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ORIGINAL PAPER

The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe

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Abstract This study investigates the influence of disaggregated renewable electricity production by source on CO_2 emission in 23 selected European countries for the period of 1990–2013. Panel data techniques were used in examining the relationships. The Pedroni cointegration results indicated that CO_2 emission, GDP growth, urbanization, financial development, and renewable electricity production by source were cointegrated. Moreover, the fully modified ordinary least-square results revealed that GDP growth, urbanization, and financial development increase CO_2 emission in the long run, while trade openness reduces it. Furthermore, renewable electricity generated from combustible renewables and waste, hydroelectricity, and nuclear power have a negative long-run effect on CO_2 emission, while renewable electricity generated from solar power and wind power is insignificant. The VECM Granger causality also revealed that GDP growth is the only variable that has causal effects on CO_2 emission in all the investigated models, while the rest of the variables have causal effects on CO_2 emission in only a few models. A number of policy recommendations were provided for the European countries.

Keywords European countries · Pollution · Renewable electricity production · Panel data analysis

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1 Introduction

It is well known that renewable energy represents an important source of energy because it is undamaging to the environment and public health. This type of energy is a continuous source that capable to increase the energy security of a country by reducing its dependency on fossil fuels. The European Union (EU) is the second biggest producers of renewable energy after the USA (World Development Indicators 2014). The role of non-carbon electricity generation in Europe increased substantially in the last two decades. In 2012, more than 55 % of total electricity in the Europe was generated from renewable energy (Energy Information Administration 2014). This phenomenon reflects the European countries' efforts in reaching the greenhouse emission targets. Most of the renewable electricity production comes from the combustible renewables and waste, hydroelectric power, nuclear power, solar power, and wind power. Renewable electricity generation has a substantial share to the total production of electricity in the Europe, which can be seen in Fig. 1.

The increase in renewable electricity production and the reduction in fossil fuels electricity production during the past 24 years might have a significant impact in reducing the pollution level in the 23[1] European Union countries, namely Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the UK.

The relationship between pollution, economic activities, and energy consumption has been thoroughly investigated by different scholars. These studies are summarized in Table 1. Most of the previous studies utilized GDP growth (Soytas et al. 2007; Sadorsky 2009; Menyah and Wolde-Rufael 2010a, b; Lean and Smyth 2010; Acaravci and Ozturk 2010; Pao and Tsai 2010; Hossain 2011; Bloch et al. 2012; Jafari et al. 2012; Shahbaz et al. 2013a, b; Govindaraju and Tang 2013; Apergis and Payne 2014; Baek and Pride 2014; Al-Mulali et al. 2015; and so forth), energy consumption (Apergis and Payne 2009, 2010; Hossain 2011; Zhang and Cheng 2009; Bloch et al. 2012; Chandran and Tang 2013; Shahbaz et al. 2013a, b; Saboori and Sulaiman 2013a, b; Bella et al. 2014; Boutabba 2014; Begum et al. 2015; Alshehry and Belloumi 2015; and so forth), urbanization (Hossain 2011; Zhang and Cheng 2009; Jafari et al. 2012; Zhang and Lin 2012; Al-mulali 2014a, b; Zhang et al. 2014; Shafiei and Salim 2014; Kasman and Duman 2015), population (Zhang and Cheng 2009; Zhang and Lin 2012; Omri 2013; Apergis and Payne 2014; Shafiei and Salim 2014; Alam et al. 2014), trade openness (Halicioglu 2009; Hossain 2011; Jayanthakumaran et al. 2012; Al-mulali 2012; Shahbaz et al. 2013a, b; Kohler 2013; Farhani et al. 2014; Yang and Zhao 2014; Boutabba 2014; Sebri and Ben-Salha 2014; Al-mulali and Ozturk 2015; Shahbaz et al. 2015; Kasman and Duman 2015), and financial development (Al-mulali and Che Sab 2012a, b; Omri 2013; Shahbaz et al. 2013a, b; Ozturk and Acaravci 2013; Boutabba 2014; Alam et al. 2014; Ziaei 2015) as indicators of economic activities. Most of the studies revealed that the above economic indicators were the main sources of pollution as they had long-run and short-run significant impacts on pollution. Moreover, most of the studies utilized CO_2 emission as an indicator of environmental pollution (Halicioglu 2009; Sadorsky 2009; Apergis and Payne 2010; Menyah and Wolde-Rufael 2010a, b; Zhang and Cheng 2009; Hossain 2011; Alam et al. 2012; Ozturk and Uddin 2012; Bloch et al. 2012; Jafari et al. 2012; Shahbaz et al. 2013a; Chandran and Tang 2013; Saboori and Sulaiman 2013a, b; Apergis and Payne 2014; Baek and Pride 2014;

[1] A number of European Union countries such as Croatia, Cyprus, Estonia, Latvia, Lithuania, Malta and Romania were not included in the investigation due to the lack of data availability.

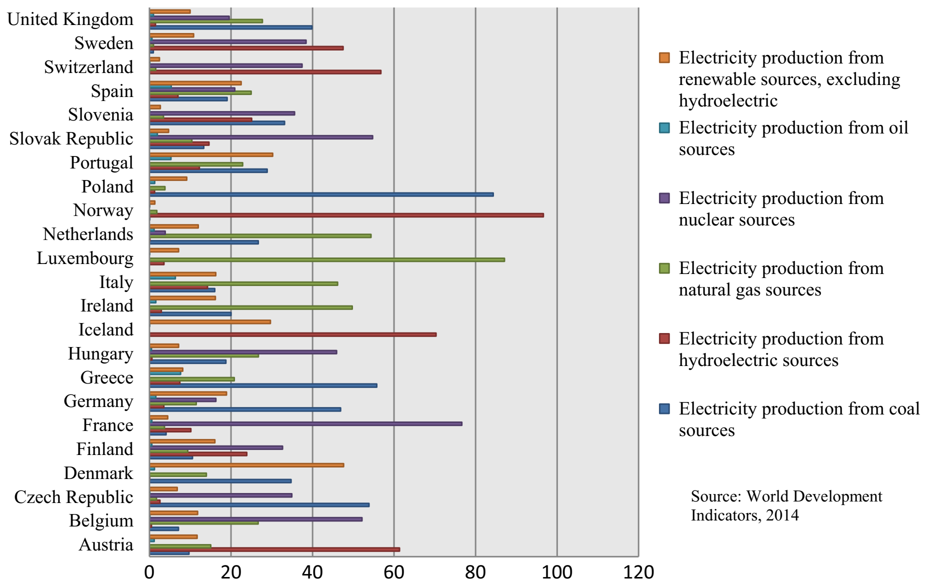

Fig. 1 Electricity production based on source as a percentage of total electricity production in 2012

Bella et al. 2014; Boutabba 2014; Heidari et al. 2015; Kasman and Duman 2015; Zhang and Da 2015; and so forth).

The influence of renewable energy on pollution was investigated (Sadorsky 2009; Menyah and Wolde-Rufael 2010a, b; Bengochea and Faet 2012; Apergis and Payne 2014; Baek and Pride 2014; Shafiei and Salim 2014; Bolük and Mert 2014; Farhani and Shahbaz 2014), but in rare cases especially in the European Union countries. In addition, most of the studies utilized total renewable energy consumption in general. However, disaggregated renewable energy consumption by source is important as it can provide an accurate relationship between each renewable energy consumption source and pollution. Moreover, each source of renewable energy might have different effects on pollution. Hence, this study examines the effect of renewable energy production[2] on pollution in European countries because Europe is the second largest renewable energy producer in the world. Moreover, this study also examines the effect of five disaggregated renewable energy sources on pollution, respectively. This step will distinguish which renewable energy source is significant in reducing pollution so that more accurate policy recommendations could be made.

2 Data and methodology

Twenty three European countries namely Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the UK are taken as the sample of this study. Learning from the literature, this study utilizes four variables that can influence pollution namely the gross domestic product (GDP) and trade

[2] This research utilized renewable electricity production instead of renewable energy consumption because the data for renewable energy consumption by source does not exist. Moreover, the researchers assume that a portion of the produced renewable electricity production is consumed by the EU producing countries.

Table 1 Summary of the literature review

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Apergis and Payne (2014)	Central American countries	1980–2010	Bai–Perron panel cointegration, fully modified OLS (FMOLS) and vector error correction model (VECM) Granger causality	CO_2 emission	GDP, renewable electricity consumption, oil and coal prices, population
Baek and Pride (2014)	Major nuclear producing countries	1990–2011	Cointegrated vector autoregression (CVAR) and Johnsen cointegration	CO_2 emission	Nuclear electricity production and GDP
Bella et al. (2014)	OECD countries	1965–2006	Panel VECM	CO_2 emission	GDP and electricity consumption
Hossain (2011)	Newly industrialized countries	1971–2007	Johansen panel cointegration and VECM Granger causality	CO_2 emission	GDP, energy consumption, and trade openness, urbanization
Zhang and Cheng (2009)	China	1960–2007	Toda–Yamamoto Granger causality	CO_2 emission	GDP, energy consumption, urbanization, capital, and population
Chandran and Tang (2013)	ASEAN	1971–2008	Johansen cointegration and VECM Granger causality	CO_2 emission	GDP, foreign direct investment, and energy consumption
Al-mulali and Sheau-Ting (2014)	Seven regions	1990–2011	Panel FMOLS	CO_2 emission	Energy consumption, trade openness, exports and imports
Sadorsky (2009)	G7	1980–2004	Pedroni cointegration, FMOLS, dynamic OLS (DOLS)	CO_2 emission	GDP, renewable energy consumption, and oil prices
Menyah and Wolde-Rufael (2010a, b)	South Africa	1965–2006	ARDL bound test approach and TY Granger causality	CO_2 emission	Energy consumption, labor, capital, and GDP
Bloch et al. (2012)	China	1977–2008	Johansen cointegration, variance decomposition and VECM Granger causality	CO_2 emission	Energy consumption, labor, capital, and GDP
Omri (2013)	MENA countries	1990–2011	GMM model	CO_2 emission	GDP, labor, capital, population, and financial development

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Heidari et al. (2015)	ASEAN	1980–2008	Prior to empirical analysis based on PSTR model	CO_2 emission	GDP and electricity consumption
Al-mulali (2014a, b)	30 major nuclear energy producing countries	1990–2010	Pedroni cointegration, FMOLS and VECM Granger causality	CO_2 emission	GDP, nuclear energy consumption, fossil fuel energy consumption, urbanization, and investment
Jafari et al. (2012)	Indonesia	1971–2007	TY Granger causality	CO_2 emission	GDP, capital, energy consumption, and urbanization
Shahbaz et al. (2013a)	Malaysia	1971–2011	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, foreign direct investment, financial development, and trade openness
Farhani et al. (2014)	Tunisia	1971–2008	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, and trade openness
Yang and Zhao (2014)	India	1970–2008	DAG contemporaneous causality tests	CO_2 emission	GDP, capital, energy consumption, and trade openness
Boutabba (2014)	India	1971–2008	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, trade openness, and financial development
Kasman and Duman (2015)	Europe	1992–2010	Kao and Pedroni cointegration, FMOLS and VECM Granger causality	CO_2 emission	GDP, energy consumption, trade openness, and urbanization
Halicioglu (2009)	Turkey	1960–2005	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, and trade openness
Apergis and Payne (2009)	Central America	1971–2004	Pedroni, FMOLS and VECM Granger causality	CO_2 emission	GDP and energy consumption
Apergis and Payne (2010)	Commonwealth of independent states	1992–2009	Pedroni, FMOLS and VECM Granger causality	CO_2 emission	GDP and energy consumption

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Menyah and Wolde-Rufael (2010a, b)	United States of America	1960–2007	TY Granger causality	CO_2 emission	GDP, nuclear energy consumption, and renewable energy consumption
Pao and Tsai (2010)	BRIC countries	1971–2005	Pedroni, Koa, and Johansen Fisher cointegration, GARCH and VECM Granger causality	CO_2 emission	GDP and energy consumption
Wang et al. (2011)	China	1995–2007	Pedroni cointegration and VECM Granger causality	CO_2 emission	GDP and energy consumption
Jayanthakumaran et al. (2012)	China and India	1971–2007	ARDL bound test approach	CO_2 emission	GDP, energy consumption, and trade openness
Alam et al. (2012)	Bangladesh	1972–2006	Johansen cointegration, ARDL bound test approach, and VECM Granger causality	CO_2 emission	GDP and electricity consumption
Zhang and Lin (2012)	China	1995–2010	Fixed-effects, the feasible generalized least-squares, the linear regression with panel-corrected standard errors and the linear regression with Driscoll–Kraay standard errors (DK)	CO_2 emission and CO_2 emission intensity	Population, urbanization, GDP, industrial output, services output, energy consumption, and energy intensity
Lee (2013)	G20	1971–2009	Johansen panel cointegration and fixed-effects model	CO_2 emission	GDP, foreign direct investment, energy consumption, and clean energy consumption
Saboori and Sulaiman (2013a, b)	Malaysia	1980–2009	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP and energy consumption
Ozcan (2013)	Middle East	1990–2008	FMOLS and VECM Granger causality	CO_2 emission	GDP and energy consumption
Kohler (2013)	South Africa	1960–2009	Johansen cointegration, ARDL bound testing approach, and VECM Granger causality	CO_2 emission	GDP, energy consumption, and trade openness

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Shafiei and Salim (2014)	OECD countries	1980–2011	STIRPAT model	CO_2 emission	GDP, population, renewable energy consumption, non-renewable energy consumption, urbanization, industrial, and services output
Cowan et al. (2014)	BRICS countries	1990–2010	Boots trap panel causality	CO_2 emission	GDP and electricity consumption
Azlina et al. (2014)	Malaysia	1975–2011	Johansen cointegration and VECM Granger causality	CO_2 emission	GDP
Al-Mulali et al. (2015)	Vietnam	1981–2011	ARDL bound test approach	CO_2 emission	GDP, capital, labor, imports, exports, renewable energy consumption, and fossil fuels energy consumption
Lean and Smyth (2010)	ASEAN	1980–2006	Johansen Fisher cointegration, DOLS and VECM Granger causality	CO_2 emission	GDP and electricity consumption
Hatzigeorgiou et al. (2011)	Greece	1977–2007	Johansen cointegration, VECM Granger causality	CO_2 emission	GDP and energy intensity
Govindaraju and Tang (2013)	China and India	1965–2009	Bayer and Hanck combine cointegration, VAR and VECM Granger causality	CO_2 emission	GDP and coal energy consumption
Pao and Tsai (Pao and Tsai 2011a, b)	BRIC	1980–2007	Pedroni, Kao, and Johansen Fisher cointegration, VECM Granger causality	CO_2 emission	GDP, energy consumption, and foreign direct investment
Pao and Tsai (Pao and Tsai 2011a, b)	Brazil	1980–2007	Johansen cointegration and VECM Granger causality	CO_2 emission	GDP and energy consumption
Pao et al. (2011)	Russia	1990–2007	Johansen cointegration and VECM Granger causality	CO_2 emission	GDP and energy consumption
Al-mulali (2011)	MENA	1980–2009	Pedroni, Kao, and Johansen Fisher cointegration, VECM Granger causality	CO_2 emission	GDP and oil consumption

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Al-mulali and Che Sab (2012a)	Sub Saharan African countries	1980–2008	Pedroni cointegration, and VECM Granger causality	CO_2 emission	GDP, energy consumption, and financial development
Al-mulali (2012)	Middle East	1990–2009	Pedroni cointegration, FMOLS, and VECM Granger causality	CO_2 emission	GDP, energy consumption, foreign direct investment, and trade openness
Saboori and Sulaiman (2013a, b)	ASEAN	1971–2009	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP and energy consumption
Bolük and Mert (2014)	European Union	1990–2008	Panel OLS and fixed-effects models	CO_2 emission	GDP, fossil fuels, and renewable energy consumption
Kivyiro and Arminen (2014)	Sub-Saharan Africa	1971–2009	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, and foreign direct investment
Tang and Tan (2015)	Vietnam	1976–2009	Johansen cointegration and the VECM Granger causality	CO_2 emission	GDP, energy consumption, and foreign direct investment
Soytas et al. (2007)	United States	1960–2004	TY Granger causality	CO_2 emission	GDP, capital, labor, and energy consumption
Zeb et al. (2014)	South Asian countries	1975–2010	Johansen cointegration, Pedroni cointegration, FMOLS and VECM Granger causality	CO_2 emission	GDP, energy consumption, natural resource depletion, and poverty
Ozturk and Acaravci (2010)	Turkey	1968–2005	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, and employment
Al-mulali and Che Sab (2012b)	19 highly financially developed countries	1980–2008	Pedroni cointegration and VECM Granger causality	CO_2 emission	GDP, financial development, and energy consumption
Shahbaz et al. (2013b)	Indonesia	1975–2011	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, energy consumption, financial development, and trade openness

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Sebri and Ben-Salha (2014)	BRIC	1971–2010	ARDL bound test approach and VECM Granger causality	CO_2 emission	GDP, renewable energy consumption, and trade openness
Farhani and Shahbaz (2014)	MENA	1980–2009	Pedroni and Kao cointegration, DOLS, FMOLS, and VECM Granger causality	CO_2 emission	GDP, renewable and non-renewable electricity consumption
Begum et al. (2015)	Malaysia	1970–2009	ARDL bound test approach, DOLS, and FMOLS	CO_2 emission	GDP, energy consumption, and population
Alshehry and Belloumi (2015)	Saudi Arabia	1971–2010	Johansen cointegration, FMOLS and VECM Granger causality	CO_2 emission	GDP, energy consumption, oil prices
Ziaei (2015)	European, East Asian and Oceania countries	1989–2011	Panel VAR variance decomposition	CO_2 emission	GDP, energy consumption, financial development, and stock traded turnover ratio
Al-mulali (2014a, b)	Top biofuel producing countries	2000–2010	Kao panel cointegration, FMOLS, and VECM Granger causality	CO_2 emission	GDP, biofuel production and consumption, agriculture production, consumption, and prices
Bengochea and Faet (2012)	European Union	1990–2004	Panel OLS, fixed-effects, random-effects, feasible generalized least-squares, and panel-corrected standard errors	CO_2 emission	Renewable energy consumption and fossil fuel energy prices

Table 1 continued

References	Country	Time period	Methodology	Pollution indicators	Economic indicators
Akhmat et al. (2014)	South Asian Association for Regional Cooperation (SAARC) countries	1975–2011	Johansen cointegration and VECM Granger causality	Average precipitation in millimeter (mm) per year, carbon dioxide emissions from transport in percentage of total fuel combustion, agriculture nitrous oxide emissions in percentage of total, methane emissions from livestock in thousand metric tons of CO_2 equivalent, and droughts, floods, and extreme temperature in percentage of population	Electricity consumption and GDP
Rafindadi et al. (2014)	Asia–Pacific countries	1975–2012	Panel least-square regression, panel fixed-effect regression, and panel two-stage least-square regression	CO_2 emission	Fossil fuel energy consumption, GDP per unit use of energy, water productivity, and natural resource rents
Alam et al. (2014)	Malaysia	1975–2013	Generalized method of moments (GMM)	CO_2 emission	Population density in terms, energy resources in terms of energy use in kilotons of oil equivalent and fossil fuel energy consumption; and financial development
Zhang and Da (2015)	China	1996–2010	Log mean Division index (LMDI)	CO_2 emission	Coal, natural gas, and oil consumption, industrial output, and GDP
Zhang et al. (2014)	China	1978–2011	The ARDL bounds testing approach, and e Toda–Yamamoto Granger causality	CO_2 emission intensity	GDP, industrial output, and urbanization

of goods and services (TD) as an indicator of trade openness, and domestic credit to private sector (DC) as an indicator of financial development. These variables are measured in millions of constant 2005 US dollars. In addition, urban population measured in thousands of individuals was also utilized as an indicator of urbanization. This study utilizes five sources of renewable electricity production (ECP), namely combustible renewables and waste generation (ECRW), hydroelectric generation (ECH), nuclear generation (ECNU), solar generation (ECS), and wind-powered generation (ECW), which are all measured in millions of kilowatt hours. Lastly, carbon dioxide emission (CO_2) was used as indicator of pollution measured in thousands of CO_2 metric tons. Annual data for all variables mentioned above were retrieved from the Euromonitor database (2014) for the period of 1990–2013.

The main model is presented as follows:

$$CO_2 = f(\text{GDP}, \text{ TD}, \text{ UR}, \text{ DC}, \text{ ECP}) \tag{1}$$

Since each of the variables was presented in its natural logarithm and the error term is included in the panel models, the econometric models can be presented as follows:

$$LCO_{2it} = \beta_{i0} + \beta_{1i}LGDP_{it} + \beta_{2i}LTD_{it} + \beta_{3i}LUR_{it} + \beta_{4i}DC_{it} + \beta_{5i}ECRW_{it} + \varepsilon_{it} \tag{2}$$

$$LCO_{2it} = \beta_{i0} + \beta_{1i}LGDP_{it} + \beta_{2i}LTD_{it} + \beta_{3i}LUR_{it} + \beta_{4i}DC_{it} + \beta_{5i}ECH_{it} + \varepsilon_{it} \tag{3}$$

$$LCO_{2it} = \beta_{i0} + \beta_{1i}LGDP_{it} + \beta_{2i}LTD_{it} + \beta_{3i}LUR_{it} + \beta_{4i}DC_{it} + \beta_{5i}ECNU_{it} + \varepsilon_{it} \tag{4}$$

$$LCO_{2it} = \beta_{i0} + \beta_{1i}LGDP_{it} + \beta_{2i}LTD_{it} + \beta_{3i}LUR_{it} + \beta_{4i}DC_{it} + \beta_{5i}ECS_{it} + \varepsilon_{it} \tag{5}$$

$$LCO2_{it} = \beta_{i0} + \beta_{1i}LGDP_{it} + \beta_{2i}LTD_{it} + \beta_{3i}LUR_{it} + \beta_{4i}DC_{it} + \beta_{5i}ECW_{it} + \varepsilon_{it} \tag{6}$$

The symbols β_1, β_2, β_3, $\beta_{4,}$ and β_5 are the slop coefficients, t represents the time series (1990–2013), i is the cross sections (23 countries for model 1 and model 2, 13 countries for model 3, and 21 countries for model 4 and 5),[3] and ε represents the error term.

The econometric analysis begins with panel unit root test to examine the integration of each variable. For robustness, three types of panel unit root tests were utilized, namely the Im–Pesaran–Shin (IPS), proposed by Im et al. (2003), ADF-Fisher and PP-Fisher, proposed by Maddala and Wu (1999). The IPS unit root permits heterogeneity in the dynamics of the autoregressive coefficients, while the ADF-Fisher and the PP-Fisher unit root allows heterogeneity across panel units. The three above panel unit root tests work under the null hypothesis of a panel unit root (non-stationary variables) and the alternative hypothesis of no unit root (stationary variables).

After examining the panel unit root and the integration of the variables indicated to be in order one (stationary at the first difference), the next step was to examine whether a long-run relationship between the variables exists. Therefore, the panel cointegration test was implemented. This study used the Pedroni (1999, 2004) cointegration test which is based on the Engle and Granger (1987) cointegration test that explain whether the residual of each variable is stationary at level which means that the variables are cointegrated, or $I(1)$ which indicates that the variables are not cointegrated. The Pedroni cointegration procedure contains several statistical tests between and within dimension to examine whether the null hypothesis of no cointegration can be rejected. The Pedroni cointegration test works under the following regression:

[3] The number of cross sections (countries) is different between the models based on the data availability for each country.

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \cdots + \beta_{Mi} x_{Mit} + e_{i,t} \tag{7}$$

y and x are presumed to be integrated in order (1), α_i and δ_i are the individual and trend effects, while e represents the residuals. If the residuals in regression (7) were integrated in order (1), the null hypothesis of no cointegration cannot be rejected. To examine the integration of the residual, one of the following regressions is used:

$$e_{it} = \rho_i e_{it-1} + u_{it} \tag{8}$$

$$e_{it} = \rho_i e_{it-1} + \sum_{j=1}^{p_i} \psi_{ij} \Delta e_{it-j} + v_{it} \tag{9}$$

Regressions 8 and 9 can be utilized for each cross section.

If cointegration is concluded among the variables, the panel-pooled fully modified ordinary least square (FMOLS) will be implemented to analyze the long-run cointegration relationship between the dependent and the independent variables. The pooled FMOLS was proposed by Phillips and Moon (1999). This cointegrating regression is more capable of preventing spurious regression generated from the involvement of the $I(1)$ variables which can cause misleading results. The pooled FMOLS estimator is presented below:

$$\hat{\beta}_{FP} = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \tilde{X}_{it} \tilde{y}_{it} \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(\tilde{X}_{it} \tilde{y}_{it} - \hat{\lambda}^{+}_{12'} \right) \tag{10}$$

$\tilde{X}_{it}\tilde{y}_{it}$ are the corresponding data removed from the individual deterministic trends and λ represents the cointegration regressors. It is fundamental to note that the pooled FMOLS estimator sums across cross sections separately in the numerator and denominator.

If cointegration is confirmed among the variables, there might be a causal relationship between the variables, at least in one direction. Therefore, the Granger causality was utilized. If cointegration exists, then the Granger causality based on vector error correction model (VECM) will be used. The VECM Granger causality can capture the short-run causality based on the F-statistic and the long-run causality based on the lagged error correction term. The VECM Granger causality is presented below:

$$\begin{bmatrix} \Delta LCO_{2it} \\ \Delta LGDP_{it} \\ \Delta LTD_{it} \\ \Delta LUR_{it} \\ \Delta LDC_{it} \\ \Delta LECP_{it} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{p=-1}^{r} \begin{bmatrix} \beta_{11,p} & \beta_{12,p} & \beta_{13,p} & \beta_{14,p} & \beta_{15,p} & \beta_{16,p} \\ \beta_{21,p} & \beta_{22,p} & \beta_{23,p} & \beta_{24,p} & \beta_{25,p} & \beta_{26,p} \\ \beta_{31,p} & \beta_{32,p} & \beta_{33,p} & \beta_{34,p} & \beta_{35,p} & \beta_{36,p} \\ \beta_{41,p} & \beta_{42,p} & \beta_{43,p} & \beta_{44,p} & \beta_{45,p} & \beta_{46,p} \\ \beta_{51,p} & \beta_{52,p} & \beta_{53,p} & \beta_{54,p} & \beta_{55,p} & \beta_{56,p} \\ \beta_{61,p} & \beta_{62,p} & \beta_{63,p} & \beta_{64,p} & \beta_{65,p} & \beta_{66,p} \end{bmatrix} \begin{bmatrix} \Delta LCO2_{it-p} \\ \Delta LGDP_{it-p} \\ \Delta LTD_{it-p} \\ \Delta LUR_{it-p} \\ \Delta LDC_{it-p} \\ \Delta LECP_{it-p} \end{bmatrix}$$
$$+ \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \\ \varphi_6 \end{bmatrix} ect_{it-1} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \\ \varepsilon_{6it} \end{bmatrix} \tag{11}$$

However, if the variables are not cointegrated, the Granger causality based on vector autoregressive (VAR) model will be used. The VAR Granger causality can only show the long-run causality among the variables. The VAR Granger causality model is presented below:

$$\begin{bmatrix} \Delta LCO_{2it} \\ \Delta LGDP_{it} \\ \Delta LTD_{it} \\ \Delta LUR_{it} \\ \Delta LDC_{it} \\ \Delta LECP_{it} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{p=-1}^{r} \begin{bmatrix} \beta_{11,p} & \beta_{12,p} & \beta_{13,p} & \beta_{14,p} & \beta_{15,p} & \beta_{16,p} \\ \beta_{21,p} & \beta_{22,p} & \beta_{23,p} & \beta_{24,p} & \beta_{25,p} & \beta_{26,p} \\ \beta_{31,p} & \beta_{32,p} & \beta_{33,p} & \beta_{34,p} & \beta_{35,p} & \beta_{36,p} \\ \beta_{41,p} & \beta_{42,p} & \beta_{43,p} & \beta_{44,p} & \beta_{45,p} & \beta_{46,p} \\ \beta_{51,p} & \beta_{52,p} & \beta_{53,p} & \beta_{54,p} & \beta_{55,p} & \beta_{56,p} \\ \beta_{61,p} & \beta_{62,p} & \beta_{63,p} & \beta_{64,p} & \beta_{65,p} & \beta_{66,p} \end{bmatrix} \begin{bmatrix} \Delta LCO2_{it-p} \\ \Delta LGDP_{it-p} \\ \Delta LTD_{it-p} \\ \Delta LUR_{it-p} \\ \Delta LDC_{it-p} \\ \Delta LECP_{it-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \\ \varepsilon_{6it} \end{bmatrix} \quad (12)$$

The i represents the cross section (number of countries), t denotes the time, ε_{it} is the error term, and *ect* is the lagged error correction term.

3 Empirical results

As mentioned earlier, the first step in the econometric analysis is to examine the stationarity of the variables. The three panel unit root tests, namely Im–Pesaran–Shin (IPS), ADF-Fisher Chi-square and the PP-Fisher Chi-square were conducted. The panel unit root tests results are displayed in Table 2. The results indicate that the null hypothesis of a panel unit root at level is not rejected by any variable. This shows that the variables are not stationary at level. However, the null hypothesis of the panel unit root is rejected at the first difference because all the variables are significant at the first difference.

Since the variables are stationary at the first difference, the second step is to examine the long-run relationship between the variables for the four models of this study (Eqs. 2–6). Therefore, the Pedroni cointegration test was conducted, and its results are reviewed in Table 3. The results reveal that four statistics are significant which, consequently, reject the null hypothesis of no cointegration for all the five models. Therefore, the long-run relationship between LCO_2, *LGDP*, *LTD*, *LUR*, *LDC*, and *LECP* is confirmed. This results was consistent with the outcome of a number of previous studies that also found a long-relationship between CO_2 emission and its main determinants (Menyah and Wolde-Rufael 2010a, b; Hossain 2011; Chandran and Tang 2013; Shahbaz et al. 2013a, b; Saboori and Sulaiman 2013a, b; Apergis and Payne 2009, 2010, 2014; Baek and Pride 2014; Bella et al. 2014; Al-mulali 2014a, b; Boutabba 2014; Sebri and Ben-Salha 2014 and so forth).

After cointegration is confirmed among the variables in all models, the panel-pooled FMOLS was utilized to examine the positive as well as the negative long-run relationship between the independent and dependent variables. The panel FMOLS results are shown in Table 4.

Table 2 Panel unit root tests results

Variables	Level		First difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
Panel I: Im–Pesaran–Shin (IPS)				
LCO_2	0.79181	4.40971	−8.40076***	−7.90625***
LGDP	−0.00265	4.01709	−6.99317***	−6.49179***
LTD	1.65599	0.59158	−8.29920***	−7.35624***
LUR	6.24683	2.25328	−1.79993**	−0.76026
LDC	−1.13684	−0.89577	−16.5011***	−13.5334***
LECRW	3.38338	1.26591	−8.45120***	−6.91237***
LECH	−0.06139	−0.08628	−23.7944***	−21.0090***
LECNU	−0.71447	2.05769	−4.24885***	−3.18271***
LECW	−0.32888	1.10539	−10.8387***	−9.56960***
LECS	4.44093	1.98921	−1.46610**	−2.96035***
Panel II: ADF-Fisher Chi square				
LCO_2	36.2222	20.0914	161.405***	146.280***
LGDP	39.4447	23.1815	135.831***	122.110***
LTD	27.5676	32.0452	150.664***	125.563***
LUR	27.7367	32.6478	62.6572*	61.0796*
LDC	35.9264	29.9241	305.907***	235.279***
LECRW	28.7906	32.0709	155.114***	126.553***
LECH	49.8182	49.6273	454.214***	363.019***
LECNU	28.4024	13.5959	59.0546***	45.9131***
LECW	35.2591	23.5142	220.341***	253.194***
LECS	18.9731	20.5740	45.3864*	109.678***
Panel III: PP-Fisher Chi square				
LCO_2	47.2689	32.2246	354.752***	667.831***
LGDP	40.1446	40.1446	206.329***	202.809***
LTD	18.0446	55.7551	305.476***	356.236***
LUR	69.5253	38.4878	65.4979**	45.7286
LDC	49.7650	26.3471	350.386***	662.109***
LECRW	48.7740	46.2189	317.727***	440.699***
LECH	58.7992	23.8430	1036.00***	1292.27***
LECNU	34.9944	32.3857	256.313***	498.915***
LECW	50.9524	46.0899	273.154***	652.730***
LECS	15.2046	27.1305	120.491***	120.315***

The unit root tests were done with individual trends and intercept for each variable lag length were selected automatically using the Schwarz Information Criteria (SIC)

*** Statistical significance at the 1 %

** Statistical significance at the 5 % levels

* Statistical significance at the 10 % levels

The FMOLS results reveal that, in all the models, GDP growth, urbanization, and financial development increase CO_2 emission in the long run, while trade openness reduces CO_2 emission. The increase in GDP growth by 1 % will increase CO_2 emission by 0.41,

Table 3 The results of Pedroni's cointegration tests

Tests	Statistics	*p* values
Model 1		
Panel *v*-statistic	−1.571148	0.9419
Panel *ρ*-statistic	2.208587	0.9864
Panel PP-statistic	−4.419279***	0.0000
Panel ADF-statistic	−4.442735***	0.0000
Group *ρ*-statistic	3.813159	0.9999
Group PP-statistic	−9.547532***	0.0000
Group ADF-statistic	−8.335435***	0.0000
Model 2		
Panel *v*-statistic	−2.296763	0.9892
Panel *ρ*-statistic	3.457203	0.9997
Panel PP-statistic	−2.340121***	0.0096
Panel ADF-statistic	−1.868165**	0.0309
Group *ρ*-statistic	4.177226	1.0000
Group PP-statistic	−10.71042***	0.0000
Group ADF-statistic	−6.523802***	0.0000
Model 3		
Panel *v*-statistic	−0.759093	0.7761
Panel *ρ*-statistic	2.949713	0.9984
Panel PP-statistic	−2.698914***	0.0035
Panel ADF-statistic	−3.446775***	0.0003
Group *ρ*-statistic	3.662856	0.9999
Group PP-statistic	−8.648986***	0.0000
Group ADF-statistic	−6.706798***	0.0000
Model 4		
Panel *v*-statistic	−2.406166	0.9919
Panel *ρ*-statistic	3.667399	0.9999
Panel PP-statistic	−3.035835***	0.0012
Panel ADF-statistic	−3.407824***	0.0003
Group *ρ*-statistic	5.059020	1.0000
Group PP-statistic	−11.65165***	0.0000
Group ADF-statistic	−6.533774***	0.0000
Model 5		
Panel *v*-statistic	−3.532239	0.9998
Panel *ρ*-statistic	2.164669	0.9848
Panel PP-statistic	−7.744663***	0.0000
Panel ADF-statistic	−4.710836***	0.0000
Group *ρ*-statistic	3.257256	0.9994
Group PP-statistic	−12.47039***	0.0000
Group ADF-statistic	−5.692765***	0.0000

Lag length and bandwidth are selected by Schwarz Information Criterion (SIC) and the Bartlett kernel Newey–West estimator

*** Significance at the 1 % level

* Significance at 10 % level

0.66, 0.027, 0.46, and 0.97 % respectively. Moreover, the increase in urbanization by 1 % will increase CO_2 emission by 0.39, 0.54, 0.49, 0.27, and 0.26 % respectively. This outcome was consistent a number of previous studies (Halicioglu 2009; Apergis and Payne

Table 4 The results of panel FMOLS

Model	Dependent variable: LCO_2				
	LGDP	*LTD*	*LUR*	*LDC*	*LECP*
Model 1	0.404528*** (3.232376)	−0.190301*** (−2.939147)	0.392976*** (2.852991)	0.051642*** (3.866030)	−0.053057*** (−4.319366)
Model 2	0.656340*** (2.744371)	−0.289171** (−2.581151)	0.535232* (1.824553)	0.050931** (2.119768)	−0.156200*** (−4.793120)
Model 3	0.026960*** (5.218951)	−0.203548*** (−3.130848)	0.492361** (3.086228)	0.086684*** (5.723587)	−0.062585* (−1.849252)
Model 4	0.460733*** (3.192292)	−0.336289*** (−4.145210)	0.271785** (2.559850)	0.103015*** (6.819789)	−0.005233 (−0.839702)
Model 5	0.970917*** (4.138921)	−0.492887*** (−4.678572)	0.261144*** (2.989825)	0.096536*** (5.115281)	−0.003085 (−0.556077)

LECP denotes the electricity production by type

Figures in the parenthesis () are the *t* statistics

***, ** and * denote significance at the 1, 5 and 10 % levels, respectively

2009; Ozturk and Acaravci 2010; Lean and Smyth 2010; Hossain 2011; Chandran and Tang 2013; Shahbaz et al. 2013a, b; Baek and Pride 2014; Bella et al. 2014; Al-mulali 2014a, b; Farhani, et al. 2014; Boutabba 2014; Kasman, and Duman 2015 and so forth). Furthermore, financial development increases pollution by its positive effect on CO_2 emission in the long run. The increase in financial development by 1 % will increase CO_2 emission by 0.05, 0.05, 0.09, 0.10, and 0.10 %, respectively, for each model. These results were similar to Boutabba (2014), while the results were not comparable to what was found by Shahbaz et al. (2013a, b). However, trade openness reduces pollution as it has a negative long-run effect on CO_2 emission. A 1 % increase in trade openness will reduce CO_2 emission in model 1, 2, 3, 4, and 5 by 0.20, 0.31, 0.20, 0.34, and 0.5 %, respectively. These results were similar to what was found by Shahbaz et al. (2013a, b), Farhani et al. (2014), and Kohler (2013). However, other scholars found a positive relationship between the two variables such as Halicioglu (2009), Al-mulali (2012), Al-mulali and Sheau-Ting (2014), and Kasman and Duman (2015).

The results for the long-run relationship between renewable electricity production by source and CO_2 emission differs across the models. For model 1, the results show that electricity production from combustible renewables and waste generation has a significant negative long-run effect on CO_2 emission. A 1 % increase in this source of electricity will reduce CO_2 emission by 0.1 %. Similarly, electricity production from hydroelectric generation has a significant negative effect on CO_2 emission as its increase by 1 % will reduce CO_2 emission by 0.2 %. However, the increase in electricity production from nuclear generation, solar generation, and wind-powered generation has a negative relationship, but an insignificant effect on CO_2 emission. A number of studies have also reached to the same results (Baek and Pride 2014; Shafiei and Salim 2014 Zeb et al. 2014), but other studies found that the relationship between the two variables was positive or insignificant (Al-mulali 2014a, b; Bolük and Mert 2014; Farhani and Shahbaz 2014; Al-mulali et al. 2015).

Since the variables are cointegrated for all models, the Granger causality based on the VECM was utilized. The results are presented in Table 5. The results for model 1 reveal the existence of long-run causality between CO_2 emission, GDP growth, financial development, and electricity production from combustible renewables and waste generation.

Table 5 VECM Granger causality results

	LCO_2	$LGDP$	LTD	LUR	LDC	$LECRW$	$Ect(-1)$
Model 1							
LCO_2	–	11.10909***	−0.523060	3.066087**	2.300727**	−2.502502**	−1.850954*
$LGDP$	11.48597***	–	57.84043***	1.900824	14.51103***	2.041457*	−2.367974**
LTD	1.412228	55.39161***	–	0.542021	13.15712***	0.252739	−1.189654
LUR	2.356796*	3.651353***	0.134190	–	2.814259*	0.785798	0.207794
LDC	4.179101***	8.014825***	2.125479*	1.392261	–	0.571705	−3.789076***
$LECRW$	0.662192	3.023469**	2.164436*	3.111956**	0.133654	–	−3.577448***
	LCO_2	$LGDP$	LTD	LUR	LDC	$LECH$	$Ect(-1)$
Model 2							
LCO_2	–	11.27688***	−1.950360*	0.416815	2.433212**	−8.551105***	−2.273034**
$LGDP$	9.478022***	–	58.51541***	2.326123***	16.38343***	1.876960	−3.174758***
LTD	2.582674**	55.21096***	–	1.091206	7.277269***	4.512371***	−1.759292*
LUR	2.060501*	2.248919**	0.209253	–	1.742018	0.788485	−0.130975
LDC	1.965369*	7.956725***	1.165064	1.416411	–	0.921828	−4.025219***
$LECH$	5.804642***	1.976392*	1.951379*	0.216311	0.803043	–	−1.694944*
	LCO_2	$LGDP$	LTD	LUR	LDC	$LECNU$	$Ect(-1)$
Model 3							
LCO_2	–	4.811579***	−1.526327	1.004046	0.808043	-3.245270***	−2.165594**
$LGDP$	4.592270***	–	28.67777***	0.618927	14.48834***	0.830301	−1.798986*
LTD	1.411657	22.14392***	–	1.536233	4.526179***	0.293974	−0.576797
LUR	1.194844	0.914701	0.339520	–	1.307863	0.299194	0.641584
LDC	2.607280**	2.154291**	0.360890	1.166174	–	0.680696	−3.238883***
$LECNU$	1.098304	2.544268**	0.185802	0.576448	0.241519	–	0.065812

Table 5 continued

	LCO_2	$LGDP$	LTD	LUR	LDC	$LECW$	$Ect(-1)$
Model 4							
LCO_2	–	6.019488***	−1.215376	1.216788	1.396579	−0.819403	0.737216
$LGDP$	2.355035**	–	2.106032*	0.297807	3.485198***	0.548568	−1.253429
LTD	6.639118***	9.307023***	–	0.858681	45.12150***	0.458014	−2.128835**
LUR	1.390987	6.301451***	0.341467	–	2.987218***	1.243618	−2.682670***
LDC	0.912112	42.63672***	13.70712***	0.896262	–	0.881366	−0.971394
$LECW$	1.847361	1.895511*	1.169708	2.548454**	0.846934	–	−0.266729

	LCO_2	$LGDP$	LTD	LUR	LDC	$LECS$	$Ect(-1)$
Model 5							
LCO_2	–	3.159349**	−1.417305	0.807924	0.625468	−0.753591	0.737582
$LGDP$	4.860211***	–	5.559559***	0.769646	47.40982***	0.930689	−1.742826*
LTD	1.262809	31.37611***	–	0.870116	10.17913***	0.936669	−1.103620
LUR	1.284251	1.371854	0.833143	–	1.886928	2.496908**	−0.109037
LDC	2.629059**	3.317451***	1.373761	0.427842		1.409691	−3.435663***
$LECS$	0.518329	2.858219*	0.551244	3.788262***	3.535491***	–	−0.312939

The optimal lag based on the AIC. D represents the first difference. Only F statistics for the explanatory lagged variables in first differences are reported here. The $ect(-1)$ is based on the t statistic and a, b and c denotes significance at the 1, 5 and 10 % level

The short-run causality shows a bidirectional causal relationship between CO_2 emission and GDP growth, CO_2 emission and urbanization, CO_2 emission and financial development, GDP growth and trade openness, GDP growth and financial development, electricity production from combustible renewables and waste generation and GDP growth, trade openness and electricity production from combustible renewables and waste generation, and trade openness and financial development. Moreover, a unidirectional causality was also found from GDP growth to urbanization, from electricity production from combustible renewables and waste generation to CO_2 emission, trade openness to electricity production from combustible renewables and waste generation, financial development to urbanization, and from urbanization to electricity production from combustible renewables and waste generation.

For model 2, the Granger causality outcome reveals a long-run causal relationship between CO_2 emission, GDP growth, trade openness, financial development, and electricity production from hydroelectric generation. The short-run causality reveals the presence of a bidirectional causality between CO_2 emission and GDP growth, CO_2 emission and trade openness, CO_2 emission and financial development, CO_2 emission and electricity production from hydroelectric generation, GDP growth and trade openness, GDP growth and urbanization, GDP growth and financial development, and trade openness and electricity production from hydroelectric generation. However, one-way causality was found from CO_2 emission to urbanization, from GDP growth to electricity production from hydroelectric generation, and from financial development to trade openness.

The Granger causality for model 3 reveals the existence of long-run causality between CO_2 emission, financial development, and GDP growth. The short-run causality results show a bidirectional causality between CO_2 emission and financial development, GDP growth and trade openness, and between GDP growth and financial development. On the other hand, a one-way causality was concluded from GDP growth to electricity production from nuclear generation, from electricity production from nuclear generation to CO_2 emission, CO_2 emission to financial development, and from financial development to trade openness.

The Granger causality outcome for model 4 shows a long-run bidirectional causality between trade openness and urbanization. The short-run causality reveals a bidirectional causality between CO_2 emission and GDP growth, GDP growth and trade openness, and GDP growth and financial development. One-way causality was also confirmed from CO_2 emission to trade openness, GDP growth to urbanization, GDP growth to electricity production from wind generation, trade openness to electricity production from wind generation, financial development to urbanization, and from urbanization to electricity production from wind generation.

The granger causality results in model 5 shows bidirectional long-run causality between GDP growth and financial development. The results for the short-run causality reveals a bidirectional causality between CO_2 emission and GDP growth, GDP growth and trade openness, GDP growth and financial development, and urbanization and electricity production from solar generation. Moreover, one-way causality was found from CO_2 emission to financial development, from GDP growth to electricity production from solar generation, and from financial development to trade openness.

The causal relationship between renewable energy consumption and CO_2 emission was also confirmed by scholars such as Menyah and Wolde-Rufael (2010a, b), Apergis and Payne (2014), Al-mulali (2014a, b), Shafiei and Salim (2014), and Farhani and Shahbaz (2014).

4 Discussion of results

The results from FMOLS show clearly that GDP growth, urbanization, and financial development are the main contributors to CO_2 emission in the European countries. Increase in economic activities, which include consumption, investment, government purchases (the main components of GDP), increases the demand for energy, and thus an increase in electricity consumption. A share of electricity consumption comes from fossil fuels (fossil fuels represent 20 % of total electricity generation in Europe) which are the main sources of greenhouse gases. With better job opportunities, urban population in the European countries is substantially increasing to the point that in 2013 urban population represented over 50 % of total population. This percentage is expected to increase in the future. The increasing density of urban population will cause the deterioration of air quality due to, for instance, the increase in electricity consumption, automobiles, and the loss of tree cover as a result of urban development.

Furthermore, the domestic credit to the private sector increases CO_2 emission in the long run. This phenomenon indicates that the financial resources that were provided for the private sectors are invested in non-environmental friendly projects. The trade openness reduces pollution in the long run in these countries, which indicates that the trade-related actions and strategies to increase environmental protection in these countries reached a point where it can reduce the environmental pollution induced by trade in general. Moreover, from the results, it seems that trade openness is stimulating the non-polluted industries which may explain the negative relationship between trade openness and CO_2 emission. Furthermore, the results for renewable energy by source were diverse because, despite that all of these renewable sources have a negative effect on pollution, only three types of renewable energy sources were significant in reducing CO_2 emission. Electricity production generated by combustible renewables and waste generation, hydroelectric generation, and nuclear generation was the only renewable energy source that reduces CO_2 emission significantly. This outcome can be clarified by indicating that the share of these three sources of renewable energy plays a significant portion of total electricity production that 55 % of total electricity produced in 2013 comes from renewable electricity production (Euromonitor 2014). For this reason, electricity production that is generated by solar and wind energy has an insignificant effect on CO_2 emission because the share of these sources in the total electricity production is small.

From the Granger causality results (focusing on the short-run causality), it was concluded that electricity production generated by combustible renewables and waste generation, hydroelectric generation, and nuclear generation was the only renewable energy source that has a negative causal relationship with CO_2 emission. However, electricity production from wind and solar generation has no causal effects on CO_2 emission. Moreover, GDP growth has a positive causal effect on CO_2 emission in all models. This indicates that GDP growth is resulting in increasing CO_2 emission in the short run. In spite of the outcome that urbanization and financial development have a positive causal effect on CO_2 emission, this phenomenon was only confirmed in few cases. Furthermore, trade openness has a negative causality with CO_2 emission in all the models except in model 2 where it was significant. Therefore, in most cases, urbanization, financial development, and trade openness have no significant causal effect in influencing CO_2 emission in the short run. Regarding renewable electricity generation based on source, it is confirmed that GDP growth has a positive causal effect in influencing all renewable electricity sources in the short run.

5 Conclusion and policy implications

There is a lack of studies that investigated the effect of renewable energy by source on pollution in the Europe despite that over 55 % of its electricity is generated from renewable sources. Therefore, the researchers of this study were encouraged to examine the influence of electricity production from renewable generation on CO_2 emission in 23 selected European countries. To achieve the study objectives, this research utilized the panel data techniques taking the period of 1990–2013. The outcome from the Pedroni cointegration indicated the existence of a long-run relationship between CO_2 emission, GDP growth, urbanization, trade openness, financial development, and renewable electricity from all sources. In addition, the FMOLS results revealed that GDP growth, urbanization, and financial development are the main factors that influence CO_2 emission positively while trade openness reduces CO_2 emission in the long run. However, electricity production from combustible renewables and waste generation, hydroelectric generation, and nuclear generation was the only renewable source that influences CO_2 emission significantly in the long run, while electricity production from wind and solar generation was insignificant.

Moreover, the VECM Granger causality showed that GDP growth is the most significant determinant that has positive causal effect on CO_2 emission while urbanization and financial development have a positive causality on CO_2 emission, but only in few of the investigated models. Moreover, trade openness has a significant negative causality on CO_2 emission, but it was only verified in model 2. Furthermore, it was found that GDP is the main determinant that has a significant positive causal effect on all renewable electricity production, while trade openness and urbanization have a positive causal influences on renewable electricity production, but in only few models.

From the outcome of this study, a number of policy recommendations can be provided for the investigated countries. Since GDP, urbanization, and financial development increase CO_2 emission, it is important to increase projects and investments that promote the role of renewable energy by providing incentives to the renewable manufactories and promoting new research in renewable energy technologies. This can increase the role of renewable energy which, as a result, will not only aid in creating more jobs in construction and manufacturing but will also help the renewable energy technologies to achieve economies of scale to reduce the cost of these sources of energy. Moreover, these countries should also increase their consumption of cleaner sources of fossil fuels, such as natural gas and higher-grade coal. In addition, encouraging the private sector to invest in more environmentally friendly projects and investments as well as increasing regulations that control the activities of the private sector can prevent the pollution caused by the credits or the financial resources that the banks provide to the private sector. Also, it is essential to utilize trade openness to stimulate non-polluted industries by inducing tax on polluted industries and establishing incentives on non-polluted industries to encourage producers to shift toward cleaner and more environmentally friendly industries. All these policies can help the countries to increase their energy efficiency in general which, consequently, reduces their environmental degradation that is caused by higher economic activities.

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