

# 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission in all the investigated models, while the rest of the variables have causal effects on CO<sub>2</sub> 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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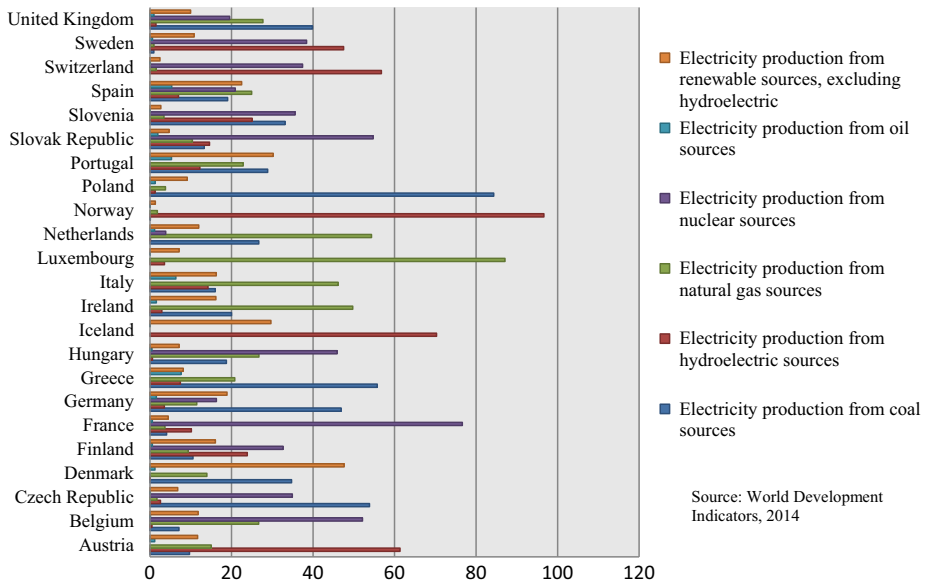
## 1 Introduction

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<sup>1</sup> 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<sub>2</sub> 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;

<sup>1</sup> 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<sup>2</sup> 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

<sup>2</sup> 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 <sub>2</sub> 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 Johansen cointegration  | CO <sub>2</sub> emission | Nuclear electricity production and GDP                                  |
| Bella et al. (2014)                | OECD countries                    | 1965–2006   | Panel VECM  | CO <sub>2</sub> emission | GDP and electricity consumption   |
| Hossain (2011)                     | Newly industrialized countries    | 1971–2007   | Johansen panel cointegration and VECM Granger causality   | CO <sub>2</sub> emission | GDP, energy consumption, and trade openness, urbanization               |
| Zhang and Cheng (2009)             | China                             | 1960–2007   | Toda–Yamamoto Granger causality   | CO <sub>2</sub> emission | GDP, energy consumption, urbanization, capital, and population          |
| Chandran and Tang (2013)           | ASEAN                             | 1971–2008   | Johansen cointegration and VECM Granger causality   | CO <sub>2</sub> emission | GDP, foreign direct investment, and energy consumption                  |
| Al-mulali and Sheau-Ting (2014)    | Seven regions                     | 1990–2011   | Panel FMOLS   | CO <sub>2</sub> emission | Energy consumption, trade openness, exports and imports                 |
| Sadorsky (2009)                    | G7                                | 1980–2004   | Pedroni cointegration, FMOLS, dynamic OLS (DOLS)  | CO <sub>2</sub> 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 <sub>2</sub> emission | Energy consumption, labor, capital, and GDP                             |
| Bloch et al. (2012)                | China                             | 1977–2008   | Johansen cointegration, variance decomposition and VECM Granger causality   | CO <sub>2</sub> emission | Energy consumption, labor, capital, and GDP                             |
| Omri (2013)                        | MENA countries                    | 1990–2011   | GMM model   | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission | GDP, nuclear energy consumption, fossil fuel energy consumption, urbanization, and investment |
| Jafari et al. (2012)     | Indonesia                                   | 1971–2007   | TY Granger causality  | CO <sub>2</sub> emission | GDP, capital, energy consumption, and urbanization  |
| Shahbaz et al. (2013a)   | Malaysia                                    | 1971–2011   | ARDL bound test approach and VECM Granger causality             | CO <sub>2</sub> 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 <sub>2</sub> emission | GDP, energy consumption, and trade openness   |
| Yang and Zhao (2014)     | India                                       | 1970–2008   | DAG contemporaneous causality tests                             | CO <sub>2</sub> emission | GDP, capital, energy consumption, and trade openness  |
| Boutabba (2014)          | India                                       | 1971–2008   | ARDL bound test approach and VECM Granger causality             | CO <sub>2</sub> 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 <sub>2</sub> emission | GDP, energy consumption, trade openness, and urbanization                                     |
| Halicioğlu (2009)        | Turkey                                      | 1960–2005   | ARDL bound test approach and VECM Granger causality             | CO <sub>2</sub> emission | GDP, energy consumption, and trade openness   |
| Apergis and Payne (2009) | Central America                             | 1971–2004   | Pedroni, FMOLS and VECM Granger causality                       | CO <sub>2</sub> emission | GDP and energy consumption  |
| Apergis and Payne (2010) | Commonwealth of independent states          | 1992–2009   | Pedroni, FMOLS and VECM Granger causality                       | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission  | GDP and energy consumption  |
| Wang et al. (2011)                 | China                    | 1995–2007   | Pedroni cointegration and VECM Granger causality   | CO <sub>2</sub> emission  | GDP and energy consumption  |
| Jayanthakumaran et al. (2012)      | China and India          | 1971–2007   | ARDL bound test approach   | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission and CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission  | GDP and energy consumption  |
| Ozcan (2013)                       | Middle East              | 1990–2008   | FMOLS and VECM Granger causality   | CO <sub>2</sub> emission  | GDP and energy consumption  |
| Kohler (2013)                      | South Africa             | 1960–2009   | Johansen cointegration, ARDL bound testing approach, and VECM Granger causality  | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission | GDP and electricity consumption  |
| Azlima et al. (2014)                 | Malaysia        | 1975–2011   | Johansen cointegration and VECM Granger causality                       | CO <sub>2</sub> emission | GDP  |
| Al-Mulali et al. (2015)              | Vietnam         | 1981–2011   | ARDL bound test approach  | CO <sub>2</sub> 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 <sub>2</sub> emission | GDP and electricity consumption  |
| Hatzigeorgiou et al. (2011)          | Greece          | 1977–2007   | Johansen cointegration, VECM Granger causality                          | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission | GDP and energy consumption   |
| Pao et al. (2011)                    | Russia          | 1990–2007   | Johansen cointegration and VECM Granger causality                       | CO <sub>2</sub> emission | GDP and energy consumption   |
| Al-mulali (2011)                     | MENA            | 1980–2009   | Pedroni, Kao, and Johansen Fisher cointegration, VECM Granger causality | CO <sub>2</sub> 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 <sub>2</sub> emission | GDP, energy consumption, and financial development                     |
| Al-mulali (2012)                | Middle East                               | 1990–2009   | Pedroni cointegration, FMOLS, and VECM Granger causality                        | CO <sub>2</sub> 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 <sub>2</sub> emission | GDP and energy consumption   |
| Bolük and Mert (2014)           | European Union                            | 1990–2008   | Panel OLS and fixed-effects models  | CO <sub>2</sub> emission | GDP, fossil fuels, and renewable energy consumption                    |
| Kiviyiro and Arminen (2014)     | Sub-Saharan Africa                        | 1971–2009   | ARDL bound test approach and VECM Granger causality                             | CO <sub>2</sub> emission | GDP, energy consumption, and foreign direct investment                 |
| Tang and Tan (2015)             | Vietnam                                   | 1976–2009   | Johansen cointegration and the VECM Granger causality                           | CO <sub>2</sub> emission | GDP, energy consumption, and foreign direct investment                 |
| Soytas et al. (2007)            | United States                             | 1960–2004   | TY Granger causality  | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission | GDP, financial development, and energy consumption                     |
| Shahbaz et al. (2013b)          | Indonesia                                 | 1975–2011   | ARDL bound test approach and VECM Granger causality                             | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> emission | GDP, renewable and non-renewable electricity consumption                                 |
| Begum et al. (2015)          | Malaysia                                   | 1970–2009   | ARDL bound test approach, DOLS, and FMOLS   | CO <sub>2</sub> emission | GDP, energy consumption, and population  |
| Alshehry and Belloumi (2015) | Saudi Arabia                               | 1971–2010   | Johansen cointegration, FMOLS and VECM Granger causality  | CO <sub>2</sub> emission | GDP, energy consumption, oil prices  |
| Ziaei (2015)                 | European, East Asian and Oceania countries | 1989–2011   | Panel VAR variance decomposition  | CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> 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<sub>2</sub>) was used as indicator of pollution measured in thousands of CO<sub>2</sub> 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:

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

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:

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

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

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

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

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

The symbols  $\beta_1, \beta_2, \beta_3, \beta_4,$  and  $\beta_5$  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),<sup>3</sup> and  $\varepsilon$  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:

<sup>3</sup> The number of cross sections (countries) is different between the models based on the data availability for each country.

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

$y$  and  $x$  are presumed to be integrated in order (1),  $\alpha_i$  and  $\delta_i$  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  $\lambda$  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:

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

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:

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

The  $i$  represents the cross section (number of countries),  $t$  denotes the time,  $\varepsilon_{it}$  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)  |           |                     |                  |                     |
| <i>LCO<sub>2</sub></i>          | 0.79181   | 4.40971             | −8.40076***      | −7.90625***         |
| <i>LGDP</i>                     | −0.00265  | 4.01709             | −6.99317***      | −6.49179***         |
| <i>LTD</i>                      | 1.65599   | 0.59158             | −8.29920***      | −7.35624***         |
| <i>LUR</i>                      | 6.24683   | 2.25328             | −1.79993**       | −0.76026            |
| <i>LDC</i>                      | −1.13684  | −0.89577            | −16.5011***      | −13.5334***         |
| <i>LECRW</i>                    | 3.38338   | 1.26591             | −8.45120***      | −6.91237***         |
| <i>LECH</i>                     | −0.06139  | −0.08628            | −23.7944***      | −21.0090***         |
| <i>LECNU</i>                    | −0.71447  | 2.05769             | −4.24885***      | −3.18271***         |
| <i>LECW</i>                     | −0.32888  | 1.10539             | −10.8387***      | −9.56960***         |
| <i>LECS</i>                     | 4.44093   | 1.98921             | −1.46610**       | −2.96035***         |
| Panel II: ADF-Fisher Chi square |           |                     |                  |                     |
| <i>LCO<sub>2</sub></i>          | 36.2222   | 20.0914             | 161.405***       | 146.280***          |
| <i>LGDP</i>                     | 39.4447   | 23.1815             | 135.831***       | 122.110***          |
| <i>LTD</i>                      | 27.5676   | 32.0452             | 150.664***       | 125.563***          |
| <i>LUR</i>                      | 27.7367   | 32.6478             | 62.6572*         | 61.0796*            |
| <i>LDC</i>                      | 35.9264   | 29.9241             | 305.907***       | 235.279***          |
| <i>LECRW</i>                    | 28.7906   | 32.0709             | 155.114***       | 126.553***          |
| <i>LECH</i>                     | 49.8182   | 49.6273             | 454.214***       | 363.019***          |
| <i>LECNU</i>                    | 28.4024   | 13.5959             | 59.0546***       | 45.9131***          |
| <i>LECW</i>                     | 35.2591   | 23.5142             | 220.341***       | 253.194***          |
| <i>LECS</i>                     | 18.9731   | 20.5740             | 45.3864*         | 109.678***          |
| Panel III: PP-Fisher Chi square |           |                     |                  |                     |
| <i>LCO<sub>2</sub></i>          | 47.2689   | 32.2246             | 354.752***       | 667.831***          |
| <i>LGDP</i>                     | 40.1446   | 40.1446             | 206.329***       | 202.809***          |
| <i>LTD</i>                      | 18.0446   | 55.7551             | 305.476***       | 356.236***          |
| <i>LUR</i>                      | 69.5253   | 38.4878             | 65.4979**        | 45.7286             |
| <i>LDC</i>                      | 49.7650   | 26.3471             | 350.386***       | 662.109***          |
| <i>LECRW</i>                    | 48.7740   | 46.2189             | 317.727***       | 440.699***          |
| <i>LECH</i>                     | 58.7992   | 23.8430             | 1036.00***       | 1292.27***          |
| <i>LECNU</i>                    | 34.9944   | 32.3857             | 256.313***       | 498.915***          |
| <i>LECW</i>                     | 50.9524   | 46.0899             | 273.154***       | 652.730***          |
| <i>LECS</i>                     | 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<sub>2</sub> emission in the long run, while trade openness reduces CO<sub>2</sub> emission. The increase in GDP growth by 1 % will increase CO<sub>2</sub> emission by 0.41,

**Table 3** The results of Pedroni’s cointegration tests

| Tests                     | Statistics   | <i>p</i> values |
|---------------------------|--------------|-----------------|
| Model 1                   |              |                 |
| Panel <i>v</i> -statistic | −1.571148    | 0.9419          |
| Panel $\rho$ -statistic   | 2.208587     | 0.9864          |
| Panel PP-statistic        | −4.419279*** | 0.0000          |
| Panel ADF-statistic       | −4.442735*** | 0.0000          |
| Group $\rho$ -statistic   | 3.813159     | 0.9999          |
| Group PP-statistic        | −9.547532*** | 0.0000          |
| Group ADF-statistic       | −8.335435*** | 0.0000          |
| Model 2                   |              |                 |
| Panel <i>v</i> -statistic | −2.296763    | 0.9892          |
| Panel $\rho$ -statistic   | 3.457203     | 0.9997          |
| Panel PP-statistic        | −2.340121*** | 0.0096          |
| Panel ADF-statistic       | −1.868165**  | 0.0309          |
| Group $\rho$ -statistic   | 4.177226     | 1.0000          |
| Group PP-statistic        | −10.71042*** | 0.0000          |
| Group ADF-statistic       | −6.523802*** | 0.0000          |
| Model 3                   |              |                 |
| Panel <i>v</i> -statistic | −0.759093    | 0.7761          |
| Panel $\rho$ -statistic   | 2.949713     | 0.9984          |
| Panel PP-statistic        | −2.698914*** | 0.0035          |
| Panel ADF-statistic       | −3.446775*** | 0.0003          |
| Group $\rho$ -statistic   | 3.662856     | 0.9999          |
| Group PP-statistic        | −8.648986*** | 0.0000          |
| Group ADF-statistic       | −6.706798*** | 0.0000          |
| Model 4                   |              |                 |
| Panel <i>v</i> -statistic | −2.406166    | 0.9919          |
| Panel $\rho$ -statistic   | 3.667399     | 0.9999          |
| Panel PP-statistic        | −3.035835*** | 0.0012          |
| Panel ADF-statistic       | −3.407824*** | 0.0003          |
| Group $\rho$ -statistic   | 5.059020     | 1.0000          |
| Group PP-statistic        | −11.65165*** | 0.0000          |
| Group ADF-statistic       | −6.533774*** | 0.0000          |
| Model 5                   |              |                 |
| Panel <i>v</i> -statistic | −3.532239    | 0.9998          |
| Panel $\rho$ -statistic   | 2.164669     | 0.9848          |
| Panel PP-statistic        | −7.744663*** | 0.0000          |
| Panel ADF-statistic       | −4.710836*** | 0.0000          |
| Group $\rho$ -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<sub>2</sub> 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: $LCO_2$ |                             |                           |                           |                             |
|---------|-----------------------------|-----------------------------|---------------------------|---------------------------|-----------------------------|
|         | <i>LGDP</i>                 | <i>LTD</i>                  | <i>LUR</i>                | <i>LDC</i>                | <i>LECP</i>                 |
| Model 1 | 0.404528***<br>(3.232376)   | -0.190301***<br>(-2.939147) | 0.392976***<br>(2.852991) | 0.051642***<br>(3.866030) | -0.053057***<br>(-4.319366) |
| Model 2 | 0.656340***<br>(2.744371)   | -0.289171**<br>(-2.581151)  | 0.535232*<br>(1.824553)   | 0.050931**<br>(2.119768)  | -0.156200***<br>(-4.793120) |
| Model 3 | 0.026960***<br>(5.218951)   | -0.203548***<br>(-3.130848) | 0.492361**<br>(3.086228)  | 0.086684***<br>(5.723587) | -0.062585*<br>(-1.849252)   |
| Model 4 | 0.460733***<br>(3.192292)   | -0.336289***<br>(-4.145210) | 0.271785**<br>(2.559850)  | 0.103015***<br>(6.819789) | -0.005233<br>(-0.839702)    |
| Model 5 | 0.970917***<br>(4.138921)   | -0.492887***<br>(-4.678572) | 0.261144***<br>(2.989825) | 0.096536***<br>(5.115281) | -0.003085<br>(-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<sub>2</sub> emission in the long run. The increase in financial development by 1 % will increase CO<sub>2</sub> 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<sub>2</sub> emission. A 1 % increase in trade openness will reduce CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission. A 1 % increase in this source of electricity will reduce CO<sub>2</sub> emission by 0.1 %. Similarly, electricity production from hydroelectric generation has a significant negative effect on CO<sub>2</sub> emission as its increase by 1 % will reduce CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission, GDP growth, financial development, and electricity production from combustible renewables and waste generation.



**Table 5** VECM Granger causality results

|                        | <i>LCO<sub>2</sub></i> | <i>LGDP</i> | <i>LTD</i>  | <i>LUR</i>  | <i>LDC</i>  | <i>LECRW</i> | <i>Ect(-1)</i> |
|------------------------|------------------------|-------------|-------------|-------------|-------------|--------------|----------------|
| <b>Model 1</b>         |                        |             |             |             |             |              |                |
| <i>LCO<sub>2</sub></i> | –                      | 11.10909*** | –0.523060   | 3.066087**  | 2.300727**  | –2.502502**  | –1.850954*     |
| <i>LGDP</i>            | 11.48597***            | –           | 57.84043*** | 1.900824    | 14.51103*** | 2.041457*    | –2.367974**    |
| <i>LTD</i>             | 1.412228               | 55.39161*** | –           | 0.542021    | 13.15712*** | 0.252739     | –1.189654      |
| <i>LUR</i>             | 2.356796*              | 3.651353*** | 0.134190    | –           | 2.814259*   | 0.785798     | 0.207794       |
| <i>LDC</i>             | 4.179101***            | 8.014825*** | 2.125479*   | 1.392261    | –           | 0.571705     | –3.789076***   |
| <i>LECRW</i>           | 0.662192               | 3.023469**  | 2.164436*   | 3.111956**  | 0.133654    | –            | –3.577448***   |
|                        | <i>LCO<sub>2</sub></i> | <i>LGDP</i> | <i>LTD</i>  | <i>LUR</i>  | <i>LDC</i>  | <i>LECH</i>  | <i>Ect(-1)</i> |
| <b>Model 2</b>         |                        |             |             |             |             |              |                |
| <i>LCO<sub>2</sub></i> | –                      | 11.27688*** | –1.950360*  | 0.416815    | 2.433212**  | –8.551105*** | –2.273034**    |
| <i>LGDP</i>            | 9.478022***            | –           | 58.51541*** | 2.326123*** | 16.38343*** | 1.876960     | –3.174758***   |
| <i>LTD</i>             | 2.582674**             | 55.21096*** | –           | 1.091206    | 7.277269*** | 4.512371***  | –1.759292*     |
| <i>LUR</i>             | 2.060501*              | 2.248919**  | 0.209253    | –           | 1.742018    | 0.788485     | –0.130975      |
| <i>LDC</i>             | 1.965369*              | 7.956725*** | 1.165064    | 1.416411    | –           | 0.921828     | –4.025219***   |
| <i>LECH</i>            | 5.804642***            | 1.976392*   | 1.951379*   | 0.216311    | 0.803043    | –            | –1.694944*     |
|                        | <i>LCO<sub>2</sub></i> | <i>LGDP</i> | <i>LTD</i>  | <i>LUR</i>  | <i>LDC</i>  | <i>LECNU</i> | <i>Ect(-1)</i> |
| <b>Model 3</b>         |                        |             |             |             |             |              |                |
| <i>LCO<sub>2</sub></i> | –                      | 4.811579*** | –1.526327   | 1.004046    | 0.808043    | –3.245270*** | –2.165594**    |
| <i>LGDP</i>            | 4.592270***            | –           | 28.67777*** | 0.618927    | 14.48834*** | 0.830301     | –1.798986*     |
| <i>LTD</i>             | 1.411657               | 22.14392*** | –           | 1.536233    | 4.526179*** | 0.293974     | –0.576797      |
| <i>LUR</i>             | 1.194844               | 0.914701    | 0.339520    | –           | 1.307863    | 0.299194     | 0.641584       |
| <i>LDC</i>             | 2.607280**             | 2.154291**  | 0.360890    | 1.166174    | –           | 0.680696     | –3.238883***   |
| <i>LECNU</i>           | 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<sub>2</sub> emission and GDP growth, CO<sub>2</sub> emission and urbanization, CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission and GDP growth, CO<sub>2</sub> emission and trade openness, CO<sub>2</sub> emission and financial development, CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission, financial development, and GDP growth. The short-run causality results show a bidirectional causality between CO<sub>2</sub> 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<sub>2</sub> emission, CO<sub>2</sub> 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<sub>2</sub> emission and GDP growth, GDP growth and trade openness, and GDP growth and financial development. One-way causality was also confirmed from CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission. Electricity production generated by combustible renewables and waste generation, hydroelectric generation, and nuclear generation was the only renewable energy source that reduces CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission. However, electricity production from wind and solar generation has no causal effects on CO<sub>2</sub> emission. Moreover, GDP growth has a positive causal effect on CO<sub>2</sub> emission in all models. This indicates that GDP growth is resulting in increasing CO<sub>2</sub> emission in the short run. In spite of the outcome that urbanization and financial development have a positive causal effect on CO<sub>2</sub> emission, this phenomenon was only confirmed in few cases. Furthermore, trade openness has a negative causality with CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission positively while trade openness reduces CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emission while urbanization and financial development have a positive causality on CO<sub>2</sub> emission, but only in few of the investigated models. Moreover, trade openness has a significant negative causality on CO<sub>2</sub> 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<sub>2</sub> 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.

## References

- Acaravci A, Ozturk I (2010) On the relationship between energy consumption, CO<sub>2</sub> emissions and economic growth in Europe. *Energy* 35(12):5412–5420

- Akhmat G, Zaman K, Shukui T, Irfan D, Khan MM (2014) Does energy consumption contribute to environmental pollutants? Evidence from SAARC countries. *Environ Sci Pollut Res* 21:5940–5951
- Alam MJ, Begum IA, Buysse J, Huylensbroeck CV (2012) Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. *Energy Policy* 45:217–225
- Alam A, Azam M, Bin Abdullah A, Malik IA, Khan A, Hamzah TAAT, Khan MM, Zahoor H, Zaman K (2014) Environmental quality indicators and financial development in Malaysia: unity in diversity. *Environ Sci Pollut Res*. doi:10.1007/s11356-014-3982-5
- Al-mulali U (2011) Oil consumption, CO<sub>2</sub> emission and economic growth in MENA countries. *Energy* 36:6165–6171
- Al-mulali U (2012) Factors affecting CO<sub>2</sub> emission in the Middle East: a panel data analysis. *Energy* 44:564–569
- Al-mulali U (2014a) Investigating the impact of nuclear energy consumption on GDP growth and CO<sub>2</sub> emission: a panel data analysis. *Prog Nucl Energy* 73:172–178
- Al-mulali U (2014b) The impact of biofuel energy consumption on GDP Growth, CO<sub>2</sub> emission, agricultural crop prices, and agricultural production. *Int J Green Energy*. doi:10.1080/15435075.2014.892878
- Al-mulali U, Che Sab CNB (2012a) The impact of energy consumption and CO<sub>2</sub> emission on the economic growth and financial development in the Sub Saharan African countries. *Energy* 39:180–186
- Al-mulali U, Che Sab CNB (2012b) The impact of energy consumption and CO<sub>2</sub> emission on the economic and financial development in 19 selected countries. *Renew Sustain Energy Rev* 16:4365–4369
- 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 Region. *Energy* 84:382–389
- Al-mulali U, Sheau-Ting L (2014) Econometric analysis of trade, exports, imports, energy consumption and CO<sub>2</sub> emission in six regions. *Renew Sustain Energy Rev* 33:484–498
- Al-Mulali U, Saboori B, Ozturk I (2015) Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy* 76:123–131
- Alshehry AS, Belloumi M (2015) Energy consumption, carbon dioxide emissions and economic growth: the case of Saudi Arabia. *Renew Sustain Energy Rev* 41:237–247
- Apergis N, Payne JE (2009) CO<sub>2</sub> emissions, energy usage, and output in Central America. *Energy Policy* 37:3282–3286
- Apergis N, Payne JE (2010) The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states. *Energy Policy* 38:650–655
- Apergis N, Payne JE (2014) Renewable energy, output, CO<sub>2</sub> emissions, and fossil fuel prices in Central America: evidence from a nonlinear panel smooth transition vector error correction model. *Energy Econ* 42:226–232
- Azlina AA, Law SH, Mustapha NHN (2014) Dynamic linkages among transport energy consumption, income and CO<sub>2</sub> emission in Malaysia. *Energy Policy* 73:598–606
- Baek J, Pride J (2014) On the income–nuclear energy–CO<sub>2</sub> emissions nexus revisited. *Energy Econ* 43:6–10
- Begum RA, Sohag K, Syed Abdullah SM, Jaafar M (2015) CO<sub>2</sub> emissions, energy consumption, economic and population Growth in Malaysia. *Renew Sustain Energy Rev* 41:594–601
- Bella G, Massidda C, Mattana P (2014) The relationship among CO<sub>2</sub> emissions, electricity power consumption and GDP in OECD countries. *J Policy Model* 36:970–985
- Bengochea A, Faet O (2012) Renewable energies and CO<sub>2</sub> emissions in the European Union. *Energy Sources Part B* 7:121–130
- Bloch H, Rafiq S, Salim R (2012) Coal consumption, CO<sub>2</sub> emission and economic growth in China: empirical evidence and policy responses. *Energy Econ* 34:518–528
- Bolük G, Mert M (2014) Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: evidence from a panel of EU (European Union) countries. *Energy* 74:439–446
- Boutabba MA (2014) The impact of financial development, income, energy and trade on carbon emissions: evidence from the Indian economy. *Econ Model* 40:33–41
- Chandran VGR, Tang CF (2013) The impacts of transport energy consumption, foreign direct investment and income on CO<sub>2</sub> emissions in ASEAN-5 economies. *Renew Sustain Energy Rev* 24:445–453
- Cowan WN, Chang T, Inglesi-Lotz R, Gupta R (2014) The nexus of electricity consumption, economic growth and CO<sub>2</sub> emissions in the BRICS countries. *Energy Policy* 66:359–368
- Energy Information Administration (2014) European nations are increasing electricity generation using no carbon sources, Washington, DC. <http://www.eia.gov/todayinenergy/detail.cfm?id=18071>. Accessed 11 Dec 2014

- Engle RF, Granger CWJ (1987) Co-integration and error correction: representation, estimation, and testing. *Econometrica* 55:251–276
- Euromonitor International from National Statistics (2014) Global Market Information (GIMD). <http://www.portal.euromonitor.com/portal/server.pt?space=Login&control=Redirect>. Accessed 20 Oct 2014
- Farhani S, Shahbaz M (2014) What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO<sub>2</sub> emissions in MENA region? *Renew Sustain Energy Rev* 40:80–90
- Farhani S, Chaibi A, Rault C (2014) CO<sub>2</sub> emissions, output, energy consumption, and trade in Tunisia. *Econ Model* 38:426–434
- Govindaraju VGRC, Tang CF (2013) The dynamic links between CO<sub>2</sub> emissions, economic growth and coal consumption in China and India. *Appl Energy* 104:310–318
- Halicioglu F (2009) An econometric study of CO<sub>2</sub> emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy* 37:1156–1164
- Hatzigeorgiou E, Polatidis H, Haralambopoulos D (2011) CO<sub>2</sub> emissions, GDP and energy intensity: a multivariate cointegration and causality analysis for Greece, 1977–2007. *Appl Energy* 88:1377–1385
- Heidari H, Katircioglu ST, Saeidpour L (2015) Economic growth, CO<sub>2</sub> emissions, and energy consumption in the five ASEAN countries. *Electr Power Energy Syst* 64:785–791
- Hossain MDS (2011) Panel estimation for CO<sub>2</sub> emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* 39:6991–6999
- Jafari Y, Othman J, Nor AHSM (2012) Energy consumption, economic growth and environmental pollutants in Indonesia. *J Policy Model* 34:879–889
- Jayanthakumaran K, Verma R, Liu Y (2012) CO<sub>2</sub> emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy* 42:450–460
- Kasman A, Duman YS (2015) CO<sub>2</sub> emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. *Econ Model* 44:97–103
- Kiviyiro P, Arminen H (2014) Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: causality analysis for Sub-Saharan Africa. *Energy* 74:595–606
- Kohler M (2013) CO<sub>2</sub> emissions, energy consumption, income and foreign trade: a South African perspective. *Energy Policy* 63:1042–1050
- Lean HH, Smyth R (2010) CO<sub>2</sub> emissions, electricity consumption and output in ASEAN. *Appl Energy* 87:1858–1864
- Lee YW (2013) The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. *Energy Policy* 55:483–489
- Maddala GS, Wu S (1999) A comparative study of unit root tests with panel data and a new simple test. *Oxf Bull Econ Stat* 61:631–652
- Menyah K, Wolde-Rufael Y (2010a) Energy consumption, pollutant emissions and economic growth in South Africa. *Energy Econ* 32:1374–1382
- Menyah K, Wolde-Rufael Y (2010b) CO<sub>2</sub> emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy* 38:2911–2915
- Omri A (2013) CO<sub>2</sub> emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models. *Energy Econ* 40:657–664
- Ozcan B (2013) The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: a panel data analysis. *Energy Policy* 62:1138–1147
- Ozturk I, Acaravci A (2010) CO<sub>2</sub> emissions, energy consumption and economic growth in Turkey. *Renew Sustain Energy Rev* 14:3220–3225
- 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
- Ozturk I, Uddin GS (2012) Causality among carbon emissions, energy consumption and growth in India. *Econ Res* 25(3):752–775
- Pao HT, Tsai CM (2010) CO<sub>2</sub> emissions, energy consumption and economic growth in BRIC countries. *Energy Policy* 38:7850–7860
- Pao HT, Tsai CM (2011a) Multivariate Granger causality between CO<sub>2</sub> emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy* 36:685–693
- Pao HT, Tsai CM (2011b) Modeling and forecasting the CO<sub>2</sub> emissions, energy consumption, and economic growth in Brazil. *Energy* 36:2450–2458
- Pao HT, Yu HC, Yang YH (2011) Modeling the CO<sub>2</sub> emissions, energy use, and economic growth in Russia. *Energy* 36:5094–5100
- Pedroni P (1999) Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxf Bull Econ Stat* 61:653–670

- Pedroni P (2004) Panel cointegration; asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econom Theory* 20:597–625
- Pesaran IKSMH, Shin Y (2003) Testing for unit roots in heterogeneous panels. *J Econom* 115:53–74
- Phillips PCB, Moon HR (1999) Linear regression limit theory for nonstationary panel data. *Econometrica* 67:1057–1111
- Rafindadi AA, Yusof Z, Zaman K, Kyophilavong P, Akhmat G (2014) The relationship between air pollution, fossil fuel energy consumption, and water resources in the panel of selected Asia-Pacific countries. *Environ Sci Pollut Res* 21:11395–11400
- Saboori B, Sulaiman J (2013a) Environmental degradation, economic growth and energy consumption: evidence of the environmental Kuznets curve in Malaysia. *Energy Policy* 60:892–905
- Saboori B, Sulaiman J (2013b) CO<sub>2</sub> emissions and economic growth in Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach. *Energy* 55:813–822
- Sadorsky P (2009) Renewable energy consumption, CO<sub>2</sub> emissions and oil prices in the G7 countries. *Energy Econ* 31:456–462
- Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO<sub>2</sub> emissions and trade openness: fresh evidence from BRICS countries. *Renew Sustain Energy Rev* 39:14–23
- Shafiei S, Salim RA (2014) Non-renewable and renewable energy consumption and CO<sub>2</sub> emissions in OECD countries: a comparative analysis. *Energy Policy* 66:547–556
- Shahbaz M, Solarin SA, Mahmood H, Arouri M (2013a) Does financial development reduce CO<sub>2</sub> emissions in Malaysian economy? A time series analysis. *Econ Model* 35:145–152
- Shahbaz M, Hye QMA, Tiwari AK (2013b) Economic growth, energy consumption, financial development, international trade and CO<sub>2</sub> emissions in Indonesia. *Renew Sustain Energy Rev* 25:109–121
- Shahbaz M, Dube S, Ozturk I, Jalil A (2015) Testing the environmental Kuznets curve hypothesis in Portugal. *Int J Energy Econ Policy* 5(2):475–481
- Soytas U, Sari R, Ewing BT (2007) Energy consumption, income, and carbon emissions in the United States. *Ecol Econ* 62:482–489
- Tang CF, Tan BW (2015) The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy* 79:447–454
- The World Bank (2014) World development indicators, Washington, DC. <http://data.worldbank.org/data-catalog/world-development-indicators>. Accessed 04 March 2014
- Wang SS, Zhou DQ, Zhou P, Wang QW (2011) CO<sub>2</sub> emissions, energy consumption and economic growth in China: a panel data analysis. *Energy Policy* 39:4870–4875
- Yang Z, Zhao Y (2014) Energy consumption, carbon emissions, and economic growth in India: evidence from directed acyclic graphs. *Econ Model* 38:533–540
- Zeb R, Salar L, Awan U, Zaman K, Shahbaz M (2014) Causal links between renewable energy, environmental degradation and economic growth in selected SAARC countries: progress towards green economy. *Renew Energy* 71:123–132
- Zhang XP, Cheng XM (2009) Energy consumption, carbon emissions, and economic growth in China. *Ecol Econ* 68:2706–2712
- Zhang YJ, Da YB (2015) The decomposition of energy-related carbon emission and its decoupling with economic growth in China. *Renew Sustain Energy Rev* 4:1255–1266
- Zhang C, Lin Y (2012) Panel estimation for urbanization, energy consumption and CO<sub>2</sub> emissions: a regional analysis in China. *Energy Policy* 49:488–498
- Zhang YJ, Liu Z, Zhang H, Tan TD (2014) The impact of economic growth, industrial structure and urbanization on carbon emission intensity in China. *Nat Hazards* 73:579–595
- Ziaei SM (2015) Effects of financial development indicators on energy consumption and CO<sub>2</sub> emission of European, East Asian and Oceania countries. *Renew Sustain Energy Rev* 42:752–759