



# Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization

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## Abstract

The continuous growth of transport sector and the increase in carbon emissions from transportation attract the attention of policy makers in sustainable transportation. Therefore, it is of great importance to understand the determinants of pollution from transportation. The aim of this study is to analyze the impacts of economic growth, renewable energy consumption and urbanization on CO<sub>2</sub> emissions from transport sector in an Environmental Kuznets Curve (EKC) framework for European countries. To end this, second-generation panel long-run estimates and non-causality test are applied on the dataset from 1980–2014. Empirical pieces of evidence show that increases in renewable energy consumption mitigate carbon emissions from transportation, while urbanization has statistically insignificant positive impact on pollution. An increase in renewable energy consumption reduces CO<sub>2</sub> from transportation by about 12 percent. The EKC hypothesis is validated. Moreover, unidirectional causality runs from renewable energy, economic growth and urbanization to emissions in transport sector. The findings of this study suggest strengthening the sustainable transportation system by promoting eco-friendly and energy-efficient modes of transportation and increase the environmental awareness of urban population and their overall concerns related to environmental issues caused by transportation. This study provides concrete evidence to the policy makers of European countries for especially sector-based renewable energy projects, drawing attention to the greenhouse gas impact of European transportation sector.

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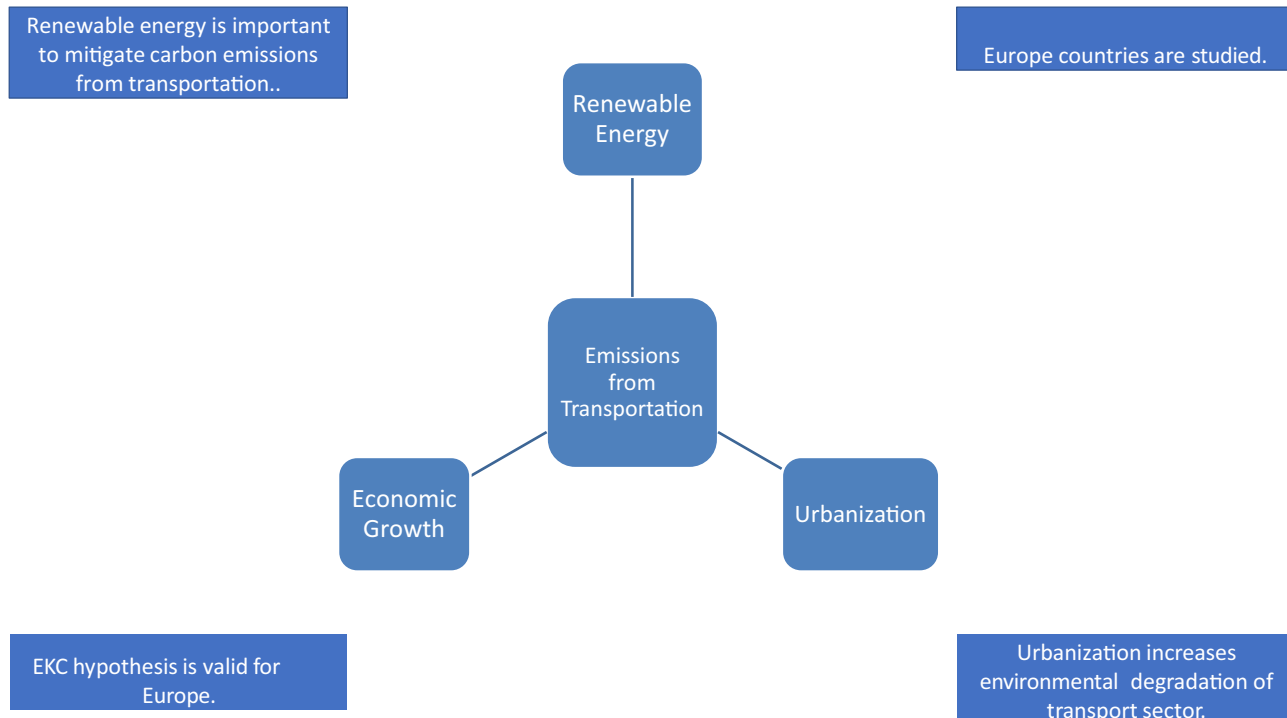
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## Graphic abstract



**Keywords** Sustainable transportation · CO<sub>2</sub> emissions · Renewable energy

## Introduction

The transport sector plays a fundamental role in a globalized economy as it enables goods to be traded (García-Lopez et al. 2015), mobility for people (Berg and Ihlström 2019), social and economic development (Krautzberger and Wetzel 2012; Danish et al. 2018) and is one of the reasons of suburbanization among cities (García-Lopez et al. 2015; García-Olivares et al. 2018). Despite a great contributor to economic development (Fan et al. 2018), it also poses a threat to global warming (Liu et al. 2020) and ranked among the world's second-largest carbon emitter (Giannakis et al. 2020). Contrary to other industries, the transport sector accounts for about 1/4 of the EU's greenhouse gas emissions (Sajida et al. 2019). Moreover, in recent decades, transport sector CO<sub>2</sub> emissions have raised from 32 to 45% in the European Union (EU) countries (González et al. 2019). Increasing carbon emission from the transport sector and its continuous growth draw the attention of transport and climate change policymakers for sustainable transportation. A sustainable transportation system is a key component for sustainable economic growth and provides accessibility and mobility to its citizens in secure and eco-friendly modes of transportation

(Alshehrya and Belloumia 2016; Ozkan et al. 2019). As on the one side, the transport sector leads to social and economic development in a country, but on the other hand, it is considered a higher energy-consuming sector (Wang and Lin 2018). From the global perspective, transport-related energy consumption accounts for one-third (about 30%) of the world's total energy consumption (Zhou et al. 2014), and turns this sector into second-biggest energy consumer after the industrial sector (Liang et al. 2017). IEA (2019) reported that, due to the increasing intensity of the transport-related energy consumption, it is expected to exceed about 60% by 2040. The carbon emission arises from various modes of transportation; for instance, road transportation (Aggarwal and Jain 2016), rail transportation (Hoffrichter et al. 2012), inland shipping (Šimenc 2016), freight systems (Kim and Wee 2011) and aviation (Zhou et al. 2016). Energy consumption adversely affects the environment and thus results in increasing CO<sub>2</sub> emissions (Talbi 2017).

To further analyze the factors leading to increasing carbon emissions from the transport sector, researchers explore urbanization as the main indicator causes pollution from transportation (Martínez-Zarzoso 2008; Poumanyong and Kaneko 2010; Bai et al. 2018; Wang

et al. 2019; Ali et al. 2019). For instance, Poumanyong and Kaneko (2010) explain urbanization, the movement of the labor force from rural to urban areas (or from agriculture to the industrial sector that is located in the urban). The movement of the labor force from rural to urban hubs dramatically changes the settlement patterns and urban economic activities and therefore cause in increasing energy consumption (Wang et al. 2016). This movement from rural to urban areas directly affects energy consumption through different channels. For instance, urbanization may cause increase energy consumption for food, transportation in urban hubs, electric devices and increased demand for road use. Urbanization has developed rapidly in recent years. Globally, the urban population was increased 751 million in 1950 to 4.2 billion in 2019 (World Economic and Social Survey 2019); currently, all over the world 55% people live in urban areas and by 2050 this percentage is expected to increase to 68% and implies that rise in urbanization would has a significant effect on energy use. Finally, it is postulated that urbanization significantly contributes to increase of CO<sub>2</sub> emissions (Shahbaz et al. 2015a, b). Urbanization highlights increasing concerns over the overlapping challenges of climate change mitigation and sustainable development from the academic circles as well as policymakers.

When environmental pollution has become a serious problem and significantly contributes to global warming, a sustainable zero-emission transportation system becomes necessary. Renewable energy is the most effective solution to protect the environment (Bhattacharya et al. 2016; Sharif et al. 2019). The existing studies mainly focused on non-renewable/aggregate energy (see e.g., Saboori et al. 2014; Yin et al. 2015; Alshehrya and Belloumia 2016; Danish et al. 2018; Nasreen et al. 2018; Peng and Wu 2019); however, no study yet has been conducted in the relationship between renewable energy consumption and its influence on transport CO<sub>2</sub> emissions. The purpose of the present study is to realize the importance of renewable energy for sustainable transportation and a clean environment. If renewable energy is produced sustainably, it is believed to mitigate carbon emissions (Danish et al. 2017; Pata 2018). In the transport sector, the following experiences have been made with renewable sources of energy. Biodiesel helps to mitigate CO<sub>2</sub> emissions, as Quirin et al. (2004) states that more than 75% of carbon emission decreases by biodiesel as compared to petroleum diesel. As a transport energy source can mitigate greenhouse gas emissions, it is produced by hydrogen. Methanol is produced by woods or natural gas and contributes to reducing carbon emissions by 60% as compared to petrol (Aßmann and Sieber 2005). Moreover, few studies have sought ways to decrease transport emissions by using alternate modes of transportation (Gambhir et al. 2015; Robertson 2016), by utilizing alternative fuels

(Nocera and Cavallaro 2016), or by adopting different policies (Harwatt et al. 2011; Mustapa and Bekhet 2016; Zhu et al. 2016). Considering the view that biochar significantly reduces carbon emissions as an alternative renewable energy source (Marousek et al. 2017, 2019), this type of fuel is another environmentally friendly fuel for the transportation sector. Biochar is being widely accepted as a promising technique of carbon sequestration (Marousek et al. 2017), and since biochar is charred at lower temperatures and in a shorter time, it causes fewer emissions during the production process than char (Marousek et al. 2019).

Over the last three decades, some western countries, such as the UK succeeded to mitigate emissions from various sectors of their economy (Al-Mulali et al. 2015), but still unable to control carbon emission which is significantly increasing from the transport sector (Brand et al. 2012). In 2016, the total amount of transport emissions reached 7866.01 Mt (about 24.34%) and the proportion is continuously increasing since the past decade (Yang et al. 2019). Increasing CO<sub>2</sub> emissions from the transport sector and its relationship with non-renewable/aggregate energy consumption has been evaluated for various countries (see e.g., for Pakistan (Danish et al. 2018); for ASEAN-5 countries (Chandran and Tang 2013); for USA (Mishalani et al. 2014); for OECD countries (Saboori et al. 2014); for China (Xu and Lin 2015; Yin et al. 2015; Peng and Wu 2019); for Tunisia (Shahbaz et al. 2015a, b); for UK (Kwon 2005); for Italy (Mazzarino 2000), for Scotland (Melo 2016); for low, middle and high-income countries (Nasreen et al. 2018) and multiple Asian countries (Timilsina and Shrestha 2009). The transport sector is known as the backbone of the European countries (Mesimeris and Partasides 2020), accounts for more than 5% of total employment and 7% of income (Eißel and Chu 2013). To build a sustainable transportation system, the European Commission launched a road-map of 40 concrete initiatives with the purpose to enhance mobility, eliminating barriers in the key areas and boost employment and growth. Meanwhile, these plans would significantly mitigate CO<sub>2</sub> emissions from transport up to 60% by 2050. The EU's share of renewable energy in transport rose slightly from 7.4% in 2017 to 8.1% in 2018. It remains an accurate to 10% target set for 2020 under the EU's Renewable Energy Directive (EC 2019). Renewable energy is important to study because it does not damage the environment and public health. An initiative to launch an environment-friendly generation of buses has been taken from the EU that meets this purpose (Corazza et al. 2016).

In light of the above motivations and discussions, the main hypothesis of the study is that urbanization and economic growth lead to an increase in emissions from the transport sector, but renewable energy consumption reduces it. Therefore, the aim of the present study is, for the first time in the literature, to investigate the nexus of renewable energy

consumption, economic growth, urbanization and transport CO<sub>2</sub> emissions for European countries over the period 1980–2014 by utilizing second-generation econometric approaches. The rapid growth of the transport sector leads to increase in transport CO<sub>2</sub> emissions, which is an obstacle to sustainable economic development. In opposite of the existing studies that use conventional econometric techniques fail to take into account cross-sectional dependence among countries. The present study fills this gap by employing second-generation panel methods (i.e., cross-sectionally augmented IPS (CIPS) unit root tests, ordinary least squares (OLS) with robust standard error and the Dumitrescu-Hurlin causality). Due to the use of appropriate panel techniques, the empirical findings of this study are robust and reliable.

## Data and model specification

This study analyzes the effect of economic growth, renewable energy consumption and urbanization on per capita CO<sub>2</sub> emissions from transport sector for European countries. In fact, although this study aims to investigate the relationship for the European Union countries, only fourteen member countries are selected depending on the availability of the data. The fourteen countries: Austria, Belgium, Bulgaria, Denmark, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain and Sweden are selected according to data availability, and data period is from 1980–2014. Inspired by Alshehry and Belloumi (2017) and Danish et al. (2018), this study focuses on the following model:

$$TCO_{2it} = f(GDP_{it}, GDP_{it}^2, REN_{it}, URB_{it}) \quad (1)$$

where TCO<sub>2</sub> denotes per capita CO<sub>2</sub> emissions from transport sector; GDP implies GDP per capita, which represent to economic growth; GDP<sup>2</sup> is square of GDP per capita; REN denotes renewable energy consumption per capita; URB implies urbanization rate,  $i = 1, \dots, 14$  stands for country; and  $t = 1980, \dots, 2014$  express to time period. The annual data for European countries obtained from the World Bank Development Indicators and US Energy Information Administration. Table 1 presents summary statistics of all variables.

**Table 1** Descriptive statistics

| Variables        | #Obs. | Min.  | Max.   | SD     |
|------------------|-------|-------|--------|--------|
| TCO <sub>2</sub> | 490   | −0.89 | 2.71   | 0.550  |
| GDP              | 490   | 8.07  | 11.62  | 0.661  |
| GDP <sup>2</sup> | 490   | 65.25 | 135.16 | 13.017 |
| REN              | 490   | −8.93 | −1.56  | 1.257  |
| URB              | 490   | 3.75  | 4.58   | 0.169  |

Table 1 includes smallest, largest values and standard deviations. Accordingly, the variation seems to be enough to do an empirical analysis.

## Methods and empirical results

### Methodology

The first stage of the analysis is to investigate the cross-sectional dependence using Pesaran's (2004) cross-sectional dependence test (CD-test). Whether there is a cross-sectional dependence or not is the reason for the unit root test used in the next stage. The presence of heterogeneity is also another justification for the use of second-generation unit root tests. The Pesaran and Yamagata (2008) slope homogeneity test is used. Therefore, the stationarity control is performed using both Im-Pesaran-Shin (IPS) first-generation and cross-sectionally augmented IPS (CIPS) second-generation unit root tests. While the IPS unit root test developed by Im et al. (2003) considers heterogeneity, the CIPS test developed by Pesaran (2007) is applied in the presence of both heterogeneity and cross-sectional dependency.

In accordance with the unit root tests, Pedroni and Westerlund cointegration tests are applied. The cointegration test developed by Pedroni (1999, 2004) calculates four within-group and three between-group cointegration statistics. Pedroni cointegration test is a widely used technique, but it ignores the cross-sectional dependence of the panel. Therefore, the other cointegration test procedure used is Westerlund (2007), which estimates four panel cointegration statistics. Two of the calculated statistics ( $G_t$  and  $G_a$ ) base on the weighted average of coefficients, the others ( $P_t$  and  $P_a$ ) to the panel. This testing procedure is based on error correction and free from common-factor restrictions.

After the existence of the cointegration relationship is determined, it is passed to the long-run coefficient estimation. It is focused on the pooled OLS with Driscoll and Kraay (1998) standard errors and dynamic ordinary least squares (DOLS) methods for parameter estimation. DOLS method developed by Pedroni (2001) regression is formulated as follows:

$$Y_{it} = \alpha_i + \beta_i X_{it} + \sum_{k=-K_i}^{K_i} \gamma_{ik} \Delta X_{it-k} + \mu_{it} \quad (2)$$

where  $-K_i$  and  $K_i$  denote the lags and leads, respectively. Also,  $Y_{it}$  is dependent variable.  $X_{it}$  represents the vector of GDP, GDP<sup>2</sup>, REN, and URB. Pedroni (2001) is obtained as the DOLS estimator from this regression as follows:

$$\hat{\beta}_{GD} = N^{-1} \sum_{n=1}^N \hat{\beta}_{DOLS, n} \tag{3}$$

where  $\hat{\beta}_{DOLS, n}$  represents obtained DOLS estimation result for each unit. The t-statistic is used for the significance of the estimated coefficient. Another method adopted in the study to increase the robustness of the results is pooled OLS with standard errors developed by Driscoll and Kraay (1998). The econometric problems caused by assumptions (i.e., normality, homogeneity) of DOLS, which are a parametric approach, are eliminated with the results obtained from pooled OLS with standard errors. This method is a non-parametric approach, and it proposes a non-parametric covariance matrix estimator which provides heteroscedasticity-consistent standard errors that are robust to general forms of spatial and temporal dependence. Therefore, this advantage eliminates that biased standard errors estimated by commonly applied covariance matrix (Hoechle 2007). Pooled OLS with standard errors is appropriate in the case of existence of cross-sectional dependence. These features are the main reasons for using the method, and the testing procedure is as follows:

$$Y_{it} = X'_{it}\beta + \mu_{it} \quad i = 1, \dots, N, \quad t = 1, \dots, T \tag{4}$$

where  $Y_{it}$  is dependent variable, and  $X_{it}$  represents independent variables with  $(K + 1) \times 1$  vector.  $\beta$  denotes unknown coefficients with  $(K + 1) \times 1$  vector. Driscoll and Kraay (1998) standard errors are obtained as the square roots of diagonal elements of the asymptotic covariance matrix as follows (Hoechle 2007):

$$V(\hat{\beta}) = (X'X)^{-1} \hat{S}_T (XX)^{-1} \tag{5}$$

Finally, it is used the panel causality method developed by Dumitrescu and Hurlin (2012) to test the existence of causality relationship between series. The advantages of this

method are that it can consider both cross-sectional dependence and heterogeneity between the countries making up the panel, can be used when the time dimension is larger or smaller than the cross-section dimension and produce effective results in unbalanced panel data. Another feature of the test is that it can be applied regardless of whether there is a cointegration relationship. This testing procedure can be expressed as follows:

$$Y_{it} = \alpha_i + \sum_{k=1}^K \gamma_i^k Y_{it-k} + \sum_{k=1}^K \beta_i^k X_{it-k} + \epsilon_{it} \tag{6}$$

where  $K$  is the optimal lag length, and the null hypothesis of the test is “ $X$  does not Granger cause  $Y$ ” for all cross section.

### Empirical result

In this section, firstly cross-sectional dependency, slope homogeneity test and unit root test results are presented in Table 2. As it is understood in Table 2, second-generation unit root tests are preferred in this study since the cross-sectional dependence and the heterogeneity of the slope coefficient are determined. While the IPS unit root test developed by Im et al. (2003) considers heterogeneity, the CIPS test developed by Pesaran (2007) is applied in the presence of both heterogeneity and cross-sectional dependency. The tests results imply that all series are I(1).

Following the stationarity tests, Pedroni and Westerlund cointegration tests are applied to test whether there is a cointegration relationship between the variables in the long run. Both cointegration test results are given in Table 3, which verifies the cointegration relationship between CO<sub>2</sub> emissions from transport sector, income, the square of income, renewable energy consumption and urbanization in the long run.

After cointegration testing procedures, the long-run coefficient estimation phase is started. In this study, both pooled

**Table 2** Results from CD-test, slope homogeneity and unit root tests

| Variables        | Levels     |        | First differences |        |
|------------------|------------|--------|-------------------|--------|
|                  | IPS        | CIPS   | IPS               | CIPS   |
| TCO <sub>2</sub> | 6.62       | -2.67  | -12.75*           | -5.52* |
| GDP              | 5.93       | -1.86  | -8.63*            | -4.01* |
| GDP <sup>2</sup> | 5.65       | -1.85  | -8.58*            | -3.99* |
| REN              | -7.09*     | -3.22* | -17.33*           | -5.89* |
| URB              | 0.95       | -2.13  | -4.26*            | -2.94* |
|                  | Statistics | Prob.  |                   |        |
| CD-test          | 9.39       | 0.00   |                   |        |
| Delta_adj        | 28.76      | 0.00   |                   |        |

\*Stands for 1% level of significance, Delta\_adj implies adjusted delta value obtained from Pesaran and Yamagata (2008) slope homogeneity test

**Table 3** Results from panel cointegration test

| Westerlund cointegration test |            |       |              | Pedroni cointegration test |            |       |           |       |
|-------------------------------|------------|-------|--------------|----------------------------|------------|-------|-----------|-------|
| Tests                         | Statistics | Prob. | Robust prob. | Tests                      | Statistics | Prob. | Tests     | Prob. |
| Gt                            | -2.84      | 0.06  | 0.40         | Panel-v                    | 0.14       | 0.45  | Group rho | 0.798 |
| Ga                            | -9.61      | 0.95  | 0.31         | Panel rho                  | -0.22      | 0.41  | Group PP  | 0.01  |
| Pt                            | -12.56     | 0.00  | 0.00         | Panel PP                   | -2.84      | 0.00  | Group ADF | 0.00  |
| Pa                            | -15.04     | 0.00  | 0.00         | Panel ADF                  | -4.05      | 0.00  |           |       |

**Table 4** Results from long-run estimators

| OLS              |         |           | DOLS   |       |
|------------------|---------|-----------|--------|-------|
| Variables        | Coeff.  | Robust SE | Coeff. | SE    |
| GDP              | 2.19*   | 0.228     | 2.93*  | 0.515 |
| GDP <sup>2</sup> | -0.06*  | 0.010     | -0.10* | 0.025 |
| REN              | -0.12*  | 0.016     | -0.11* | 0.026 |
| URB              | 0.10    | 0.097     | 0.16   | 0.232 |
| CONS             | -16.90* | 1.432     |        |       |

\*Stands for 1% level of significance

OLS with Driscoll-Kraay standard errors and DOLS estimation approaches are used. Long-run coefficient estimation results calculated according to both test procedures are presented in Table 4, which provides important clues regarding the sustainability of the transport sector in European area.

First of all, the validity of the Environmental Kuznets Curve (EKC) hypothesis is confirmed for the transport sector. Examples of studies that this result is compatible in terms of overall carbon emission-growth relationship are Shahbaz et al. (2015a, b); Jebli et al. (2016); Sharif et al. (2019); Ozkan et al. (2019). The same result is confirmed by Ozkan et al. (2019) for the transportation sector. This means that the increase in economic growth first damages to air quality, but later improves it. Confirming the EKC hypothesis for emissions from the transport sector reveals the role of countries' income level on the environmental impact of this sector. Accordingly, the economic costs of sustainable investments planned with a focus on the transportation sector are directly related to the income level. Also, in these countries, it is understood that there is a dependency on fossil fuels in the transportation sector as in many sectors in the early development stages, and sustainability awareness has emerged in freight and passenger transportation in the later development stages.

Another finding from both methodological approaches is that renewable energy consumption reduces CO<sub>2</sub> emissions from the transport sector as expected. Accordingly, an increase in renewable energy consumption mitigates air pollution from the transportation sector by approximately 0.11 percent. Based on this result, it is observed that renewable energy developments in the European countries are reflected in the transportation sector. Also, this

result confirms that the emission-reducing effect of fuel types proposed by Quirin et al. (2004) and Aßmann and Sieber (2005) for the transport sector. It is also complementary to the recommendations of Gambhir et al. (2015), Robertson (2016), Nocera and Cavallaro (2016), Harwatt et al. (2011), Mustapa and Beckhet (2016) and Zhu et al. (2016). When evaluated together with the validity of EKC, this result also can be associated with the emergence of renewable energy use awareness and the necessity to follow international environmental developments. In such an environment, it is a reasonable result that each development in renewable energy provides a benefit to sustainability beyond cost. Lastly, the attitude of European countries toward renewable energy development also serves sustainable growth through the transport sector, which has a significant share in air pollution.

The last evidence obtained from the coefficient estimation according to both methods suggests that the effect of urbanization on CO<sub>2</sub> emissions from the transport sector is positive but statistically insignificant. This result is incompatible with Martinez-Zarsoso (2008), Paumanyong and Kaneko (2010), Xu and Lin (2015) and Ali et al. (2019), which determine the positive linkage among them. According to the European Environment Agency Transport and Environment Report 2019, the share of the transport sector in greenhouse gas emissions is quite large. Therefore, considering the number and length of travel, the type of transport, and the transport technologies directly related to the environmental impacts of this sector, it is reasonable that the developments provided especially in terms of income and renewable energy consumption decrease the emissions of the sector. Nevertheless, the insignificant effect of urbanization on emissions is evidence that the green city projects that Europe has focused on in recent years are beneficial for the transport sector to a certain extent. Besides, the transition to technology-intensive production with urbanization also causes some transformations in the transportation sector. The proliferation of autonomous vehicles is an example of this and is likely to contribute to the reduction of emissions (Putnam et al. 2019). On the other hand, urbanization may cause intensity in transportation even though daily life activities such as food service to home or office increasing in the fast life cycle (Vochozka et al. 2019). Therefore, the positive coefficient obtained from both methods confirms

**Table 5** Results from Dumitrescu–Hurlin non-causality test

| Hypothesis                                 | Z-bar | Prob | Conclusion  |
|--|-------|------|---|
| GDP (GDP <sup>2</sup> ) → TCO <sub>2</sub> | 7.01  | 0.00 | Unidirectional causality from GDP to TCO <sub>2</sub> |
| TCO <sub>2</sub> → GDP (GDP <sup>2</sup> ) | 1.12  | 0.34 |   |
| REN → TCO <sub>2</sub>                     | 1.85  | 0.09 | Unidirectional causality from REN to TCO <sub>2</sub> |
| TCO <sub>2</sub> → REN                     | 0.73  | 0.53 |   |
| URB → TCO <sub>2</sub>                     | 2.49  | 0.07 | Unidirectional causality from URB to TCO <sub>2</sub> |
| TCO <sub>2</sub> → URB                     | 0.57  | 0.70 |   |

that urbanization is a risk for the sustainability problem caused by the transportation sector.

Causality test results are summarized in Table 5, which concludes that there is a unidirectional causality relationship from income, renewable energy consumption and urbanization to CO<sub>2</sub> emissions from transport sector. These causalities are compatible with long-run parameter estimation results. Thus, it is inevitable that a change in economic growth, renewable energy consumption and urbanization affect the emissions from transport sector. In the European countries discussed, sustainable economic growth policies, substitution of fossil fuels with renewable energy and focusing on green city policies can eliminate the negative effect of transport sector on air quality.

## Conclusion and policy implications

Transport is considered as the key economic sector that promotes socio-economic development in a country. Despite being an important contributor to economic growth, it plays a major role in producing carbon emissions, which is a major obstacle to promote sustainable transportation systems. The present study investigates the relationship between renewable energy consumption, economic growth, urbanization and transport CO<sub>2</sub> emissions for European countries over the period 1980–2014. For the empirical analysis, the present study firstly employs cross-sectional dependence and slope homogeneity test. Because of the existence of heterogeneity and cross-sectional dependence, the stationarity of the dataset is checked by the IPS and the CIPS tests. Given that the dataset has I(1) process, Pedroni and Westerlund cointegration methods are used to verify long-run relationship between transport CO<sub>2</sub> emissions, renewable energy consumption, income, the square of income and urbanization. In accordance with the cointegration tests, pooled OLS with Driscoll Kraay standard errors and DOLS coefficient estimation methods are applied. The study also contains some empirical limitations. First of all, since the availability of data is the main determinant of sample selection, some European countries are inevitably excluded from the analysis. Besides, the cross-sectional dependency and heterogeneity problem of the dataset is another limitation. Therefore, the

primary empirical aim of this study is to obtain more reliable results with methods that overcome these problems and to compare these results with conventional methods. Considering the limitations related to dataset and method selection, adopting the appropriate methods under these limitations ensures that the findings are noteworthy.

The results from the OLS with robust standard error and the DOLS estimators report that a 1% increase in renewable energy consumption mitigates CO<sub>2</sub> emissions from transport by about 0.12%. The EKC hypothesis is validated for the European countries as the elasticity of carbon emissions concerning income and the square of income is found positive and negative, respectively. The effect of urbanization on transport CO<sub>2</sub> emissions depicts positive outcomes. The obtained results confirm the main research hypothesis that there is a negative relationship between renewable energy consumption and TCO<sub>2</sub> and a positive relationship between urbanization and TCO<sub>2</sub>. The Dumitrescu–Hurlin results reveal the existence of unidirectional causality from growth to TCO<sub>2</sub>, from renewable energy to TCO<sub>2</sub> and from urbanization to transport emissions. Considering that transportation consumes approximately one-third of all the final energy within the EU, the results are guiding for the future energy and environmental policies of these countries. This means that it is inevitable to consider the applicability of these policies in the transportation sector, especially when implementing renewable energy policies. Within this framework, admittedly, the European countries' achievement of sustainability goals is closely related to the focus on emissions from the transportation sector. Besides, it is a fact that the increase in “quality of life” as a result of urbanization is complementary with “environmental quality.” Considering the facilitation of transportation as a component of quality of life, sustainability is an important point in addition to being fast, reliable and diverse. However, every step that is likely to be taken to increase the environmental quality, especially for the transportation sector or for the general economy, is possible with technological progress, and also brings with it an automation process. The environmental as well as the economic consequences of this transformation process should inevitably be considered in possible policy implementations. On the other hand, technological innovations change the consumption behavior of individuals (Graessley

et al. 2019) and generate wealth if workers improve their skills and creativity (Udell et al. 2019).

By utilizing appropriate estimation methods, the empirical results of this study are robust and reliable. Based on empirical findings, it is recommended that

- Since the transport sector is considered a high energy-consuming sector and causes to increase CO<sub>2</sub> emissions. Thus, it is suggested to strengthen the sustainable transportation system by promoting eco-friendly and energy-efficient modes of transportation.
- A unidirectional causality running from renewable energy to transport carbon emissions has an important policy implication. The evidence reveals that the EU can mitigate transport carbon emissions by increasing renewable energy consumption, as it helps to clean the environment and reduces CO<sub>2</sub> emissions.
- The findings suggest that in the initial stages, an increase in income first damages to air quality but later improves it by mitigating carbon emissions. Thus, it reveals the importance of economic growth for the EU to promote the sustainable transportation sector.
- Necessary measures should be taken to increase the environmental awareness of the urban population and their awareness of the use of clean energy for a clean environment.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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