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## Article

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## Research paper

# Estimating the Railways Kuznets Curve for high income nations—A GMM approach for three pollution indicators

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## ABSTRACT

Railways transportation is still taken as an account of economic growth without considering the cost of environmental damages. Therefore, it is an urgent need at the national and global level to take into account the sustainability of environment by key sector. So this analysis has contributed in unveiling the striking facts and figures for environment with regard to railways transportation sector. The aim of this study is to investigate the “Railways Kuznets Curve” in context of three key pollution emissions Carbondioxide emission, Nitrous oxide emissions and Methane emissions for 37 High income nations during 1990 to 2017. The econometric results of Panel GMM shows that there exists “U shaped” Railways Kuznets curve for carbondioxide and methane emissions indicating increased level of pollution. While nitrous oxide emissions exhibit the “inverted U shaped curve” validating the Railways Kuznets curve. The Pairwise Dumitrescu Hurlin Panel Causality shows a bidirectional relation of nitrous and methane emissions and uni-directional association of CO<sub>2</sub> emissions to railways transportation. The Impulse Response function and Variance decomposition indicates a diverging drift of CO<sub>2</sub> and CH<sub>4</sub> emissions while converging trend of N<sub>2</sub>O emissions to railways transport sector. The diagnostic test of ARCH-effect and serial correlation shows the homoscedasticity and no autocorrelation along with CUSUM test that shows stability of all the three models. On the basis of econometric results, this analysis suggests that developed nations should focus on exploiting renewable energy resources along with adopting fuel-saving traveler and freight technologies including hybrid switch trains and hydrogen-powered steam engines that thorough cuts the diesel fuel.

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## 1. Introduction

The transportation sector is an influential factor in the significant growth of economy but at the same time environmental impact cannot be underrated. Regardless of energy efficient measures in automobiles, even then they have their detrimental effects on the environment, together with the emission of carbon, nitrogen dioxide and particulate matter that contributes in pollution (Venemo and Aunan, 2018).

Transportation conjures the diverse image of connectivity, leisure, recreation, business productivity, social contact and cultural exchange. Yet, it is a critical challenge to the environment. It derives economic growth by enhancing mobility of resources, instrument of globalization (integration of economics, social, political and cultural activities) along with destructive threats to the environment as well (Bissell and Fuller, 2017).

Nonetheless not as prevalent as the automobiles, railways remain to be an imperative means of transportation for both passengers and cargo. Railways is considered as a diversity equal at

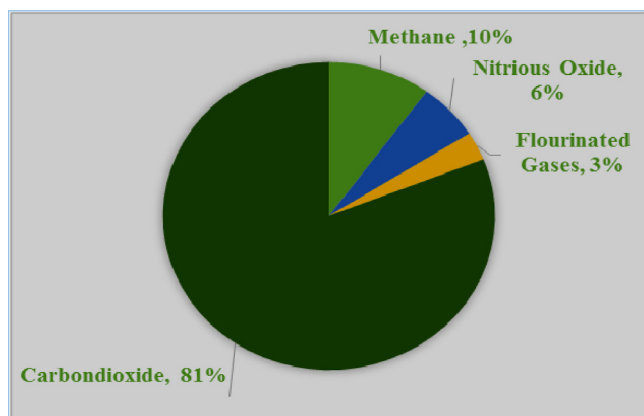
technical and infrastructural level. In developed nations railways is the most efficient mode of transportation. Even so railways system is still at keen in lowering the detritus emissions (Scholten and Künneke, 2016).

The railways operations and constructions have a serious implications on the environment. Particulate matter (PM<sub>10</sub>) and Nitrogen oxides are the most dangerous for exposure and health problems. The emissions has increased by 34% and ozone depletion substances by 40% (Ahn et al., 2010). Nevertheless, local air pollution, in specific from transport, remains a main hazard. New burning technologies, efficient conduction systems and exhausts after-treatment can ensure that railways diesel power can be more eco-friendly in the future than that of road (Nithyanandan, 2017).

In this regard, railways transportation in context of pollution emission is analyzed based on the theory of Environmental Kuznets Curve (EKC). This hypothesis posits that how per capita effects the environmental degradation at different stages in the economic growth. This argues that a reduction in environmental degradation arises from economic growth as nations become wealthier and per capita income rises (Sarigiannidou and Palivos, 2012). The transportation as a railways mode in case of developed nations explicitly depicts the efficient mode because of electrification and

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**Fig. 1.** Overview of greenhouse gases and sources of emissions.  
Source: USEPA-inventory GHG emissions.

advanced technologies. On the contrary, many studies show the significant GHG emissions by transport sector of developed nations. The below pie chart shows the emissions and sources of emissions only in US (USEPA, 2015) (see Fig. 1).

Moving towards the emissions by trade openness and related FDI there is a diversity of association with the debris emissions. Higher the internalization, trade and FDI leads to increase the market-based instruments that are more efficient, advanced infrastructure that reduce the negative externalities of transport and improve impartiality between modes. The inward FDI and trade are the crucial factors increasing the economic growth and productivity by providing high skill labor, technology transfer, research and development, finance, infrastructure, capital, export promotion, and market accessibility (Acharyya, 2009). At one node, developed nations might reduce environmental degradation by adopting environmental policies, financial liberalization, FDI and trade that attracts higher level of R&D related improvement in environmental quality (Tamazian et al., 2009). The technology is closely related to the trade openness as this phenomenon contemplates that trade will bring research and development that will decrease the environmental degradation (Katircioğlu and Taşpınar, 2017a,b).

Moreover, population is the significant aspect in increasing environmental degradation by depleting the natural resources as well as increases the demand of energy and fuel for earning and livelihood for their survival (Nagdeve, 2007). Population growth and per capita income directly influence the environmental quality showing controversial debate. Population growth with high per capita income might reduce the environmental degradation by investing in the R&D to improve environmental quality and adoption of policies whereas the higher growth of population with low per capital increases poverty which badly affects the economy and environment all together (Omri et al., 2015). The increase in population leads to increase in the energy demand that greatly emits high amount to waste emissions in context of environment damages. Summing up, transportation is interlinked with the population, trade, FDI, economic growth and then energy demand that collectively increases the environmental degradation.

## 2. Review of literature

The various studies mentioned below show different variables for different nations limited to the specified traditional analysis. Canas et al. (2003) studied the relationship between direct material input and income per capita during 1960 to 1998 for 16 industrialized countries. This paper examines the analytical value to the

“dematerialization” since direct material input (DMI) per capita as the dependent variable in empirical implication of environmental Kuznets curve (EKC) and is gross domestic product per capita as an explanatory variable. By using panel data for the quadratic and cubic versions of EKC the intensity of material consumption first increases, but eventually starts exhibiting a decreasing trend after a certain income threshold is reached. The result shows a strong and robust support for both the quadratic and cubic EKC relationships between material input and income, in industrialized economies. The study for the existence of EKC also reveals that an increase of material use in low-income levels may be interconnected to responses to infra-structural needs, materials categories, evolution in economic structural change and share of the service sector contribution.

Kenworthy (2003) attempted to study the relationship between greenhouse gasses and transport energy in urban passenger transport system. The sample of 84 cities used in the research included cities from USA, Australia, Canada, Western Europe, high income Asia, Eastern Europe, the Middle East, Africa, low income Asia, Latin America and China. This study examines the CO<sub>2</sub> emission in contrast to the other variables such as population density, transport infrastructure, public transport and non-motorized mode use. The econometric results imply that transport energy use and greenhouse gas emissions can be linked directly to the extent and quality of public transportation system. In relation to CO<sub>2</sub> emissions, USA is leading the way, followed by Australian and Canadian cities, while Chinese cities are at the lowest. Finally this analysis suggests that in order to cut down greenhouse gas emissions, better quality transport system be introduced, and also people should consider alternate modes of transportation which are fuel efficient.

Colella et al. (2005) tried to analyze the effects of changing fossil-fuel on-road vehicles (FFOV) to hydrogen fuel cell vehicles (HFCV) on environment i.e. air pollution and global climate. The study is based on US EPA's National Emission Inventory. The methodology Life-cycle assessment (LCA) on alternative fuel supply has been used. The econometric results imply that all HFCVs are a source of reducing net air pollution emission. In addition, it may also reduce the global warming impact, greenhouse gasses and pollutant particles. Thus, the study suggests that hydrogen is not only an efficient means for transportation, in addition it will also lead to the reduction in environmental degradation.

Norman et al. (2006) studied the relationship between residential densities (i.e., population), energy use and greenhouse gas emissions. The study was based in Toronto city, US. The economic variables considered in the study were building operations, construction materials and transportation. By using the technique of economic input–output life-cycle assessment (EIO-LCA) the results show that urban development plays a key role in GHG emissions and in turn, environmental degradation. Low density sub-urban development is more GHG producing as compared to the high density city core development. Thus, in order to minimize GHG, efforts should be made in transportation in suburban development, while in order to minimize energy usage the focus should be on building materials.

Von Blottnitz and Curran (2007) assessed bio-ethanol as a transportation fuel with regard to the environmental life along with net energy and greenhouse gas. The study was conducted on 47 published assessments comparing bio-ethanol and conventional fossil fuel. The study uses life-cycle approach for the comparison. The results of this research concluded that regarding energy and greenhouse gasses, bio-ethanol is in advantage because it is time and energy efficient. But its production has other environmental hazards such as acidification, ecological toxicity and human toxicity. Due to increasing transportation usage, bio-ethanol is favorable as a resource.

Acharyya (2009) analyzed the phenomenon EKC for Turkey during the time period 1968 to 2005. The econometric results of

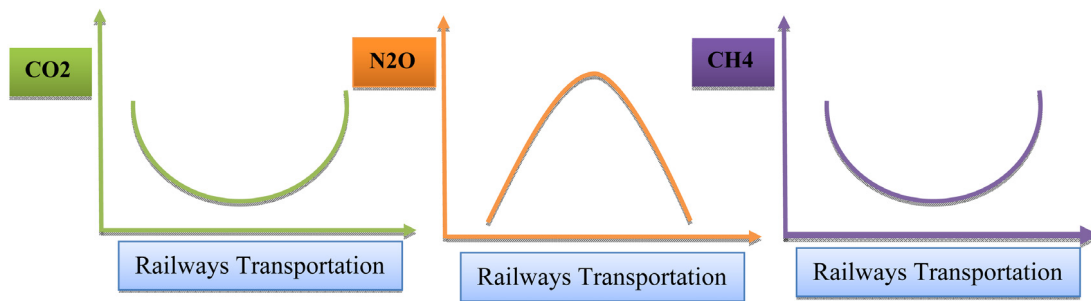


Fig. 2. EKC for CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> emissions.

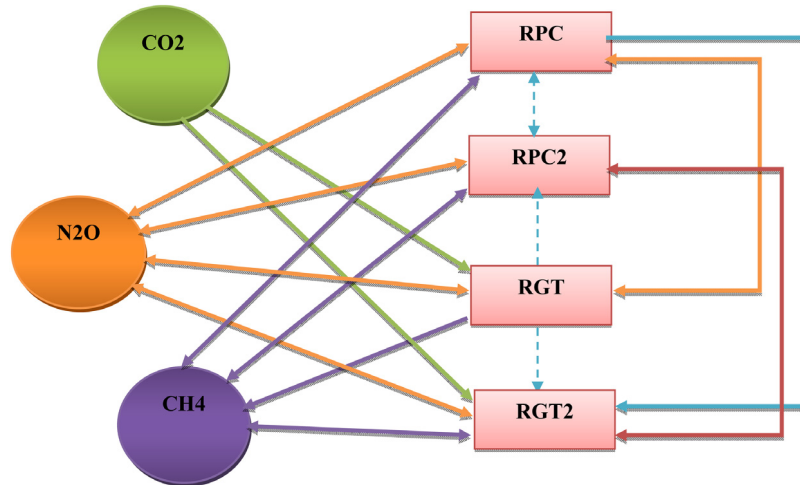


Fig. 3. Pairwise granger causality.

ARDL Bound test approach indicate that EKC is not valid during this time frame. Moreover, there is statistically positive relationship between economic growth and environmental pollution.

Similarly, [Ozturk and Acaravci \(2010\)](#) attempted to find the association between urbanization, GDP and GHG (Green House Gases) emissions for the India during 1980 to 2003. The cointegration regression shows that one unit increase in GDP and urbanization increases the GHG (Green House Gases) by 86% and 57% respectively.

In the same context, [Cristea et al. \(2013\)](#) worldwide studied the global transport emissions and manufacturing sectors in regard to environment during 1990 to 2010. The Global Trade Analysis Project (GTAP) is applied to quantify the worldwide emissions by transport and trade. The econometric results show that 33% emissions are resulted from trade transport while manufacturing sectors are responsible for 75% emissions.

[Hassaballa \(2013\)](#) attempted to analyze the effect of FDI on environment for 8 developing nations during the time frame 1982 to 1992. By employing the Fixed Effect and Random Effect the econometric results revealed that FDI does not affect environment. Similarly, [Pazienza \(2015\)](#) studies the impact of FDI on 30 OECD nations during 1981 to 2005 in context to environmental degradation. The econometric results of Fixed Effect and Random Effect shows the existence of positive and significant relation of FDI to CO<sub>2</sub> emissions. This means that emerging OEDC nations are contributing negative to ecology by mode of FDI.

[Al-Mulali and Ozturk \(2015\)](#) attempted to analyze the relationship of energy consumption, trade openness and urbanization to environmental degradation for MENA region during 1996 to 2012. The results of Fully Modified-OLS (FMOLS) indicate that all the variables are positively and significantly associated to ecology. The results show that the increase in energy consumption, trade

openness and urbanization significantly increases the CO<sub>2</sub> emissions. Moreover, [Akomolafe et al. \(2015\)](#) study the phenomena of Pollution haven hypothesis and EKC for Nigeria during the 1990 to 2010. The results of Vector error Correction model (VECM) indicates the validation of both hypotheses such as PHH and EKC. Furthermore, in there exist positive and significant relation of trade, economic growth and energy to environment while negative association exist in long run.

Most recent literature are enlisted [Table 1](#) that shows different studies in perspective of environmental pollution and other economic variables.

### 2.1. Significance of the study

This analysis has developed a novel contribution in the literature by rational analysis for the existence of Railways Transportation Kuznets curve hypotheses in the perspective to carbon dioxide, methane and nitrous oxide emissions. Railways transportation in perspective of energy is naive feature of this research in context of three striking environmental degrading indicators. Hence, a wide-range analysis is carried out at panel data incorporating other key influential variables affecting environment such as trade openness, economic growth, population, energy consumption and FDI which has been not carried out in the previous studies.

All the previous studies are either carried out on few countries or for selective years considering certain variables (Energy consumption, Growth or population) only in context of CO<sub>2</sub> but current study is conducted on panel data for three different prominent environment degrading indicators (CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions) individually.

**Table 1**  
Recent literature review.

Study	Country	Time frame	Methodology	Results
Oh and Bhuyan (2018)	Bangladesh	1975–2013	ARDL bound test	CO2 to EC (+), PD (+)
Mikayilov et al. (2018)	Azerbaijan	1992–2013	ARDL to cointegration	EG to CO2 emissions (+)
Ilham (2018)	8 ASEAN's Nations	2004–2013	Simultaneous equation model	CO2 to GDP, EC, TR, Economic development (+), EC to GDP (+), ED (–)
Rafindadi et al. (2018)	GCC nations	1990–2014	Pooled mean group	ED to FDI, EC (+)
Abdouli et al. (2018)	BRICTS <sup>a</sup> countries	1990–2014	GMM	Kuznets curve validates for BRICTS countries. FDI, PD to CO2 emissions (–) EG to CO2 emissions (+)
Jiang et al. (2018)	30 provinces of China	2002–2015	Panel cointegration	EKC hypothesis is confirmed in Chinese provinces TR, FDI to CO2 emissions (–)
Khan and Khan (2018)	America continent, low, lower-middle, upper-middle income	1990–2014	Two stages least square (2SLS)	PHH and EKC does not validates PD to CO2 emissions (+) ED to CO2 emissions (–)
Saleem et al. (2018)	Next-11 countries	1975–2015	Panel FMOLS	ED, PD to carbon emission (–) Bidirectional link between railways transportation and Carbon emissions Unidirectional link ED, EG to Carbon emissions
Mitic et al. (2017)	17 different nations	1997–2017	DOLS & MOLS	GDP to CO2 (35%)
Sinha et al. (2017)	N-11 Nations	1990–2015	Cointegration	N-shaped EKC
Shahzad et al. (2017)	Pakistan	2003–2015	ARDL to Cointegration	Trade to CO2 (0.24%), Financial Development to CO2 (0.087%),
Zheng and Sheng (2017)	China	1997–2009	GMM	FDI to CO2 (+)
Jamel and Maktouf (2017)	40 European Nations	1985–2014	OLS	Bi-direction EG to CO2, EKC exist.
Vu (2017)	China	1971–2011	ARDL bounds testing approach	PD, ED to CO2 emissions (+) in long run PD, ED to CO2 emissions (–) in short run.
Zhou et al. (2018)	285 cities from China	2003–2015	GMM	Inverse N-shape relationship found for per capita GDP to CO2 emissions FDI to CO2 emissions (–)

Note: ED: Environmental Degradation, EC: Energy Consumption, PD: Population Density, EG: Economic Growth, TR: Trade openness.

<sup>a</sup>(Brazil, Russian Federation, India, China, Turkey and South Africa).

## 2.2. Objectives of the study

- To explore the existence of Railways Transportation Kuznets curve for high transition economies in context of CO2 emissions.
- To investigate the Railways Transportation Kuznets curve for high transition economies in perspective of N2O emissions.
- To examine the Railways Transportation Kuznets curve for high transition economies in context of CH4 emissions.

## 2.3. Hypotheses of the study

- $H_1$ : There exists Railways Kuznets Curve to carbon dioxide under different explanatory factors in a panel high income countries.
- $H_2$ : There exists Railways Kuznets Curve to nitrous oxide emissions under different explanatory factors in a panel high income countries.
- $H_3$ : There exists Railways Kuznets Curve to methane emission under different explanatory factors in a panel high income countries.

## 2.4. Correlation analysis

The Table 3 portrays the correlation matrix. The relationship of CO2 emission with methane emission (–0.006), railways passenger carried (–0.125), population growth (–0.220) have negative and weak while CO2 emission with nitrous oxide emission (0.019), railways good transported (0.053), energy demand (0.004),

GDP (0.402), trade openness (0.402) and FDI (0.016) have positive but weak relationship. The association of methane emission with nitrous oxide (0.938), railways good transported (0.923), have strong positive relationship. Methane emission with railways passenger carried (–0.002), trade openness (–0.252) and population growth (–0.080) have negative weak relationship. While methane emission with energy demand (0.372), GDP (0.079) and FDI (0.503) have positive relationship. The relationship of nitrous oxide with railways good transported (0.951) have strong positive relationship and nitrous oxide with trade openness (–0.233), population growth (–0.057) have negative weak relationship and railways passenger carried (0.075), energy demand (0.305), GDP (0.090) and FDI (0.490) have weak relationship. Trade openness (–0.218) and population growth (–0.052) have weak relationship. The relationship of railways passenger carried with railways good transported (–0.022), energy demand (–0.077), trade openness (–2.66) and population growth (–0.014) have negative weak relationship. While railways passenger carried with FDI (0.047) and GDP (0.081) have weak relationship. The relationship of railways good transported with energy demand (0.311), GDP (0.103), FDI (0.568) have positive relationship while railways good transported with population growth (–0.051) and trade openness (–0.189) have negative relationship. The relationship of energy demand with GDP (0.594), trade openness (0.222), population growth (0.073) and FDI (0.190) have positive relationship. Finally, the relationship of GDP with trade openness (0.254), population growth (0.057) and FDI (0.208) have positive weak relationship. The relationship of trade openness with population growth (0.641) has positive relationship while FDI (–0.021) has negative relationship. There is weak association between population growth and FDI (0.042).

**Table 2**  
Descriptive statistics.

Statistics	CO2	CH4	N2O	RPC	RGT	ED	GDP	TOP	PG	FDI
Mean	27.59	15 362	3313	17 673	80 472	4166	34 375	95	296	24 100
Median	25.87	2040.4	646.98	3687	8385	3772.88	33 682.24	74.131	102.492	60 200
Maximum	69.75	25 238	82 671	260 014	283 912	12 087	111 968	441.60	8010.66	7.341
Minimum	4.503	98.685	8.349	8.465	13.490	723.846	5 140.528	16.012	2.221	−4.391
Skewness	0.772	4.773	5.790	4.392	5.926	1.112	0.974	2.449	5.944	5.346
Kurtosis	3.975	26.725	36.123	23.876	37.611	4.430	4.175	10.189	37.872	41.804
Jarque–Bera	144	28 230	53 148	22 143	57 774	301	223	3266	58 593	69 931
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	1036	1036	1036	1036	1036	1036	1036	1036	1036	1036

Note: CO2 is Carbon dioxide emissions, CH4 is Methane emissions, N2O is Nitrous oxide emissions, Note: RPC is Railways Passenger Carriage, RGT is Railways Goods Transported, ED is Energy Demand, GDP is Gross Domestic Product, TOP is Trade Openness, PG is Population Growth and FDI is Foreign Direct Investment.

**Table 3**  
Correlation analysis.

Correlation probability	CO2	CH4	N2O	RPC	RGT	ED	GDP	TOP	PG	FDI
CO2	1.000									
CH4	−0.007	1.000								
	0.832	−								
N2O	0.019	0.938	1.000							
	0.532	0.000	−							
RPC	−0.126	−0.003	0.075	1.000						
	0.000	0.925	0.016	−						
RGT	0.054	0.923	0.951	−0.023	1.000					
	0.083	0.000	0.000	0.467	−					
ED	0.004	0.372	0.306	−0.078	0.311	1.000				
	0.893	0.000	0.000	0.012	0.000	−				
GDP	0.402	0.080	0.090	0.081	0.103	0.594	1.000			
	0.000	0.010	0.004	0.009	0.001	0.000	−			
TOP	0.011	−0.253	−0.233	−0.266	−0.190	0.222	0.254	1.000		
	0.714	0.000	0.000	0.000	0.000	0.000	0.000	−		
PG	−0.221	−0.081	−0.058	−0.015	−0.052	0.073	0.052	0.641	1.000	
	0.000	0.009	0.064	0.633	0.094	0.019	0.096	0.000	−	
FDI	0.016	0.503	0.490	0.047	0.568	0.191	0.209	−0.021	0.043	1.000
	0.606	0.000	0.000	0.128	0.000	0.000	0.000	0.498	0.168	−

### 3. Data source and methodology

#### 3.1. Data source

The data has been taken from World Bank (WB, 2018) and World Development Indicator (WB, 2018). Based on the World Bank income division the total availability of data for high income nations are 47, out of which 10 is missing. Therefore, 37 high income nations have been selected enlisted in Appendix A.

#### 3.2. Conceptual framework

The American Economist Simon Smith Kuznets proposed the inverted U-shaped relationship between environmental indicators and economic growth during 1955 and 1963. The shapes of EKC may vary according to the nature of development and pollution indicators like inverted “U” shaped, “U” shaped and “N” shaped etc. The most consistent thought of classical school is concerned with the long run consequences of economic growth which may impart positive and negative impact on the nations. In this regard, the EKC theory supports the current analysis such as economic growth by transportation and pollution emissions as environmental indicators. The debate of EKC continues to the other pollution indicators and the level of economic development of diverse income based nations. Hence, pollution-income relationship as EKC depicts that the environmental quality and economic growth tends to get worsen until a certain level of income where the nations invest to recover environment quality. However, the economic growth can be enhanced by improving technology, advanced industrializations process, mechanized agriculture, skilled labors along with encompassing research and development (Adenle et al., 2017). Endogenous growth model also encompass the interaction between trade,

economic growth, and the environment. Transportation systems are related with an extensive range of environmental contemplations at all geographical scales, from native to the international level. The nature of these environmental impressions are connected to the transport means themselves, their energy stream systems, their releases and the infrastructures over which they function (Ford et al., 2017).

#### 3.3. Econometric models

The econometric models based on the theory of EKC are formulated as RKC (Railways Kuznets Curve) in context to CO2, N2O and CH4 emissions that are exhibited without taking log form because FDI has negative values.

$$CO2 = \alpha_0 + \alpha_1(PCGDP)_{it} + \alpha_2(RPC)_{it} + \alpha_3(RPC)_{it}^2 + \alpha_4(RTG)_{it} + \alpha_5(RGT)_{it}^2 + \alpha_6(FDI)_{it} + \alpha_7(TOP)_{it} + \alpha_8(ED)_{it} + \alpha_9(PG)_{it} + \varepsilon_{it} \quad (1)$$

$$N2O = \alpha_0 + \alpha_1(PCGDP)_{it} + \alpha_2(RPC)_{it} + \alpha_3(RPC)_{it}^2 + \alpha_4(RTG)_{it} + \alpha_5(RGT)_{it}^2 + \alpha_6(FDI)_{it} + \alpha_7(TOP)_{it} + \alpha_8(ED)_{it} + \alpha_9(PG)_{it} + \varepsilon_{it} \quad (2)$$

$$CH4 = \alpha_0 + \alpha_1(PCGDP)_{it} + \alpha_2(RPC)_{it} + \alpha_3(RPC)_{it}^2 + \alpha_4(RTG)_{it} + \alpha_5(RGT)_{it}^2 + \alpha_6(FDI)_{it} + \alpha_7(TOP)_{it} + \alpha_8(ED)_{it} + \alpha_9(PG)_{it} + \varepsilon_{it} \quad (3)$$

“i” shows high income nations, “t” is time period of 1990 to 2017 and  $\alpha$ 's are the respective coefficients. The dependent variables as environment degrading emissions, such as CO2 emissions from transport (“% of total fuel combustion”), Nitrous oxide and Methane

emissions as “(thousand metric tons of CO<sub>2</sub> equivalent)”. While dependent variables are: Per capita Income: PCGDP (Constant 2010 US\$), RTG or RGT (Railways Goods transported (million ton-km)), RPC (Railways passengers carried (million passenger-km)), ED (Energy Demand (kg of oil equivalent per capita)), FDI (Inflows: net (BoP, current US \$)), TOP (Trade openness: “Trade (% of GDP)”) and PG (Population Growth: “Population density (people per sq. km of land area)”).

### 3.4. Panel unit root test summary

The panel data is treated firstly by the panel unit root test summary that is an extension of the univariate unit root test. The LLC test is based on the pooled panel data as follows (Levin and Lin, 1992).

$$y_{it} = \rho y_{i,t-1} + \alpha_0 + \sigma t + \sigma_i + \theta t + \varepsilon_{it}$$

where,  $\rho$ ,  $\alpha_0$ ,  $\sigma$  are coefficients,  $\alpha_i$  is individual specific effect,  $\theta t$  is time specific effect. Secondly, ADF test is applied to each individual series having normalized disturbance.

The ADF model is expressed as:

$$\Delta y_{it} = \rho y_{it} - 1 + \sum_{j=1}^{p_i} \delta_{ij} \Delta y_{i,t-j} + \alpha_i + \varepsilon_{it}$$

The null hypothesis and the alternative hypothesis is expressed as:

$$H_0: \rho_i = 0$$

$$H_A: \rho_i < 0$$

The null hypothesis of unit root test is that all series are non-stationary process under the alternative hypothesis that fraction of the series in the panel are assumed to be stationary.

### 3.5. Panel cointegration

After unit root, Panel Cointegration is applied in order to analyze the long run cointegration among the series of three models separately. The series are integrated on the significance of two statistics based on Fisher Statistics such that max-eigen test and trace test. The null hypothesis states that there is no long run cointegration among the series against the alternative hypothesis of long run cointegration.

### 3.6. Panel GMM

Before applying the panel or dynamic GMM for the panel data, it is better to test the existence the correlational random or fixed effect in the models. For this purpose Hausman test is applied and significant probability values indicates the rejection of null hypothesis that Random effect is better. In the current literature of econometrics, the most widely circulated advance technique is GMM that has explicit connection to other estimating methods which produces “efficient” estimators. The accuracy and efficiency of finite sample size is examined by the variant of Arellano–Bond and the Blundell–Bond GMM estimations which considers the existence of heteroskedasticity due to dynamic nature of data along with endogeneity (Kiviet et al., 2017). In this analysis, GMM is applied to account for the dynamics in the model along with covering the issue of endogeneity and heteroskedasticity. When there are changes in one explicative variable, they impact the dependent variable but it adjusts over time to that impact towards its long run equilibrium. GMM umbrellas OLS estimators, 2SLS and IV technique that is not only applicable to single equation but as a whole system of equations in case of panel data along with an extension to panel study. The dynamics of panel data is better handled by this technique by covering the cross section differences and by taking differenced lagged value as an instruments making the estimators consistent.

### 3.7. Impulse response and variance decomposition

In addition, Impulse responses are applied that shows how a variable responds to a shock in the other variable initially and whether the effect of the shock persists or dies out quickly. Moreover, variance decomposition analysis is applied to point out the variation in a variable that can be explained by the changes in another variable in the same VAR system.

## 4. Results and discussions

### 4.1. Descriptive analysis

The mean value of CO<sub>2</sub> emission is (27.59) % of total fuel combustion, methane emission are (15 362) thousand metric tons of CO<sub>2</sub> equivalent, nitrous oxide emission is (3313) thousand metric tons of CO<sub>2</sub> equivalent, railways passenger carried is (17 673) million passenger-km, railways goods transported is (80 471) million ton-km, energy demand is (4166) kg of oil equivalent per capita, GDP is (34 375) Constant 2010 US\$, trade openness is (95) % of GDP, population growth is (296) people per sq. km of land area and FDI is (24 100) BOP, current US\$. The maximum of CO<sub>2</sub> emission is (69.756) % of total fuel combustion, methane emission is (252 381.8), nitrous oxide emission is (82 671.32). Skewness indicate to which extent the data is not symmetrical. The value of skewness of CO<sub>2</sub> emission (0.772), methane emission (4.773), nitrous oxide emission (5.790), railways passenger carried (4.392), railways good transported (5.925), energy demand (1.112), GDP (0.974), trade openness (2.448), population growth (5.944), FDI (5.345) showing positively skewed. Kurtosis indicates the peakedness or tailedness of the probability distribution. The value of CO<sub>2</sub> emission (3.947) indicating standard value while rest values shows leptokurtic pattern such as methane emission (26.724), nitrous oxide emission (36.122), railways passenger carried (23.875), railways good transported (37.611), energy demand (4.430), GDP (4.174), trade openness (10.188), population growth (37.871), FDI (41.803). Jarque–bera measure the normality of the distribution. The values of CO<sub>2</sub> emission is (144.024), methane emission is (28 230.94), nitrous oxide emission is (53 148.02), railways passenger carried is (22 143.33), railways good transported is (57 774.97), energy demand is (301.899), GDP is (223.547), trade openness is (3266.206), population growth is (58 593.93), FDI is (69 931.65). Table 2 shows the detail outlay of the descriptive analysis.

### 4.2. Panel unit root test summary

The null hypothesis of unit root test (see Table 4) is that all series are non-stationary process under the alternative hypothesis that fraction of the series in the panel are assumed to be stationary. The N<sub>2</sub>O emissions, Railways passenger carriage, FDI and Energy demand are stationary at level as shown by ADF and PP-Fisher Chi-square test. While, all the variables are first difference integrated at 1% probability value shown in all the unit root tests such as LLC, IPS, ADF and PP Fisher.

### 4.3. Panel cointegration

All the variables shows significant probability statistics by either test (see Table 5). The null hypothesis states that there is no long run cointegration among the series that is rejected at 5% probability against the alternative hypothesis of long run cointegration. The estimated panel fisher cointegration shows that considered variables are connected in long run cointegration.

**Table 4**  
Panel unit root.

Variables	Unit root methods	High income transition											
		Level		1st difference		Level		1st difference		Level		1st difference	
		Stats.	Prob.	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.
CO <sub>2</sub> , N <sub>2</sub> O, CH <sub>4</sub>	LLC	1.299	0.903	−9.52	0.000	−1.82	0.0347	−7.29	0.000	0.304	0.6196	−11.00	0.000
	IPS	5.1260	1.000	−14.83	0.000	−0.76	0.2222	−9.59	0.000	2.662	0.9961	−12.17	0.000
	ADF	37.634	0.999	363.1	0.000	116.9	0.0011	245.3	0.000	77.22	0.3759	301.87	0.000
	PPF	41.592	0.999	675.2	0.000	132.5	0.0000	484.7	0.000	84.67	0.1860	470.84	0.000
RPC, RGT, FDI	LLC	0.0670	0.526	−14.46	0.000	2.518	0.9941	−83.16	0.000	−2.15	0.0157	−13.99	0.000
	IPS	−0.61	0.270	−15.60	0.000	2.836	0.9977	−27.76	0.000	−3.39	0.0003	−21.12	0.000
	ADF	116.83	0.001	374.27	0.000	59.08	0.8968	371.5	0.000	113.3	0.0022	519.75	0.000
	PPF	161.39	0.000	577.8	0.000	61.25	0.8553	600.1	0.000	199.6	0.0000	923.66	0.000
TOP, GDP, ED	LLC	−1.33	0.092	−16.08	0.000	−2.81	0.0025	−11.81	0.000	−1.27	0.1022	−10.69	0.000
	IPS	1.0125	0.844	−15.84	0.000	3.643	0.9999	−12.83	0.000	−0.53	0.2987	−13.30	0.000
	ADF	60.874	0.863	380.10	0.000	35.89	0.9999	308.5	0.000	120.0	0.0006	318.63	0.000
	PPF	51.004	0.981	615.30	0.000	31.34	1.0000	423.3	0.000	111.8	0.0030	652.26	0.000
PG	LLC	0.9293	0.823	−4.64	0.000								
	IPS	7.5112	1.000	−5.01	0.000								
	ADF	67.654	0.685	152.39	0.000								
	PPF	101.18	0.019	170.41	0.000								

Note: LLC: Levin, Lin & Chu t\*, IPS: Im, Pesaran and Shin W-stat ADF: ADF-Fisher Chi-square, PPF: PP-Fisher Chi-square.

**Table 5**  
Panel cointegration.

Independent Variable	GDP, RPC, RPC <sup>2</sup> , RGT, RGT <sup>2</sup> , FDI, TOP, ED, PG											
	CO <sub>2</sub>				N <sub>2</sub> O				CH <sub>4</sub>			
Dependent Variable	Fisher Stat.*		Fisher Stats.*		Fisher Stat.*		Fisher Stats.*		Fisher Stat.*		Fisher Stats.*	
Hypothesized No. of CE(s)	(from trace test)	Prob.	(from max-eigen test)	Prob.	(from trace test)	Prob.	(from max-eigen test)	Prob.	(from trace test)	Prob.	(from max-eigen test)	Prob.
None	48.52	0.9765	48.52	0.9765	48.52	0.9765	48.52	0.9765	48.52	0.9765	48.52	0.9765
At most 1	47.13	0.9837	65.55	0.6283	44.36	0.9929	99.62	0.0115	44.36	0.9929	99.62	0.0115
At most 2	30.50	1.0000	270.0	0.0000	31.88	1.0000	252.9	0.0000	23.57	1.0000	355.1	0.0000
At most 3	8.318	1.0000	542.5	0.0000	1.386	1.0000	627.7	0.0000	6.931	1.0000	559.6	0.0000
At most 4	644.7	0.0000	644.7	0.0000	644.7	0.0000	644.7	0.0000	644.7	0.0000	644.7	0.0000
At most 5	1538.	0.0000	943.2	0.0000	155.1.	0.0000	957.4	0.0000	1549.	0.0000	906.2	0.0000
At most 6	1018.	0.0000	568.9	0.0000	1019.	0.0000	539.4	0.0000	1020.	0.0000	550.0	0.0000
At most 7	581.4	0.0000	348.6	0.0000	597.6	0.0000	378.4	0.0000	590.0	0.0000	383.9	0.0000
At most 8	335.5	0.0000	264.6	0.0000	320.2	0.0000	257.9	0.0000	310.1	0.0000	231.6	0.0000
At most 9	192.7	0.0000	192.7	0.0000	185.0	0.0000	185.0	0.0000	214.6	0.0000	214.6	0.0000

Note: \* indicates 1%, \*\* indicate 5% and \*\*\* indicate 10% level of significance respectively.

#### 4.4. Correlated random effects – Hausman test

The correlational random or fixed effect in the models is applied after cointegration. For this purpose Hausman test is applied and significant probability values at 1% indicates the rejection of null hypothesis that Random effect is better (see Table 6). Therefore, fixed effect is used for all the considered models.

#### 4.5. Panel generalized method of moments

In the first model where carbon dioxide is dependent variable shows the significant impact on environment by influential considered regressors. Similarly, N<sub>2</sub>O emissions and then CH<sub>4</sub> emissions are regressed as dependent variables to quantify the impact of railways sector along with other considered independent variables. The detail analysis is described in Table 7.

The GMM estimate of coefficient GDP depicts positive relation to carbon emission. It indicates that one unit increase in GDP leads to increase the carbon emission by 5.855 units that is significant at one percent. Similarly, trade openness leads to increase carbon emission by 0.095 percent.

In case of railways passenger and cargo, there exist 'U' shaped Railways Kuznets Curve. The econometric results shows that the first degree coefficient is negative. While second order coefficient

**Table 6**  
Hausman test.

Dependent variable	Chi-Sq. statistic	Chi-Sq. d.f.	Prob.	Decision
CO <sub>2</sub>	61.366183	10	0.0000	Fixed effect
N <sub>2</sub> O	52.659108	10	0.0000	Fixed effect
CH <sub>4</sub>	29.048897	10	0.0012	Fixed effect

of both Railways passenger and Railways Cargo is positive. The turning points of railways transportation for 'U' shaped Curve is 0.795 and 1.201 for railways passenger and cargo respectively. This indicates that with the increase of Trade openness, economic growth and transportation by railways increase carbon emissions significantly. Results are consistent with the study of Cristea et al. (2013). Moreover for energy demand, and Population density decreases the one unit increase in emission by −3.651, 0.034 & 0.027 units respectively for the selected time frame. The results are consistent with Jones and Kammen (2014).

In the second model, where Nitrous oxide is dependent variable shows that one unit increase in per capita growth, Trade openness and Population growth increase the nitrous oxide emissions by 0.516, 0.2778 and 0.053 respectively. Consistency with the carbon emission, one unit increase in FDI and Energy demand decreases the nitrous emission by 1.106 and 4.554 units respectively. In case



**Table 7**  
GMM estimators.

Dependent variable	CO <sub>2</sub>		N <sub>2</sub> O		CH <sub>4</sub>	
	Coefficient (Std. error)	<i>t</i> -statistic	Coefficient (Std. error)	<i>t</i> -statistic	Coefficient (Std. error)	<i>t</i> -statistic
C	2.753* (0.992)	2.775202	1.0256* (0.051)	20.1098	0.969* (0.080)	12.1125
GDP	5.855* (1.9405)	3.017264	0.516* (0.0536)	9.626866	−0.046* (0.00935)	−4.91979
RPC	−5.796* (1.301)	−4.45503	1.069* (0.0423)	25.27187	−1.013* (0.061)	−16.6066
RPC2	3.641* (1.103)	3.300997	−2.071* (0.145)	−14.2759	4.7108** (2.481)	1.898751
RGT	−7.88* (2.811)	−2.80327	1.119* (0.411)	2.722628	−1.638*** (0.912)	−1.79605
RGT2	3.28* (0.687)	4.774381	−8.141* (0.976)	−8.34119	2.261* (0.324)	6.975309
FDI	−3.651** (1.911)	−1.91052	−1.72* (0.438)	−3.92694	4.0509** (1.629)	2.48674
TOP	0.095** (0.0417)	2.278177	0.2778 (0.193)	1.439378	−0.941* (0.135)	−6.97037
ED	−0.0346** (0.0184)	−1.88043	−0.0128** (0.006)	−2.13333	0.0974** (0.0504)	1.93254
PG	−0.0275* (0.00786)	−3.49873	0.0374 (0.053)	0.70566	−0.034* (0.0088)	−3.86364

Note: \* indicates 1%, \*\* indicate 5% and \*\*\* indicate 10% level of significance respectively.

of railways passenger and Cargo the nitrous oxide validates the existence of inverted 'U' shaped Railways Kuznets Curve. The turning points of railways passenger and cargo is 0.2580 and 0.0687 respectively. The relations are consistent with the study of Zhang (2011).

In the third model for the case of methane emission, there exist significantly positive relation of FDI and Energy demand. The econometric results indicate that one unit increase in FDI and energy use increases the methane emission by 4.0506 and 0.0974 unit. While one unit increase in GDP, Trade openness and Population density decreases the methane emission by 0.046, 0.941 and −0.034 respectively. Finally, there exist 'U' shaped railways Kuznets Curve for the methane emission. The turning points for the railways passenger and cargo is 0.1075 and 0.3622 respectively. The econometric results are consistent with Cole and McCoskey (2013). The below curves shows the basis of EKC for railways transportation in context of carbon dioxide emissions (U shaped), nitrous oxide emissions (inverted U shaped) and methane emissions (U shaped) respectively. The crux of three models with regard to EKC are portrayed in Fig. 2.

#### 4.6. Impulse response function

The CO<sub>2</sub> respond to population growth, energy demand and railways goods transportation positively and nearer to the mean position. The GDP has an increasing and diverging response from the average value while railways passenger transportation has a negative response to carbon emission. The response GDP to all the regressors is decreasing and away from mean position. Similarly, response of RGT to FDI is negative and diverging and all of the other variables have increasing drift. The response of RPC to trade openness is diverging from average position while energy demand and carbon emissions have positive increasing variation. The N<sub>2</sub>O responds a decreasing trend to energy demand and RPC while trade openness converges back to mean position after a minor decrease. The railways transportation response to all the variables positively and later on diverging trend from the mean position. The response of CH<sub>4</sub> to railways transportation is throughout increasing and diverging from average position while energy demand and FDI

respond positively but converging trend. Finally, CH<sub>4</sub> to trade openness shows decreasing and deviating position from the mean value. Table 8 shows the impulse response statistics for the next ten years.

#### 4.7. Variance decomposition effect

The variance decompositions are explained for the same VAR system. The demonstrated table (see Table 9) shows the variance decomposition analysis for the coming ten years (see Table 9).

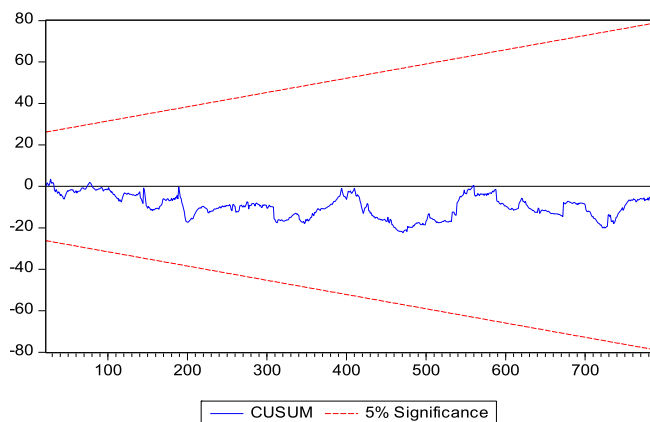
The self-shock in carbon emission respond to a minor decline from 97% to 96%. However, in the first quarter the response from dependent variable carbon dioxide to independent series is positive e.g. 1.89% to GDP 0.001% in railways passenger, 0.0019% in railways cargo, 0.072% in FDI, 0.0993% in energy use and 0.048% in population density. In the 5th quarter all the shocks moved positively showing a positive trend from previous years. There are minor fluctuations in long run shocks after 8th quarter and finally railways transport respond to 0.21% as passenger carried and 0.23% of railways cargo transport that is significantly increasing yearly.

The self-shock of Nitrous oxide slightly declines from 99% to 95% for the decade years. In case of railways transport there is positive increasing trend emerging from 0.009% to 0.039% for passenger carried and 0.060% to 2.75% in case of railways goods transported. Rest of the explanatory variables shows increasing shock dispersion from 0.008% to 0.06% in GDP, 0.125% to 0.822% in FDI, 0.036% to 0.145% in trade openness, and 0.0013% to 0.014% in population growth from the quarter 1 to quarter 10th. While energy demand in first quarter shows 0.072% shock and then 0.051% for 7th and 8th quarter showing increasing trend to 10th quarter for 0.04% shock. Finally, in the case of methane emission the self-shock or own shock has declined from 99% to 88%. The quarter 3rd shows variation in the shocks of independent variables such as 0.045% in GDP, 1.43% in RPC, 0.441% in RGT, 0.095% in FDI, 0.106% in energy demand. Trade openness shows a minor shock trend throughout the years moving from 0.0003% to 0.0016%. Population growth and trade responds less to methane emissions for the upcoming next 10 years.

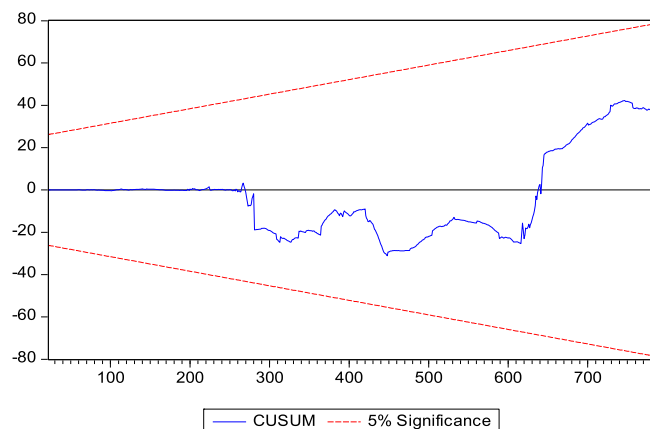


**Table 10**  
Serial LM and Heteroskedasticity tests.

Diagnostic tests	Dependent variable	CO <sub>2</sub>	N <sub>2</sub> O	CH <sub>4</sub>
Breusch–Godfrey serial correlation LM test	F-statistic	0.611	0.444	0.111
	Obs * R-squared	1.251	1.607	1.556
	Prob. F(stats)	0.543	0.430	0.532
	Prob. Chi-Square	0.533	0.438	0.538
Heteroskedasticity test: ARCH	F-statistic	0.477	0.730	0.870
	Obs * R-squared	0.478	0.785	0.850
	Prob. F(stats)	0.827	0.711	0.271
	Prob. Chi-Square	0.826	0.681	0.268



**Fig. 4.** Dependent variable: CO<sub>2</sub> emissions.



**Fig. 5.** Dependent variable: N<sub>2</sub>O emissions.

#### 4.8. Pairwise Dumitrescu Hurlin Panel Causality tests

The granger causation shows a bidirectional association of railways transport and its square term to N<sub>2</sub>O and CH<sub>4</sub> emissions (see Fig. 3). While there is uni causation running from carbon emissions to railways goods transport and square term. Moreover, railways passenger shows bidirectional causation to railways cargo and uni directional association is running from railways passenger to railways cargo. This causation is sketched only in context to railways transportation to pollution emissions rest whole statistical causation tables are given in Appendix B.

#### 4.9. Diagnostic test

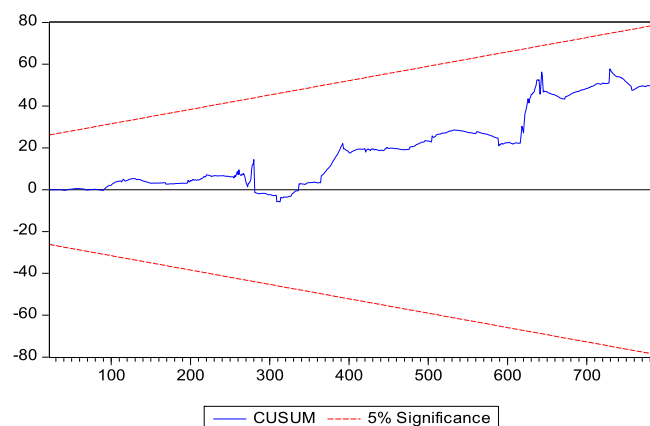
The null hypotheses of Serial Correlation LM and Heteroskedasticity are accepted for insignificant values (see Table 10). The probability statistics of LM test for the CO<sub>2</sub> model is 0.543, NO<sub>2</sub> has 0.438 and methane has 0.538. This shows the absence of serial correlation in the considered models. The Heteroskedasticity test shows the insignificant probability value for the CO<sub>2</sub> model is 0.827, NO<sub>2</sub> has 0.711 and methane has 0.271 that accepts the null hypothesis i.e. there is no heteroscedasticity.

#### 4.10. CUSUM stability test

The CUSUM shows that collective sum of randomness. The CUSUM plots (see Figs. 4, 5, and 6) show the stability of the models such as, the plotted lines exist in the critical region signifying the stability of the all the three models.

### 5. Conclusion and recommendations

The most central element and the real challenge to the global world is the climate change. Transportation system contributes largest share and develops many environmental challenges. The current analysis validates the existence of “inverted U shaped” only



**Fig. 6.** Dependent variable: CH<sub>4</sub> emissions.

for nitrous oxide emissions in case of railways transport. On the contrary, the other two detrimental emissions carbondioxide and methane emissions exhibit “U shaped” railways Kuznets curve. As a whole developed nations have almost achieved a certain level in lowering pollution emission but still “U” shaped in case of CO<sub>2</sub> and CH<sub>4</sub> requires the strategic pollution control policies.

The econometric results reveals the phenomenon of environmental degradation even by the high developed nations. Moreover, GDP and trade openness increases the pollution emissions in all the cases of degrading ecological emissions. It exhibits that without introducing technological advancement, premeditated environmental policies and eco-environment fuel utilization, the high income nations could not achieve the basic environmental standards.

In addition, the developed nations have contributed positively to environment in context of FDI, energy demand and population in case of carbon emissions. While trade openness and economic growth needs to be controlled at sustainable level by considering environmental protection policies.

Table B.1

Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 09/15/18 Time: 18:07			
Sample: 1990 2017			
Lags: 1			
Null hypothesis:	W-Stat.	Z bar-Stat.	Prob.
GDP does not homogeneously cause CO2	3.99863	10.6906	0.0000
CO2 does not homogeneously cause GDP	1.96369	3.20888	0.0013
RPC does not homogeneously cause CO2	2.67257	5.81516	6.E–09
CO2 does not homogeneously cause RPC	3.23613	7.88715	3.E–15
RPC2 does not homogeneously cause CO2	2.78984	6.24630	4.E–10
CO2 does not homogeneously cause RPC2	3.23192	7.87169	4.E–15
RGT does not homogeneously cause CO2	2.55527	5.38388	7.E–08
CO2 does not homogeneously cause RGT	3.39049	8.45467	0.0000
RGT2 does not homogeneously cause CO2	2.48792	5.13628	3.E–07
CO2 does not homogeneously cause RGT2	3.76976	9.84910	0.0000
FDI does not homogeneously cause CO2	1.43661	1.27101	0.2037
CO2 does not homogeneously cause FDI	3.07865	7.30816	3.E–13
TOP does not homogeneously cause CO2	3.00010	7.01935	2.E–12
CO2 does not homogeneously cause TOP	1.68103	2.16964	0.0300
ED does not homogeneously cause CO2	2.06541	3.58286	0.0003
CO2 does not homogeneously cause ED	2.29360	4.42185	1.E–05
PG does not homogeneously cause CO2	4.58775	12.8566	0.0000
CO2 does not homogeneously cause PG	5.90216	17.6891	0.0000
RPC does not homogeneously cause GDP	2.36102	4.66972	3.E–06
GDP does not homogeneously cause RPC	5.10538	14.7597	0.0000
RPC2 does not homogeneously cause GDP	2.14014	3.85763	0.0001
GDP does not homogeneously cause RPC2	5.68408	16.8873	0.0000
RGT does not homogeneously cause GDP	1.87051	2.86628	0.0042
GDP does not homogeneously cause RGT	4.08641	11.0133	0.0000
RGT2 does not homogeneously cause GDP	1.95359	3.17175	0.0015
GDP does not homogeneously cause RGT2	4.76533	13.5094	0.0000
FDI does not homogeneously cause GDP	1.43652	1.27066	0.2038
GDP does not homogeneously cause FDI	3.84569	10.1283	0.0000
TOP does not homogeneously cause GDP	2.32239	4.52769	6.E–06
GDP does not homogeneously cause TOP	2.61701	5.61087	2.E–08
ED does not homogeneously cause GDP	1.77284	2.50718	0.0122
GDP does not homogeneously cause ED	3.62420	9.31393	0.0000
PG does not homogeneously cause GDP	1.48901	1.46367	0.1433
GDP does not homogeneously cause PG	12.3056	41.2321	0.0000
RPC2 does not homogeneously cause RPC	4.69992	13.2689	0.0000
RPC does not homogeneously cause RPC2	9.48670	30.8681	0.0000
RGT does not homogeneously cause RPC	19.8916	69.1228	0.0000
RPC does not homogeneously cause RGT	4.39268	12.1394	0.0000
RGT2 does not homogeneously cause RPC	2.86551	6.52454	7.E–11
RPC does not homogeneously cause RGT2	5.82961	17.4224	0.0000
FDI does not homogeneously cause RPC	1.28071	0.69782	0.4853
RPC does not homogeneously cause FDI	3.01574	7.07688	1.E–12
TOP does not homogeneously cause RPC	3.89804	10.3208	0.0000
RPC does not homogeneously cause TOP	1.69845	2.23371	0.0255
ED does not homogeneously cause RPC	4.50817	12.5640	0.0000
RPC does not homogeneously cause ED	2.90802	6.68082	2.E–11
PG does not homogeneously cause RPC	2.71334	5.96507	2.E–09
RPC does not homogeneously cause PG	4.45355	12.3631	0.0000
RGT does not homogeneously cause RPC2	4.10986	11.0995	0.0000
RPC2 does not homogeneously cause RGT	2.77429	6.18916	6.E–10
RGT2 does not homogeneously cause RPC2	22.3372	78.1145	0.0000
RPC2 does not homogeneously cause RGT2	6.16927	18.6712	0.0000
FDI does not homogeneously cause RPC2	1.43469	1.26393	0.2063
RPC2 does not homogeneously cause FDI	2.97887	6.94133	4.E–12
TOP does not homogeneously cause RPC2	4.30527	11.8180	0.0000
RPC2 does not homogeneously cause TOP	1.67370	2.14269	0.0321
ED does not homogeneously cause RPC2	4.89400	13.9825	0.0000
RPC2 does not homogeneously cause ED	2.59760	5.53951	3.E–08

(continued on next page)

**Table B.1** (continued).

Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 09/15/18 Time: 18:07			
Sample: 1990 2017			
Lags: 1			
Null hypothesis:	W-Stat.	Z bar-Stat.	Prob.
PG does not homogeneously cause RPC2	4.14220	11.2184	0.0000
RPC2 does not homogeneously cause PG	4.69939	13.2670	0.0000
RGT2 does not homogeneously cause RGT	2.19784	4.06977	5.E–05
RGT does not homogeneously cause RGT2	10.5163	34.6536	0.0000
FDI does not homogeneously cause RGT	1.85965	2.82636	0.0047
RGT does not homogeneously cause FDI	3.07249	7.28553	3.E–13
TOP does not homogeneously cause RGT	3.42840	8.59405	0.0000
RGT does not homogeneously cause TOP	2.24698	4.25041	2.E–05
ED does not homogeneously cause RGT	3.13143	7.50220	6.E–14
RGT does not homogeneously cause ED	3.59704	9.21407	0.0000
PG does not homogeneously cause RGT	4.46766	12.4150	0.0000
RGT does not homogeneously cause PG	7.38889	23.1553	0.0000
FDI does not homogeneously cause RGT2	1.91548	3.03164	0.0024
RGT2 does not homogeneously cause FDI	3.26272	7.98490	1.E–15
TOP does not homogeneously cause RGT2	4.01677	10.7573	0.0000
RGT2 does not homogeneously cause TOP	1.93127	3.08968	0.0020
ED does not homogeneously cause RGT2	3.25412	7.95329	2.E–15
RGT2 does not homogeneously cause ED	3.66275	9.45566	0.0000
PG does not homogeneously cause RGT2	5.40504	15.8614	0.0000
RGT2 does not homogeneously cause PG	6.93365	21.4815	0.0000
TOP does not homogeneously cause FDI	2.31625	4.50511	7.E–06
FDI does not homogeneously cause TOP	1.88167	2.90733	0.0036
ED does not homogeneously cause FDI	2.04039	3.49087	0.0005
FDI does not homogeneously cause ED	1.85239	2.79967	0.0051
PG does not homogeneously cause FDI	3.53212	8.97540	0.0000
FDI does not homogeneously cause PG	3.41339	8.53887	0.0000
ED does not homogeneously cause TOP	1.35603	0.97477	0.3297
TOP does not homogeneously cause ED	3.14953	7.56875	4.E–14
PG does not homogeneously cause TOP	2.17584	3.98888	7.E–05
TOP does not homogeneously cause PG	5.14861	14.9186	0.0000
PG does not homogeneously cause ED	4.75704	13.4790	0.0000
ED does not homogeneously cause PG	15.6534	53.5409	0.0000
Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 15/09/18 Time: 22:25			
Sample: 1990 2017			
Lags: 1			
Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.
GDP does not homogeneously cause N2O	8.97593	28.9902	0.0000
N <sub>2</sub> O does not homogeneously cause GDP	1.56002	1.72475	0.0846
RPC does not homogeneously cause N2O	4.67244	13.1679	0.0000
N <sub>2</sub> O does not homogeneously cause RPC	4.05423	10.8950	0.0000
RPC2 does not homogeneously cause N2O	4.44726	12.3400	0.0000
N <sub>2</sub> O does not homogeneously cause RPC2	5.42184	15.9232	0.0000
RGT does not homogeneously cause N2O	6.27732	19.0684	0.0000
N <sub>2</sub> O does not homogeneously cause RGT	4.09068	11.0290	0.0000
RGT2 does not homogeneously cause N2O	6.04937	18.2304	0.0000
N <sub>2</sub> O does not homogeneously cause RGT2	6.07791	18.3353	0.0000
FDI does not homogeneously cause N2O	2.20120	4.08210	4.E–05
N <sub>2</sub> O does not homogeneously cause FDI	2.04552	3.50974	0.0004
TOP does not homogeneously cause N2O	5.67708	16.8616	0.0000
N <sub>2</sub> O does not homogeneously cause TOP	1.63733	2.00900	0.0445
ED does not homogeneously cause N2O	4.37938	12.0904	0.0000
N <sub>2</sub> O does not homogeneously cause ED	2.19766	4.06908	5.E–05
PG does not homogeneously cause N2O	8.57879	27.5301	0.0000
N <sub>2</sub> O does not homogeneously cause PG	15.6378	53.4835	0.0000

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**Table B.1** (continued).

Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 15/09/18 Time: 22:25			
Sample: 1990 2017			
Lags: 1			
RPC does not homogeneously cause GDP	2.36102	4.66972	3.E–06
GDP does not homogeneously cause RPC	5.10538	14.7597	0.0000
RPC2 does not homogeneously cause GDP	2.14014	3.85763	0.0001
GDP does not homogeneously cause RPC2	5.68408	16.8873	0.0000
RGT does not homogeneously cause GDP	1.87051	2.86628	0.0042
GDP does not homogeneously cause RGT	4.08641	11.0133	0.0000
RGT2 does not homogeneously cause GDP	1.95359	3.17175	0.0015
GDP does not homogeneously cause RGT2	4.76533	13.5094	0.0000
FDI does not homogeneously cause GDP	1.43652	1.27066	0.2038
GDP does not homogeneously cause FDI	3.84569	10.1283	0.0000
TOP does not homogeneously cause GDP	2.32239	4.52769	6.E–06
GDP does not homogeneously cause TOP	2.61701	5.61087	2.E–08
ED does not homogeneously cause GDP	1.77284	2.50718	0.0122
GDP does not homogeneously cause ED	3.62420	9.31393	0.0000
PG does not homogeneously cause GDP	1.48901	1.46367	0.1433
GDP does not homogeneously cause PG	12.3056	41.2321	0.0000
RPC2 does not homogeneously cause RPC	4.69992	13.2689	0.0000
RPC does not homogeneously cause RPC2	9.48670	30.8681	0.0000
RGT does not homogeneously cause RPC	19.8916	69.1228	0.0000
RPC does not homogeneously cause RGT	4.39268	12.1394	0.0000
RGT2 does not homogeneously cause RPC	2.86551	6.52454	7.E–11
RPC does not homogeneously cause RGT2	5.82961	17.4224	0.0000
FDI does not homogeneously cause RPC	1.28071	0.69782	0.4853
RPC does not homogeneously cause FDI	3.01574	7.07688	1.E–12
TOP does not homogeneously cause RPC	3.89804	10.3208	0.0000
RPC does not homogeneously cause TOP	1.69845	2.23371	0.0255
ED does not homogeneously cause RPC	4.50817	12.5640	0.0000
RPC does not homogeneously cause ED	2.90802	6.68082	2.E–11
PG does not homogeneously cause RPC	2.71334	5.96507	2.E–09
RPC does not homogeneously cause PG	4.45355	12.3631	0.0000
RGT does not homogeneously cause RPC2	4.10986	11.0995	0.0000
RPC2 does not homogeneously cause RGT	2.77429	6.18916	6.E–10
RGT2 does not homogeneously cause RPC2	22.3372	78.1145	0.0000
RPC2 does not homogeneously cause RGT2	6.16927	18.6712	0.0000
FDI does not homogeneously cause RPC2	1.43469	1.26393	0.2063
RPC2 does not homogeneously cause FDI	2.97887	6.94133	4.E–12
TOP does not homogeneously cause RPC2	4.30527	11.8180	0.0000
RPC2 does not homogeneously cause TOP	1.67370	2.14269	0.0321
ED does not homogeneously cause RPC2	4.89400	13.9825	0.0000
RPC2 does not homogeneously cause ED	2.59760	5.53951	3.E–08
PG does not homogeneously cause RPC2	4.14220	11.2184	0.0000
RPC2 does not homogeneously cause PG	4.69939	13.2670	0.0000
RGT2 does not homogeneously cause RGT	2.19784	4.06977	5.E–05
RGT does not homogeneously cause RGT2	10.5163	34.6536	0.0000
FDI does not homogeneously cause RGT	1.85965	2.82636	0.0047
RGT does not homogeneously cause FDI	3.07249	7.28553	3.E–13
TOP does not homogeneously cause RGT	3.42840	8.59405	0.0000
RGT does not homogeneously cause TOP	2.24698	4.25041	2.E–05
ED does not homogeneously cause RGT	3.13143	7.50220	6.E–14
RGT does not homogeneously cause ED	3.59704	9.21407	0.0000
PG does not homogeneously cause RGT	4.46766	12.4150	0.0000
RGT does not homogeneously cause PG	7.38889	23.1553	0.0000
FDI does not homogeneously cause RGT2	1.91548	3.03164	0.0024
RGT2 does not homogeneously cause FDI	3.26272	7.98490	1.E–15
TOP does not homogeneously cause RGT2	4.01677	10.7573	0.0000
RGT2 does not homogeneously cause TOP	1.93127	3.08968	0.0020
ED does not homogeneously cause RGT2	3.25412	7.95329	2.E–15
RGT2 does not homogeneously cause ED	3.66275	9.45566	0.0000
PG does not homogeneously cause RGT2	5.40504	15.8614	0.0000
RGT2 does not homogeneously cause PG	6.93365	21.4815	0.0000

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**Table B.1** (continued).

Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 15/09/18 Time: 22:25			
Sample: 1990 2017			
Lags: 1			
TOP does not homogeneously cause FDI	2.31625	4.50511	7.E–06
FDI does not homogeneously cause TOP	1.88167	2.90733	0.0036
ED does not homogeneously cause FDI	2.04039	3.49087	0.0005
FDI does not homogeneously cause ED	1.85239	2.79967	0.0051
PG does not homogeneously cause FDI	3.53212	8.97540	0.0000
FDI does not homogeneously cause PG	3.41339	8.53887	0.0000
ED does not homogeneously cause TOP	1.35603	0.97477	0.3297
TOP does not homogeneously cause ED	3.14953	7.56875	4.E–14
PG does not homogeneously cause TOP	2.17584	3.98888	7.E–05
TOP does not homogeneously cause PG	5.14861	14.9186	0.0000
PG does not homogeneously cause ED	4.75704	13.4790	0.0000
ED does not homogeneously cause PG	15.6534	53.5409	0.0000
Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 09/15/18 Time: 18:42			
Sample: 1990 2017			
Lags: 1			
Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.
GDP does not homogeneously cause CH <sub>4</sub>	10.2549	33.6925	0.0000
CH <sub>4</sub> does not homogeneously cause GDP	2.52628	5.27731	1.E–07
RPC does not homogeneously cause CH <sub>4</sub>	5.12542	14.8333	0.0000
CH <sub>4</sub> does not homogeneously cause RPC	4.15954	11.2822	0.0000
RPC2 does not homogeneously cause CH <sub>4</sub>	4.66184	13.1289	0.0000
CH <sub>4</sub> does not homogeneously cause RPC2	6.65483	20.4564	0.0000
RGT does not homogeneously cause CH <sub>4</sub>	5.90509	17.6999	0.0000
CH <sub>4</sub> does not homogeneously cause RGT	2.18874	4.03631	5.E–05
RGT2 does not homogeneously cause CH <sub>4</sub>	5.46551	16.0837	0.0000
CH <sub>4</sub> does not homogeneously cause RGT2	7.08057	22.0217	0.0000
FDI does not homogeneously cause CH <sub>4</sub>	1.92264	3.05796	0.0022
CH <sub>4</sub> does not homogeneously cause FDI	3.17518	7.66308	2.E–14
TOP does not homogeneously cause CH <sub>4</sub>	4.82996	13.7470	0.0000
CH <sub>4</sub> does not homogeneously cause TOP	2.60616	5.57099	3.E–08
ED does not homogeneously cause CH <sub>4</sub>	6.27848	19.0727	0.0000
CH <sub>4</sub> does not homogeneously cause ED	3.15296	7.58136	3.E–14
PG does not homogeneously cause CH <sub>4</sub>	11.0734	36.7019	0.0000
CH <sub>4</sub> does not homogeneously cause PG	9.90928	32.4218	0.0000
RPC does not homogeneously cause GDP	2.36102	4.66972	3.E–06
GDP does not homogeneously cause RPC	5.10538	14.7597	0.0000
RPC2 does not homogeneously cause GDP	2.14014	3.85763	0.0001
GDP does not homogeneously cause RPC2	5.68408	16.8873	0.0000
RGT does not homogeneously cause GDP	1.87051	2.86628	0.0042
GDP does not homogeneously cause RGT	4.08641	11.0133	0.0000
RGT2 does not homogeneously cause GDP	1.95359	3.17175	0.0015
GDP does not homogeneously cause RGT2	4.76533	13.5094	0.0000
FDI does not homogeneously cause GDP	1.43652	1.27066	0.2038
GDP does not homogeneously cause FDI	3.84569	10.1283	0.0000
TOP does not homogeneously cause GDP	2.32239	4.52769	6.E–06
GDP does not homogeneously cause TOP	2.61701	5.61087	2.E–08
ED does not homogeneously cause GDP	1.77284	2.50718	0.0122
GDP does not homogeneously cause ED	3.62420	9.31393	0.0000
PG does not homogeneously cause GDP	1.48901	1.46367	0.1433
GDP does not homogeneously cause PG	12.3056	41.2321	0.0000
RPC2 does not homogeneously cause RPC	4.69992	13.2689	0.0000
RPC does not homogeneously cause RPC2	9.48670	30.8681	0.0000
RGT does not homogeneously cause RPC	19.8916	69.1228	0.0000
RPC does not homogeneously cause RGT	4.39268	12.1394	0.0000
RGT2 does not homogeneously cause RPC	2.86551	6.52454	7.E–11
RPC does not homogeneously cause RGT2	5.82961	17.4224	0.0000
FDI does not homogeneously cause RPC	1.28071	0.69782	0.4853
RPC does not homogeneously cause FDI	3.01574	7.07688	1.E–12
TOP does not homogeneously cause RPC	3.89804	10.3208	0.0000
RPC does not homogeneously cause TOP	1.69845	2.23371	0.0255

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**Table B.1** (continued).

Pairwise Dumitrescu Hurlin Panel Causality tests			
Date: 09/15/18 Time: 18:42			
Sample: 1990 2017			
Lags: 1			
ED does not homogeneously cause RPC	4.50817	12.5640	0.0000
RPC does not homogeneously cause ED	2.90802	6.68082	2.E–11
PG does not homogeneously cause RPC	2.71334	5.96507	2.E–09
RPC does not homogeneously cause PG	4.45355	12.3631	0.0000
RGT does not homogeneously cause RPC2	4.10986	11.0995	0.0000
RPC2 does not homogeneously cause RGT	2.77429	6.18916	6.E–10
RGT2 does not homogeneously cause RPC2	22.3372	78.1145	0.0000
RPC2 does not homogeneously cause RGT2	6.16927	18.6712	0.0000
FDI does not homogeneously cause RPC2	1.43469	1.26393	0.2063
RPC2 does not homogeneously cause FDI	2.97887	6.94133	4.E–12
TOP does not homogeneously cause RPC2	4.30527	11.8180	0.0000
RPC2 does not homogeneously cause TOP	1.67370	2.14269	0.0321
ED does not homogeneously cause RPC2	4.89400	13.9825	0.0000
RPC2 does not homogeneously cause ED	2.59760	5.53951	3.E–08
PG does not homogeneously cause RPC2	4.14220	11.2184	0.0000
RPC2 does not homogeneously cause PG	4.69939	13.2670	0.0000
RGT2 does not homogeneously cause RGT	2.19784	4.06977	5.E–05
RGT does not homogeneously cause RGT2	10.5163	34.6536	0.0000
FDI does not homogeneously cause RGT	1.85965	2.82636	0.0047
RGT does not homogeneously cause FDI	3.07249	7.28553	3.E–13
TOP does not homogeneously cause RGT	3.42840	8.59405	0.0000
RGT does not homogeneously cause TOP	2.24698	4.25041	2.E–05
ED does not homogeneously cause RGT	3.13143	7.50220	6.E–14
RGT does not homogeneously cause ED	3.59704	9.21407	0.0000
PG does not homogeneously cause RGT	4.46766	12.4150	0.0000
RGT does not homogeneously cause PG	7.38889	23.1553	0.0000
FDI does not homogeneously cause RGT2	1.91548	3.03164	0.0024
RGT2 does not homogeneously cause FDI	3.26272	7.98490	1.E–15
TOP does not homogeneously cause RGT2	4.01677	10.7573	0.0000
RGT2 does not homogeneously cause TOP	1.93127	3.08968	0.0020
ED does not homogeneously cause RGT2	3.25412	7.95329	2.E–15
RGT2 does not homogeneously cause ED	3.66275	9.45566	0.0000
PG does not homogeneously cause RGT2	5.40504	15.8614	0.0000
RGT2 does not homogeneously cause PG	6.93365	21.4815	0.0000
TOP does not homogeneously cause FDI	2.31625	4.50511	7.E–06
FDI does not homogeneously cause TOP	1.88167	2.90733	0.0036
ED does not homogeneously cause FDI	2.04039	3.49087	0.0005
FDI does not homogeneously cause ED	1.85239	2.79967	0.0051
PG does not homogeneously cause FDI	3.53212	8.97540	0.0000
FDI does not homogeneously cause PG	3.41339	8.53887	0.0000
ED does not homogeneously cause TOP	1.35603	0.97477	0.3297
TOP does not homogeneously cause ED	3.14953	7.56875	4.E–14
PG does not homogeneously cause TOP	2.17584	3.98888	7.E–05
TOP does not homogeneously cause PG	5.14861	14.9186	0.0000
PG does not homogeneously cause ED	4.75704	13.4790	0.0000
ED does not homogeneously cause PG	15.6534	53.5409	0.0000

For nitrous oxide emissions only trade openness and population density increases the pollution. Finally, methane emission increases due to increase in GDP, trade openness and population growth. Therefore, in regards to CH<sub>4</sub> emissions environmental policies, emissions standards and conservation is still lag behind the optimal level in case of high income transitions.

This analysis suggests that railways sector should be modified to zero carbon emissions by adopting electric engines based on exploiting renewable energy resources, eco-driving and remarkable operational measures. Fuel-saving traveler and freight equipment, hybrid switch engines and hydrogen-powered fuel cell trains can radically cut the diesel fuel as well as to the emissions of carbon, methane and nitrogen oxide (Gurz et al., 2017).

Summing up, railways system can become sustainable mode if fuel efficient resources are employed, modernization and upgradation in sector is made along with adopting superstructure eco-friendly natural (renewable) resources.

#### Appendix A. List of high income nations

1. Australia
2. Austria
3. Belgium
4. Canada
5. Chile
6. Czech Republic
7. Denmark



8. Estonia
9. Finland
10. France
11. Germany
12. Greece
13. Hungary
14. Ireland
15. Israel
16. Italy
17. Japan
18. Korea, Rep.
19. Latvia
20. Lithuania
21. Luxembourg
22. Netherlands
23. New Zealand
24. Norway
25. Poland
26. Portugal
27. Saudi Arabia
28. Singapore
29. Slovak Republic
30. Slovenia
31. Spain
32. Sweden
33. Switzerland
34. United Arab Emirates
35. United Kingdom
36. United States
37. Uruguay

## Appendix B. Pairwise Dumitrescu Hurlin Panel Causality tests

See Table B.1.

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