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DOES RENEWABLE ENERGY MATTER FOR ECONOMIC GROWTH IN CENTRAL AND EASTERN EUROPEAN COUNTRIES? EMPIRICAL EVIDENCE FROM HETEROGENEOUS PANEL COINTEGRATION ANALYSIS

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Abstract: *The aim of the paper is to provide empirical evidence in support of the relationship between renewable energy consumption and economic growth in eleven Central and Eastern European (CEE) countries over the period 1995-2015 within a multivariate panel data analysis. Based on World Bank data, the panel cointegration analysis reveals that renewable energy consumption and economic growth are positively associated in the long run in CEE countries. The heterogeneous panel causality test indicates a bi-directional causality relationship in support of the feedback hypothesis between economic growth and renewable energy consumption in Central and Eastern European countries.*

Keywords: renewable energy, economic growth, heterogeneous panel analysis, CEE countries

JEL Classification: Q20, O40, C23

1. Introduction

The increased attention given by researchers as well as by policymakers to consumption from renewable energy sources and economic growth can be

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connected to several factors: the environmental impact of carbon emissions, dependency on foreign energy resources, the volatility of oil prices, the occurrence of markets for renewable energy, government policies stimulating energy production, standards for energy portfolios (i.e. Apergis and Payne, 2010a).

An impressive amount of studies exploring the renewable energy-growth nexus emerged in the last decades. Renewable energy consumption plays a key role in promoting economic growth (e.g., Gozgor et al., 2018; Armeanu et al., 2017; Bhattacharya et al., 2016; Inglesi-Lotz, 2016; Al-Mulali, 2013) and a significant part of GDP per capita can be explained by the share of renewable energy source on electricity generation (e.g., Ohler and Fetters, 2014; Bayraktutan et al., 2011; Silva et al., 2012). A positive effect of renewable energy was also identified in the technical efficiency of the economy (i.e. Chien and Hu, 2007) and fixed capital formation (i.e. Chien and Hu, 2008). A unidirectional causality from renewable energy production to economic development was found in the middle human developed countries on short term and bidirectional causality in the long term (Kazar and Kazar, 2014). On the other hand, some recent studies concluded that renewable energy consumption can slow economic growth (see: Maji and Sulaiman, 2019).

Renewable energy sources represent a major component of the EU's energy mix and a significant contributor to the transition of Europe's energy sector. Renewable energy technologies achieved in last year's high market share and the share of solar photovoltaic (PV) electricity, biogas electricity and solid biomass use are very close to the levels anticipated by countries in their renewable action plans (EEA, 2018, p.5).

The renewable energy-growth nexus in the EU economies was explored in a panel data approach by Menegaki (2011), Silva et al. (2012), Ucan et al. (2014), Dogan and Seker (2016), Armeanu et al. (2017), Șoava et al. (2018). Other studies provide evidence from individual economies, such as Lithuania (Bobinaite et al., 2011), Italy (Vaona, 2012 and Bento and Moutinho, 2016), Portugal (Leitao, 2014), Italy and Germany (Bozturk and Destek, 2015), Finland and Denmark (Irandoust, 2016), Romania and Bulgaria (Koçak and Șargüneși, 2017).

The Central and Eastern European (CEE) countries under examination in this paper have a distinct evolution within the EU context. They are new Members States, which joined the EU in 2004 (Hungary, Poland, Czech Republic, Latvia, Lithuania, Estonia, Slovak Republic) respectively in 2007 (Romania and Bulgaria) and in 2013 (Croatia). As former communist countries, they faced the challenges of economic and social transition and structural changes incumbent by the EU accession process and integration in the European single market. In accordance with the general frame of the EU energy policy, these countries set up renewable energy targets to be achieved by 2020 (European Parliament and the Council, 2009; European Commission, 2010). Further goals regarding renewable energy included in the European initiative Roadmap to 2050 (European Commission, 2011) and for the period of 2020-2030 (European Commission, 2014) are integrated also in national policies of all the EU Member States.

The present paper is focused on the CEE countries due to four main reasons. First, the group of these countries has some common characteristics that impact their energy mix and policy: their geographical position in the Central and Eastern part of the EU (with consequences on the European trade and connection with the European energy market and infrastructure); their common past (as centralized economies under a communist regime); their natural resources (i.e. coal-Poland, gas-Romania); their fast growth rate in the last five years, higher than the EU average and the Western developed countries (EUROSTAT, 2019a). Their increasing growth rates will induce an increase in the energy demand; therefore, diversification of sources in their energy mix, increasing shares of renewable sources and the transition from the carbon economy is critical. In the frame of the EU energy policy aiming to the security of energy supply, energy efficiency and a competitive and sustainable energy sector, the energy policies in CEE countries are aligned with the EU 2020 targets, with binding national targets for each country.

A second reason is the low level of energy productivity in comparison with the EU level of 8.5 Eur/kgoe in 2016. The lowest level of energy productivity is registered in Bulgaria (2.4 Eur/kgoe) and Estonia (2.8 Eur/kgoe) and the highest in Slovenia (5.6 Eur/kgoe) and Croația (5.4 Eur/kgoe) (EUROSTAT, 2019b). The trend of energy productivity in the last ten years is positive in all these countries, but developing alternative sources of energy (i.e. renewable) remains a realistic option for the improvement of their energy efficiency in the next years.

Third, the relationship between renewable energy and growth in Central and Eastern Europe is less examined and discussed in the literature and there is a gap in analyzing the latest developments in these countries taken as a specific group. Countries from Central and Eastern Europe (CEE) were included in some studies focused on renewable energy-growth nexus as members of panels at the EU level (please see: Menegaki, 2011; Armeanu et al., 2018; Șoava et al., 2018) and frequently in analyses at the individual level of economies: Lithuania (Bobinaite et al., 2011), Czech Republic, Bulgaria, Estonia, Hungary, Poland, Slovenia (Alper and Oguz, 2016), Romania and Bulgaria (Koçak and Șargüneși, 2017).

Fourth, the highest share of renewable sources in the final consumption from the whole European Union is registered in 2017 in two CEE countries (Latvia and Estonia) (EUROSTAT, 2019c).

The CEE countries experienced strong growth in the renewable energy sector during 2004-2017: the average share in the total gross final consumption coming from renewable energy sources (RES) increased from 14.37% in 2004 to 21.51% in 2017 (higher than the EU's average of 17.5%). The shares of RES among CEE countries are ranging in 2017 from 10.9% in Poland to 39.01% in Latvia (Figure 1). In the group of countries under examination, Hungary had the highest growth, by tripling the level of 2004 (from 4.36% in 2004 to 13,33% in 2017) and the lowest speed is registered in Croatia and Latvia (only of 1,1 times). In absolute terms, Estonia had the highest increase (10.85 percentage points). The best performer in the group is Latvia, with a share of renewable sources in the final consumption of 39.01% in 2017 (from 32.79% in 2004) and the lowest in Poland, from 6.91% (2004) to 10.9% (2017). Seven CEE countries have already reached their 2020 national targets (set up based on the Directive 2009/28/EC on the promotion of the use of energy from renewable sources, in order to translate the Community 20% target by 2020): Bulgaria, Czech Republic, Croatia, Estonia, Hungary, Lithuania and Romania. Latvia is very close to the 2020 target and Poland, Slovenia and the Slovak Republic have only 2.5 to 4 percentage points distance to their 2020 objectives.

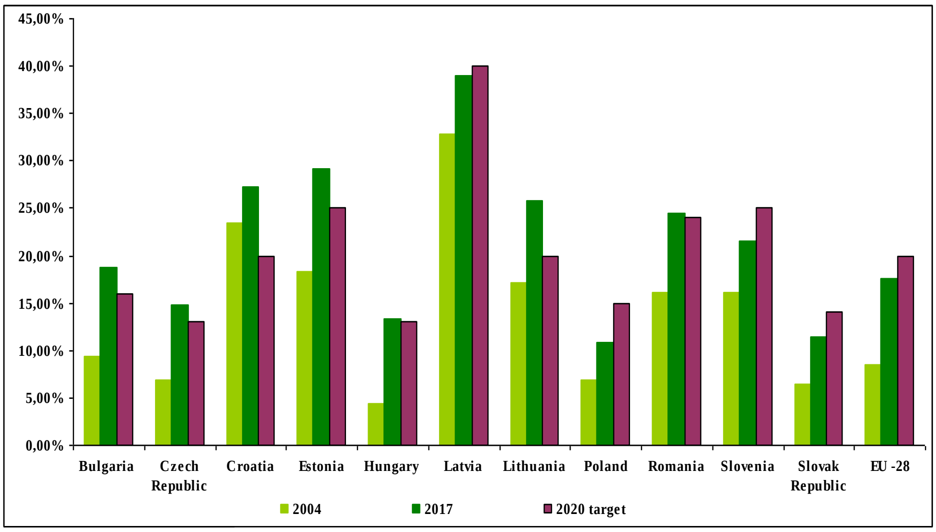

Figure 1 Progress towards renewable energy source targets by country, 2004-2017
Source: EUROSTAT. 2019c. Energy balances the 2019 edition.

The aim of the paper is to provide empirical evidence on the causal relationship between economic growth and renewable energy in eleven CEE countries. The study consists of a heterogeneous panel data analysis by using a panel unit root and panel cointegration approach in order to put in evidence the long-run correlation between Gross Domestic Product and Renewable Energy Consumption (REC) (as a share of the gross final consumption). The direction of causality is also examined by the heterogeneous panel causality test developed by Dumitrescu-Hurlin (2012).

The first contribution of the paper is that it examines the specific situation of renewable energy consumption and economic growth in a panel of CEE countries, a group of Member States with common past and present efforts to sustain their process of economic convergence and fill in this way the existing research gap in the literature.

The second contribution is the usage of heterogeneous panel estimation techniques in the analysis of renewable energy-growth nexus. Even if we consider that countries under examination have common economic and social features, neglecting heterogeneity could induce inference errors. As a third contribution, the findings of this study will provide valuable deductions and implications regarding renewable energy-growth nexus, as well as for energy mix, energy efficiency, clean energy, and decarbonization policies in these countries.

The paper is organized as follows. After a literature review on the causality relationship between economic growth and renewable energy consumption, section 3 presents materials and method, section 4 exposes the estimation results, section 5 discusses the results and the last section is dedicated to conclusions and policy implications.

2. Literature review

Four hypotheses about the causal relationship between economic growth and energy consumption are revealed in the specific literature: growth, conservation, feedback and neutrality According to the growth hypothesis, renewable energy consumption contributes to economic growth, directly and/or indirectly, by complementing to gross fixed capital formation and labor in the production process and the Granger causality test indicates such direction. The conservation hypothesis is supported in the case of achieving unidirectional Granger causality from real GDP to renewable energy consumption. An interdependent causal relationship between GDP and the renewable energy consumption is suggested by the feedback hypothesis, while the absence of Granger causality indicates the neutrality hypothesis.

2.1. Feedback hypothesis

Bidirectional causality between renewable energy consumption and economic growth was reported in the studies developed by Apergis and Payne (2010a, 2010b,

2011a, 2011b, 2012) in a panel approach of OECD, Eurasia, Central American, developed and developing countries. Tugcu et al. (2012) and Chang et al. (2015) found similar results for the panel of G7 countries. Bayraktutan et al. (2011) identified a reciprocal causality between renewable electricity generation and economic growth within OECD countries. Saidi and Mbarek (2016) detected bidirectional causality in the short and long run from renewable energy consumption to real GDP per capita in a panel of nine developed countries over the period 1990-2013. Jebli et al. (2016) obtained similar findings for a panel of 25 OECD countries over the period 1980-2010. Kahia et al. (2016, 2017) provide also evidence for the existence of bidirectional causality in the long-run between renewable energy use and economic growth for a sample of MENA net exporting countries (NOECs) and MENA net oil-importing countries (NOICs). Koçak and Șargüneși (2017) found also evidence in support of the feedback hypothesis in a panel of nine countries from the Black Sea and Balkans, as well as Dong et al. (2018) for a panel of 128 countries.
The feedback hypothesis was confirmed also in individual economies: Italy (Vaona, 2012), China (Lin and Moubarak, 2014), Pakistan (Shahbaz et al., 2015), U.S.A (Bozturk and Destek, 2015), Greece and South Korea (Destek and Alper, 2017).

2.2. Conservation hypothesis

Apergis and Payne (2011c) revealed unidirectional causality from economic growth to renewable electricity consumption in the short run within a panel of 16 developing countries. Sadorsky (2009) obtained similar results for a panel of 18 emerging countries and Kazar and Kazar (2014) for a panel of 154 countries. Kahia et al. (2016, 2017) found evidence in support of this hypothesis in the short run for the MENA net oil-exporting and importing countries for the period 1980-2012. Aneja et al. (2017) obtained the same conclusions for BRICS countries and Dong et al. (2018) for Africa, the Middle East and South&Central America.
The conservation hypothesis was also reported by Oguz and Alper (2013) for Turkey, Azlina et al. (2014) for Malaysia, Bozturk and Destek (2015) for Germany, Bento and Moutinho (2016) for Italy, Irandoust (2016) for 4 Nordic countries (Sweden, Norway, Denmark and Finland), Alper and Oguz (2016) for the Czech Republic, Destek and Alper (2017) for Colombia and Thailand, Șoava et al. (2018) for Bulgaria, Denmark, Latvia and the United Kingdom.

2.3. Growth hypothesis

Payne (2011) discovered unidirectional causality from biomass energy consumption to real output for the US over the period 1949–2007. Apergis and

Danuletiu (2014) provided evidence in support of the growth hypothesis in a sample of 80 countries. Ucan et al. (2014) found a positive association between renewable energy consumption and economic growth for a panel of fifteen European Union countries over the period of 1990-2011. Sebri and Ben-Salha (2014) reported similar results for the BRICS countries. Long-run causality from renewable energy consumption to economic growth was identified by Bhattacharya (2016) within 85 economies (1991-2012) and by Anwar et al. (2017) in the case of 29 Organization of Islamic Cooperation (OIC) countries for 1990-2014 as well as by Armeanu et al. (2017) for the EU-28 (2003-2014).

The growth hypothesis is confirmed in the Lithuanian economy (Bobinaite et al. 2011), in Romania for the short-run (Pirlogea and Cicea, 2012), USA (Yildirim et al., 2012), Portugal (Leitao, 2014), India (Zeb et al., 2014), Turkey (Dogan, 2015), Peru (Destek and Alper (2017) and Indonesia (Khobai, 2018).

2.4. Neutrality hypothesis

The neutrality hypothesis was identified by Menegaki (2011) in his analysis of 27 European countries for the period 1997-2007. Evidence for the same hypothesis was also provided by Dogan and Seker (2016) in their study on a panel of fifteen European Union countries over 1980-2012. Bozturk and Destek (2015) found no causality in Italy and Turkey for data over the period 1980-2012, as well as Bulut and Muratoglu (2018) in the case of Turkish economy over the period 1990-2015. The neutrality hypothesis is supported in the case of the Turkish economy (e.g.: Bulut and Muratoglu (2018) for the period 1990-2015 and Koçak and Șargüneși (2017) over the period 1990-2012). It is also valid in North America, Europe and Asia countries (Dong et al., 2018), in 12 countries (Brazil, Chile, China, Egypt, India, Indonesia, Malaysia, Portugal, South Africa, Turkey) (Destek and Alper, 2017) and Malta (Dong et al., 2018).

Table 1 Empirical studies on the relationship between renewable energy consumption and economic growth

Authors	Period	Country	Methodology	Causality relationship
Sadorsky (2009)	1994-2003	18 emerging countries	Panel cointegration Panel causality test	$REC \leftarrow GDP$
Apergis and Payne (2010a)	1985-2005	20 OECD countries	Panel cointegration PVECM Granger causality	$REC \leftrightarrow GDP$ short and long run
Apergis and Payne (2010b)	1992-2007	13 countries in Asia	Heterogeneous Panel cointegration PVECM Granger causality	$REC \leftrightarrow GDP$
Apergis and Payne (2011a)	1980-2006	6 Latin American countries	Heterogenous panel cointegration PVECM Granger causality	$REC \leftrightarrow GDP$
Apergis and Payne (2011b)	1990-2007	25 developed 55 developing countries	Heterogeneous panel cointegration PVECM Granger causality	$REC \leftrightarrow GDP$
Apergis and Payne (2011c)	1990-2007	16 developing countries	Heterogeneous Panel cointegration PVECM Granger causality	$REC_{el} \leftarrow GDP$

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Bayraktutan et al.(2011)	1980-2007	OECD countries	Panel cointegration Holtz-Eakin, Newey and Rosen causality test	REC_{el}-$E \leftrightarrow GDP$
Bobinaite et al. (2011)	1990-2009	Lithuania	Cointegration method Granger causality test	$REC \rightarrow GDP$ short-run
Menegaki (2011)	1997-2007	27 EU countries	Random effect model PVECM Granger causality	No causality (neutrality hypothesis)
Tiwari (2011)	1960-2009	India	Structural VAR approach	$REC \rightarrow GDP$
Tugcu et al. (2012)	1980-2009	G7 countries	ARDL approach Hatemi-J. causality test	$REC \leftrightarrow GDP$
Vaona (2012)	1861-2000	Italy	Granger non-causality test (Box and Jenkins)	$REC \leftrightarrow GDP$
Yildirim et al. (2012)	1949-2010	USA	Toda-Yamamoto and bootstrap-corrected procedure	$REC_{biomas\text{-}waste} \leftrightarrow GDP$
Oguz and Alper (2013)	1990-2010	Turkey	ARDL approach Toda-Yamamoto procedures	$REC \leftarrow GDP$
Azlina et al.(2014)	1975-2011	Malaysia	VECM Granger causality test	$REC \leftarrow GDP$
Apergis and Danuletiu (2014)	1990-2012	80 countries	Canning and Pedroni causality test	$REC \rightarrow GDP$
Leitao (2014)	1970 - 2010	Portugal	VEC model Grange causality test	$REC \rightarrow GDP$
Lin and Moubarak (2014)	1977-2011	China	ARDL VECM Granger causality	$REC \leftrightarrow GDP$
Ohler and Fetters (2014)	1990-2008	20 OECD countries	PECM model	$REC_{el} \leftrightarrow GDP$
Sebri and Ben-Salha (2014)	1971-2010	BRICS countries	ARDL VECM Granger causality	$REC \rightarrow GDP$
Ucan et al. (2014)	1990-2011	15 EU countries	Heterogeneous panel cointegration Granger causality	$REC \rightarrow GDP$
Zeb et al.(2014)	1975-2010	SAARC countries	Johansen cointegration test Granger causality	$REC \rightarrow GDP$ India. Neutrality for the rest of the countries (Nepal, Pakistan, Sri Lanka)
Bozturk and Destek (2015)	1980-2012	selected OECD countries (USA, Italy, Germany, Turkey)	ARDL approach Toda-Yamamoto procedures	$REC \leftarrow GDP$ (Germany) $REC \leftrightarrow GDP$ (USA) No causality (Italy, Turkey)
Chang et al.(2015)	1990-2011	G7 countries	Granger causality test in heterogeneous mixed panels	$REC \leftrightarrow GDP$
Dogan (2015)	1990-2012	Turkey	ARDL cointegration approach Johansen cointegration test Gregory-Hansen cointegration test with structural breaks Granger causality test	$REC \rightarrow GDP$
Jebli and Youssef (2015)	1980-2010	69 countries	Panel cointegration Panel causality test	$REC \leftrightarrow GDP$
Shahbaz et al.(2015)	1972Q1 2011Q4	Pakistan	ARDL approach VECM Granger causality test	$REC \leftrightarrow GDP$
Alper and Oguz (2016)	1990-2009	8 new Member States	ARDL approach Asymmetric causality test	$REC \leftarrow GDP$ Czech Republic $REC \rightarrow GDP$ Bulgaria neutrality Cyprus, Estonia, Hungary, Poland, Slovenia
Bhattacharya et al. (2016)	1991-2012	85 economies	Panel cointegration test Heterogeneous panel causality test	$REC \rightarrow GDP$
Bento and Moutinho (2016)	1960-2011	Italy	ARDL approach Granger causality	$REC \leftarrow GDP$
Dogan and Seker (2016)	1980-2012	EU-15 countries	EKC model Dumitrescu-Hurlin panel causality	neutrality

			test	
Kahia et al. (2016)	1980-2012	MENA net oil- exporting countries (NOECs)	Panel cointegration test Panel Granger causality test	*REC* ← *GDP* short-run *REC* ↔ *GDP* long run
Irandoust (2016)	1975-2012	4 Nordic countries	VAR model modified Granger causality test	*REC* ← *GDP*
Jebli et al.(2016)	1980-2010	25 OECD countries	Panel cointegration test Granger causality test	*REC* ↔ *GDP*
Saidi and Mbarek (2016)	1990-2012	9 developed countries	Panel cointegration test Granger causality test	*REC* ↔ *GDP*
Rafindadi and Ozturk (2016)	1971QI-2013 QIV	Germany	ARDL approach Clemente-Montagnes-Reyes detrended structural break test, Bayer-Hanck combined test VECM Granger causality test	*REC* ↔ *GDP*
Anwar et al. (2017)	1990-2014	20 Organization of Islamic Cooperation countries	Panel cointegration test Panel Granger causality test	*REC* → *GDP*
Armeanu et al. (2017)	2003-2014	EU-28	PVECM model Granger causality test	*REC* → *GDP*
Destek and Alper (2017)	1980-2010	18 emerging countries	Bootstrap panel causality test	*REC* → *GDP* (Peru) *REC* ← *GDP* (Colombia, Thailand) *REC* ↔ *GDP* (Greece, South Korea) Neutrality (in the rest of the countries)
Kahia et al. (2017)	1980-2012	MENA net oil-importing countries (NOICs)	Panel cointegration test Panel Granger causality test	*REC* ← *GDP* short-run *REC* ↔ *GDP* long run
Koçak and Şargüneşi (2017)	1990-2012	9 Black Sea and Balkan countries	Panel cointegration Dumitrescu-Hurlin causality test	*REC* ↔ *GDP* (panel) *REC* ↔ *GDP* (Albania, Georgia, Romania) *REC*→*GDP* (Bulgaria, Greece, Macedonia, Russia, Ukraine) Neutrality (Turkey)
Bulut and Muratoglu (2018)	1990-2015	Turkey	ARDL approach Hacker and Hatemi, Granger, Hatemi-J. asymmetric causality test	Neutrality
Dong et al. (2018)	1990-2014	a panel of 128 countries	Panel cointegration test Dumitrescu-Hurlin causality test	*REC* ↔ *GDP* (global panel and Asia Pacific panel) *REC* ← *GDP* (Africa, Middle East, South &Central America panels) neutrality (North America, Europe&Asia panels
Şoava et al. (2018)	1995-2015	EU-28	Granger causality	*REC* ↔ *GDP* Czech Republic, Ireland, Greece, Croatia, Cyprus, Lithuania, Luxembourg, Netherlands, Austria, Poland, Slovak Republic, Finland *REC* → *GDP* Belgium, Denmark, Estonia, Spain, France, Hungary, Portugal, Romania, Slovenia, Sweden *REC* ← *GDP* Bulgaria, Denmark, Latvia, United Kingdom neutrality Malta

Abbreviations: **ARDL**, Autoregressive Distributed Lag; PVECM, Panel Vector Error Correction Model; VECM, Vector Error Correction Model; EKC, Environmental Kuznets Curve REC, renewable energy consumption; GDP, Gross Domestic Product.

It can be noticed in Table 1 the lack of studies focused on the group of Central and Eastern European Union countries, which represents one of the main motivations of the present paper.

3. Materials and methods

3.1. Model and data

The relationship between economic growth and renewable energy is examined through a neo-classical production function:

$$y_{it} = f(K_{it}, L_{it}, REC_{it}) \quad (1)$$

This production function was proposed in several studies analyzing the relationship between energy and economic growth (e.g.: Lorde et al., 2010; Apergis and Payne, 2010a, 2010b, 2010c, 2010d; Apergis and Payne, 2011a, 2011b; Apergis and Payne, 2012; Pao and Fu, 2013; Apergis and Danuletiu, 2014; Dogan, 2015; Shahbaz et al., 2015; Alper and Oguz, 2016; Kahia et al., 2016, 2017; Destek and Alper, 2017; Sasana and Ghozali, 2017; Koçak and Șargüneși, 2017; Ntanos et al. 2018; Taeyoung and Jinsoo, 2018).

Equation 1 can be written as follows:

$$y_{it} = \alpha K_{it}^{\beta_{i1}} L_{it}^{\beta_{i2}} REC_{it}^{\beta_{i3}} \quad (2)$$

where: y_{it} stands for economic output, respectively gross domestic product (GDP) per capita, K_{it} for stock of physical capital, L_{it} for labor and REC_{it} share of renewable energy in the energy consumption, α represents the total factor productivity and β_{i1}, β_{i2}, β_{i3} are the output elasticities to capital, respectively labor and renewable energy consumption.

GDP per capita is largely used as proxy for economic growth in the literature of renewable energy-growth nexus (e.g.: Sadorsky, 2009; Menegaki, 2011; Lin and Moubarak, 2014; Sebri and Ben-Salha, 2014; Jebli and Youssef, 2015; Shahbaz et al., 2015; Koçak and Șargüneși, 2017; Armeanu et al., 2018).

Taking the logarithm in equation 2 and adding the trend and error term, we obtain:

$$\ln y_{it} = \alpha_i + \delta_i t + \beta_{1i} \ln K_{it} + \beta_{i2} \ln L_{it} + \beta_{i3} \ln REC_{it} + \varepsilon_{it} \quad (3)$$

The use of the logarithm permits the removal of heteroskedasticity from the regression model.

In equation 3, α_i is the intercept, δ_i is a parameter associated with the trend and ε_{it} is the error term, the *i* index denotes the country (i=1, ..., 11), and *t* the time.

The study is based on panel data consisting of 11 CEE countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovak Republic and Slovenia) for a time span from 1995 to 2015.

The following data series were extracted from the World Bank database: GDP per capita (constant 2010 USD) for economic output, gross fixed capital formation (GCF) (as % of GDP) for the stock of physical capital, labor force participation rate (LFPR), total (% of the population aged 20+) for labor, and renewable energy consumption (REC) (shares of renewable energy in total final energy consumption, %). Thus, equation 3 is re-written as below:

$$\ln GDP_{it} = \alpha_i + \delta_i t + \beta_{1i} \ln GCF_{it} + \beta_{2i} \ln LFPR_{it} + \beta_{3i} \ln REC + \varepsilon_{it} \quad (4)$$

Table 2 shows the descriptive statistics of the used variables.

Table 2 Descriptive statistics

	lnGDP	*lnGCF*	*lnLFPR*	*lnREC*
Mean	3.164	9.307	4.033	2.607
Median	3.168	9.385	4.054	2.696
Maximum	3.620	10.144	4.207	3.697
Minimum	2.545	8.229	3.863	1.133
Standard deviation	0.194	0.442	0.073	0.637
Observations	231	231	231	231

Source: authors' computation based on World Bank data

3.2. Econometric methodology

The panel of countries under examination is heterogeneous, the variability among cross-sections (countries under examination) may exist due to differences of economic structure and energy mix and it must be taken into consideration; otherwise, it may bias the results and cause incorrect inference.

The relationship between economic growth and renewable energy is examined through the panel data analysis method. The following steps are carried out: (1) stationarity of data series will be tested with panel unit root test, (2) the long-term relationship between variables will be investigated by using the panel cointegration method, (3) estimation of long-run parameters with the fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) and (4) panel causality will be examined with the Dumitrescu and Hurlin (2012) test.

Panel cointegration method is largely used in the literature in order to investigate the relationship between economic growth and renewable energy (e.g.: Sadorski, 2009; Al-mulali et al., 2013, Apergis and Payne 2010a, 2010b, 2011a, 2011b, 2011c; Bayraktutan et al., 2011; Ucan et al., 2014; Jebli and Youssef, 2015; Kahia et al., 2016; Jebli et al., 2016; Inglesi-Lotz 2016; Bhattacharya et al., 2016; Saidi and Mbarek, 2016; Anwar et al., 2017; Koçak and Şargüneşi, 2017; Dong et al., 2018). The estimation of long-run parameters with FMOLS and DMOLS methods is also employed in such studies (i.e. Sadorski, 2009; Bhattacharya et al., 2016; Koçak and Şargüneşi, 2017). In order to reveal the causality direction in heterogeneous panel data, the Dumitrescu and Hurlin test is appropriate (e.g., Dogan and Seker, 2016; Koçak and Şargüneşi, 2017; Dong et al., 2018; Neagu and Teodoru, 2019).

3.2.1. Panel unit root test

To test the stationarity of panel variables, we use the panel unit root tests developed by Levin et al. (2002), appropriate for balanced panel data.

In the LLC (2002) panel unit root test, the assumption is that all units (countries) in the panel share the same autoregressive coefficient $\rho_i=\rho$ for all i.

The following model is estimated for the LLC test:

$$\Delta y_{it} = \mu_i + \rho y_{i,t-1} + \sum_{j=1}^{m} \alpha_j \Delta y_{i,t-j} + \delta_{it} + \theta_t + \varepsilon_{it} \qquad (5)$$

where: Δ is the first difference operator, m denotes the number of lags μ_i and θ_t denotes unit-specific fixed and respectively, time effects.

ε_{it} is independently distributed across panels and follows a stationary invertible autoregressive moving-average process for each unit in the panel.

The null hypothesis of the LLC test states that y_t each unit (country) contains a unit root ($\rho=0$), against the alternative, that all series are stationary ($\rho<0$).

3.2.2. Cointegration test

The results of the unit root test are determining the next decision. If the series is stationary at the level value then the relationship between variables can be estimated through the OLS method of regression. If the first-differences series are stationary, the cointegration relationship should be examined.

Panel cointegration test developed by Pedroni (1999, 2004) is used to test the long term cointegration relationship between non-stationary variables.

In this test, the null hypothesis states that there is no cointegration for all i, against the alternative that there is a cointegration relationship for all i. Seven different test statistics are developed: four of them consist of in-group statistics (panel-v, panel-ρ, semiparametric panel-t, and parametric panel-t) and the other three consist of intergroup (group-ρ statistics, semiparametric group-t and parametric group-t) statistics. The interpretation of test results is the following. The values of Prob corresponding to each statistics under the selected significance level (1% or 5%) are taken into consideration. If the number of these statistics is at least 4, the null hypothesis (of no cointegration for all i) is rejected meaning that there is a long-term relationship between the variables.

3.2.3. Estimation of long-run parameters

After the cointegration test, we estimate the long term cointegration coefficients by using the panel fully modified ordinary least squares (FMOLS) and panel dynamic ordinary least squares (DOLS) methods developed by Pedroni (2001a, 2001b).
The panel FMOLS method is based on the following regression model:

$$y_{it} = \alpha_{it} + \delta_{it} t + \beta x_{it} + \mu_{it} \quad (6)$$

$$x_{it} = x_{it-1} + e_i \quad (7)$$

where: y_{it} is the dependent variable and x_{it} the independent variable α_{it} denotes the constant effects, β is the long-term cointegration coefficient/vector that should be estimated if we assume that there is no dependence between panel units.
The panel FMOS estimator is obtained by the formula below:

$$\hat{\beta}^{*}_{FM} = n^{-1} \sum_{i=1}^{n} \hat{\beta}^{*}_{FM,i} \quad (8)$$

where: $\hat{\beta}^{*}_{FM}$ is the FMOLS estimation result for the cross-section that forms each *i*-th section.
The cointegration coefficient for the overall panel is estimated with the average of FMOLS coefficients in the cross-sections. T-statistic for the panel cointegration coefficient ($t^{*}_{\hat{\beta}^{*}_{FM}}$) is calculated as below:

$$t^{*}_{\hat{\beta}^{*}_{FM}} = n^{-1} \sum_{i=1}^{n} t_{\hat{\beta}^{*}_{FM,i}} \quad (9)$$

The DOLS estimator introduced by Pedroni (2001b) is based on a panel regression model as follows:

$$y_{it} = \alpha_i + \beta_i x_{it} + \sum_{k=-K_i}^{K_i} \gamma_{it} \Delta x_{it-K} + \varepsilon_{it} \quad (10)$$

This equation is estimated for each cross-section of the panel and then the cointegration coefficient for the overall panel is calculated as the average of the DOLS coefficients for each section.
The panel DOLS estimator is calculated as below:

$$\hat{\beta}^{*}_{D} = n^{-1} \sum_{i=1}^{n} \hat{\beta}^{*}_{D,i} \quad (11)$$

and the t-statistic for the panel cointegration coefficient:

$$t^{*}_{\hat{\beta}^{*}_{D}} = n^{-1} \sum_{i=1}^{n} t_{\hat{\beta}^{*}_{D,i}} \quad (12)$$

3.2.4. Panel causality test

To find the direction of causality between the variables we used the test developed by Dumitrescu and Hurlin (2012).

In this test, the null hypothesis (of no causality from x to y) is defined as follows:

H0: $\beta_i=0$ for $\forall i=1, \ldots, n$; $\beta_i^{(1)}, \beta_i^{(2)}, \ldots, \beta_i^{(k)}$

Under the alternative hypothesis, we assume that there are $n_1<n$ individual processes with no causality from x to y:

H1: $\beta_i=0$ for $\forall i=1, \ldots, n_1$

$\beta_i \neq 0$ for $\forall i=n_1, n_1+1, n_1+2, \ldots, n$

where: n_1 is unknown and $0 \leq \frac{n_1}{n} < 1$. If $n_1=n$ then there is no causality for any sections in the panel which is equivalent with no causality. If $n_1=0$ then there is causality for all sections in the panel. If $n_1>0$ then the causality relationship is heterogeneous, meaning that the regression model and causality relations are different from one section to another. In this context, Dumitrescu and Hurlin (2012) proposed to use the average Wald statistic in association with the test of non-causality hypothesis $i=1, \ldots, n$.

Individual Wald statistics for each section are calculated to reveal the causality relationship in each section of the panel and then the Wald statistic for the overall panel is obtained as the average of the individual Wald statistics:

$$W_{n,T} = \frac{1}{n}\sum_{i=1}^{n} W_{i,T} \tag{13}$$

Under the null hypothesis of non-causality, each Wald statistic converges to a chi-squared distribution with K degrees of freedom:

$$W_{i,T} \xrightarrow[T \to \infty]{d} \chi^2(K), \forall i = 1, \ldots, n \tag{14}$$

When $T \to \infty$, the individual Wald statistics are identically distributed, under the assumption that individual residuals ε_i are independently distributed across groups.

When T, $n \to \infty$ and $T \to \infty$ first and then $n \to \infty$, meaning that $T<n$, which the case of the present study, the standardized test under this condition is shown below:

$$Z_{n,T} = \sqrt{\frac{n}{2K}}\left(W_{n,T} - k\right) \to n(0,1) \tag{15}$$

When Z-statistic is higher than the corresponding critical value for a given level of risk, the homogenous noncausality hypothesis is rejected.

4. Estimation results

Table 3 displays the results of the LLC panel unit root test for 2 options: with individual intercept and with individual intercept and trend. The series of variables *lnGDP*, *lnGCF*, *lnLFPR* and *lnREC* are not stationary at the value level (the values of Prob are higher than 0.05 in almost all cases) but they are integrated of the first order (the series of the first order are stationary) for 1% level of significance.

Table 3 Results of LLC panel unit root test

Variable	Individual intercept		Individual intercept and trend	
	Statistic	P-value	Statistic	P-value
lnGDP	-2.552	0.005	-0.494	0.310
lnGCF	-2.777	0.002	-1.922	0.027
lnLFPR	-1.163	0.122	0.672	0.749
lnREC	0.251	0.599	-1.413	0.078
$\Delta \ln GDP$	-6.054	0.000	-4.965	0.000
$\Delta \ln GCF$	-7.125	0.000	-4.866	0.000
$\Delta \ln LFPR$	-7.590	0.000	-6.863	0.000
$\Delta \ln REC$	-9.434	0.000	-8.292	0.000

Note: Newey-West Bandwidth selection with Bartlett Kernel is used.

Table 4 exposes the panel cointegration results. Because for 5 of 7 test statistics the value Prob is under 0.05 a cointegration relationship between *lnGDP*, *lnGCF*, *lnLFPR* and *lnREC* is detected.

Table 4 Cointegration results
(Pedroni Cointegration test for *lnGDP*, *lnGCF*, *lnFPR*, *lnREC*)

Test	Statistic	Prob.	
Panel v-statistic	3.272	0.000	common AR coefficients (within-dimension)
Panel rho-statistic	0.702	0.758	
Panel PP-statistic	-3.173	0.000	
Panel ADF-statistic	-2.232	0.012	
Panel rho-statistic	2.453	0.992	individual AR coefficients (between-dimension)
Panel PP-statistic	-1.752	0.039	
Panel ADF-statistic	-3.247	0.000	

Note: Newey-West Bandwidth selection with Bartlett Kernel is used, under the assumption of deterministic intercept and trend

In order to estimate the long-term parameters, we estimate the panel FMOLS and DMOLS equations (Table 5).

Table 5 Panel long-term parameters for CEE countries (1995-2015)

Variable	Panel FMOLS			Panel DMOLS		
	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
lnGCF	0.403	3.685	0.000	0.523	3.327	0.001
lnLFPR	-1.404	-2.911	0.004	-0.887	-1.540	0.127
lnREC	0.540	9.864	0.000	0.712	8.896	0.000

According to the panel FMOLS results, coefficients for *lnGCF* and *lnREC* are positive and statistically significant at a 1% level of significance, indicating that gross capital formation and renewable energy have a positive and significant impact on economic growth in the CEE countries in the period of 1995-2015. The negative coefficient of the labor force is not statistically validated (the corresponding Prob is higher than 0.05). The situation is similar in the case of the panel DMOLS equation.

The last step in our analysis is to check the direction of the causality between *lnGDP* and *lnREC*. We run the test developed by Dumitrescu and Hurlin (2012) for lag=1, 2 and 3. The results are exposed in Table 6.

$\Delta \ln GDP \rightarrow \ln REC$

Table 6 Panel causality results for GDP and RE in CEE countries

	$\Delta \ln GDP \rightarrow \ln REC$	$\Delta \ln GDP \leftarrow \ln REC$	Number of lags
Wald statistic	2.432	2.823	
Zbar-statistic	2.423	3.152	lag=1
Prob	0.015	0.001	
Wald statistic	4.293	3.706	
Zbar-statistic	2.354	1.649	lag=2
Prob	0.018	0.099	
Wald statistic	6.096	6.606	
Zbar-statistic	2.055	2.489	lag=3
Prob	0.039	0.012	

We notice that for lag=1 and lag=3 there is bi-directional causality between GDP and renewable energy for a significance of 5%. For lag=2 the causality is from GDP to RE. This result supports the feedback hypothesis between renewable energy consumption and economic growth in the CEE countries. GDP per capita is a factor conductive to the increase of the share of renewable sources in the energy mix, with a delay of one or 3 years and reciprocally, a higher share of renewable sources in the energy mix can induce economic growth.

5. Discussion

Based on data displayed in Annex 1 and the latest progress reports regarding renewable energy in the Member States, a discussion on the use of renewable energy in the CEE countries is provided below.

According to EUROSTAT data (2018 Energy balances), six CEE countries (Bulgaria, Croatia, Estonia, Latvia, Slovenia and Romania) exceeded in 2017 the EU-28 average share of renewable sources in the gross final energy consumption and Bulgaria and Estonia has overcome the EU-28 average speed of renewable energy adoption.

The advance of renewable sources in the final consumption is higher than the GDP per capita growth in seven CEE countries while Latvia, Lithuania, Croatia and Romania are excluded from this trend. The share of renewable sources in the final consumption is tripled in Hungary and doubled in the Czech Republic in the period 2004-2017. At the same time, the greenhouse gas (GHG) emissions declined in all countries, except Estonia and Latvia, where a slight increase of 3 to 8% is noticed (EUROSTAT, 2019 d). The reductions are ranging from 2.69% in Bulgaria to 25% in Romania (which registered the deepest decline of GHG emissions).

The levels of energy intensity across the CEE countries exceed the EU's average and the levels from the Western European part in 2017. The highest values are registered in Bulgaria (426.18 kgoe per thousand euro), Estonia (316.96) and Poland (232.22), compared with Ireland (54.7) Denmark (69.04) (EUROSTAT 2019e), indicating a lower energy efficiency and a large share of energy-intensive industries. To reduce the energy consumption and achieve the national targets assumed for 2020 and 2030 (based on Europe 2020 Strategy, Directive 2012/27/EU and Directive 2018/2002/EU on energy efficiency) renewable sources development could bring the needed impulse.

The contributions of renewable sources in the sectoral consumption increased during 2004-2017, in all eleven CEE countries. The largest share of renewable sources belongs to the heating and cooling sector in all countries, ranging from 14.48% (Poland) to 54.8% (Latvia) in 2017. The share of renewable sources in electricity production increased in all countries (e.g. Lithuania rose from 3.59% to 18.25% and Poland from 2.21% to 12.09%); and the highest values are registered in Latvia (54.36%), Croatia (46.42%) and Romania (41.63%). In the transport sector, renewable sources have a small share, of 7.24% in Bulgaria, 7.03% in Slovakia, and 6.56% in Romania. The electricity production mix is diversified over the examined period, from hydro-power plants as a unique source in 2004 to the wind, solar and biofuels. In Latvia and Estonia, solar energy was not capitalized while in other countries the contribution of this source increased from 0% in 2004 to 22.05% (Czech Republic) or 18.58% (Bulgaria). The share of wind energy in electricity production rose from 0% in 2004 to 54.61% in Lithuania, 10.17% in Hungary and 13.85% in Croatia. The increase of renewable sources in electricity production is accompanied by the reduction in GHG emissions in most countries (except Latvia and Poland). The GDP per capita growth is associated with increasing shares of renewable energy in the final consumption (i.e. Romania, Poland, Czech Republic and Slovenia) (Appendix 1; European Commission, 2017).

6. Conclusions and policy implications

The paper examined the impact of renewable energy consumption on economic growth in eleven CEE countries in the period of 1995-2015 through a multivariate panel analysis framework.

The results of the heterogeneous panel cointegration test reveal that there is a long-run equilibrium relationship between real GDP per capita, gross fixed capital formation, labor force and renewable energy consumption in CEE countries.

The estimation of panel FMOLS and DMOLS cointegrating equations show a valid positive impact of renewable energy consumption on economic growth. The long-run relationship indicates that 1 percent increase in renewable energy could lead to an increase in GDP per capita by 0.45 percent.

The panel causality analysis developed by Dumitrescu and Hurlin (2012) concludes a bi-directional causality relationship between renewable energy consumption and economic growth in CEE countries over 1995 -2015, meaning that economic growth stimulates the use of more renewable energy sources and renewable energy consumption fosters economic growth. This conclusion of feedback hypothesis is in line with other relevant studies exploring the relationship between renewable energy and growth in Europe (i.e., Apergis and Payne, 2010a, 2010b, 2011; Koçak and Şargüneşi, 2017).

The paper's results have several policy implications in CEE countries, as follows.

First, it reiterates the benefits associated with government policies in these countries aiming to foster investment in renewable energy (i.e. tax policy, incentives for renewable energy sources, financial aid for renewable energy systems, green certificates) and development of renewable industries, generating economic and social development and progress on achieving their sustainable development goals.

Second, a higher growth rate can sustain the investment in research and development regarding new renewable technologies (photovoltaic, smart grid systems) and stimulate the diversification of renewable energy sources (solar, wind, biomass).

Third, the governments of the 11 examined countries assumed national and European targets regarding renewable energy and carbon emissions while their economies grow by a rate that exceeds the EU average. Thus, specific policy measures regarding diversification of energy mix, reduction of fossil fuels, and reduction of import dependency are further motivated.

Fourth, even if notable progress was made in the reduction of GHG emissions, improving the air quality and thus in the decarbonization process, the share of renewable sources in the transport sector remains low. Therefore, appropriate policies (administrative, financial and informational measures) encouraging hybrid and electric cars, investments in research on clean transport technologies are further needed.

Fifth, supporting the increase of renewable sources in energy consumption will add to the efficiency of energy, based on the positive trend of energy productivity in these countries in the last years.

Sixth, in order to meet the 2020 renewable energy targets and sustain them as a baseline from 2020 to 2030, CEE countries must continue their efforts to deploy renewable sources across the three sectors while reducing energy intensity.

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Appendix 1

Country	GDP per capita (constant 2010 USD)	GHG emissions (thousand tones)	Renewable energy sources in the gross final consumption (%)	Renewable energy mix (consumption) (%)			Electricity generation from sources (%):			
				Share of renewable sources in Electricity	Share of renewable sources in Transport	Share of renewable sources in heating and cooling	Hydro	Wind	Solar	Solid biofuels
Bulgaria										
2004	5.152,41	63.804,99	9,45	9,09	0,88	14,6	99	1	0	0
2017	8.311,93	62.085,59	18,73	19,12	7,24	29,9	57,22	19,92	18,58	2,38
Czech Republic										
2004	16.930,19	151.575,11	6,86	3,69	1,57	9,93	71,3	0,37	0	22,44
2017	22.779,29	130.466,42	14,76	13,65	6,58	19,65	22,4	5,6	22,05	22,25
Estonia										
2004	13.346,40	19.468,63	18,36	0,47	0,18	33,22	0	27,05	0	58,8
2017	18.977,39	21.060,75	29,21	17,03	0,4	51,64	0	39,95	0	57,48
Croatia										
2004	12.603,86	29.839,24	23,41	35,03	0,99	29,44	99,92	0	0	0,08
2017	15.219,88	25.472,57	27,75	46,42	1,18	36,55	79,19	13,85	0,9	2,48
Latvia										
2004	9.717,11	11.375,04	32,79	45,96	2,14	42,49	97,31	1,45	0	0,18
2017	15.553,33	11.755,88	39,01	54,36	2,54	54,58	73,4	3,63	0	12,95
Lithuania										
2004	9.624,01	21.750,3	25,84	3,59	0,41	30,45	98,31	0	0	1,12
2017	16.793,25	20.737,67	17,22	18,25	3,69	46,5	19,91	54,61	3	13,53
Hungary										
2004	12.544,09	76.311,78	4,36	2,22	0,92	6,45	19,97	0,63	0	74,17
2017	15.647,85	64.488,77	13,33	7,49	6,45	19,64	6,75	20,5	10,17	48,04
Poland										
2004	9.610,44	403.839,42	6,91	2,21	1,44	10,21	65,2	3,67	0	28,3
2017	15.751,23	416.298,55	10,9	13,09	4,2	14,48	10,31	60,18	0,73	5,21
Romania										
2004	6.523,98	152.984,52	16,19	24,97	1,6	17,34	99,97	0	0	0,3
2017	10.932,33	114.811,43	24,47	41,63	6,56	26,58	64,7	25,93	7,3	1,8
Slovenia										
2004	21.218,25	20.274,74	16,13	29,27	0,85	18,36	97,15	0	0	1,92
2017	25.662,41	17.527,8	21,55	32,43	2,74	33,25	88,59	0	5,63	3,07
Slovak Republic										
2004	12.376,06	51.198,27	6,39	15,4	1,46	5,06	99,41	0	0	0,39
2017	19.897,15	43.482,84	11,49	21,34	7,03	9,94	66,05	0	7,78	16,6