971[b]	0.7549[b]
RD	-0.0497[a]	-0.4085[a]	-0.4301[a]
REN	-0.5241[a]	-	-0.3540[b]
FF	-	1.2752[a]	1.1402[a]
TR	-0.2858[a]	-0.8735[a]	-0.6506[a]
POP	0.5262[a]	1.6396[a]	1.7747[a]
Constant	72.2501[a]	9.6845[b]	31.0374[b]
Hansen's J statistics	3.3653	4.3381	1.0251
DWH Test statistics	7.8992[a]	9.8994[a]	9.2404[a]

Shape of EKC	N-shaped	N-shaped	N-shaped
Turnaround points	a. 31.29 b. 63,626.27	a. 1,832.10 b. 15,436.61	a. 4,253.07 b. 23,799.43

a value at 1% significance level
b value at 5% significance level
c value at 10% significance level

Let us begin with the Fossil Fuel model. The coefficients of Y, Y^2 and Y^3 are positive, negative, and positive, respectively, and they are statistically significant, as well. The EKC has been found to be N-shaped in this case, and the turnaround points are \$1,832.10 and \$15,436.61. For CO_2 emissions, there are several evidences of N-shaped EKCs, and a summary of those studies can be found in the review of EKC studies by Shahbaz and Sinha (2019). As the APEC countries can be characterized by high industrialization, it can be expected that the capital formation might have a negative impact on the environmental quality, and this phenomenon is visible in the coefficient of GCF. It has positive impact on the N_2O emissions, and it signifies that the nature of industrialization is exerting pressure on environmental quality by catalyzing more GHG emissions. This negative pressure of environmental quality is also caused by the rise in population, which has resulted in a pressure on the urban infrastructure. Similar kind of condition has been identified by Paramati et al. (2017) in case of Next 11 countries, Sinha and Bhattacharya (2016, 2017) for Indian cities, and Shahbaz et al. (2018a) for G7 countries. Rise in industrialization is resulting in shrinkage of the agricultural lands, and therefore, people from the rural areas are shifting towards the urban areas in search of vocational opportunities. This rise in urbanization is coexisting with the rise in overall population, and consequently, the economic growth achieved by these nations is achieved at the cost of the sustainable development of these nations. This rapid industrialization is predominantly fueled by fossil fuel-based energy sources, and combustion of the fossil fuels is further aggravating the situation by increasing the level of N_2O in the ambient atmosphere. This is evident from the coefficient of FF in the model.

However, the technological innovations in pursuit of cleaner technologies brought forth by means of international trade and R&D are having negative impacts on N_2O emissions, and it is visible from the coefficients of TR and RD.

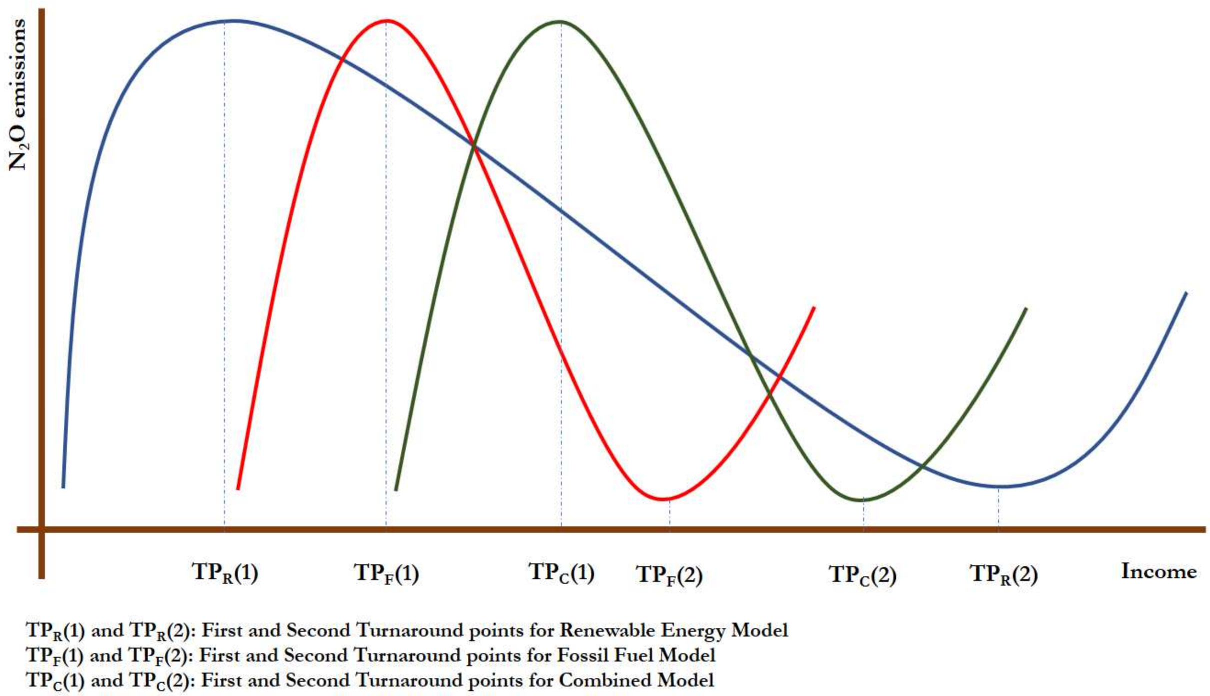

Figure 2: EKCs of N_2O emissions for the three estimated models

Now, we will move towards the Renewable Energy model. The coefficients of Y, Y^2 and Y^3 are positive, negative, and positive, respectively, and they are statistically significant, as well. The EKC has been found to be N-shaped in this case, and the turnaround points are \$31.29 and \$63,626.27. The natures of GCF, POP, RD, and TR have been found to be similar to that of in case of the Fossil Fuel model. In contrast with the Fossil Fuel model, here we will analyze the impact of renewable energy consumption on N_2O emissions, and it is visible in Table 4 that the coefficient of REN is negative and significant. Amidst the industrial growth, the emergence of renewable energy solutions has started to exert positive impact on environmental quality, by reducing the emission of GHGs. Now, it is very crucial to notice the turnaround points for both of the models. For the Fossil Fuel model, the second turnaround point is achieved much faster than the second turnaround point in case of Renewable Energy model. It signifies that the economic growth achieved through the consumption of renewable energy solutions is more sustainable compared to the growth achieved through fossil fuel consumption, as the consumption of renewable energy might prove to be more effective in terms of reducing the level of emissions.

The behaviors of the variables in the combined model are similar to that of in case of the previous two models. However, this model demonstrates the scenario, if both fossil fuel and renewable energy solutions are used in a nation. Now, the coefficients of Y, Y^2 and Y^3 are positive, negative, and positive, respectively, and they are statistically significant, as well. The EKC has been found to be N-shaped in this case, and the turnaround points are \$4,253.07 and \$23,799.43. We can observe that the first turnaround point is higher compared to previous two models, but the second turnaround point is between the second turnaround points of renewable energy model and fossil fuel model. This shows the sustainability of an economy when both the sources of energy are utilized in the production process, as the environmental damage caused by one is recovered by another. Increase in the second turnaround point indicates the flattening of the EKC, thereby showing the efficacy of the renewable energy solutions in reducing the level of GHG emissions.

3.4. Heterogeneous panel causality analysis

Table 5: Results of Dumitrescu and Hurlin (2012) causality tests

Dependent Variables	*Independent Variables*							
	N_2O	Y	GCF	RD	REN	FF	TR	POP
N_2O	-	12.3407[a]	7.9331[a]	11.1077[a]	7.3954[a]	12.7481[a]	7.2629[a]	15.9594[a]
Y	4.1532[a]	-	8.8506[a]	9.9528[a]	1.8029[c]	10.4864[a]	6.4943[a]	13.7285[a]
GCF	6.4259[a]	12.7536[a]	-	8.7155[a]	1.4086	9.0534[a]	6.1432[a]	11.8660[a]
RD	5.5566[a]	13.5008[a]	7.4738[a]	-	1.0662	7.6995[a]	12.8966[a]	9.4310[a]

REN	1.7488[c]	6.8242[a]	2.4927[b]	6.7122[a]	-	9.6321[a]	7.5380[a]	12.0522[a]
FF	2.6050[a]	3.0876[a]	3.7280[a]	6.0763[a]	2.5164[b]	-	6.3272[a]	5.2441[a]
TR	0.0767	4.5977[a]	1.5961	4.4562[a]	-0.1092	4.4700[a]	-	7.1829[a]
POP	16.7459[a]	28.0692[a]	18.6297[a]	29.8677[a]	10.0878[a]	24.0475[a]	11.1049[a]	-

a significant value at 1%

b significant value at 5%

c significant value at 10%

As the final step of analysis, Dumitrescu and Hurlin (2012) heterogeneous panel causality test has been conducted, and the results of this test are reported in table 5. The test has been conducted on the aggregate data, as the APEC countries use both the renewable and non-renewable energy solutions in the production process. We can find that bidirectional causal associations exist between Y and N_2O emissions, GCF and N_2O emissions, FF and N_2O emissions, REN and N_2O emissions, RD and N_2O emissions, and POP and N_2O emissions. Apart from that, unidirectional causality runs from TR to N_2O emissions. These causal associations demonstrate different avenues for designing the energy policies in APEC countries. The bidirectional associations mentioned above indicate not only the impacts of Y, GCF, FF, REN, RD, and POP on N_2O emissions, but also the impact of N_2O emissions on these variables. These causal associations demonstrate that the energy policies need to consider these parameters at the formulation stage, as GHG emissions have direct impacts on these parameters. Therefore, on one hand, when the economic growth pattern in these countries might lead to changes in the pattern of N_2O emissions, on the other hand, the N_2O emissions also have an impact on the pattern of economic growth, and existence of this bidirectionality paves the way for sustainable development in these nations.

4. Conclusion and Policy Implications

By far, we have tested the EKC hypothesis for N_2O emissions in APEC countries over the period of 1990-2015, and in this pursuit, we have tested three models of EKC by segregating the renewable and non-renewable energy sources, as well as by combining them. In the course of analysis, we have found that the EKCs for N_2O emissions APEC countries are N-shaped, and the second turnaround point of the EKC using renewable energy consumption is higher compared to the second turnaround point of the EKC achieved using fossil fuel consumption. We have also found that bidirectional causal associations exist between N_2O emissions and rest of the model parameters, except for trade openness.

Now, when we delve deeper into the findings of the study, the policy implications can emerge. It can be seen that the renewable energy consumption is more effective in terms of decreasing the level of N_2O emissions compared to the fossil fuel consumption, but this can have negative implications on the economic growth pattern, as well. As the cost of implementation of renewable energy solutions is higher than that of the fossil fuel-based energy solutions, direct replacement of fossil fuel-based energy solutions with renewable energy solutions might affect the economic growth pattern negatively, as this has been seen in the bidirectional causal association between economic growth and renewable energy consumption. Now, saying this, it is to be remembered that the policy-level solutions must ensure sustainable development, which is one of the major targets of these nations. In order to ensure the sustainable development, the results obtained in this study must cater to the objectives of SDGs, which the nations have to fulfill by 2030 (UNDP, 2017). Therefore, while redesigning the energy policies of these countries, it has to be remembered that the redesigned energy policy should address at least three SDG objectives: (a) SDG 7 – affordable and clean energy, (b) SDG 8 – decent work and economic growth, and (c) SDG 13 – climate action (UNDP, 2017). In order to achieve these three objectives, it is necessary to look into the second objective, i.e. decent work and economic growth, as this objective largely encompasses the other two SDG objectives. Availability of affordable and clean energy, along with the actions against climate change will have a significant impact on the hygienic state of the labor force, and therefore, this might have an impact on the economic growth. If the renewable energy solutions start to be implemented across these nations, then it will result in the creation of a number of new organizations, which might open up new vocational opportunities. Renewable energy solutions should necessarily create more job opportunities, and thereby, uplift the livelihood of the citizens. The newly created job will help in increasing the level of per capita income in these nations, and at the same time, these jobs will also help in reducing the GHG emissions by cutting down the fossil fuel consumption. This might ensure the decent work and economic growth. In order to achieve this, the technological innovation should be endogenous, as the R&D expenditure is having a positive impact on the environmental quality. Though the technological innovations brought by means of international trade is also having a positive impact on the environmental quality, it will be having a pressure on the balance of payment, and therefore, it will contribute to deterioration of the exchange rate. Therefore, the policymakers in these nations should stress on endogenous capacity building, in terms of enhancement of research and innovation capabilities.

Along with this, the policymakers should also remember that the rise in industrialization is also causing the shrinkage of agricultural field, and therefore, the existing urban infrastructure might encounter difficulties. In such a situation, creation of new job opportunities might turn out to be critical. Now, this job creation can be carried out in terms of providing the renewable energy solutions to both industries and households at differential rates, where renewable energy solution to households can be subsidized by the income received from the industries (cross-subsidization). While providing the renewable energy solutions, the existing fossil fuel solutions can be replaced, starting with the households, and then gradually the industries. In this way, the demand for renewable energy can be sustained, and that too without harming the economic growth pattern. For the marginalized households, the policymakers can provide the renewable energy solutions for free for a certain duration, mutually decided by the policymakers and the households. Once that period is over, those households can repay the amount to the government with small installments, which will again be subsidized by the industries. In this way, a phase-wise shift from fossil fuel-based energy solutions to renewable energy solutions can be possible.

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