Environmental Science and Pollution Research (2021) 28:58405–58425
https://doi.org/10.1007/s11356-021-14731-7

RESEARCH ARTICLE

The nexus between road transport intensity and road-related CO_2 emissions in G20 countries: an advanced panel estimation

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Received: 9 April 2021 / Accepted: 1 June 2021 / Published online: 11 June 2021

Abstract

This study determines the dynamic linkages between road transport intensity, road transport passenger and road transport freight, and road carbon emissions in G20 countries in the presence of economic growth, urbanization, crude oil price, and trade openness for the period of 1990 to 2016, under the multivariate framework. This study employs the residual-based Kao and Westerlund cointegration technique to find long-run cointegration, and continuously updated bias-corrected (CUP-BC) and continuously updated fully modified (CUP-FM) methods to check the long-run elasticities between the variables. The long-run estimators' findings suggest a positive and significant impact of road transport intensity, road passenger transport, road freight transport on road transport CO_2 emissions. Economic growth and urbanization are significant contributing factors in road transport CO_2 emissions, while trade openness and crude oil price significantly reduce road transport CO_2 emissions. The Dumitrescu and Hurlin causality test results disclose unidirectional causality from road transport intensity and road transport freight to the road transport CO_2 emissions. However, the causality between road passenger transport and road transport CO_2 emissions is bidirectional. Finally, comprehensive policy options like subsidizing environmental-friendly technologies, developing green transport infrastructure, and enacting decarbonizing regulations are suggested to address the G20 countries' environmental challenges.

Keywords Road transport intensity; · Road transport CO_2 emissions; · CUP-FM & CUP-BC; · Road passenger transport; · Road freight transport; · G20

Introduction

Carbon dioxide is thought to be the most prevalent greenhouse gas (GHG), which is more responsible for global warming (Xu and Lin 2017; Paramati et al. 2017; Peng et al. 2018). Carbon is estimated to account for over 74% of all GHGs (IEA 2020a). A substantial portion of energy-related CO_2 emissions comes from the transport sector, contributing about 24% (8 billion tonnes) of global anthropogenic GHG emissions (IEA 2019a). On a global average, road transport contributes to about 75% (three-quarters) of overall transportation emissions in 2018. Within road transport, light-duty vehicles (passenger vehicles) contribute 45.1%, and the other 29.4% of transport CO_2 emissions come from heavy-duty vehicles (trucks carrying freight) (IEA 2019b; CIAT 2020). A major contributing factor to CO_2 emissions in all regions is transportation infrastructure and fossil fuel consumption.

The transport industry uses a significant amount of energy, which fuels economic development and stimulates urbanization, resulting in more private vehicles (Lu et al. 2007; Achour and Belloumi 2016a). This trend suggests that almost half of all potential travel growth will be caused by increased passenger vehicles and trucks (Dulac 2013; IEA 2020b). As a result, the transport sector is a substantial and growing source for CO_2 emissions, economic growth, and country development (Andrés and Padilla 2018; Sajid et al. 2019; Dong et al. 2020).

Responsible Editor: Nicholas Apergis

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While fossil fuels constitute 81% of global energy consumption in 2018 (IEA 2020c), the mounting CO_2 emissions generated by road freight transport are not expected to slow or cut down. No single solution will be adequate to challenge mitigating these emissions (OECD 2019). The number of passengers (roughly 2.4 billion Millennial passengers) projected to travel globally by 2050 is predicted to be approximately two times greater than it was in 2010. Although transport sector emissions have risen dramatically over the last 25 years, contributing to rising regional emissions, the transport sector's share of the total has remained persistent, with approximately 10% of emissions across countries (Aggarwal and Jain 2016; Amin et al. 2020).

Transport infrastructure is a significant economic segment that fosters economic and social growth and enables effectual resource allocation and materials and mobility (Kuştepeli et al. 2012; Maparu and Mazumder 2017). Transportation facilities can, directly (efficiency and productivity channels) and indirectly (effects on trade, urbanization, fuel-energy consumption, and CO_2 emissions), significantly contribute to economic development (Beyzatlar et al. 2014). The demand for transport increased with high economic growth, swift pace in urban growth, growing disposable income, assortment in leisure pursuits, the imbalanced distribution of energy and material resources, and rapid growth in private cars' numbers. However, the environmental effects of transport activities raise significant challenges. The transport sector contributes substantially and steadily to GHG emissions, and its share in environmental degradation is rising in all world regions. The transport sector's share of CO_2 emissions and its continuing growth have drawn policymakers' attention to economic growth, transport activities, and environmental stress.

The EKC hypothesis is an effective conceptual framework for addressing environmental problems associated with greenhouse gas emissions because it emphasizes the structural changes in the transportation sector, energy efficiencies, and scale effects in the economy (Al-Mulali and Ozturk 2016; Sarkodie and Strezov 2019a, 2019b). In the revised environmental Kuznets curve theory, the concept of scale-effect suggested by Grossman and Krüger could initially stimulate the demand for transportation and travel activities, leading to a remarkable increase in energy consumption for transportation and other sectors (Grossman and Krueger 1991; Sarkodie 2018). As a result, increased road transportation could exacerbate air pollution through the economy's scale effect. Therefore, increasing environmental impacts should be considered in conjunction with increased road transport activities, operations, and energy usage. Energy consumption may increase carbon dioxide emissions as the transportation system enormously contributes to the energy-emission nexus (Franco and Mandla 2014; Erdogan et al. 2020). This means that the transport sector contributes more to greenhouse gas emissions than other sectors of the economy because emissions from the transport sector directly impact the environment (IEA 2009; Alshehry and Belloumi 2017; Andrés and Padilla 2018; Solaymani 2019). Therefore, more stringent environmental regulations and policies are needed to decouple the strong relationship between transportation intensity and carbon dioxide emissions (Ben Abdallah et al. 2013; Ouyang et al. 2019).

Given the above discussion, a clear and strong linkage exists between transport infrastructure and activity, economic development, and transport-related CO_2 emissions. The first empirical studies branch is primarily concerned with economic growth and energy consumption relationship. After the seminal work of Kraft and Kraft (1978), with the different econometric techniques, energy consumption, and economic growth causal relationship has been investigated in prior studies (Akarca and Long 1980; Yu and Hwang 1984; Belloumi 2009; Apergis and Payne 2010; Zhang and Ren 2011; Dagher and Yacoubian 2012; Kandemir Kocaaslan 2013; Mutascu 2016). The second group of literature looks at the relationship between economic growth and CO_2 emissions. This strand underlines the linkage between economic growth and environmental impacts, which has been explored in past empirical work (Shafik 1994; Cole et al. 1997; Cole 2004; Fodha and Zaghdoud 2010; Lotfalipour et al. 2010; Andreoni and Galmarini 2012; Kofi Adom et al. 2012; Abid 2015; Al-Mulali et al. 2016; Alam et al. 2016; Anastacio 2017; Awad and Abugamos 2017; Ahmad et al. 2017). The third group is primarily concerned with the connection between transportation infrastructure and activity and economic development. The basic conception is that enhancements in transport infrastructure and increased transport activity trigger economic growth, but economic growth can also enhance transport activity. Numerous studies have investigated and proven this relationship, including (Canning and Bennathan 2000; Kuştepeli et al. 2012; Pradhan and Bagchi 2013; Pradhan et al. 2013; Beyzatlar et al. 2014; Achour and Belloumi 2016b; Maparu and Mazumder 2017; Saidi et al. 2018).

The fourth strand appeared in recent literature, combining the previous three classes to examine the multifaceted link between the transport sector, environmental pollution and degradation, transport-energy use, and economic growth. Several empirical reviews exist in the literature. The most relevant studies that considered transport-energy consumption and gasoline demand are (Bentzen 1994) for Denmark; (Eltony and Al-Mutairi 1995) for Kuwait;(Ramanathan and Parikh 1999) for India. Also, Liddle (2009), Ramanathan (2001), Samimi (1995), and Xu and Lin (2015) identified the cointegrating relationship between transport demand and performance and macro-economic variables for the USA, India, Australia, and China, respectively. Equally, Azlina et al. (2014), Botzoris et al. (2015), Liddle and Lung (2013), and Saboori et al. (2014) scrutinized the dynamic long-run causal relationship between transport-related energy usage, economic growth, and environmental degradation.

Consequently, there is a strong relationship between transport sector-related activities and transport CO_2 emissions with other macro-economic factors. However, recent studies neglect specific prestigious panels of countries such as G20 countries and road transport-related variables that affect pollution. Therefore, this study's strong emphasis is to consider the impact of road transport intensity, road passenger transport, and road freight transport with additional macro-economic variables on road transport CO_2 emissions in the G20 countries.

For several reasons, the selection of G20 (group of twenty) countries in this study is justified. First, the G20 countries have a significant impact on global economic development, growth, and global emissions. Precisely, the G20 countries seized approximately 85% of the global GDP and also responsible for approximately 80% of GHG emissions, with 70% of the climate impacts. Because of compelling economic growth and higher energy demand and consumption, transport-related CO_2 emissions of G20 countries increased by 1.2% in 2018. Figure 1 shows the yearly uptrend for road transport CO_2 emissions for G20 countries in 1990–2016. Second, most of the G20 countries' energy supply is from coal and oil has increased, and 82% of the energy mix is still based on fossil fuels. Furthermore, most G20 countries have similar transport-energy consumption trends, share of transport CO_2 emissions, and economic growth. Despite the critical role of the G20 countries in the world economy, the factors contributing to transport CO_2 emissions are worth investigating.

This current research extends in several respects beyond the established literature. First, there is no established literature that focuses on the relationship between road transport intensity, road transport CO_2 emissions, and other macro-economic factors, to the best of our knowledge. Environmentally sustainable, effective, and economically productive, and efficient policies addressing the transportation sector are needed due to their potential impact on the environment. Second, this study uses a large sample of 19 G-20 countries and utilizes a long period (1990–2016), containing recent data. Third, our research model also develops an overall measure of road transport intensity comprised of road freight transport and road passenger transport because ecological issues are anthropogenic and a key role of the transport sector in the world's economy. Fourth, as per methodological perspective, CADF and CIPS second-generation unit root tests, Kao and Westerlund panel cointegration tests, advanced panel long-run cointegrating regression Continuously Updated Fully Modified (CUP-FM) and Continuously Updated Bias-Corrected (CUP-BC) estimators, and panel granger Dumitrescu-Hurlin (D-H) causality test are employed to exhibits more reliable, accurate and robust results considering the problem of cross-sectional dependence, residual autocorrelation, heteroscedasticity, endogeneity, and slope heterogeneity.

The rest of the paper is organized in the following way: the "Data, model construction, and methodology" section provides data source information, model construction, and econometric methodology; the "Empirical results and discussion" section presents the empirical findings with discussion, and it concludes the study with some policy implications in the "Conclusion and policy implications" section.

Data, model construction, and methodology

Data

This research is intended to build a linkage between road transport intensity, road passenger transport, road freight transport, and CO_2 emissions from road transport, considering economic growth, urbanization, crude oil price, and trade

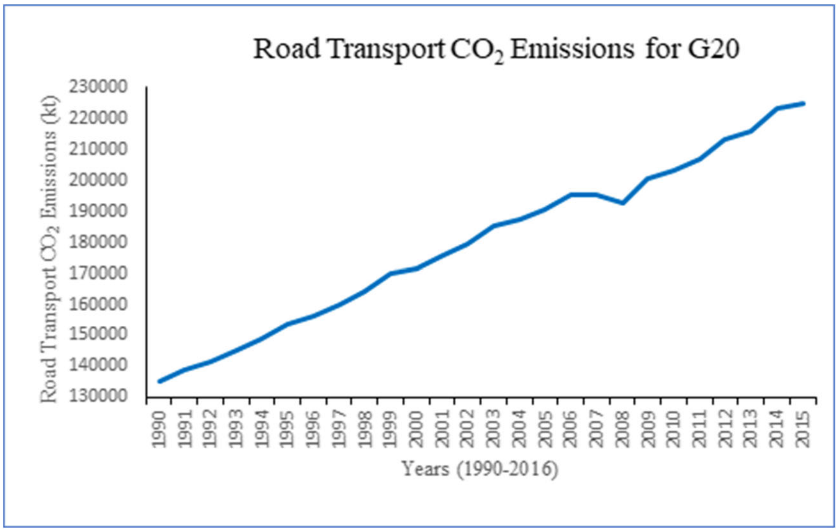

Fig. 1 Trend for road transport CO_2 emissions for G20 countries 1990–2016

openness as additional determinants of road transport carbon emissions. The road transport intensity is classified as road passenger transport and road freight transport or a combination of both measures using the concepts of the net and gross mass movement (Peake 1994; Scholl et al. 1996; Michaelis and Davidson 1996; SACTRA 1999; Arvin et al. 2015). In this study, we also disaggregate the combined measures of road transport intensity into road passenger transport and road freight transport for investigating the impact of both modules simultaneously because the environmental effect of road passenger and freight transport might be different.

The unique data on road transport CO_2 emissions (kt) is subscribed and compiled from the International Energy Agency online data services (IEA 2021). We have used the OECD (OECD 2020) database to gather data on road passenger transport (RDPT) and road freight transport (RDFT). The data for urbanization (%), economic growth (GDP), and trade openness (%) are amassed from the World Bank Indicators platform (WDI 2021), while the crude oil price data is taken from DataStream. West Texas Intermediate (WTI) is an index to measure crude oil price in US dollar per barrel (Sadorsky 2014; Khalfaoui et al. 2015; Basher and Sadorsky 2016; Sarwar et al. 2019; Nguyen et al. 2020; Habib et al. 2020), which aptly reflects the global oil demand and supply (Kao and Wan 2012; Cross and Nguyen 2017); many prior studies have used it as a significant determinant of carbon emissions (Zeng et al. 2017; Zou 2018; Mensah et al. 2019; Malik et al. 2020). The crude oil prices may have a diverse effect on the energy demand curve of each country (Kilian 2009; Mensah et al. 2019; Ahmed et al. 2020a). Therefore, it may influence the environment quality differently based on the structure of the economy and oil demand. For example, according to Boufateh (2019), the positive change in crude oil price harms environmental quality. In other words, positive shocks in crude oil prices cause an increase in the use of polluting energy.

This study uses annual data that covered the period of 1990–2016 for G20 (Group of Twenty) countries. The list of G20[1] countries covers Argentina, Australia, Brazil, Canada, People's Republic of China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the UK, and the US. Yearly trends for road passenger transport and road freight transport are presented in Appendix. A comprehensive description, sources, and measurement of variables are tabulated in Table 1.

Principal component analysis

Two variables, road passenger transport (RDPT) and road freight transport (RDFT), were utilized together by employing principal component analysis (PCA) to construct an air transport intensity index. Being a distinct form of factor analysis, to form an index, the PCA reduces variable's variance (dimensionality) by melding the variables into a smaller and more compact linear combination based on their inherent variance (Gries et al. 2009; Menyah et al. 2014; Jollife and Cadima 2016; Latif et al. 2018). However, this study aims to formulate an index of road transport intensity (RDTI) for an in-depth and extensive analysis. This analysis uses the road transport intensity index, a weighted index of all road transport intensity indicators. This index also offers a single weighted relative measure, integrating most of the information on specific intensity parameters to comprehend the proper connection between road transport intensity and CO_2 emissions from road transport. It also contributes to our study because it is the first time for the RDTI index to be measured by PCA. The PCA process involves matrix construction for the dataset, standardized variables formation, computation of the correlation matrix, sorting of the eigenvalues and corresponding eigenvectors, and the panel component's selection and reorienting (Jolliffe 2011; Hassan et al. 2011; Mirshojaeian Hosseini and Kaneko 2011). Table 2 demonstrates the PCA analysis for the RDTI index.

Table 2 showed that the first factor's highest eigenvalue is 1.851, while the second factor has the lowest eigen value, i.e., 0.149. Ensuing, the variance range of the first factor (0.925) and second factor (0.075) are given. The table also includes the eigenvectors that display the two main component factors' loadings. RDTI index was developed with PC 1 as it has no negative value and contains most of the variable information relative to another component.

Economic modeling

Consistent with the prior studies (Stead 2001; Åhman 2004; Alises et al. 2014; Arvin et al. 2015; Adams et al. 2020), the current study adopted an empirical model; in our scenario, road transport CO_2 emissions is a dependent variable dictated by other independent variables like road transport intensity, road passenger transport, road freight transport, GDP per capita, urbanization, crude oil price, and trade openness are expressed as:

$$RDCO_2 = f(RDTI, RDPT, RDFT, GDP, URB, COP, TROP) \tag{1}$$

In Eq. (1), $RDCO_2$ refers to road transport CO_2 emissions, RDTI denotes road transport intensity, RDPT indicates road passenger transport, RDFT is road freight transport, GDP is

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[1] This study consider only 19 member countries of Group of twenty(G20) and excludes European Union (EU).

Table 1 Description of variables

Variables name	Symbols	Unit of measurement	Source
Road Transport CO_2 emissions	$RDCO_2$	Kt CO_2	IEA
Road Transport Intensity	RDTI	Index value	OECD
Road Passenger Transport	RDPT	million passenger-kilometers	OECD
Road Freight Transport	RDFT	million tonne-kilometers (goods)	OECD
Gross Domestic Product	GDP	(constant 2010 US $)	WDI
Urbanization	URB	Urban population (% of the total population)	WDI
Crude Oil Price	COP	Dollars per barrel	DataStream
Trade Openness	TOP	Trade (% of GDP)	WDI

economic growth, URB shows urbanization, COP is the crude oil price, while TROP is trade openness. In this study, the log-linear enhanced function is used to transform the data into natural logarithmic form to remove data dispersion, reduce nonnormality and generate more reliable and consistent results than a standard linear augmented function (Vogelvang 2004; Charfeddine and Ben Khediri 2016; Kahia et al. 2017; Charfeddine and Kahia 2019). The specifications of the log-linear function for our empirical model can be seen in Eq (2).

$$\begin{aligned}\ln RDCO_{2it} &= \varphi_o + \xi_1(\ln RDTI_{it}) + \xi_2(\ln RDPT_{it}) + \xi_3(\ln RDFT_{it}) + \xi_4(\ln GDP_{it})\\ &+\xi_5(\ln URB_{it}) + \xi_6(\ln COP_{it}) + \xi_7(\ln TROP_{it}) + \omega_{it}\end{aligned} \tag{2}$$

where i *denotes* the number of the countries ($i = 1,2,3.....19$), t indicates the time dimension (from 1990 to 2016), $\varphi_o$is an intercept, and $\omega_{it}$is the stochastic term, The coefficients of road transport intensity, road passenger transport, road freight transport, economic growth, urbanization, crude oil price, and trade openness are signified by ξ_1, ξ_2, ξ_3, ξ_4, ξ_5, ξ_6, and $\xi_7$respectively. Road Transport intensity is the degree to which road transport facilities are used, which can also be expressed as road freight transport and road passenger transport or a combination of both measures (Stead 2001). These intensity measures and economic growth have been originated from contributing to environmental degradation (Arvin et al. 2015; Wang et al. 2020a). By taking into account the impact of road transport intensity on road transport CO_2 emissions, Model 1 can be derived as follows:

$$\begin{aligned}\ln RDCO_{2it} &= \varphi_o + \xi_1(\ln RDTI_{it}) + \xi_2(\ln GDP_{it}), +\xi_3(\ln URB_{it}) + \xi_4(\ln COP_{it})\\ &+\xi_5(\ln TROP_{it}) + \omega_{it}\end{aligned} \tag{3}$$

We replaced road transport intensity with road passenger transport (million passenger-kilometers) in model 2.

$$\begin{aligned}\ln RDCO_{2it} &= \varphi_o + \xi_1(\ln RDPT_{it}) + \xi_2(\ln GDP_{it}), +\xi_3(\ln URB_{it}) + \xi_4(\ln COP_{it})\\ &+\xi_5(\ln TROP_{it}) + \omega_{it}\end{aligned} \tag{4}$$

We replaced road passenger transport component with road freight transport (million tonne-kilometers-goods) in model 3.

$$\begin{aligned}\ln RDCO_{2it} &= \varphi_o + \xi_1(\ln RDFT_{it}) + \xi_2(\ln GDP_{it}), +\xi_3(\ln URB_{it}) + \xi_4(\ln COP_{it})\\ &+\xi_5(\ln TROP_{it}) + \omega_{it}\end{aligned} \tag{5}$$

The linkage between road transport CO_2 emissions and urbanization can explain the environmental impact of the urban population. Previous research identified urbanization as a significant environmental degradation determinant with positive and negative outcomes (Poumanyvong and Kaneko 2010; Ozturk et al. 2016; Wang et al. 2016; Charfeddine et al. 2018). The rigorous empirical works on the environmental effect of international trade are at best mixed. The following studies endorsing the pro-environmental repercussions of trade openness (Birdsall and Wheeler 1993; Frankel and Rose 2005; Ozturk and Acaravci 2013; Al-Mulali and Ozturk 2015), while (Dauda et al. 2021; Pata and Caglar 2021) exemplify a negative elasticity of CO_2 emissions in terms of trade openness. We have also included crude oil price as an explanatory variable because variations in fuel price control CO_2 emissions, boost energy efficiency, and promote vehicle fuel economy (He et al. 2005; Maghelal 2011; Shahbaz et al. 2015; Talbi 2017).

Table 2 PCA results for weighted RDTI index

Number	Eigenvalue	Difference	Proportion	Cumulative	Eigenvectors (Factor loadings)		
					Variable	PC 1	PC 2
1	1.851	1.701	0.925	0.925	RDPT	0.707	0.707
2	0.149	---	0.075	1	RDFT	0.707	-0.707

Econometric methodology

This study analyzes road transport intensity, road passenger transport, and road freight transport on road transport CO_2 emissions in G20 countries. This study follows econometric panel techniques suited to large T and N panels. We carry out CD tests, perform panel unit root and panel cointegration tests, and then move into long-run panel estimations and perform causality tests. Figure 2 shows the flowchart of econometric analysis used in this study.

Testing cross-sectional dependence

Our research instigates by examining the dependence in the empirical model between cross-sectional (units) countries. In the case where the cross-sectional units are dependent on one another, the cross-sectional dependence (CSD) problem arises (Nathaniel et al. 2021; Liu et al. 2021). Due to the high degree of globalization, international trade, economic and financial integration, and financial crisis spillover, one country is more sensitive to the economic shocks that can be widely shared with other countries (Munir et al. 2020). This interaction of nations has the potential to create an inappropriate dependency in panel data between cross-section countries. The presumption of cross-sectional independence is one of the drawbacks of traditional econometrics and analytical approaches (Andrews 2005). If cross-sectional dependence in a panel is ignored, the results obtained from such methods can be biased and misleading (Aydin 2019). Overlooking CSD precedes spurious and skewed elasticity estimations (Behera and Mishra 2020).

To that extent, Breusch and Pagan (1980) posited the Lagrange Multiplier (LM) simple test is used to investigate and counter cross-sectional dependency. By using the following panel data model, the LM statistic can be determined:

$$CSD_{lm} = T_{ij}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}^{\,2}_{ij}. \tag{6}$$

where T is the time dimension, N designates the number of cross-sectional countries (units), and $\widehat{\rho}_{ij}$ signifies an estimation of the pair-wise correlation between residuals derived from estimates of Ordinary Least Squares (OLS) for each sequence.

The LM test is only valuable and effective for such cases where the T is amply large and the N is comparatively short (Chou 2013). Pesaran (2020) has suggested the following CD test based on the LM statistic as a solution to this problem:

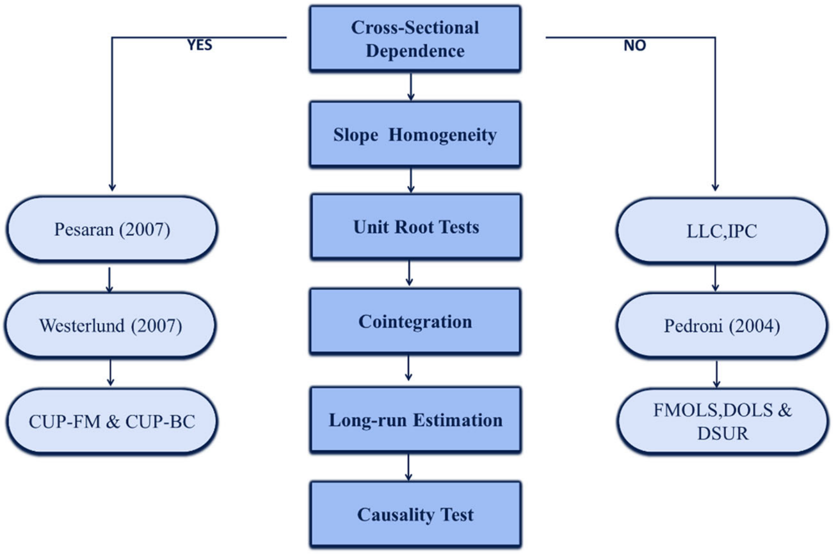
$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}T_{ij}\widehat{\rho}^{\,2}_{ij}\right)\Rightarrow N(0,1). \tag{7}$$

Under both tests' null hypothesis, cross-section units' independence is presumed and spread as a standard two-tailed normal distribution. In contrast, the alternative hypothesis postulates the dependency between countries (cross-section units).

Slope of homogeneity

Based on Hashem Pesaran and Yamagata (2008) slope homogeneity tests, we examined the slope coefficients' homogeneity after checking the cross-sectional dependence. Earlier empirical approaches with an assumption of slope homogeneity ignored the country-specific characteristics (Breitung 2005; Bedir and Yilmaz 2016). Assuming homogeneity, in the case of large (N) and small (T), could yield misleading results. The problem of heterogeneity is critical to address because, due to differences in demographic, social, and economic structures of G20 countries, there is a possibility of heterogeneity in slope parameters, which could affect the consistency and accuracy of panel estimators. For this purpose, this study applied

Fig. 2 Flowchart of econometric analysis



the robust slope homogeneity method proposed by Blomquist and Westerlund (2013). Blomquist and Westerlund (2013) suggested, based on Swamy's model (Swamy 1970) and a robust version of the Hashem Pesaran and Yamagata (2008) test (denoted Δ), a generalized test to deal with both heteroskedasticity and serially correlated errors. This approach is very effective against more generalized cross-correlation constructs and considers the trivial size distortions in all assessments. To extend Δ, the data-generating process is provided as:

$$y_{i,t} = \alpha_i + \xi_i \chi_{i,t} + \omega_{i,t}, \tag{8}$$

where $i = 1 \ldots N$ $\chi_{i,\ t}$is a vector of regressors, with ξ_i the slope coefficients for the associated vector. The HAC version of Δ proposed by Blomquist and Westerlund (2013) is derived as :

$$\widetilde{\Delta}_{HAC} = \sqrt{N}\left(\frac{N^{-1}St_{HAC} - k_2}{\sqrt{2k_2}}\right) \tag{9}$$

$$St_{HAC} = \sum_{i=1}^{N} T_i \left(\mathit{\Gamma}_{2i} - \mathit{\Gamma}_{2HAC}\right)' \left(X_{i,T_i} V_{i,T_i}^{-1} X_{i,T_i}\right)\left(\mathit{\Gamma}_{2i} - \mathit{\Gamma}_{2HAC}\right) \tag{10}$$

where $\mathit{\Gamma}_{2HAC}$ is a robust HAC estimator, and X_{i,T_i} is a trajectory matrix that partially eliminates the heterogeneous variables. $V_{i,T}$ implies variance estimator with kernel function k and bandwidth parameter $B_{i,\ T}$.

Panel unit root test

After checking the CSD and slope homogeneity, the next step in the analysis is to test the order of the cointegration of the various variables considered in this study. If the CSD is existent across cross-sections, then the first-generation panel unit root tests may offer misleading and worthless results (Dogan and Seker 2016a). Indeed, to address this issue, Khan et al. (2020) and Rauf et al. (2018) suggested non-parametric and parametric tests to avoid bias in findings. Except for Dickey and Fuller (1979) ADF test, Im et al. (2003) IPS test, Levin et al. (2002) LLC test, and Phillips and Perron (1988) PP test, the cross-sectional dependency and slope heterogeneity problems can also be countered by the both CADF (Cross-sectional augmented Dickey-Fuller) and CIPS (Cross-sectional Im, Pesaran and Shin) tests. The findings from both methods are also more robust and accurate. Pesaran (2007) has suggested both of these tests. CADF test statistic is stated as follows:

$$\Delta Y_{i,t} = \Gamma_i + \Gamma_i Z_{i,t-1} + \Gamma_i \overline{Y}_{t-1} + \Gamma_i \Delta \overline{Y_t} + \varsigma_{it} \tag{11}$$

where Δ displays change operator, Y denotes studied variable, and $\varsigma_{it}$is a residual term. Based on the Eq.(11), CIPS equation is specified as:

$$\Delta Y_{i,t} = \Gamma_i + \Gamma_i Z_{i,t-1} + \Gamma_i \overline{Y}_{t-1} + \sum_{j=0}^{p} \Gamma_{ij} \Delta \overline{Y_{t-j}} + \sum_{j=1}^{p} \Gamma_{ij} \Delta Y_{i,t-j} \tag{12}$$

where $\overline{Y}$ is the average for cross-sectional units and is illustrated as:

$$Y^{i,t} = \Gamma^1 \overline{\log RDTI}^{i,t} + \Gamma^2 \overline{\log RDPT}^{i,t} + \Gamma^3 \overline{\log RDFT}^{i,t} + \Gamma^4 \overline{\log GDP}^{i,t} + \Gamma^5 \overline{\log URB}^{i,t} + \Gamma^6 \overline{\log TROP}^{i,t} + \Gamma^7 \overline{\log COP}^{i,t} \tag{13}$$

CIPS test statistics are labeled as:

$$CIPS = N^{-1} \sum_{i=1}^{N} CADF_i \tag{14}$$

Panel cointegration tests

The current study is aimed at building a linkage between CO_2 emissions from road transport and road transport intensity, road passenger transport, and road freight transport, considering urbanization, economic growth, trade openness, and crude oil price as additional determinants for the G20 countries. It deploys two cointegration tests, i.e., Kao (1999) and CSD-robust Westerlund (2007) panel cointegration tests. To check the long-run non-heterogeneous connection, the residual-based Kao test is used. This test also uses the specific DF and ADF statistics to verify the null hypothesis of having no cointegration over the alternative hypothesis, namely, cointegration.

For estimation of residuals, we used the following regression:

$$u_{i,t} = \varsigma u_{i,t-1} + \sum_{j=1}^{n} \Phi_j \Delta u_{i,t-j} + \omega_{it} \tag{15}$$

For instance, Basile et al. (2011) determined ADF statistics as:

$$ADF = \frac{t_{ADF} + \dfrac{\sqrt{6N}\sigma_v}{(2\sigma_v)}}{\sqrt{\dfrac{\sigma_{0v}^2}{(2\sigma_v^2)} + \dfrac{3\sigma_v^2}{(10\sigma_{0v}^2)}}} \tag{16}$$

where $\sigma_v^2 = \sum_{ae} - \sum_{ae} \sum_e^{-1}, \sigma_{0v}^2 = \mathfrak{R}_a - \mathfrak{R}_{ae} \mathfrak{R}_e^{-1}, \mathfrak{R}$ exhibits the long-run covariance matrix. Next, we also utilize Westerlund (2007) cointegration technique. It provides robust and accurate results and helps to handle cross-sectional error term dependence (Kapetanios et al. 2011). Besides, the test has no limitation for the common factor (Khan et al. 2020). The null hypothesis, in this case, implies that cointegration between cross-section units does not exist. Besides that, the alternative hypothesis indicates the presence of cointegration between considered variables.

Hence, the baseline equation for Westerlund (2007) test can be simplified as:

$$\gamma_i(L)\Delta y_{it} = \xi_{1i} + \xi_{2i}t + \gamma_i\left(y_{it-1} - \Psi_i' x_{it-1} + \lambda_i(L)' \nu_{it}\right. + \varepsilon_{it} \tag{17}$$

where γ_i holds the cointegration vector between studied variables x and y. γ_i signifies the coefficient for the rectification of errors. The four group and panel test statistics can be specified as:

$$G_\tau = N^{-1}\sum_{i=1}^{N}\frac{\theta_i}{SE\left(\widehat{\theta}_i\right)} \tag{18}$$

$$G_\alpha = N^{-1}\sum_{i=1}^{N}\frac{T\theta_i}{\theta'_i(1)} \tag{19}$$

$$P_\tau = \frac{\widehat{\theta}_i}{SE\left(\widehat{\theta}_i\right)} \tag{20}$$

$$P_\alpha = T\alpha' \tag{21}$$

G_τ and G_α characterize the group means statistics, while $P_\tau$and P_α denote the panel statistics. The pre-requisite for conducting the regression analysis is fulfilled by statistical evidence of cointegrating links between the variables.

Long run estimations

Prior studies have used various first-generation econometric methods to estimate long-run effects but neglect the issue of cross-sectional dependency (Ulucak and Bilgili 2018; Zafar et al. 2019; Ahmed et al. 2020b). In order to overcome this problem, we calculate the long-run parameters with the CUP-BC and CUP-FM estimators, developed by Bai et al. (2009) and Bai and Kao (2006), following the recent studies (Fang and Chen 2017; Koçak et al. 2020; Wang et al. 2020b; Ahmed et al. 2020b; Ahmed and Le 2021). Both methods have certain benefits: i) the issue of cross-sectional dependency and unobserved non-linearity is being considered; (ii) these approaches are preferable over other estimators because they are capable of generating accurate and robust results even within sight of residual autocorrelation, endogeneity, and heteroscedasticity (Bai et al. 2009; Camarero et al. 2014; Ahmed et al. 2021); iii) consistent results are also achieved even with factors and regressors having a mixed integration order, i.e., (I(1) and I (0)) (Bai et al. 2009; Tamarit et al. 2011). Owing to these advantages, these estimators for our sample have the appropriate size and power estimates. The CUP-FM is the most suitable tool for this analysis because it is ideal for a small data sample. Additionally, these estimators are extensively used to estimate the long-run parameters (Fang and Chang 2016; Fang and Chen 2017; Ulucak and Bilgili 2018; Koçak et al. 2020).

For CUP-FM and CUP-BC estimators, the following equation is employed:

$$\left(\widehat{B}_{CUP}, \widehat{F}_{CUP}\right) = \mathrm{argmin}\frac{1}{nT^2} \times \sum_{i=1}^{n}(w_i - y_i\beta)' M_F (w_i - y_i\beta). \tag{22}$$

where $M_F = X_T - T^{-2}VV'$, the identity matrix for dimension T is X_T. V assumes a vector of common latent factors.

Moreover, heterogeneous FMOLS, DOLS, and DSUR were used to validate CUP-BC and CUP-FM estimators' findings.

Heterogeneous panel causality test

We analyze the directional flow and causal relationships between interest variables by utilizing the heterogeneous Dumitrescu and Hurlin (2012) (D-H) panel granger causality test to provide additional details to the policymakers. This approach addresses the question of heterogeneity and CSD and also has no constraint T >N (Dogan and Seker 2016b; Koçak and Şarkgüneşi 2017). In this case, the null hypothesis of the D-H causality is presumed to reflect that no causal direction was found between variables contrary to the alternative hypothesis, which directs the causal associations among considered variables. The model can be formulated as:

$$y_{i,t} = \varphi_i + \sum_{k=1}^{p}\xi_i^k y_{i,t-k} + \sum_{k=1}^{p}\chi_i^j T_{i,t-k} + \omega_{i,t} \tag{23}$$

k signifies the lag length, whereas $\xi^i(j)$represents the autoregressive parameters.

The Wald statistics of all panel are computed to test the null hypothesis by averaging the values for each cross-section of the individual Wald statistics:

$$Wbar_{N,T}^{Hnc} = \frac{1}{N}\sum_{i=1}^{N}W_{i,T} \tag{24}$$

Empirical results and discussion

This study examines the nexus between road transport intensity, road passenger transport, road freight transport, and CO_2 emissions from road transport for a panel of G20 countries. In Table 3, descriptive statistics disclose the average road transport CO_2 emissions of 178095.418 kt of CO_2 with the maximum value of 1544553 kt of CO_2.

The average urban population level is 70.838%, with the maximum value approaching 91%. The average GDP (million

Table 3 Summary of descriptive statistics (before natural logarithms)

Variables	$RDCO_2$	RDFT	RDPT	URB	GDP	COP	TROP
Mean	178095.418	441780.916	915621.717	70.838	22121.566	47.611	47.872
Median	107756.893	159200	393200	76.883	17171.392	28.831	48.268
Maximum	1544553	6108010	17496000	91.627	55714.739	111.670	110.577
Minimum	24456.837	11301	22203.4949	25.547	575.362	12.716	13.753
Std. Dev.	296978.261	960777.684	1831884.201	16.514	16825.759	33.203	18.533
Skewness	3.653	3.590	4.841	-1.386	0.294	0.777	0.426
Kurtosis	15.298	16.062	32.492	3.981	1.509	2.150	3.212
Jarque-Bera	4373.689	4748.875	20595.090	184.738	54.933	67.030	16.487
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	513	513	513	513	513	513	513

Note: The values of GDP are expressed in million US dollars (Panel data for the period = 1990–2016 and 27 years)

2010 US dollars) is 22121.566 US$, which directs the high economic growth in G20 countries. The Pearson correlation results in Table 4 validate that CO_2 emissions from road transport are positively correlated with road transport intensity. As with this point, all the other independent variables RDFT, RDPT, URB, GDP, and COP, have a strong positive association with CO_2 emissions except trade openness, which negatively correlates. Road passenger transport and road freight transport are positively and substantially linked to each other. The correlation of RDTI, RDFT, and RDPT with urbanization and TROP are negative, while positive relationship with GDP and crude oil price is observed.

The estimation of cross-sectional dependency (CSD) has become the main focal point in recent literature. The failure to contain CSD may lead to biased results and efficacy loss. Thus, the Breusch-Pagan LM and Pesaran Scaled LM tests were used to assess the existence of CSD.

Table 5 documents the results of cross-sectional dependency. Based on respective p-values of LM and CD statistics, we reject the null hypothesis of no cross-sectional independence at the 1% statistical significance level for road transport CO_2 emissions, road transport intensity, road passenger transport, road freight transport, urbanization, economic growth, crude oil price, and trade openness. These findings indicate the prevalence of an unobserved common factor as shocks in road

Table 4 Correlation analysis

Probability	$RDCO_2$	RDTI	RDPT	RDFT	URB	GDP	COP	TROP
$RDCO_2$	1							
RDTI	0.735***	1						
	[0.000]							
RDPT	0.719***	0.851***	1					
	[0.000]	[0.000]						
RDFT	0.735***	1.000***	0.851***	1				
	[0.000]	[0.000]	[0.000]					
URB	0.106***	-0.313***	-0.314***	-0.313***	1			
	[0.016]	[0.000]	[0.000]	[0.000]				
GDP	0.912***	0.694***	0.746***	0.694***	0.171***	1		
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]			
COP	0.195***	0.147***	0.107***	0.147***	0.140***	0.223***	1	
	[0.000]	[0.001]	[0.016]	[0.001]	[0.001]	[0.000]		
TROP	-0.193***	-0.068	-0.038	-0.068	0.061	-0.211***	0.310***	1
	[0.000]	[0.125]	[0.393]	[0.125]	[0.168]	[0.000]	[0.000]	

Note: *** denote a 1% significance level. Prob-values are reported in parentheses

Table 5 Cross-sectional dependence

Variables	Breushch-Pagan LM		Pesaran Scaled LM	
	Statistics	*p*-values	Statistics	*p*-values
$RDCO_2$	1605.216***	[0.000]	77.554***	[0.000]
RDTI	1424.399***	[0.000]	67.776***	[0.000]
RDPT	998.985***	[0.000]	44.7723***	[0.000]
RDFT	1424.399***	[0.000]	67.776***	[0.000]
URB	1644.341***	[0.000]	79.669***	[0.000]
GDP	1768.361***	[0.000]	86.375***	[0.000]
COP	4445.632***	[0.000]	231.146***	[0.000]
TROP	1071.040***	[0.000]	48.669***	[0.000]

Note: *** denote a 1% significance level. Prob-values are indicated in parentheses

Table 7 Unit root tests

	CIPS Test		CADF Test	
Variables	Levels	Difference	Levels	Difference
$RDCO_2$	-1.822	-4.147***	-2.02	-2.743**
			[0.913]	[0.021]
RDTI	-2.579	-4.448***	-2.19	-3.237***
			[0.713]	[0.000]
RDPT	-2.027	-4.604***	-2.041	-2.842***
			[0.896]	[0.000]
RDFT	-2.579	-4.448***	-2.19	-3.237***
			[0.713]	[0.000]
URB	-1.794	-3.055***	-1.635	-3.055***
			[0.999]	[0.000]
GDP	-1.866	-3.813***	-2.202	-3.813***
			[0.693]	[0.000]
COP	-1.96	-4.532***	-1.7903	-3.202***
			[0.972]	[0.000]
TROP	-2.262	-4.276***	-1.942	-3.528***
			[0.958]	[0.000]

Note: ***, ** denote statistical significance at the 1% and 5% levels, respectively. The critical values for CIPS test are -2.63 (10%), -2.72(5%), -2.88(1%). The figures in the parenthesis are the prob-values

transport intensity occurring in one country may cause variations in other countries' related factors. In other words, all variables in this analysis have a cross-sectional dependency.

Concerning the CSD, the issue of slope heterogeneity is disclosed in Table 6 by both tests of the slope's homogeneity. Both tests ($\widetilde{\Delta}$ and $\widetilde{\Delta}_{adj}$) have *p*-values less than 1%, so the alternative hypothesis of slope heterogeneity is accepted for G-20 countries and affirming the existence of heterogeneity. Table 6 shows that the problem of slope heterogeneity persists in the panel based on the significance values of the given tests.

Table 7 tabulates the outcomes of CIPS and CADF panel unit root tests. The empirical findings of both CIPS and CADF tests propose that all variables have unit root and showing stationary behavior when their first differences are made. Put differently, these results suggested that all variables are integrated at *1(1)*, and also, there must be an indication of a long-run cointegration nexus between the analyzed variables.

Next, we deploy the panel cointegration tests of Kao (1999) and Westerlund (2007). The results of Kao (1999) are shown in Table 8, which endorses the cointegration relationship among selected variables. The ADF statistic displays a cointegration relationship and rejects the null hypothesis at a 1% or 5% significance level. Furthermore, the Kao test traces the long-term equilibrium relationship between road transport CO_2 emissions, road transport intensity, road passenger transport, road freight transport, economic growth, urbanization, crude oil price, and trade openness.

Likewise, the Westerlund (2007) test approximations in Table 9 validate that road transport CO_2 emissions, road transport intensity, road passenger transport, road freight transport, urbanization, economic growth, crude oil price, and trade openness have a long-run equilibrium relationship. Using group (G_τ) and panel (P_τ) statistics, the null hypothesis, depending on corresponding p-values, has been refuted at 5% and 10% significance levels for all models. The results of both tests imply the cointegration existence among analyzed variables in the selected panel.

After establishing cointegrating nexus among considered variables, we determine the long-run effects of variables. For this purpose, we employ the CUP-BC and CUP-FM approaches. Figure 3 shows the graphical summary of long-run relationships. Table 10 offers key estimates of this analysis.

Table 6 Slope homogeneity analysis

	Model 1		Model 2		Model 3	
Tests	HAC Stats	*p*-values	HAC Stats	*p*-values	HAC Stats	*p*-values
Delta-Tilde ($\widetilde{\Delta}$)	4.168***	[0.000]	2.041**	[0.041]	4.168***	[0.000]
Adj Delta-tilde ($\widetilde{\Delta}_{adj}$)	4.875***	[0.000]	2.388**	[0.017]	4.875***	[0.000]

Note: ***, ** denote statistical significance at the 1% and 5% levels, respectively. Prob-values are specified in parentheses

Table 8 Kao panel cointegration tests

	Model 1		Model 2		Model 3	
	Statistic	*P*-value	Statistic	*P*-value	Statistic	*P*-value
ADF	-3.578***	[0.000]	-3.457***	[0.000]	-3.606***	[0.000]
Residual variance	0.002		0.002		0.002	
HAC variance	0.002		0.001		0.002	

Note: *** denote statistical significance at the 1% level. Prob-values are specified in parentheses

Our study's primary purpose is to explore the effect of road transport intensity on road transport emissions. Empirical evidence shows that road transport intensity positively and significantly affects road transport CO_2 emissions at a 1% critical level in model 1. Assuming other factors unchanged, a 1% increase in road transport intensity will increase road transport CO_2 emissions by 0.015% (according to CUP-FM) and 0.008 % (according to CUP-BC). This result implies that road transport intensity increases the road transport CO_2 emissions in G20 countries and suggests that more economic activity leads to higher energy demand and deter the environment. Immense energy demand inevitably leads to fossil fuels such as diesel and gasoline consumption, thereby emitting large amounts of CO_2 emissions. This finding is aligned with the prior studies (Wang et al. 2018; Song et al. 2019).

In model 2, the coefficient of road passenger transport has a positive and significant effect on road transport CO_2 emissions under CUP-FM and CUP-BC. The results indicate that a 1% increase in road passenger transport raises road transport CO_2 emissions by 0.021 and 0.017% based on CUP-BC and CUP-FM long-run estimation methods. The estimated coefficient for road passenger transport is positive and statistically significant. These findings confirm the argument that road passenger transport escalates transportation demands, fuel consumption, and associated environmental degradation. The main reason for the increase in road transport CO_2 emissions is passenger transport, roughly half of all transport emissions. Passenger transport produces more emissions than other transportation modes because of the comparatively high demand for road transportation. In effect, road passenger transport burns more gasoline, resulting in higher emissions. This result is synchronized with the previous findings of (Ribeiro and Balassiano 1997; Li and Yu 2019) that road passenger transport increases road transport CO_2 emissions.

Table 9 Westerlund (2007) cointegration tests

Statistic	Value	*Z*-value	*P*-value	Robust *P*-value
Model 1				
Gt	-2.434	-1.009**	0.157	[0.037]
Ga	-4.373	4.173	1.000	[0.943]
Pt	-10.613	-1.974*	0.024	[0.063]
Pa	-4.908	1.712	0.957	[0.593]
Model 2				
Gt	-2.355	-1.593**	0.056	[0.050]
Ga	-5.850	2.469	0.993	[0.628]
Pt	-9.206	-1.704*	0.044	[0.081]
Pa	-5.287	0.493	0.689	[0.430]
Model 3				
Gt	-2.401	-0.869*	0.192	[0.063]
Ga	-4.764	3.951	1.000	[0.918]
Pt	-10.263	-1.687*	0.046	[0.088]
Pa	-5.179	1.564	0.941	[0.545]

Note: **,* denote statistical significance at the 5% and 10% levels, respectively

Regarding road freight transport and road transport CO_2 emissions, we again verify the positive relationship in model 3. It shows that a 1% increase in RDFT raises $RDCO_2$ by 0.010% (CUP-FM) and 0.012% (CUP-BC). These outcomes are plausible because road freight transport establishes a significant share in road transport CO_2 emissions. Additionally, the prior literature documents that road freight transport degrades the environment. Besides, future environmental transport issues cannot be ignored because the rise in vehicle numbers upsurges road expansion, so the rising demand for energy and the growing usage of low-quality fuels has increased environmental pollution. The major sources of energy use for most public transports are electricity and coal.

In contrast, fossil fuels like oil and natural gas are used as the key source of energy for private vehicles (Saboori et al. 2014). The findings are congruent with (McKinnon and Piecyk 2009; Xu and Lin 2018; Anwar et al. 2020) and differ with findings of (Danish et al. 2020). All the three measures of road transport intensity, based on passenger and freight transport, in our empirical results reveal the pollution-enhancing role of road transport activities. These findings imply that the higher level of road transport intensity stimulates environmental degradation via related CO_2 emissions. Road transportation operates through the scale effect because G20 countries have tremendous growth patterns and account for approximately 85% of global GDP and around 75% of international trade (OECD 2021). Therefore, these countries are faced with the challenges of balancing economic growth and environmental

Table 10 Long-run estimation of CUP-FM and CUP-BC estimator

	Model 1		Model 2		Model 3	
Variables	CUP-FM	CUP-BC	CUP-FM	CUP-BC	CUP-FM	CUP-BC
RDTI	0.015***	0.008***				
	[5.607]	[2.936]				
RDPT			0.021***	0.017***		
			[6.808]	[5.452]		
RDFT					0.010***	0.012***
					[-2.985]	[-3.735]
URB	0.032***	0.027***	0.055***	0.056***	0.015***	0.015***
	[10.711]	[9.083]	[15.749]	[16.050]	[4.354]	[4. 341]
GDP	0.041***	0.036***	0.029***	0.028***	0.017***	0.016***
	[15.274]	[13.543]	[9.437]	[9.197]	[5.385]	[5.111]
COP	-0.025***	-0.020***	-0.034***	-0.036***	-0.019***	-0.021***
	[10.564]	[8.482]	[12.399]	[13.424]	[6.924]	[7.502]
TROP	-0.008***	-0.015***	0.029***	0.031***	-0.007*	-0.006*
	[-2.883]	[-5.419]	[8.931]	[9.705]	[-1.991]	[-1.872]

Note: ***, ** and * show significance at the 1%, 5% and 10% levels, respectively

quality to achieve sustainable development. Though G20 countries have comparatively more advanced and efficient transportation system than other countries, yet the road transport activities are intensifying the road emissions in these countries. Figure 1 also supports these arguments, which exhibits an overall rising trend of road-related carbon emissions in G20 panel over the time. The scale effect of road transportation mainly stimulates the energy demand especially for fossil fuel resources in these countries. Moreover, the recent figures show that transport-related CO_2 emissions surge

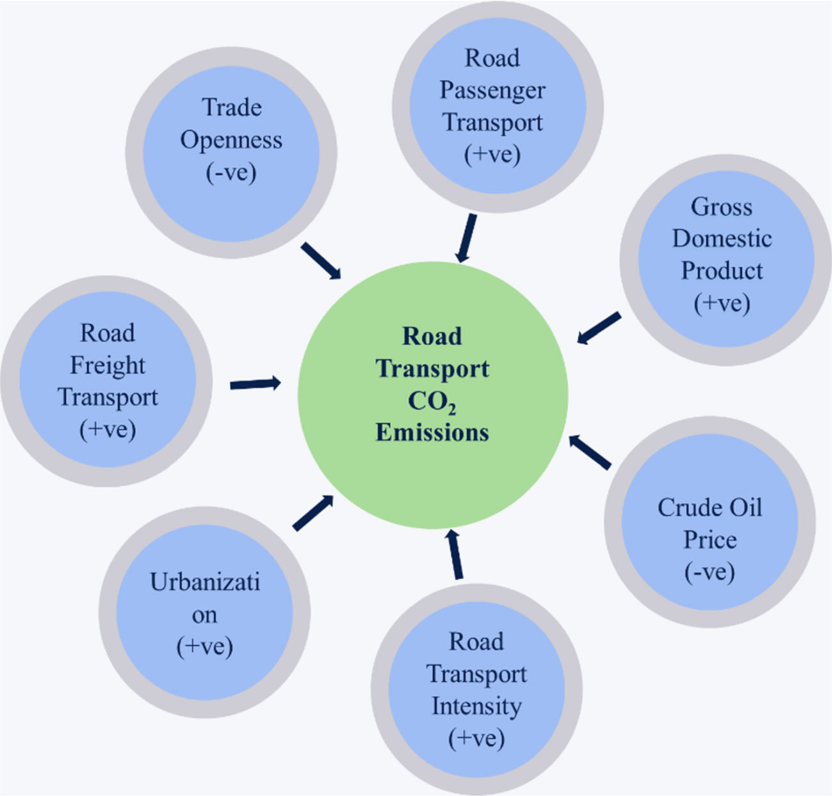


Fig. 3 Long-run relationships

by approximately 1.2% because international trade and economic growth have significantly enhanced freight and passenger transport (Climate Transparency 2021). These rising trends of road-related environmental degradation require the urgent attention to further improve the energy efficiencies in the road transport sector and implement the renwable energy options.

Urbanization also has a positive effect on road transport CO_2 emissions in G20 countries. A 1% rise in urbanization may increase $RDCO_2$ by 0.0323% (CUP-FM), and 0.027% (CUP-BC) in model 1, 0.0549% (CUP-FM) and 0.0555% (CUP-BC) in model 2, and 0.015% (CUP-FM) and 0.015% (CUP-BC) in model 3. From the results, urbanization significantly influences road transport CO_2 emissions, the urban population in G20 countries deteriorates environmental quality by rising energy demand and expansion of the road transport infrastructure. Urbanization is the population migration from rural to urban areas, which has shown remarkable growth for the private transport industry as urban private transport networks expand in urban areas for long-distance travel. As cities expand, public infrastructure projects, including highways and roads, are being pursued. The empirical outcomes are aligned with the Poumanyvong and Kaneko (2010); Martínez-Zarzoso and Maruotti (2011); Wang et al. (2017); Song et al. (2018); Fan et al. (2020); and Hashmi et al. (2021) and contradict the result of Adams et al. (2020). These findings reveal that the urban population in G20 countries has caused a substantial increase in road-related carbon emissions by stimulating travel and energy demand. Therefore, the national and municipal authorities should mitigate the steady decline in environmental quality due to the tremendous growth of urbanization in these economies by designing and launching environmental-friendly and energy-efficient road transport vehicles and green transportation systems.

The economic development coefficient (GDP) has a positive and significant effect (under both CUP-FM and CUP-BC) at a 1% level in all three models. When economic growth increases by 1%, $RDCO_2$ also accelerates by 0.041% and 0.036% in the case of CUP-FM and CUP-BC, respectively. This acceleration may be due to the scale effect, which is dominant in G-20 countries as compared to technique and composition effects. As income level rises, people purchase and consume more goods, move to cities for better health care facilities and educational services, enhance transport demand, and expand the road network. This empirical outcome is aligned with the findings of Danish et al. (2020); and Godil et al. (2021). As stated above, G20 countries hold more than 80% of global GDP, which has intensified the environmental degradation by aggregating the demand for both passengers and freight transport to meet the pace of economic development. Therefore, economic growth has a scale effect on road transport activities, which are mainly dependent on fossil fuel and other energy resources for transport vehicles leading to more air pollution in G20 countries.

Considering crude oil price and road transport CO_2 emissions, we again found evidence of a strong negative linkage between them. It shows that a 1% increase in COP reduces $RDCO_2$ by 0.025% and 0.020% under CUP-FM and CUP-BC, respectively. As crude oil prices rise, the road transport CO_2 emissions decrease because the people reduce their cars' use. This result is consistent with the previous research findings (Maghelal 2011; Rasool et al. 2019; Abumunshar et al. 2020). Thus, the overall findings in all three models unveil that oil price improves the environmental quality in G20 countries by reducing the demand for oil resources. As road vehicles mainly consume fossil fuel energy resources, the rising oil prices significantly reduce the demand for non-renewable energy resources, causing the decline in road-related emissions in the long run.

Finally, the relationship between TROP and $RDCO_2$ is negative, implying that TROP increases environmental quality. A 1% increase in TROP lessens $RDCO_2$ by 0.008 (CUP-FM) and 0.015 (CUP-BC) in G-20 countries. This suggests that with increasing economic level, the impact of trade openness on carbon emissions also changes and notably enhances the environment of affluent and rich G20 countries. The recent trend of augmented trade would stimulate the transfer of high emission-intensive industrial units from developed to developing countries, causing developed countries to accomplish emission reduction at the expense of developing countries. This is consistent with the acknowledged carbon transfer phenomenon in the international trade process (Essandoh et al. 2020). This result confirms the outcomes of Acheampong (2018), which indicate that trade openness in sub-Saharan African countries cuts carbon emissions and opposes the findings of Ahmed et al. (2017); and Chen et al. (2021). The empirical findings confirm the positive role of trade openness in effect with CO_2 emissions in G20 countries because the higher level of exports and imports creates healthy competition among the countries to improve the environmental quality. Moreover, these countries are highly developed and have introduced comparatively stringent environmental regulations about foreign trade, state of the art transportation system, and environmental-friendly trade policies.

In addition, all three models are estimated using heterogeneous and robust FMOLS, DOLS and DSUR, and the results are presented in Table 11. The results of FMOLS, DOLS, and DSUR are aligned with the CUP-FM and CUP-BC estimates. These robust results show that this study's findings are accurate and can be extended for policy consequences.

We utilize the method of Dumitrescu and Hurlin (2012) (DH) to examine and find the causal paths of relationships in the short run between variables after assessing the long-term coefficients and the existence of CSD. Table 12 shows the findings of the heterogeneous DH panel causality test. The

Table 11 Results of HFMOLS, DOLS, and DSUR

	HFMOLS			DOLS			DSUR		
Variables	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
RDTI	0.111**			0.182**			0.216**		
	[0.014]			[0.091]			[0.026]		
RDPT		0.063**			-0.057*			0.048**	
		[0.014]			[0.096]			[0.027]	
RDFT			0.086**			0.141*			0.168**
			[0.011]			[0.070]			[0.020]
URB	0.809*	0.8578*	0.809*	0.782	0.662	0.782	0.183*	-0.051*	0.183*
	[0.056]	[0.055]	[0.056]	[0.371]	[0.362]	[0.371]	[0.062]	[0.073]	[0.062]
GDP	0.778**	0.828**	0.778**	0.874	1.116	0.874	0.620**	0.742**	0.620**
	[0.021]	[0.020]	[0.021]	[0.146]	[0.123]	[0.146]	[0.026]	[0.035]	[0.026]
COP	-0.070**	-0.071**	-0.070**	-0.052**	-0.111**	-0.052**	-0.006**	0.000**	-0.006**
	[0.005]	[0.005]	[0.005]	[0.028]	[0.026]	[0.028]	[0.023]	[0.025]	[0.023]
TROP	-0.045**	-0.077**	-0.045**	-0.158*	0.000*	-0.158*	-0.052**	-0.015**	-0.052**
	[0.013]	[0.014]	[0.013]	[0.075]	[0.086]	[0.075]	[0.038]	[0.043]	[0.038]

Note: ** and * show significance at the 5% and 10% levels, respectively

most exciting outcome from this causality analysis documents the bidirectional causality and feedback relation between road transport passenger and road transport CO_2 emissions. That means the road transport passenger changes lead to variations in road transport CO_2 emissions, and vice versa. However, our results designate a unidirectional relationship from road transport freight to road transport CO_2 emissions, signifying that road transport freight Granger-causes road transport CO_2 emissions, but not the other way around. Referring to the above finding, unidirectional causality extending from road transport intensity to road transport CO_2 emissions has been found. Besides, our results also confirm feedback (bidirectional) causal link between the GDP and road transport CO_2 emissions, between urban population and road

Table 12 Dumitrescu-Hurlin panel causality tests

Variables	$RDCO_2$	RDTI	RDPT	RDFT	URB	GDP	COP	TROP
$RDCO_2$		3.046***	3.579***	3.046***	9.899***	2.658***	2.334***	1.809***
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.062]
RDTI	1.365				9.987***	3.127***	3.360***	1.801*
	[0.481]				[0.000]	[0.000]	[0.000]	[0.065]
RDPT	2.609***				8.704***	3.993***	3.291***	2.711***
	[0.000]				[0.000]	[0.000]	[0.000]	[0.000]
RDFT	1.365				9.987***	3.127***	3.360***	1.801**
	[0.481]				[0.000]	[0.000]	[0.000]	[0.065]
URB	6.725***	7.711***	5.609***	7.711***		4.558***	2.295***	3.583***
	[0.000]	[0.000]	[0.000]	[0.000]		[0.000]	[0.002]	[0.000]
GDP	9.658***	5.014***	4.955***	5.014***	9.663***		1.757*	2.579***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]		[0.083]	[0.000]
COP	6.687***	4.222***	3.818***	4.222***	6.047***	3.877***		1.691
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]		[0.119]
TROP	7.001***	2.348***	4.132***	2.348***	6.524***	2.523***	1.922**	
	[0.000]	[0.001]	[0.000]	[0.001]	[0.000]	[0.000]	[0.031]	

Note: ***,**,* indicates 1%, 5% and 10% significance levels, respectively transport CO_2 emissions. A strong interdependence between economic growth and road transport CO_2 emissions is demonstrated. This outcome is consistent with the findings of Aslan et al. (2021) for Mediterranean countries but is not aligned with (Zhang et al. 2014; Arvin et al. 2015).

Similarly, the bidirectional relationship between urbanization and road transport CO_2 emissions implies that urbanization leads to road transport CO_2 emissions, while high road transportation emissions motivate policymakers and legislators to formulate and implement current urban policies obstructing rural to urban migration and relocation. The finding of this feedback relationship is also supported by (Al-Mulali et al. 2013). Moreover, empirical findings also posit that there is a two-way causality between crude oil price and road transport CO_2 emissions. Finally, both trade openness and road transport CO_2 emissions affect each other in the Granger causality sense and found a bidirectional link.

Conclusion and policy implications

This study scrutinized the influence of road transport intensity, road passenger transport, and road freight transport on road transport CO_2 emissions in G20 countries in a multivariate framework for the period of 1990–2016 while incorporating economic growth, urbanization, trade openness, and crude oil price. Numerous econometric approaches were employed to achieve the objectives of this analysis. For instance, CSD, robust unit root tests such as CADF and CIPS are used to verify unit root properties, and the residual-based Kao's (1999) and Westerlund's (2007) panel cointegration tests are used to check the existence of cointegration among the studied variables. The long-run CUP-FM and CUP-BC estimators are used to measure long-term elasticities. Finally, panel causality is checked through Dumitrescu-Hurlin (DH) heterogeneous panel causality test. These latest econometrics techniques help to address the problems of slope homogeneity and cross-sectional dependency in panel data.

The results of the cointegration tests suggest the long-term equilibrium between variables. The long-run estimation unfolds a positive association between road transport intensity, road passenger transport, road freight transport, and road transport CO_2 emissions. Simply speaking, road transport intensity, road passenger transport, road freight transport contribute to enhancing road transport CO_2 emissions. Economic growth and urbanization are significant factors in promoting road transport CO_2 emissions, while trade openness and crude oil price significantly reduce road transport CO_2 emissions. The causality test estimates indicate that a unidirectional relationship extends from road freight transport and road transport intensity to road transport CO_2 emissions, signifying that road transport freight and road transport intensity Granger-cause road transport CO_2 emissions. We also found that bidirectional causality and feedback relation exists between road passenger transport and road transport CO_2 emissions.

Based on the empirical results, several relevant policy implications for G20 countries are proposed. Road transport intensity degrades the environment as a whole, increases transport-related CO_2 emissions, and enhances economic activity. However, G20 countries should take two major steps to remove barriers to the transport sector's decarbonization. Incomplete commitments of international agreements (Kyoto Protocol and Paris Agreement) and the high cost for transport-related clean technologies have precluded significant reductions in overall GHG emissions and the transport sector in particular. All Parties of The Paris Agreement, especially the G20 countries as the largest emitters of carbon emissions, uphold their pledges towards emission reduction targets and intensify these efforts in the future. To deliver nationally determined contributions (NDCs), the governments should use taxes and subsidies as a tool to change the clean energy's relative costs in the transport sector. They should provide subsidies to promote environmental-friendly technologies. They should also provide incentives to foster the research and development (R&D) of public and private clean and renewable technologies, capitalize and develop green infrastructure like urban road transport systems, and enact regulations, which will gradually decarbonize all economic sectors, including the transport sector. Movings towards sustainable transportation require strategies at individual levels like awareness regarding sustainable transport benefits, an adaptation of sustainable lifestyle, and car-sharing.

This research has some limitations because it focuses on G20 countries and country-specific analysis is not included. Based on this limitation, a time-series estimation at the individual and country-level would help to understand the link between road transport intensity and the environment. Also, this relationship with other transport modes like air transport and railways would be more vital for understanding this relationship.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-021-14731-7.

Author contribution The paper has been written with the following four authors' joint efforts, each contributing significantly to the final manuscript's development. It is also stated here that all author contributions have been stated and included in the manuscript, and there is no conflict of interest.

Yasir Habib drafted and written the overall manuscript and worked on methodological and analytical work.

Prof. Enjun Xia supervised the overall research and conceptualization of the main idea, and without his due support and insightful guidance, this work was not possible.

Shujahat Haider Hashmi made the data collection and helped in data analysis. He also reviewed the manuscript for its refinement and final shape.

Zahoor Ahmed helped in data analysis, software management, and technical editing.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

References

Abid M (2015) The close relationship between informal economic growth and carbon emissions in Tunisia since 1980: The (ir)relevance of structural breaks. Sustain Cities Soc 15:11–21. https://doi.org/10.1016/j.scs.2014.11.001

Abumunshar M, Aga M, Samour A (2020) Oil price, energy consumption, and CO2emissions in Turkey. New evidence from a bootstrap. ARDL test. Energies 13:5588. https://doi.org/10.3390/en13215588

Acheampong AO (2018) Economic growth, CO2 emissions and energy consumption: What causes what and where? Energy Econ 74:677–692. https://doi.org/10.1016/j.eneco.2018.07.022

Achour H, Belloumi M (2016a) Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. Transp Policy 52:64–71. https://doi.org/10.1016/j.tranpol.2016.07.008

Achour H, Belloumi M (2016b) Investigating the causal relationship between transport infrastructure, transport energy consumption and economic growth in Tunisia. Renew Sust Energ Rev 56:988–998

Adams S, Boateng E, Acheampong AO (2020) Transport energy consumption and environmental quality: Does urbanization matter? Sci Total Environ 744:140617. https://doi.org/10.1016/j.scitotenv.2020.140617

Aggarwal P, Jain S (2016) Energy demand and CO2 emissions from urban on-road transport in Delhi: current and future projections under various policy measures. J Clean Prod 128:48–61. https://doi.org/10.1016/j.jclepro.2014.12.012

Ahmad N, Du L, Lu J et al (2017) Modelling the CO2 emissions and economic growth in Croatia: Is there any environmental Kuznets curve? Energy 123:164–172. https://doi.org/10.1016/j.energy.2016.12.106

Åhman M (2004) A Closer Look at Road Freight Transport and Economic Growth in Sweden Are There Any Opportunities for Decoupling?

Ahmed Z, Le HP (2021) Linking Information Communication Technology, trade globalization index, and CO2 emissions: evidence from advanced panel techniques. Environ Sci Pollut Res 28:8770–8781. https://doi.org/10.1007/s11356-020-11205-0

Ahmed K, Bhattacharya M, Shaikh Z, Ramzan M, Ozturk I (2017) Emission intensive growth and trade in the era of the Association of Southeast Asian Nations (ASEAN) integration: An empirical investigation from ASEAN-8. J Clean Prod 154:530–540. https://doi.org/10.1016/j.jclepro.2017.04.008

Ahmed Z, Ali S, Saud S, Shahzad SJH (2020a) Transport CO2 emissions, drivers, and mitigation: an empirical investigation in India. Air Qual Atmos Health 13:1367–1374. https://doi.org/10.1007/s11869-020-00891-x

Ahmed Z, Zafar MW, Ali S, Danish (2020b) Linking urbanization, human capital, and the ecological footprint in G7 countries: An empirical analysis. Sustain Cities Soc 55:102064. https://doi.org/10.1016/j.scs.2020.102064

Ahmed Z, Nathaniel SP, Shahbaz M (2021) The criticality of information and communication technology and human capital in environmental sustainability: Evidence from Latin American and Caribbean countries. J Clean Prod 286:125529. https://doi.org/10.1016/j.jclepro.2020.125529

Akarca AT, Long TV (1980) On the relationship between energy and GNP: a reexamination. J Energy Dev 326–331

Alam MM, Murad MW, Noman AHM, Ozturk I (2016) Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. Ecol Indic 70:466–479. https://doi.org/10.1016/j.ecolind.2016.06.043

Alises A, Vassallo JM, Guzmán AF (2014) Road freight transport decoupling: A comparative analysis between the United Kingdom and Spain. Transp Policy 32:186–193. https://doi.org/10.1016/j.tranpol.2014.01.013

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. https://doi.org/10.1016/j.energy.2015.03.004

Al-Mulali U, Ozturk I (2016) The investigation of environmental Kuznets curve hypothesis in the advanced economies: The role of energy prices. Renew Sust Energ Rev 54:1622–1631

Al-Mulali U, Fereidouni HG, Lee JYM, Sab CNBC (2013) Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries. Renew Sust Energ Rev 23:107–112

Al-Mulali U, Ozturk I, Solarin SA (2016) Investigating the environmental Kuznets curve hypothesis in seven regions: The role of renewable energy. Ecol Indic 67:267–282. https://doi.org/10.1016/j.ecolind.2016.02.059

Alshehry AS, Belloumi M (2017) Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia. Renew Sust Energ Rev 75:1339–1347

Amin A, Altinoz B, Dogan E (2020) Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. Clean Techn Environ Policy 22:1725–1734. https://doi.org/10.1007/s10098-020-01910-2

Anastacio JAR (2017) Economic growth, CO2 emissions and electric consumption: Is there an environmental Kuznets curve? An empirical study for North America countries. Int J Energy Econ Policy 7:65–71

Andreoni V, Galmarini S (2012) Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption. Energy 44:682–691. https://doi.org/10.1016/j.energy.2012.05.024

Andrés L, Padilla E (2018) Driving factors of GHG emissions in the EU transport activity. Transp Policy 61:60–74. https://doi.org/10.1016/j.tranpol.2017.10.008

Andrews DWK (2005) Cross-Section Regression with Common Shocks. Econometrica 73:1551–1585. https://doi.org/10.1111/j.1468-0262.2005.00629.x

Anwar A, Ahmad N, Madni GR (2020) Industrialization, Freight Transport and Environmental Quality: Evidence from Belt and Road Initiative Economies. Environ Sci Pollut Res 27:7053–7070. https://doi.org/10.1007/s11356-019-07255-8

Apergis N, Payne JE (2010) Energy consumption and growth in South America: Evidence from a panel error correction model. Energy Econ 32:1421–1426. https://doi.org/10.1016/j.eneco.2010.04.006

Arvin MB, Pradhan RP, Norman NR (2015) Transportation intensity, urbanization, economic growth, and CO<inf>2</inf> emissions in the G-20 countries. Util Policy 35:50–66. https://doi.org/10.1016/j.jup.2015.07.003

Aslan A, Altinoz B, Özsolak B (2021) The nexus between economic growth, tourism development, energy consumption, and CO2 emissions in Mediterranean countries. Environ Sci Pollut Res 28: 3243–3252. https://doi.org/10.1007/s11356-020-10667-6

Awad A, Abugamos H (2017) Income-carbon emissions nexus for middle East and North Africa countries: A semi-parametric approach. Int J Energy Econ Policy 7:152–159

Aydin M (2019) The effect of biomass energy consumption on economic growth in BRICS countries: A country-specific panel data analysis. Renew Energy 138:620–627. https://doi.org/10.1016/j.renene.2019.02.001

Azlina AA, Law SH, Nik Mustapha NH (2014) Dynamic linkages among transport energy consumption, income and CO2 emission in Malaysia. Energy Policy 73:598–606. https://doi.org/10.1016/j.enpol.2014.05.046

Bai J, Kao C (2006) Chapter 1 On the Estimation and Inference of a Panel Cointegration Model with Cross-Sectional Dependence. Elsevier, pp 3–30

Bai J, Kao C, Ng S (2009) Panel cointegration with global stochastic trends. J Econ 149:82–99. https://doi.org/10.1016/j.jeconom.2008.10.012

Basher SA, Sadorsky P (2016) Hedging emerging market stock prices with oil, gold, VIX, and bonds: A comparison between DCC, ADCC and GO-GARCH. Energy Econ 54:235–247. https://doi.org/10.1016/j.eneco.2015.11.022

Basile R, Costantini M, Destefanis S (2011) Unit Root and Cointegration Tests for Cross-sectionally Correlated Panels. Estimating Regional Production Functions. SSRN Electron J. https://doi.org/10.2139/ssrn.936324

Bedir S, Yilmaz VM (2016) CO2 emissions and human development in OECD countries: granger causality analysis with a panel data approach. Eur Econ Rev 6:97–110. https://doi.org/10.1007/s40822-015-0037-2

Behera J, Mishra AK (2020) Renewable and non-renewable energy consumption and economic growth in G7 countries: evidence from panel autoregressive distributed lag (P-ARDL) model. Int Econ Econ Policy 17:241–258. https://doi.org/10.1007/s10368-019-00446-1

Belloumi M (2009) Energy consumption and GDP in Tunisia: Cointegration and causality analysis. Energy Policy 37:2745–2753. https://doi.org/10.1016/j.enpol.2009.03.027

Ben Abdallah K, Belloumi M, De Wolf D (2013) Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector. Renew Sust Energ Rev 25:34–43

Bentzen J (1994) An empirical analysis of gasoline demand in Denmark using cointegration techniques. Energy Econ 16:139–143. https://doi.org/10.1016/0140-9883(94)90008-6

Beyzatlar MA, Karacal M, Yetkiner H (2014) Granger-causality between transportation and GDP: A panel data approach. Transp Res Part A Policy Pract 63:43–55. https://doi.org/10.1016/j.tra.2014.03.001

Birdsall N, Wheeler D (1993) Trade Policy and Industrial Pollution in Latin America: Where Are the Pollution Havens? J Environ Dev 2: 137–149. https://doi.org/10.1177/107049659300200107

Blomquist J, Westerlund J (2013) Testing slope homogeneity in large panels with serial correlation. Econ Lett 121:374–378. https://doi.org/10.1016/j.econlet.2013.09.012

Botzoris GN, Galanis AT, Profillidis VA, Eliou NE (2015) Coupling and decoupling relationships between energy consumption and air pollution from the transport sector and the economic activity. Int J Energy Econ Policy 5:949–954

Boufateh T (2019) The environmental Kuznets curve by considering asymmetric oil price shocks: evidence from the top two. Environ Sci Pollut Res 26:706–720. https://doi.org/10.1007/s11356-018-3641-3

Breitung J (2005) A parametric approach to the estimation of cointegration vectors in panel data. Aust Econ Rev 24:151–173. https://doi.org/10.1081/ETC-200067895

Breusch TS, Pagan AR (1980) The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics. Rev Econ Stud 47:239. https://doi.org/10.2307/2297111

Camarero M, Gómez E, Tamarit C (2014) Is the “euro effect” on trade so small after all? New evidence using gravity equations with panel cointegration techniques. Econ Lett 124:140–142. https://doi.org/10.1016/j.econlet.2014.04.033

Canning D, Bennathan E (2000) The social rate of return on infrastructure investments. World Bank Policy Res Work Pap

Charfeddine L, Ben Khediri K (2016) Financial development and environmental quality in UAE: Cointegration with structural breaks. Renew Sust Energ Rev 55:1322–1335

Charfeddine L, Kahia M (2019) Impact of renewable energy consumption and financial development on CO2 emissions and economic growth in the MENA region: A panel vector autoregressive (PVAR) analysis. Renew Energy 139:198–213. https://doi.org/10.1016/j.renene.2019.01.010

Charfeddine L, Yousef Al-Malk A, Al Korbi K (2018) Is it possible to improve environmental quality without reducing economic growth: Evidence from the Qatar economy. Renew Sust Energ Rev 82:25–39

Chen F, Jiang G, Kitila GM (2021) Trade Openness and CO2 Emissions: The Heterogeneous and Mediating Effects for the Belt and Road Countries. Sustainability 13:1958. https://doi.org/10.3390/su13041958

Chou MC (2013) Does tourism development promote economic growth in transition countries? A panel data analysis. Econ Model 33:226–232. https://doi.org/10.1016/j.econmod.2013.04.024

CIAT (2020) World, Transportation, Total | Greenhouse Gas (GHG) Emissions | Climate Watch Data. https://www.climatewatchdata.org/ghg-emissions?end_year=2017&sectors=transportation&start_year=1990. Accessed 1 Mar 2021

Climate Transparency (2021) Transport | Climate Transparency. https://www.climate-transparency.org/transport. Accessed 27 May 2021

Cole MA (2004) Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. Ecol Econ 48:71–81. https://doi.org/10.1016/j.ecolecon.2003.09.007

Cole MA, Rayner AJ, Bates JM (1997) The environmental Kuznets curve: An empirical analysis. Environ Dev Econ 2:401–416. https://doi.org/10.1017/S1355770X97000211

Cross J, Nguyen BH (2017) The relationship between global oil price shocks and China’s output: A time-varying analysis. Energy Econ 62:79–91. https://doi.org/10.1016/j.eneco.2016.12.014

Dagher L, Yacoubian T (2012) The causal relationship between energy consumption and economic growth in Lebanon. Energy Policy 50: 795–801. https://doi.org/10.1016/j.enpol.2012.08.034

Danish ZJ, Hassan ST, Iqbal K (2020) Toward achieving environmental sustainability target in Organization for Economic Cooperation and Development countries: The role of real income, research and development, and transport infrastructure. Sustain Dev 28:83–90. https://doi.org/10.1002/sd.1973

Dauda L, Long X, Mensah CN, Salman M, Boamah KB, Ampon-Wireko S, Kofi Dogbe CS (2021) Innovation, trade openness and CO2 emissions in selected countries in Africa. J Clean Prod 281: 125143. https://doi.org/10.1016/j.jclepro.2020.125143

Dickey DA, Fuller WA (1979) Distribution of the Estimators for Autoregressive Time Series With a Unit Root. J Am Stat Assoc 74:427. https://doi.org/10.2307/2286348

Dogan E, Seker F (2016a) The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew Sust Energ Rev 60:1074–1085

Dogan E, Seker F (2016b) Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. Renew Energy 94:429–439. https://doi.org/10.1016/j.renene.2016.03.078

Dong E, Du H, Gardner L (2020) An interactive web-based dashboard to track COVID-19 in real time. Lancet Infect Dis 20:533–534

Dulac J (2013) Global land transport infrastructure requirements. Paris Int Energy Agency 20:2014

Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29:1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Eltony MN, Al-Mutairi NH (1995) Demand for gasoline in Kuwait. An empirical analysis using cointegration techniques. Energy Econ 17:249–253. https://doi.org/10.1016/0140-9883(95)00006-G

Erdogan S, Fatai Adedoyin F, Victor Bekun F, Asumadu Sarkodie S (2020) Testing the transport-induced environmental Kuznets curve hypothesis: The role of air and railway transport. J Air Transp Manag 89:101935. https://doi.org/10.1016/j.jairtraman.2020.101935

Essandoh OK, Islam M, Kakinaka M (2020) Linking international trade and foreign direct investment to CO2 emissions: Any differences between developed and developing countries? Sci Total Environ 712:136437. https://doi.org/10.1016/j.scitotenv.2019.136437

Fan H, Hashmi SH, Habib Y, Ali M (2020) How Do Urbanization and Urban Agglomeration Affect CO2Emissions in South Asia? Testing Non-Linearity Puzzle with Dynamic STIRPAT Model. Chin J Urban Environ Stud 8:2050003. https://doi.org/10.1142/S2345748120500037

Fang Z, Chang Y (2016) Energy, human capital and economic growth in Asia Pacific countries - Evidence from a panel cointegration and causality analysis. Energy Econ 56:177–184. https://doi.org/10.1016/j.eneco.2016.03.020

Fang Z, Chen Y (2017) Human capital and energy in economic growth – Evidence from Chinese provincial data. Energy Econ 68:340–358. https://doi.org/10.1016/j.eneco.2017.10.007

Fodha M, Zaghdoud O (2010) Economic growth and pollutant emissions in Tunisia: An empirical analysis of the environmental Kuznets curve. Energy Policy 38:1150–1156. https://doi.org/10.1016/j.enpol.2009.11.002

Franco S, Mandla VR (2014) Analysis of road transport energy consumption and emissions: A case study. Int J Energy Sect Manag 8:341–355. https://doi.org/10.1108/IJESM-03-2013-0004

Frankel JA, Rose AK (2005) Is trade good or bad for the environment? sorting out the causality. Rev Econ Stat 87:85–91. https://doi.org/10.1162/0034653053327577

Godil DI, Yu Z, Sharif A, Usman R, Khan SAR (2021) Investigate the role of technology innovation and renewable energy in reducing transport sector <scp> CO $_2$ </scp> emission in China: A path toward sustainable development. Sustain Dev sd.2167. https://doi.org/10.1002/sd.2167

Gries T, Kraft M, Meierrieks D (2009) Linkages Between Financial Deepening, Trade Openness, and Economic Development: Causality Evidence from Sub-Saharan Africa. World Dev 37:1849–1860. https://doi.org/10.1016/j.worlddev.2009.05.008

Grossman G, Krueger A (1991) Environmental Impacts of a North American Free Trade Agreement. Natl Bur Econ Res. https://doi.org/10.3386/w3914

Habib Y, Xia E, Fareed Z, Hashmi SH (2020) Time–frequency co-movement between COVID-19, crude oil prices, and atmospheric CO2 emissions: Fresh global insights from partial and multiple coherence approach. Environ Dev Sustain 23:9397–9417. https://doi.org/10.1007/s10668-020-01031-2

Hashem Pesaran M, Yamagata T (2008) Testing slope homogeneity in large panels. J Econ 142:50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Hashmi SH, Fan H, Habib Y, Riaz A (2021) Non-linear relationship between urbanization paths and CO2 emissions: A case of South, South-East and East Asian economies. Urban Clim 37:100814. https://doi.org/10.1016/j.uclim.2021.100814

Hassan MK, Sanchez B, Yu JS (2011) Financial development and economic growth: New evidence from panel data. Q Rev Econ Financ 51:88–104. https://doi.org/10.1016/j.qref.2010.09.001

He K, Huo H, Zhang Q, He D, An F, Wang M, Walsh MP (2005) Oil consumption and CO2 emissions in China's road transport: Current status, future trends, and policy implications. Energy Policy 33:1499–1507. https://doi.org/10.1016/j.enpol.2004.01.007

IEA (2009) Transport, Energy and CO2 – Analysis - IEA. https://www.iea.org/reports/transport-energy-and-co2. Accessed 26 May 2021

IEA (2019a) Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030 – Charts – Data & Statistics - IEA. https://www.iea.org/data-and-statistics/charts/transport-sector-co2-emissions-by-mode-in-the-sustainable-development-scenario-2000-2030. Accessed 1 Mar 2021

IEA (2019b) Data – World Energy Outlook 2019 – Analysis - IEA. https://www.iea.org/reports/world-energy-outlook-2019/data#abstract. Accessed 1 Mar 2021

IEA (2020a) IEA webstore. CO2 Emissions from Fuel Combustion Overview (2020 edition). https://webstore.iea.org/co2-emissions-from-fuel-combustion-overview-2020-edition. Accessed 1 Mar 2021

IEA (2020b) Trucks and buses – Tracking Transport 2020 – Analysis - IEA. https://www.iea.org/reports/tracking-transport-2020/trucks-and-buses#abstract. Accessed 9 Mar 2021

IEA (2020c) World Energy Balances – Analysis - IEA. https://www.iea.org/reports/world-energy-balances-overview. Accessed 9 Mar 2021

IEA (2021) International Energy Agency (IEA) Data Services Subscriptions. http://data.iea.org/. Accessed 9 Feb 2021

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econ 115:53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

Jollife IT, Cadima J (2016) Principal component analysis: A review and recent developments. Philos Trans R Soc A Math Phys Eng Sci. 374

Jolliffe I (2011) Principal Component Analysis. In: International Encyclopedia of Statistical Science. Springer, Berlin Heidelberg, pp 1094–1096

Kahia M, Ben AMS, Lanouar C (2017) Renewable and non-renewable energy use - economic growth nexus: The case of MENA Net Oil Importing Countries. Renew Sust Energ Rev 71:127–140

Kandemir Kocaaslan O (2013) The causal link between energy and output growth: Evidence from Markov switching Granger causality. Energy Policy 63:1196–1206. https://doi.org/10.1016/j.enpol.2013.08.086

Kao C (1999) Spurious regression and residual-based tests for cointegration in panel data. J Econ 90:1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

Kao CW, Wan JY (2012) Price discount, inventories and the distortion of WTI benchmark. Energy Econ 34:117–124. https://doi.org/10.1016/j.eneco.2011.03.004

Kapetanios G, Pesaran MH, Yamagata T (2011) Panels with non-stationary multifactor error structures. J Econ 160:326–348. https://doi.org/10.1016/j.jeconom.2010.10.001

Kraft J, Kraft A (1978) On the relationship between energy and GNP. J Energy Dev 401–403

Khalfaoui R, Boutahar M, Boubaker H (2015) Analyzing volatility spillovers and hedging between oil and stock markets: Evidence from wavelet analysis. Energy Econ 49:540–549. https://doi.org/10.1016/j.eneco.2015.03.023

Khan Z, Ali S, Umar M, Kirikkaleli D, Jiao Z (2020) Consumption-based carbon emissions and International trade in G7 countries: The role of Environmental innovation and Renewable energy. Sci Total Environ 730:138945. https://doi.org/10.1016/j.scitotenv.2020.138945

Kilian L (2009) Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. Am Econ Rev 99:1053–1069. https://doi.org/10.1257/aer.99.3.1053

Koçak E, Şarkgüneşi A (2017) The renewable energy and economic growth nexus in black sea and Balkan Countries. Energy Policy 100:51–57. https://doi.org/10.1016/j.enpol.2016.10.007

Koçak E, Ulucak R, Ulucak ZŞ (2020) The impact of tourism developments on CO2 emissions: An advanced panel data estimation. Tour Manag Perspect 33:100611. https://doi.org/10.1016/j.tmp.2019.100611

Kofi Adom P, Bekoe W, Amuakwa-Mensah F, Mensah JT, Botchway E (2012) Carbon dioxide emissions, economic growth, industrial structure, and technical efficiency: Empirical evidence from Ghana, Senegal, and Morocco on the causal dynamics. Energy 47: 314–325. https://doi.org/10.1016/j.energy.2012.09.025

Kuştepeli Y, Gülcan Y, Akgüngör S (2012) Transportation infrastructure investment, growth and international trade in Turkey. Appl Econ 44: 2619–2629. https://doi.org/10.1080/00036846.2011.566189

Latif Z, Mengke Y, Danish et al (2018) The dynamics of ICT, foreign direct investment, globalization and economic growth: Panel estimation robust to heterogeneity and cross-sectional dependence. Telemat Inform 35:318–328. https://doi.org/10.1016/j.tele.2017.12.006

Levin A, Lin CF, Chu CSJ (2002) Unit root tests in panel data: Asymptotic and finite-sample properties. J Econ 108:1–24. https://doi.org/10.1016/S0304-4076(01)00098-7

Li X, Yu B (2019) Peaking CO2 emissions for China's urban passenger transport sector. Energy Policy 133:110913. https://doi.org/10.1016/j.enpol.2019.110913

Liddle B (2009) Long-run relationship among transport demand, income, and gasoline price for the US. Transp Res Part D Transp Environ 14: 73–82. https://doi.org/10.1016/j.trd.2008.10.006

Liddle B, Lung S (2013) The long-run causal relationship between transport energy consumption and GDP: Evidence from heterogeneous panel methods robust to cross-sectional dependence. Econ Lett 121: 524–527. https://doi.org/10.1016/j.econlet.2013.10.011

Liu J, Murshed M, Chen F, Shahbaz M, Kirikkaleli D, Khan Z (2021) An empirical analysis of the household consumption-induced carbon emissions in China. Sustain Prod Consum 26:943–957. https://doi.org/10.1016/j.spc.2021.01.006

Lotfalipour MR, Falahi MA, Ashena M (2010) Economic growth, CO2 emissions, and fossil fuels consumption in Iran. Energy 35:5115–5120. https://doi.org/10.1016/j.energy.2010.08.004

Lu IJ, Lin SJ, Lewis C (2007) Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. Energy Policy 35:3226–3235. https://doi.org/10.1016/j.enpol.2006.11.003

Maghelal P (2011) Investigating the relationships among rising fuel prices, increased transit ridership, and CO2 emissions. Transp Res Part D Transp Environ 16:232–235. https://doi.org/10.1016/j.trd.2010.12.002

Malik MY, Latif K, Khan Z, Butt HD, Hussain M, Nadeem MA (2020) Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and non-linear ARDL approach. Sci Total Environ 726:138421. https://doi.org/10.1016/j.scitotenv.2020.138421

Maparu TS, Mazumder TN (2017) Transport infrastructure, economic development and urbanization in India (1990–2011): Is there any causal relationship? Transp Res Part A Policy Pract 100:319–336. https://doi.org/10.1016/j.tra.2017.04.033

Martínez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO2 emissions: Evidence from developing countries. Ecol Econ 70: 1344–1353. https://doi.org/10.1016/j.ecolecon.2011.02.009

McKinnon AC, Piecyk MI (2009) Measurement of CO2 emissions from road freight transport: A review of UK experience. Energy Policy 37:3733–3742. https://doi.org/10.1016/j.enpol.2009.07.007

Mensah IA, Sun M, Gao C, Omari-Sasu AY, Zhu D, Ampimah BC, Quarcoo A (2019) Analysis on the nexus of economic growth, fossil fuel energy consumption, CO2 emissions and oil price in Africa based on a PMG panel ARDL approach. J Clean Prod 228:161–174. https://doi.org/10.1016/j.jclepro.2019.04.281

Menyah K, Nazlioglu S, Wolde-Rufael Y (2014) Financial development, trade openness and economic growth in African countries: New insights from a panel causality approach. Econ Model 37:386–394. https://doi.org/10.1016/j.econmod.2013.11.044

Michaelis L, Davidson O (1996) GHG mitigation in the transport sector. Energy Policy 24:969–984

Mirshojaeian Hosseini H, Kaneko S (2011) Dynamic sustainability assessment of countries at the macro level: A principal component analysis. Ecol Indic 11:811–823. https://doi.org/10.1016/j.ecolind.2010.10.007

Munir Q, Lean HH, Smyth R (2020) CO2 emissions, energy consumption and economic growth in the ASEAN-5 countries: A cross-sectional dependence approach. Energy Econ 85:104571. https://doi.org/10.1016/j.eneco.2019.104571

Mutascu M (2016) A bootstrap panel Granger causality analysis of energy consumption and economic growth in the G7 countries. Renew Sust Energ Rev 63:166–171

Nathaniel SP, Murshed M, Bassim M (2021) The nexus between economic growth, energy use, international trade and ecological footprints: the role of environmental regulations in N11 countries. Energy, Ecol Environ 1–17. https://doi.org/10.1007/s40974-020-00205-y

Nguyen TT, Pham TAT, Tram HTX (2020) Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries☆. J Environ Manag 261:110162. https://doi.org/10.1016/j.jenvman.2020.110162

OECD (2019) Sectoral shares of transport CO2 emissions by scenario

OECD (2020) OECD Data. https://data.oecd.org/. Accessed 9 Feb 2021

OECD (2021) About - Organisation for Economic Co-operation and Development. https://www.oecd.org/g20/about/. Accessed 27 May 2021

Ouyang X, Shao Q, Zhu X, He Q, Xiang C, Wei G (2019) Environmental regulation, economic growth and air pollution: Panel threshold analysis for OECD countries. Sci Total Environ 657:234–241. https://doi.org/10.1016/j.scitotenv.2018.12.056

Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ 36:262–267. https://doi.org/10.1016/j.eneco.2012.08.025

Ozturk I, Al-Mulali U, Saboori B (2016) Investigating the environmental Kuznets curve hypothesis: the role of tourism and ecological footprint. Environ Sci Pollut Res 23:1916–1928. https://doi.org/10.1007/s11356-015-5447-x

Paramati SR, Mo D, Gupta R (2017) The effects of stock market growth and renewable energy use on CO2 emissions: Evidence from G20 countries. Energy Econ 66:360–371. https://doi.org/10.1016/j.eneco.2017.06.025

Pata UK, Caglar AE (2021) Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: Evidence from augmented ARDL approach with a structural break. Energy 216:119220. https://doi.org/10.1016/j.energy.2020.119220

Peake S (1994) Transport in transition: Lessons from the history of energy. Earthscan

Peng T, Ou X, Yuan Z, Yan X, Zhang X (2018) Development and application of China provincial road transport energy demand and GHG emissions analysis model. Appl Energy 222:313–328. https://doi.org/10.1016/j.apenergy.2018.03.139

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22:265–312. https://doi.org/10.1002/jae.951

Pesaran MH (2020) General diagnostic tests for cross-sectional dependence in panels. Empir Econ 60:13–50. https://doi.org/10.1007/s00181-020-01875-7

Phillips PCB, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75:335–346. https://doi.org/10.1093/biomet/75.2.335

Poumanyvong P, Kaneko S (2010) Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. Ecol Econ 70:434–444. https://doi.org/10.1016/j.ecolecon.2010.09.029

Pradhan RP, Bagchi TP (2013) Effect of transportation infrastructure on economic growth in India: The VECM approach. Res Transp Econ 38:139–148. https://doi.org/10.1016/j.retrec.2012.05.008

Pradhan RP, Norman NR, Badir Y, Samadhan B (2013) Transport Infrastructure, Foreign Direct Investment and Economic Growth Interactions in India: The ARDL Bounds Testing Approach. Procedia Soc Behav Sci 104:914–921. https://doi.org/10.1016/j.sbspro.2013.11.186

Ramanathan R (2001) The long-run behavior of transport performance in India: A cointegration approach. Transp Res Part A Policy Pract 35:309–320. https://doi.org/10.1016/S0965-8564(99)00060-9

Ramanathan R, Parikh JK (1999) Transport sector in India: An analysis in the context of sustainable development. Transp Policy 6:35–45. https://doi.org/10.1016/S0967-070X(98)00030-4

Rasool Y, Zaidi SAH, Zafar MW (2019) Determinants of carbon emissions in Pakistan’s transport sector. Environ Sci Pollut Res 26:22907–22921. https://doi.org/10.1007/s11356-019-05504-4

Rauf A, Liu X, Amin W et al (2018) Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from belt and road initiative economies. Environ Sci Pollut Res 25:32066–32080. https://doi.org/10.1007/s11356-018-3052-5

Ribeiro SK, Balassiano R (1997) CO2 emissions from passenger transport in Rio de Janeiro. Transp Policy 4:135–139. https://doi.org/10.1016/S0967-070X(97)00003-6

Saboori B, Sapri M, Bin Baba M (2014) Economic growth, energy consumption and CO2 emissions in OECD (Organization for Economic Co-operation and Development)’s transport sector: A fully modified bi-directional relationship approach. Energy 66:150–161. https://doi.org/10.1016/j.energy.2013.12.048

SACTRA (1999) Transport and the Economy

Sadorsky P (2014) Modeling volatility and correlations between emerging market stock prices and the prices of copper, oil and wheat. Energy Econ 43:72–81. https://doi.org/10.1016/j.eneco.2014.02.014

Saidi S, Shahbaz M, Akhtar P (2018) The long-run relationships between transport energy consumption, transport infrastructure, and economic growth in MENA countries. Transp Res Part A Policy Pract 111:78–95. https://doi.org/10.1016/j.tra.2018.03.013

Sajid MJ, Cao Q, Kang W (2019) Transport sector carbon linkages of EU’s top seven emitters. Transp Policy 80:24–38. https://doi.org/10.1016/j.tranpol.2019.05.002

Samimi R (1995) Road transport energy demand in Australia A cointegration approach. Energy Econ 17:329–339. https://doi.org/10.1016/0140-9883(95)00035-S

Sarkodie SA (2018) The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ Sci Pollut Res 25:21993–22022. https://doi.org/10.1007/s11356-018-2347-x

Sarkodie SA, Strezov V (2019a) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871. https://doi.org/10.1016/j.scitotenv.2018.07.365

Sarkodie SA, Strezov V (2019b) A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. Sci Total Environ 649:128–145

Sarwar S, Khalfaoui R, Waheed R, Dastgerdi HG (2019) Volatility spillovers and hedging: Evidence from Asian oil-importing countries. Res Policy 61:479–488. https://doi.org/10.1016/j.resourpol.2018.04.010

Scholl L, Schipper L, Kiang N (1996) CO2 emissions from passenger transport: A comparison of international trends from 1973 to 1992. Energy Policy 24:17–30. https://doi.org/10.1016/0301-4215(95)00148-4

Shafik N (1994) Economic development and environmental quality: An econometric analysis. Oxf Econ Pap 46:757–773. https://doi.org/10.1093/oep/46.Supplement_1.757

Shahbaz M, Khraief N, Ben JMM (2015) On the causal nexus of road transport CO2 emissions and macroeconomic variables in Tunisia: Evidence from combined cointegration tests. Renew Sust Energ Rev 51:89–100

Solaymani S (2019) CO2 emissions patterns in 7 top carbon emitter economies: The case of transport sector. Energy 168:989–1001. https://doi.org/10.1016/j.energy.2018.11.145

Song C, Liu Q, Gu S, Wang Q (2018) The impact of China’s urbanization on economic growth and pollutant emissions: An empirical study based on input-output analysis. J Clean Prod 198:1289–1301. https://doi.org/10.1016/j.jclepro.2018.07.058

Song Y, Zhang M, Shan C (2019) Research on the decoupling trend and mitigation potential of CO2 emissions from China’s transport sector. Energy 183:837–843. https://doi.org/10.1016/j.energy.2019.07.011

Stead D (2001) Transport intensity in Europe - Indicators and trends. Transp Policy 8:29–46. https://doi.org/10.1016/S0967-070X(00)00034-2

Swamy PAVB (1970) Efficient Inference in a Random Coefficient Regression Model. Econometrica 38:311. https://doi.org/10.2307/1913012

Talbi B (2017) CO2 emissions reduction in road transport sector in Tunisia. Renew Sust Energ Rev 69:232–238

Tamarit C, Gómez-Herrera E, Tamarit C, Gómez-Herrera E (2011) The euro effect on trade: evidence in gravity equations using panel cointegration techniques

Ulucak R, Bilgili F (2018) A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. J Clean Prod 188:144–157. https://doi.org/10.1016/j.jclepro.2018.03.191

Vogelvang B (2004) Econometrics: Theory and Applications with EViews | 1st edition | Pearson. https://www.pearson.com/store/p/econometrics-theory-and-applications-with-eviews/P100000231117. Accessed 27 Feb 2021

Wang Q, Wu SD, Zeng YE, Wu BW (2016) Exploring the relationship between urbanization, energy consumption, and CO2 emissions in different provinces of China. Renew Sust Energ Rev 54:1563–1579

Wang H, Ou X, Zhang X (2017) Mode, technology, energy consumption, and resulting CO2 emissions in China’s transport sector up to 2050. Energy Policy 109:719–733. https://doi.org/10.1016/j.enpol.2017.07.010

Wang B, Sun Y, Chen Q, Wang Z (2018) Determinants analysis of carbon dioxide emissions in passenger and freight transportation sectors in China. Struct Chang Econ Dyn 47:127–132. https://doi.org/10.1016/j.strueco.2018.08.003

Wang H, Han J, Su M, Wan S, Zhang Z (2020a) The relationship between freight transport and economic development: A case study of China. Res Transp Econ 100885. https://doi.org/10.1016/j.retrec.2020.100885

Wang Z, Bui Q, Zhang B (2020b) The relationship between biomass energy consumption and human development: Empirical evidence from BRICS countries. Energy 194:116906. https://doi.org/10.1016/j.energy.2020.116906

WDI (2021) World Development Indicators | DataBank. https://databank.worldbank.org/source/world-development-indicators. Accessed 9 Feb 2021

Westerlund J (2007) Testing for Error Correction in Panel Data. Oxf Bull Econ Stat 69:709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Xu B, Lin B (2015) Factors affecting carbon dioxide (CO2) emissions in China's transport sector: A dynamic nonparametric additive regression model. J Clean Prod 101:311–322. https://doi.org/10.1016/j.jclepro.2015.03.088

Xu B, Lin B (2017) What cause a surge in China's CO2 emissions? A dynamic vector autoregression analysis. J Clean Prod 143:17–26. https://doi.org/10.1016/j.jclepro.2016.12.159

Xu B, Lin B (2018) Investigating the differences in CO2 emissions in the transport sector across Chinese provinces: Evidence from a quantile regression model. J Clean Prod 175:109–122. https://doi.org/10.1016/j.jclepro.2017.12.022

Yu ESH, Hwang BK (1984) The relationship between energy and GNP. Further results. Energy Econ 6:186–190. https://doi.org/10.1016/0140-9883(84)90015-X

Zafar MW, Shahbaz M, Hou F, Sinha A (2019) From nonrenewable to renewable energy and its impact on economic growth: The role of research & development expenditures in Asia-Pacific Economic Cooperation countries. J Clean Prod 212:1166–1178. https://doi.org/10.1016/j.jclepro.2018.12.081

Zeng S, Nan X, Liu C, Chen J (2017) The response of the Beijing carbon emissions allowance price (BJC) to macroeconomic and energy price indices. Energy Policy 106:111–121. https://doi.org/10.1016/j.enpol.2017.03.046

Zhang Z, Ren X (2011) Causal relationships between energy consumption and economic growth. In: Energy Procedia. Elsevier Ltd, pp 2065–2071

Zhang YJ, Liu Z, Zhang H, De Tan T (2014) The impact of economic growth, industrial structure and urbanization on carbon emission intensity in China. Nat Hazards 73:579–595. https://doi.org/10.1007/s11069-014-1091-x

Zou X (2018) VECM Model Analysis of Carbon Emissions, GDP, and International Crude Oil Prices. Discret Dyn Nat Soc 2018:1–11. https://doi.org/10.1155/2018/5350308