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Cointegration and causality: considering Iberian economic activity sectors to test the environmental Kuznets curve hypothesis

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Abstract
Few studies have attempted to study the environmental Kuznets curve (EKC) hypothesis at the individual sector level using more than one sector at once. This paper investigates the existence of the EKC hypothesis in the Iberian countries (Portugal and Spain) using thirteen economic activity sectors for each, analyzing each individual sector's cointegration and causality relationships considering carbon dioxide (CO_2) emissions, sector gross value added and energy consumption. The findings of this paper using the autoregressive distributed lag (ARDL) approach only validate cointegration in six Portuguese sectors and in five of the Spanish sectors. Results confirm both short- and long-run bi-directional and unidirectional causality between economic growth, energy consumption and CO_2 emissions, using the error correction model (ECM) and Toda and Yamamoto's causality approaches. Moreover, results for Portuguese and Spanish sectors indicate an inverted U-shaped relationship only for one sector each. In some sectors there was evidence of a U-shaped relationship and in others the EKC hypothesis could be verified but no statistical significance was obtained. The study has significant contributions for sector policy, including implications to curtail energy pollutants by implementing environmental friendly regulations to sustain economic development at the sector level in the Iberian market. It also allows inferences to be made about the existence of different behaviors in comparative terms for the same economic activity sectors of the individual countries.

Keywords Economic activity sectors · Iberian market · Environmental Kuznets curve · Cointegration · Causality

JEL Codes C32 · O13 · Q43 · Q51 · Q54

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1 Introduction

The EKC (environmental Kuznets curve) hypothesis propounds that an inverted U-shaped relationship exists between environmental degradation and income. In this sense, it posits that environmental degradation increases up to some point as income decreases, known as the turning point, after which this degradation starts to decrease with an increase in income level. The EKC topic has drawn much academic interest for individual countries (Shahbaz et al. 2014), groups of countries (Fujii and Managi 2013; Pablo-Romero et al. 2017; Chiu 2017), different types of country groups like developed and emerging nations (Özokcu and Özdemir 2017) and for specific economic activity sectors (Alshehry and Belloumi 2017; Pablo-Romero et al. 2017), but very few for several economic activity sectors at once (Congregado et al. 2016; Moutinho et al. 2017) and even then, not considering a sector-by-sector approach as we do here. Özcan and Öztürk’s (2019) manual provides a comprehensive summary of EKC studies. This includes econometric advances, comprehensive literature reviews of case studies and some historical perspectives, exploring frequently-utilized proxies for environmental quality.

While it is relevant to study the hypothesis that CO_2 emissions decrease as further economic growth in a country occurs, it is even more interesting to know this at the sector level, as stated and indicated by Eurostat’s report on greenhouse gas emissions by industries and households (Eurostat 2016). For the EU-28 in 2014, the percentage of the total emissions in CO_2 equivalents of greenhouse gas emissions, by order, in electricity, gas, steam and air conditioning supply was 26%, 19% for manufacturing, 19% for households, 12% for agriculture, forestry and fishing, 11% in transportation and storage and also in other services, water supply and construction, and 2% for mining and quarrying. These amounts evidence considerable differences among sectors and justify the need to explore the EKC hypothesis at the individual sector level.

The Iberian, Portuguese and Spanish sectors were chosen given the availability of data in terms of common sectors, considering their geographic proximity and concerning the fact that both share a common electricity market (MIBEL—the Iberian electricity market), the goal of which is a free electricity competition zone to trade electricity. Moreover, their market dimensions are very different in geographical size and the Spanish economy is much greater than that of Portugal with respect to the number of enterprises operating within each sector, allowing us to see if there are different EKC behaviors among the same economic activity sectors of the two close but different economies (Moutinho et al. 2017). Shahbaz et al. (2014) argue that the validity of the EKC is debatable as it may depend on the unique country characteristics and that energy consumption, economic growth and pollutant emissions may be closely interrelated. As such, if this is valid for countries, it may also be extended to sectors.

In this paper we try to examine the causal relationships between income, energy consumption and CO_2 emissions and study their correlation at the sector level. The empirical analysis uses the autoregressive distributed lag (ARDL) approach to cointegration and the Toda-Yamamoto causality tests to validate the standard version of the EKC at the sectoral level in Portugal and Spain during the period 1975–2012. The results of this study would help policymakers in Iberian and similar markets to develop comprehensive energy and environmental policies to sustain economic growth in Portugal and/or in Spain. The book by Fuinhas and Marques (2019) provides a rich set of working tools (including databases and Stata and EViews codes) to understand advanced literature and current methodologies within the energy-growth nexus. Menegaki's (2018) manual combines the existing theory and practice to classify and summarize the literature and explain the econometrics of the energy-growth nexus, with advanced econometric examples. Menegaki (2019) provides a comprehensive review that suggests the steps to be followed to implement ARDL procedures regarding causality and robust analysis.

The contribution of this paper is that it takes into account potential advantages as compared to previous literature. This is the first study for Portugal and Spain where both cointegration and causality methods are applied in order to make the results robust, also being applied at the individual sector level. Moreover, the unit root properties are examined and we provide empirical evidence of the EKC by economic activity sector. Therefore, in light of the above specified goals, this study investigates and provides answers to the following questions: (i) Is there evidence of the EKC hypothesis for Portuguese and Spanish economic activity sectors? (ii) Is there causality between economic growth (using the gross value added (GVA) measure given that we present a sector analysis), CO_2 emissions and total energy consumption? (iii) Is there causality between sector-wise energy consumption (i.e. total energy consumption at the sector level), GVA growth and CO_2 emissions?

By using data at the individual sector level, we take a step forward with respect to previous literature given the scarcity of studies exploring the EKC hypothesis at the sector level. Different sectors have different productivity ratios and their specific set of characteristics justifies an analysis at the sector level. Moreover, the Iberian electricity market integration imposed common characteristics of both Portuguese and Spanish countries (Moutinho et al. 2017) such as the common Kyoto commitment and the commonality of economic activity sectors. However, the clear differences with respect to the number of companies inside each and their geographic dimension, the exciting period of economic turbulence and the common difficulties faced by both (although Portugal had a rescue plan) create a set of interesting and peculiar situations, making the study of the EKC hypothesis relevant in this context. Additionally, no other studies use such a large set of sectors for these countries, analyzing their causality and cointegration characteristics, which would give valuable insights for policymakers and for the adoption of specific political mitigation measures at the sector level. For a more detailed description of the context and motivation with respect to the selected sectors, see Moutinho et al. (2017).

The remainder of this paper is structured as follows: a review of the relevant literature is presented in Sect. 2. Section 3 presents the methods and the data, while Sect. 4 outlines and presents the empirical results. Section 5 provides a critical analysis of the results achieved, presenting conclusions and policy implications.

2 Relevant literature review

The study of the EKC hypothesis (the inverted U-shaped relationship between economic growth and environmental degradation) has drawn much academic interest. The goal has been basically to ascertain if environmental degradation and pollution increase in the early stages of economic growth, thus validating the EKC hypothesis. Some studies validate the hypothesis while others contradict it for the country, region, and individual economic activity sector or even the country group or set of joint sectors (Zhang et al. 2019a, b; Shahbaz and Sinha 2019; Sarkodie and Strezov 2019). Fewer studies have been applied to understand how different economic activity sectors behave with respect to cointegration and causality since different sectors behave differently with respect to CO_2 emissions, validating a study of this kind.

At the individual country level, we can find several studies exploring the EKC hypothesis, some in favor, and others refuting it. For a survey on the EKC hypothesis of the latter type, we refer to Dinda (2004) and since that time, there is no agreement in the literature regarding the income level at which environmental degradation starts declining. A conceptual overview, background history, policy and methodological critique is provided by the author. More recent surveys and replication for the emissions-growth nexus are those of Sheldon (2017) and of Shahbaz et al. (2017). The latter revised the CO_2-growth nexus using non-parametric econometric techniques applied to the G7 economies over nearly two centuries. More recently, Özcan and Öztürk (2019) provide a comprehensive summary of the EKC hypothesis and its econometric advances.

A detailed analysis of the EKC hypothesis is also provided by the recent literature surveys of Shahbaz and Sinha (2019) and Sarkodie and Strezov (2019). For the period 1991–2017, Shahbaz and Sinha (2019) provide a survey of the empirical literature on EKC estimation of CO_2 emissions. They conclude that the results of the EKC hypothesis estimation are inconclusive in nature, attributing this discrepancy to the choice of contexts, time period, explanatory variables and methodological issues. However, they noticed that CO_2 is one of the most studied pollutants in ecological economics and within the EKC hypothesis framework. For a summary of EKC model outcomes for the reviewed period, we refer to Tables 1, 2, 3, 4, 5 of their study.

Using bibliometric and meta-analysis, Sarkodie and Strezov (2019) reveal that the collection of studies where the inverted-U shaped relationship was identified, confirming the EKC hypothesis, has an average of US$ 8910 as the turning point of annual income level. They also present evidence for the presence of heterogeneity due to differences in the period of study and econometric methods used in model estimation. Table 1 of their study on pages 133–134 provides a compilation of studies of the EKC hypothesis. Studies with invalid EKC hypothesis (U-shaped, monotone, N-shaped) have an average turning point of US$ 5702, where Sarkodie and Strezov (2019) also noticed below average (US$ 8910) turning points for low- and middle-income countries, and above average for high-income countries.

Table 1 EKC studies chronology: national and regional level

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Lise and Montfort (2007)	Turkey	1970–2003	Cointegration	Cointegration between EC and GDP	No
Jalil and Mahmud (2009)	China (CE, EC, I, FT)	1975–2005	ARDL and Granger causality	Quadratic relationship between income and CO_2 emissions	Yes
Shahbaz et al. (2012)	Pakistan	1971–2009	Cointegration and causality	Long-run relationship	Yes
Saboori et al. (2012)	Malaysia	1980–2009	ARDL and VECM Granger causality	Unidirectional causality from EG to CO_2 emissions in the long-run	Yes
Tiwari et al. (2013)	India	1966–2009	ARDL and Granger causality	Long-run cointegration EKC in short and long-run	Yes
Shahbaz et al. (2014)	Tunisia	1971–2010	ARDL and VECM Cointegration and causality	Long-run relationship between EG, EC, TO and CO_2 emissions	Yes
Al-Mulali et al. (2015)	Vietnam	1981–2011	ARDL	RE consumption has no effect in reducing pollution	No
Jebli and Youssef (2015)	Tunisia	1980–2009	ARDL with structural breaks VECM	Do not find support for the EKC shape	No
Seker et al. (2015)	Turkey	1974–2010	ARDL, VECM and Granger causality	Long-run causality from all explanatory variables to CO_2 emissions	Yes
Menegaki and Tsagarakis (2015)	33 European members and candidate	1990–2010	Random effects model with Arellano Bond estimator	Identify the U-shape for the EKC only for RE and coal production	Yes, partially
Bento and Moutinho (2016)	Italy	1960–2011	ARDL and Granger causality	IT Granger causes CO2 emissions and nonrenewable electricity production per capita	Yes

Table 1 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Al-Mulali et al. (2016)	Kenya	1980–2012	ARDL	EC, GDP, urbanization and trade openness increase air pollution. Financial development reduces air pollution	Yes
Zambrano-Monserrate et al. (2016)	Equator	1971–2011	ARDL and Granger causality	Only GDP Granger causes energy consumption in the short-run	No
Ahmad et al. (2017)	Croatia (quarterly data)	1992–2011	ARDL and VECM	Inverted U-shape relationship between CO_2 and EG in long-run	Yes
Zoundi (2017)	25 African countries	1980–2012	Panel cointegration approach	CO_2 emissions are found to increase with income per capita	No
Ali et al. (2017)	Malaysia	1971–2012	ARDL and Granger causality	Only EC and emissions seem to have bidirectional relationships	Yes
Mrabet and Alsamara (2017)	Qatar	1980–2011	ARDL	Need to improve diversification (technology intensive and environmental-friendly) industries to improve environmental quality	No
Mrabet et al. (2017)	Qatar	1980–2011	ARDL	Use EF as an indicator of environmental degradation	No

Table 1 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Charfeddine (2017)	Qatar	1970–2015	Markov switching equilibrium correction model	Use EF, CO_2 emissions, EC and economic development	Yes
Benavides et al. (2017)	Austria	1970–2012	ARDL and cointegration tests	Use methane emissions and find unidirectional causality from these and variables involved	Yes
Chiu (2017)	99 countries	1971–2010	Panel smooth transition regression model	Evidence of the EKC for the three income groups	Yes
Pal and Mitra (2017)	China and India	1971–2012	ARDL	Probe cointegration between CO_2 emissions, economic growth, energy use and trade	Yes
Ouyang and Lin (2017)	China and Japan	1978–2011	Cointegration model Granger causality and VECM	Energy intensity is the most important factor influencing China's CO_2 emissions, followed by EG, cement manufacture and urbanization	Yes
Gokmenoglu and Taspinar (2018)	Turkey	1974–2010	ARDL bounds test Error correction model Causality tests	Validity of the pollution haven hypothesis, the scale effect and EKC	Yes
Esmaeilpour Moghadam and Dehbashi (2018)	Iran	1970–2011	ARDL and VECM	Financial development accelerates the degradation of the environment	No
Liu et al. (2019)	USA	1997–2015	Panel ARDL Quantile regressions	Income inequality reduces more carbon emissions in states with higher per capita carbon emissions	Yes

Table 1 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Sasana and Aminata (2019)	Indonesia	1990–2014	OLS	EG, primary EC and population growth positively affect CO_2 emissions. RE consumption negatively affects CO_2 emissions	No
Ganda (2019)	South Africa	1980–2014	Granger causality and VECM	Mixed findings depending over variables and if the analysis is for the short or long-run	Yes
Shahbaz et al. (2019)	87 countries	1970–2012	Cross-correlation approach	EKC validated for 16. A rise in globalization will increase carbon emissions	Yes
Hanif et al. (2019)	15 Asian countries	1990–2013	ARDL	Foreign direct investment is a source of environmental degradation. Reduce fossil fuel consumption and implement environmental friendly EG	Yes
Sarkodie and Ozturk (2020)	Kenya	1971–2013	ARDL, SIMPLS regression and U test	EC exacerbated CO2 emissions by 3.6% in the long-run RE consumption negates CO_2 emissions	Yes
Ullah and Khan (2020)	Pakistan	1972–2014	Johansen cointegration ARDL bounds testing Variance decomposition	The green revolution in Pakistan significantly causes carbon dioxide emissions	Yes

EG economic growth, *EC* energy consumption, *TO* trade openness, *CE* carbon emissions, *I* income, *FT* foreign trade, *RE* renewable energy, *ARDL* autoregressive distributed lag model, *VECM* vector error correction model, *EKC* environmental Kuznets curve hypothesis, *GDP* gross domestic product, *IT* international trade, *EF* ecological footprint

Tables 1 and 2 provide a chronology of national and regional (countries and groups) and economic activity sector EKC hypothesis studies, respectively, by publication date. It is evident from the tables that the results found change in accordance with the points identified by previous and recent authors' literature reviews. The use of CO_2 emissions within the EKC hypothesis framework is clear (Shahbaz and Sinha 2019; Özcan and Öztürk 2019). Therefore, other environmental indicators should also be used in the estimation of the EKC (Sarkodie and Strezov 2019).

Moreover, many recommendations derive from these already existent studies in general terms. Environmental quality can be improved by replacing obsolescent energy technologies for innovative and modern ones. Energy efficiency should improve by incorporating clean and energy technologies into the energy mix. Thus, the incorporation of renewable energy and/or cleaner fossil fuel energy technologies in the energy mix should be a priority. Sustainable development may be achieved through trade and foreign direct investment. Climate change mitigation requires the integration of climate change measures, as does their effective incorporation into national policies.

From both Tables 1 and 2 it is possible to infer a lack of studies at the economic activity sector level which are able to incorporate several sectors at once. In view of this literature review, we find that very little is known at the individual economic activity sector about cointegration and causality exploring the EKC hypothesis, providing evidence for the need for a deeper exploration of the issue.

3 Methods and data

Cointegration and causality analysis have recently being extensively applied. In this section we present the methods and the data which have been used to explore the EKC hypothesis at the Iberian sector level.

3.1 Data and variables specification

All data used for the analysis was collected from a total of 13 sectors in Portugal and Spain, for the period between 1975 and 2012. Although there is data available for CO_2 emissions until 2015 in the International Energy Agency (IEA), we collected data for this period since we wanted to capture the first transitory period of Kyoto (2005–2007) and the first effective period of the Kyoto implementation (2008–2012). The data for CO_2 emissions (defined in millions of tons of CO_2 equivalent) and of energy consumption (in millions of tons of oil equivalent—TOE) was collected from the Energy Balance Data of the IEA. Gross value added (GVA) data (defined in millions of euros) was collected from the national statistics office of each country. Following Shahbaz et al. (2014), we converted all the series into natural logarithms to obtain efficient and consistent results.

The sector classification was based on the International Standard Industrial Classification of All Economic Activities (ISIC) division. As stated by Alcantara (2007) and Alcantara and Duro (2004), CO_2 emissions through energy consumption may not be considered in the sectoral structure, i.e., data provided by the IEA discrimi-

Table 2 EKC studies chronology: economic activity sectors level

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Abdallah et al. (2013)	Transport sector, Tunisia	1980–2010	Cointegration techniques	Do not support the neutrality hypothesis	No
Fujii and Managi (2013)	10 different industries, OECD countries	1970–2005	Decomposition analysis	EKC hypothesis differs among industries in accordance to the type of fuel used	Yes/No
Congregado et al. (2016)	Commerce, electricity, industry, housing and transport sectors, USA	1973–2015	Dynamic ordinary least squares	Existence of EKC only when structural breaks are allowed Industrial sectors show a different pattern than do other sectors	Yes
Fujii and Managi (2016)	16 individual industrial sectors, industrial sector, 39 countries	1995–2009	Panel regressions	Relationship differs among industries depending over the pollution substance considered	Yes/No
Jebli (2016)	Rail transport, Tunisia	1990–2011	ARDL and Granger	Existence of long-term relationship. Both short and long-run causalities found	Yes
Xu and Lin (2016)	Manufacturing industry, 30 Chinese provinces	2000–2013	Nonparametric additive regression models	Specific EC has a positive U-shaped impact due to the difference in the speed of technological progress at different times	Yes
Samargandi (2017)	Saudi Arabia, Dominant GDP sectors	1970–2014	ARDL	The increase in value of growth in industry and services is responsible for a higher CO_2 emissions growth, opposite to the agriculture sector	Yes, partially

Table 2 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Alshehry and Belloumi (2017)	Saudi Arabia, Transport sector	1971–2011	Usual cointegration and causality procedures ARDL and Granger	Continuous economic growth only possible with continuous CO_2 emissions growth	No
Pablo-Romero et al. (2017)	Transport sector, UE-27 countries	1995–2009	Cointegration Feasible generalized least squares	Environmental quality changing point is not reached at any moment	No
Talbi (2017)	Transport sector, Tunisia	1980–2014	VAR model	Energy efficiency and the fuel tax over CO_2 emissions perform a dominant role in the decrease of CO_2 emissions	Yes
del Pablo-Romero and Sánchez-Braza (2017)	EU-28, Residential sector	1990–2013	Panel data models Multilevel mixed effects model. Elasticities.	Turning point reached in 5 European countries	Yes
Jebli and Belloumi (2017)	Maritime and rail transport, Tunisia	1980–2011	ARDL and Granger	Bidirectional short-run causality	Yes
Kharbach and Chfadi (2017)	Maroccan, Road transport sector	2000–2011	Cointegration VECM Decomposition analysis	Relationship between CO_2 emissions, EC and EG	Yes
Zafeiriou et al. (2017)	Agriculture sector, Bulgaria, Czech Republic, Hungary	1970–2014	ARDL	In the long-run for B and H; short-run for CR	Yes, in B and H
Jebli and Youssef (2017)	Agricultural sector, Tunisia	1980–2011	VECM and Granger	Bidirectional causality between agriculture value added, emissions and trade	No

Table 2 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Xu and Lin (2017)	Iron and Steel industry, 30 Chinese provinces	2000–2013	Nonparametric additive regression models	Energy efficiency improvement follows the EKC shape in relation to CO_2 emissions due to different R&D funding and personnel investments at different times	Yes
Moutinho et al. (2017)	13 economic activity sectors, Portugal and Spain	1975–2012	Panel data models	Do not study cointegration nor even causality for individual sectors	Yes
Aslan et al. (2018)	Commercial, electrical, industrial, residential and transportation. USA	1973–2015	Rolling-windows	EKC hypothesis not supported for the commercial and transport sectors	Yes, but not in all
Raza et al. (2019)	Residential, Next-11 and BRICS	1990–2015	Cointegration Fully modified OLS Heterogeneous panel causality	Significant and positive influence of residential EC, EG and financial development on environmental degradation To reduce CO_2 emissions there is an essential role of renewables	Yes
Zhang et al. (2019a, 2019b)	Manufacturing and construction industries, 121 countries	1960–2014	5 different EKC model estimations Turning points computed	EKC hypothesis validated by 95 countries Higher income countries reached turning points	Yes/No
Zhang et al. (2019a)	Agricultural sector, China	1996–2015	ARDL, Granger causality and VECM	Agricultural EC has both short and long-run negative impacts on agricultural carbon emissions	Yes

Table 2 continued

Authors	Applied to	Period	Methodology	Conclusion	EKC evidence?
Ahmad et al. (2019)	Construction sector, 30 Chinese provinces	2000–2016	STIRPAT	Urbanization-driven construction expansion impact identified. Long-run equilibrium relationship among variables	Yes
Ma and Cai (2019)	Commercial building sector, China	2001–2015	Decoupling methods EKC theory	Decoupling effects observed in recent years due to energy efficiency	Yes

EG economic growth, *EC* energy consumption, *TO* trade openness, *CE* carbon emissions, *I* income, *FT* foreign trade, *RE* renewable energy, *ARDL* autoregressive distributed lag model, *VECM* vector error correction model, *EKC* environmental Kuznets curve hypothesis, *B* Bulgaria, *CR* Czech Republic, *H* Hungary, *OLS* ordinary least squares, *STIRPAT* Stochastic Impacts by Regression on Population, Affluence, and Technology nates between CO_2 emissions by mean of transport and not by users. For this reason, we chose not to include the transport sector (divisions 60, 61 and 62). According to Alcantara (2007), we also decided not to include the residential sector (division 95) and the fisheries sector (division 05), since the data available of CO_2 emissions for these sectors is practically inexistent for the period between 1975 and 1990. The data respecting energy sector emissions, and from these values imputed to the other sectors, is given by the average CO_2 emissions coefficient estimated by IEA (Alcantara 2007).

Additionally, Marrero and Ramos-Real (2013) argue that the transport and the residential sectors should be analyzed separately because of their particular features. Energy use in the transportation sector is not considered within the trade and services sector, since a percentage of its use is due to domestic transportation which is not directly associated with any specific production activity. Moreover, the GVA of the transport sector is not comparable to transport consumption, since energy use in this sector is part of the companies and activities included in all economic sectors. Concerning residential sector energy use, it was also excluded from the data since it is not directly related to any specific production process (Marrero and Ramos-Real 2013; Lima et al. 2017; Moutinho et al. 2017). Summing up, the transport, residential and fisheries sectors were excluded from the study since their characteristics require a specific analysis that is outside the scope of this article. Moreover, by excluding these sectors from the analysis we avoid problems concerning the sector definition across CO_2 emissions, energy and economic variables. The literature reports the use of GVA to decompose energy intensity for Spain and the EU region in the transport section, but as evidenced by Mendiluce et al. (2010) and Marrero and Ramos-Real (2008), this is a bad proxy, since the inconsistency in sector definitions may cause large errors, leading to ambiguous conclusions (Huntington 2010). As an example, and as argued by Lima et al. (2017), if there is a prevalence of the more intensive sectors, there will be more energy needs over time, which will lead to an increase.

Considering the above, the sectors included in the study are agriculture and forestry (divisions 01 and 02), extractive (divisions 13 and 14), food and beverages (divisions 15 and 16), textiles and leather (divisions 17, 18 and 19), wood and its products (divisions 20), paper and printing (divisions 21 and 22), chemical and petrochemical (division 24), nonmetallic minerals (division 26), metallurgy and machinery (divisions 27, 28, 29, 30, 31 and 32), transport equipment (divisions 34 and 35), other industries (divisions 25, 33, 36 and 37), construction (division 45), and trade and services (divisions 41–50, 52–67, 70, 75, 80, 85, 90 and 93–99). CO_2 emissions from energy sectors (divisions 10, 12, 23 and 40) are allocated to each of the 13 above-mentioned productive sectors. Our sample was divided in 13 sectors from Portugal and the same 13 sectors from Spain, where we applied the cointegration approach as presented in the previous section.

3.2 Testing for stationarity

The first step in cointegration analysis is testing for unit roots. Unit root analysis is important in that it allows us to better understand the order of integration of each variable. In order to run the ARDL analysis and to satisfy the normality assumption of the ARDL bounds testing approach to cointegration, each variable must be integrated of order zero or of order one, hence I(0) or I(1). To validate this estimation approach, no variable can be integrated of order 2 so that the ARDL bounds test is based on the assumption that all variables are I(0) or I(1). Therefore, we need to ensure that they are not I(2) in order to avoid spurious regression results.

Unit root analysis is performed with the augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests which are asymptotically more robust in the absence of structural breaks than the break-based unit root testing approach (Dickey and Fuller 1979; Phillips and Perron 1988). On top of those traditional unit root tests, we also employ structural break unit root tests to assess that the variables are not I(2). It has become common practice to do both traditional and structural break unit root tests, but unlike other studies, this study tests for structural breaks in examining the long-run and short-run relationships of the EKC model. We compute both the Zivot and Andrews (1992) trended structural break unit root test and the Clemente et al. (1998) detrended structural break and unit root test. The inclusion of the former is to ascertain whether or not a structural break exists in the data, while the latter unit root test is used with two endogenous structural breaks to supplement both the traditional ADF and PP unit root tests. According to Zivot and Andrews (1992), the results of the conventional unit root tests may be reversed by endogenously determining the time of structural breaks. For this reason, they proposed the null hypothesis which is a unit root without any exogenous structural change, the alternative hypothesis being a stationary process that allows for a one-time unknown break in the intercept and/or the slope.

Moreover, we use the Gregory-Hansen residual based test for cointegration to detect the existence of a structural break by estimating the most general model with a regime shift, since the power of the Johansen test falls drastically when a structural break exists in the data (Johansen 1988; Gregory and Hansen 1996).

3.3 Testing for cointegration

We continue the cointegration tests using the autoregressive distributed lag bounds tests (ARDL) framework, which offers flexibility in such a way that it can be run on the I(1) or I(0) or I(1)/I(0) variables (Pesaran et al. 2001a, b; Turner 2006; Menegaki 2019). The cointegration relations among the variables used in this study were established within the ARDL framework. Break-periods detected in the structural breaks and unit root analysis were taken into account in estimating each of the ARDL models.

The ARDL bounds test approach to cointegration is based on the following unrestricted error correction models expressed as follows:

$$\Delta LY_t = \delta_0 + \delta_1 t + \sum_{i=1}^{m} \delta_{2i} \Delta LY_{t-i} + \sum_{i=0}^{n} \delta_{3i} \Delta LX_{t-i} + \delta_4 \Delta LY_{t-1} + \delta_5 \Delta LX_{t-1} + \varepsilon_{1t} \tag{1}$$

$$\Delta LX_t = \gamma_0 + \gamma_1 t + \sum_{i=1}^{m} \gamma_{2i} \Delta LX_{t-i} + \sum_{i=0}^{n} \gamma_{3i} \Delta LY_{t-i} + \gamma_4 \Delta LX_{t-1} + \gamma_5 \Delta LY_{t-1} + \varepsilon_{2t} \tag{2}$$

where Δ is the first difference operator and ε is the error term or residual term which is assumed to be serially independent, homoscedastic and normally distributed. All δ and γ coefficients are non-zero while δ_4 and γ_4 are expected to have a negative coefficient. The parameters δ_{2i} and δ_{3i} indicate the short-run coefficients, whereas δ_4 and δ_5 represent long-run coefficients in the ARDL model.

Lag selection of the ARDL model is selected by a criterion such as the Akaike information criterion (hereafter AIC). The joint significant F-test or Wald statistic of the lagged level variables is employed for investigating the existence of long-run behavior among the variables under scrutiny. The ARDL bounds testing approach to cointegration proposed by Pesaran et al. (2001a, b) is an econometric method that can be applied regardless of whether underlying regressors are purely integrated of order one or integrated of order zero, hence stationary. This means that the pre-testing problems associated with conventional cointegration, which require variables not to be stationary, can be overlooked.

Testing for cointegration is carried out by testing the null hypothesis of having no cointegration, H_0: $\delta_1 = \delta_2 = \cdots = \delta_n = 0$ against the alternative hypothesis, H_1: $\delta_1 \neq \delta_2 \neq \cdots \neq \delta_n \neq 0$, using the F-test. The variables are said to be cointegrated if the null hypothesis of no cointegration is rejected. Otherwise, the variables are not cointegrated. For this purpose, the two sets of critical values, one for the upper bound and another for the lower bound, are those tabulated by Pesaran et al. (2001a, b). If the existence of cointegration is confirmed in both equations above, the long-run and the short-run models are estimated and both long- and short-run elasticities are obtained.

Moreover, we further applied Kripfganz and Schneider (2018) for the estimation of autoregressive distributed lag (ARDL) models in a time-series context, using response surface regressions to obtain finite-sample and asymptotic critical values, as well as approximate p-values, for the lower and upper bound of all independent variables being purely $I(0)$ or purely $I(1)$ (and not mutually cointegrated), respectively. If the computed F-statistic exceeds the upper bound of the critical values, then the null hypothesis of no cointegration is rejected. If it is less than the lower bounds value, then the null hypothesis cannot be rejected, but if it falls between the two levels of the bands, the cointegration test becomes inconclusive. If the bounds test does not reject the null hypothesis of no long-run relationship, an ARDL model purely in first differences (without an equilibrium correction term) might be estimated. The validity of the bounds test relies on normally distributed error terms that are homoscedastic and serially uncorrelated, as well as on the stability of the coefficients over time.

After assuring both the non-stationarity of the variables of the equation and the presence of cointegration between them, it is possible to infer what deviations from the long-term equilibrium of the variables influence the short-term dynamics. The answer to these deviations can be represented by an error correction model (ECM), represented by the following re-parameterization Eq. (4) (ARDL (p, q,…,q) model):

$$y_{i,t} = c_0 + c_1 t + \sum_{k=1}^{p} \emptyset_{i,k} y_{i,t-k} + \sum_{k=0}^{q} \beta'_{i,k} X_{i,t-k} + u_{i,t} \tag{3}$$

in which $p \geq 1,\ q \geq 0$, q lag order equal to all variables in the vector $X_{i,t}$; i stands for the sector and t for the year. The conditional equilibrium correction is given by

$$\Delta y_{i,t} = c_0 + c_1 t - \alpha_i \left(y_{i,t-1} - \theta X_{i,t} \right) + \sum_{k=1}^{p-1} \varphi_{y_{i,k}} \Delta y_{i,t-k} + \sum_{k=0}^{q-1} \varphi'_{X_{i,k}} \Delta X_{i,t-k} + u_{i,t} \tag{4}$$

The speed of adjustment coefficient is given by: $\alpha_i = 1 - \sum_{j=1}^{p} \emptyset_{i,k}$ and long run coefficients by: $\theta = \frac{\sum_{j=0}^{q} \beta_{i,k}}{\alpha_i}$. In this study, particular attention is directed to the following two parameters: α_i and θ_i, namely the speed of adjustment from the error correction term and the vector of parameter of long-run equilibrium relationship. The long-run coefficients θ_i represents the equilibrium effects of the explanatory variables on the dependent variable, and in presence of cointegration, they correspond to the negative cointegration coefficients after normalizing the coefficient of dependent variable to unity. The negative coefficient, commonly known as the speed-of-adjustment, measures how quickly such an equilibrium distortion is corrected, in other words, how strongly the dependent variable reacts to a deviation from the equilibrium relationship in one period. It is expected that the term α_i would be different from zero and that this parameter would be significantly negative under the assumption that the variables return to their equilibrium in the long run. The short-run coefficients account for short-run fluctuations not due to deviation from the long-run equilibrium.

3.4 Causality approach

As argued by Menegaki (2019), the ARDL approach is more suitable for small samples as compared to Johansen and Juselius's cointegration methodology. Additionally, the author argues that the simultaneous estimation of short and long-run effects and the ability to test hypothesis on the estimated coefficients under ARDL in the long-run is not possible under the Engle-Granger method. Under no cointegration, a simple Granger causality might be followed (with the unrestricted vector autoregressive (VAR) model). With this, the Toda and Yamamoto (1995) test is a solution for Granger causality testing in this case. If cointegration is found (meaning there is a known and established theoretical relationship among variables) we need to proceed with the establishment of the error correction mechanism (ECM). Finding cointegration means that there is a known and established long-run relationship between the variables and their connection is a permanent one and not short-lived, being recovered any time when there is a disturbance.

Econometric analysis demands that we should apply the VECM model to explore the causal relationship between the variables once cointegration relationships are found between the series. The Granger representation theorem is conventionally applied by estimating the vector autoregressive (VAR) model. After the VAR definition with regard to the lags and deterministic components, it is of all interest to carry out causality tests. These will allow identification of the interdependence relations between the different variables and validating whether a multi-equational approach can be dispensed in favor of a uni-equational one. The concept of Granger causality (which refers strictly to the notion of precedence rather than to cause) may be useful in the specification of VAR models, insofar as it allows inferences to be made about the relevance of the inclusion of a certain explanatory variable in the VAR (Mello and Nell 2001; Ghosh 2002; Harris and Sollis 2003). Granger (1986) shows that if a pair of series, integrated of order one, are cointegrated, then there must be at least a unidirectional or bidirectional causality. It is argued by Granger (1969) that the VECM is the appropriate model to examine causality between the variables when the series are integrated of order one or I(1).

In case of bivariate Granger causality, one variable, for example y, is said to Granger-cause x if the values y_{t-1} contain information that helps foresee the value x_t. According to the data analyzed, the causality model will be represented by:

$$\begin{bmatrix} \ln CO_{2t} \\ \ln Y_t \\ \ln Y_t^2 \\ \ln EC_t \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} + \sum_{i=1}^{P} (1-L) \begin{bmatrix} b_{11i} & b_{12i} & b_{13i} & b_{14i} \\ b_{21i} & b_{22i} & b_{23i} & b_{24i} \\ b_{31i} & b_{32i} & b_{33i} & b_{34i} \\ b_{41i} & b_{42i} & b_{43i} & b_{44i} \end{bmatrix}$$

$$\times \begin{bmatrix} \ln CO_{2t-1} \\ \ln Y_{t-1} \\ \ln Y_{t-1}^2 \\ \ln EC_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \delta \\ \lambda \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \tag{5}$$

where (1 − L) indicates difference operator. The lagged residual term in the VECM model is indicated by ECT_{t-1} which is obtained from long-run relationships and the error terms (ε_i's) are supposed to be homoscedastic (of constant variance). The statistical significance of the coefficient associated with the lagged error term ECT_{t-1} using t-statistics evidences long-run causal relationships between the variables. CO_2 represents carbon emissions by sector, Y the sector gross value added (GVA) and Y^2 the GVA squared, while EC stands for energy consumption. The short run causality is shown by statistical significance of the F-statistic using the Wald test by including differenced and lagged differenced of independent (exogenous) variables in the VECM model. Finally, the joint significance of the lagged error term with differenced and lagged differences of independent variables ensures joint long- and short-run causality.

Toda and Yamamoto (1995) propose a simple procedure when economic time series are integrated of different orders, non-cointegrated, or when we have both cases. This approach is known as the Toda and Yamamoto augmented Granger causality procedure, which allows for causality between integrated variables to be tested based on asymptotic theory. This procedure requires the estimation of an "augmented" VAR, which guarantees the asymptotic distribution of the Wald statistic, namely an asymptotic χ^2 distribution, since the testing procedure is robust to the integration and cointegration process properties. We have followed Dritsaki (2017) in implementing this procedure, since this is recommended by Menegaki (2019) for small samples as in our case. The VAR model of Toda and Yamamoto causality is set up as (Dritsaki 2017):

$$
\begin{aligned}
y_{it} = \mu_{i,0} &+ \left(\sum_{k}^{j=1} \alpha_{1,i,t} y_{i,t-j} + \sum_{j=k+1}^{d_{max}} \alpha_{2,i,t} y_{i,t-j} \right) \\
&+ \left(\sum_{k}^{j=1} \beta_{1,i,t} X_{i,t-j} + \sum_{j=k+1}^{d_{max}} \beta_{2,i,t} X_{i,t-j} \right) + \varepsilon_{1,i,t}
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
y_{it} = \emptyset_{i,0} &+ \left(\sum_{k}^{j=1} \gamma_{1,i,t} y_{i,t-j} + \sum_{j=k+1}^{d_{max}} \gamma_{2,i,t} y_{i,t-j} \right) \\
&+ \left(\sum_{k}^{j=1} \delta_{1,i,t} X_{i,t-j} + \sum_{j=k+1}^{d_{max}} \delta_{2,i,t} X_{i,t-j} \right) + \varepsilon_{2,i,t}
\end{aligned}
\tag{7}
$$

where k is the optimal time lag on the initial VAR model and d_{max} is the maximum integration order on variables VAR systems (Dritsaki, 2017).

4 Empirical results

In the following section, we will discuss the results attained through initial specification tests and those associated with cointegration and causality analysis in order to infer from these results whether or not we are able to confirm the EKC hypothesis of an inverted U-shaped relationship at the individual sector level for each of the countries.

4.1 Results of unit root tests

In this section, we present the results of the analysis by testing the non-stationary and stationary hypothesis for all series in the 13 sectors. These tests are pursued by using the conventional augmented ADF unit root test and the PP unit root test, as presented in Tables 3 and 4, for Portugal and Spain, respectively.

For both ADF and PP tests, the premise is that the null hypothesis is non-stationary. In these conventional unit root tests, the rejection of one of the tests is usually consistent with the non-rejection of the other (Alcantara and Padilla 2009). Altogether, both unit root tests reveal that all variables series are integrated of order zero or of order one. Results are only presented (Tables 3 and 4) for the sectors in each country where cointegration relationships were found through ARDL bounds test (Tables 9, 10, 11, and 12).

A cointegration relationship was found for 8 sectors in Portugal and only in 6 for Spain. However, the cointegration decision was only validated in four of the sectors,

Table 3 Stationary tests for Portugal by economic activity sector

	Augmented Dickey-Fuller				Philips-Perron			
	Intercept		Trend and intercept		Intercept		Trend and intercept	
	Levels	1st differences	Levels	1st differences	Levels	1st differences	Levels	1st differences
Sector 3: Food and beverage								
CO_2	– 1.838	– 8.544***	– 1.548	– 8.900***	– 1.764	– 8.458***	– 1.327	– 9.097***
GVA	– 3.438**	– 4.845***	3.203	– 4.709***	– 3.464**	– 4.757***	– 3.262**	– 4.682***
GVA^2	– 3.303**	– 4.925***	– 3.100	– 4.876**	– 3.342**	– 4.841***	– 3.160	– 4.771***
Energy Cons.	– 1.479	– 8.275***	– 3.659**	– 8.219***	– 1.241	– 9.741***	– 3.651**	– 9.806***
Sector 4: Textile and leather								
CO_2	– 2.097	– 7.075***	– 2.357	– 7.045***	– 2.058	– 7.115***	– 2.311	– 7.122***
GVA	– 3.626**	– 3.011**	– 2.067	– 3.866**	– 3.103**	– 2.959*	– 1.981	– 3.855**
GVA^2	– 2.825*	– 3.230**	– 1.582	– 3.938**	– 2.535	– 3.228**	– 1.600	– 3.927**
Energy Cons.	– 2.384	– 5.756***	– 2.675	– 5.771***	– 5.752***	– 5.71*	– 2.758	– 5.767***
Sector 6: Paper and printing								
CO_2	– 1.960	– 6.110***	– 1.543	– 6.240***	– 1.954	– 6.138***	– 1.472	– 6.339***
GVA	– 2.151	– 5.263***	– 1.506	– 5.493***	– 2.516	– 5.261***	– 1.224	– 5.712***
GVA^2	– 1.758	– 5.526***	– 1.540	– 5.652***	– 1.969	– 5.627***	– 1.227	– 5.961***
Energy Cons.	– 1.133	– 5.758***	– 1.411	– 5.729***	– 1.135	– 5.755***	– 1.555	– 5.725***
Sector 7: Chemical and petrochemical								
CO_2	– 2.075	– 7.140***	– 2.048	– 7.635***	– 2.032	– 7.379***	– 2.086	– 7.724***
GVA	– 3.023**	– 6.300***	– 2.789	– 6.462***	– 3.057**	– 6.295***	– 2.809	– 6.455***
GVA^2	– 2.754*	– 6.362***	– 2.607	– 6.438***	– 2.824	– 6.358***	– 2.654	– 6.436***
Energy Cons.	– 2.474	– 6.850***	– 2.637	– 6.985***	– 2.374	– 7.128***	– 2.553	– 7.514***

Table 3 continued

	Augmented Dickey-Fuller				Philips-Perron			
	Intercept		Trend and intercept		Intercept		Trend and intercept	
	Levels	1st differences	Levels	1st differences	Levels	1st differences	Levels	1st differences
Sector 8: Non metallic miners								
CO_2	– 1.639	– 6.438***	– 1.665	– 6.465***	– 1.635	– 6.426***	– 1.822	– 6.457***
GVA	– 1.589	– 3.604**	0.166	– 3.842**	– 1.429	– 3.740***	– 0.670	– 3.947**
GVA^2	– 1.028	– 3.788***	– 0.763	– 3.803**	– 1.033	– 3.944**	– 1.536	– 3.944**
Energy Cons.	– 1.695	– 5.971***	– 1.703	– 6.033***	– 1.697	– 5.971***	– 1.912	– 6.034***
Sector 10: Transport equipment								
CO_2	– 1.256	– 6.428***	– 2.289	– 6.349***	– 1.225	– 6.433***	– 2.461	– 6.355***
GVA	– 0.651	– 4.138***	– 1.734	– 4.077**	– 0.821	– 4.063***	– 2.036	– 3.999**
GVA^2	– 0.646	– 4.302***	– 1.834	– 4.241**	– 0.801	– 4.217***	– 2.093	– 4.151**
Energy Cons.	– 1.138	– 5.356***	– 2.029	– 5.287***	– 1.169	– 5.331***	– 2.255	– 5.259***
Sector 11: Others industries								
CO_2	– 3.053**	– 7.171***	– 4.369***	– 7.078***	– 2.965**	– 7.767***	– 4.257**	– 7.658***
GVA	– 1.971	– 6.230***	– 3.085	– 6.320***	– 1.983	– 6.254***	– 3.223*	– 6.344***
GVA^2	– 1.612	– 6.076***	– 2.813	– 6.090***	– 1.608	– 6.089***	– 3.008	– 6.100***
Energy Cons.	– 4.334***	– 7.082***	– 4.244**	– 7.035***	– 4.199***	– 7.710***	– 4.094**	– 7.670***
Sector 12: Construction								
CO_2	– 1.074	– 7.750***	– 1.122	– 7.800***	– 1.063	– 7.586***	– 1.071	– 7.631***
GVA	– 1.375	– 5.268***	– 1.822	– 5.299***	– 1.389	– 5.331***	– 2.114	– 5.337***
GVA^2	– 1.281	– 5.491***	– 1.940	– 5.431***	– 1.306	– 5.565***	– 2.225	– 5.492***
Energy Cons.	– 1.142	– 8.359***	– 1.285	– 8.436***	– 1.119	– 8.077***	– 1.248	– 8.178***

Values presented are those of the statistical test results. ***, **, * denotes statistical significance at 1 per cent, 5% and 10%, respectively. The optimal lag length for the Augmented Dickey-Fuller unit root test is selected using the Akaike Information Criteria (AIC), while the bandwidth for the Philips-Perron stationary tests is selected using Newey (1987a, b)-West Barlett kernel

Table 4 Stationary tests for Spain by economic activity sector

	Augmented Dickey-Fuller				Philips-Perron			
	Intercept		Trend and intercept		Intercept		Trend and intercept	
	Levels	1st differences	Levels	1st differences	Levels	1st differences	Levels	1st differences
Sector 3: Food and beverage								
CO_2	– 0.550	– 7.766***	– 2.139	– 7.930***	– 0.345	– 7.730***	– 2.018	– 8.027***
GVA	– 1.477	– 4.839***	– 1.382	– 4.857***	– 1.483	– 4.855***	– 1.620	– 4.863***
GVA^2	– 1.290	– 4.986***	– 1.513	– 4.955***	– 1.335	– 4.991***	– 1.755	– 4.952***
Energy Cons.	– 1.309	– 3.429**	– 0.486	– 3.452*	– 1.471	– 3.674**	– 1.207	– 3.705**
Sector 4: Textile and leather								
CO_2	– 2.479	– 8.775***	– 3.449*	– 8.817***	– 2.463	– 8.907***	– 3.448*	– 9.041***
GVA	– 1.452	– 5.995***	– 2.621	– 5.911***	– 1.641	– 5.995***	– 2.903	– 5.915***
GVA^2	– 1.432	– 5.846***	– 2.705	– 5.762***	– 1.639	– 5.848***	– 2.995	– 5.765***
Energy Cons.	– 1.817	– 9.609***	– 2.869	– 9.465***	– 1.615	– 9.678***	– 2.889	– 9.535***
Sector 6: Paper and printing								
CO_2	– 0.283	– 6.839***	– 1.818	– 7.050***	0.090	– 7.048***	– 1.581	– 7.607***
GVA	– 0.820	– 5.211***	– 1.278	– 5.188***	– 0.819	– 5.244***	– 1.747	– 5.222***
GVA^2	– 0.469	– 4.866***	– 1.595	– 4.796***	– 0.538	– 4.895***	– 1.937	– 4.828***
Energy Cons.	– 1.533	– 6.581***	– 1.347	– 6.620***	– 1.537	– 6.572***	– 1.484	– 6.606***
Sector 8: Non metallic miners								
CO_2	– 0.094	– 6.852***	– 1.757	– 7.047***	– 0.022	– 6.804***	– 1.717	– 7.030***
GVA	– 0.956	– 4.422***	– 1.156	– 4.415***	– 0.977	– 4.406***	– 1.741	– 4.403***

Table 4 continued

	Augmented Dickey-Fuller				Philips-Perron			
	Intercept		Trend and intercept		Intercept		Trend and intercept	
	Levels	1st differences	Levels	1st differences	Levels	1st differences	Levels	1st differences
GVA^2	– 0.793	– 4.225***	– 1.389	– 4.179**	– 0.893	– 4.202***	– 1.878	– 4.158**
Energy Cons.	– 1.418	– 7.871***	– 2.205	– 7.751***	– 1.344	– 7.775***	– 2.177	– 7.661***
Sector 10: Transport equipment								
CO_2	– 0.952	– 7.235***	– 2.583	– 7.128***	– 0.872	– 7.244***	– 2.680	– 7.137***
GVA	– 1.069	– 5.422***	– 2.066	– 5.354***	– 1.122	– 5.413***	– 2.328	– 5.347***
GVA^2	– 1.030	– 5.159***	– 1.920	– 5.093***	– 1.118	– 5.156***	– 2.236	– 5.093***
Energy Cons.	– 1.532	– 4.008***	– 1.491	– 4.051**	– 1.532	– 3.719***	– 1.660	– 3.766**
Sector 11: Others industries								
CO_2	– 0.065	– 6.389***	– 1.559	– 7.097***	– 0.050	– 6.374***	– 1.455	– 7.173***
GVA	– 0.867	– 3.562**	– 0.807	– 3.537*	– 0.840	– 3.471**	– 1.417	– 3.444*
GVA^2	– 0.330	– 3.451**	– 1.275	– 3.399*	– 0.456	– 3.376**	– 1.708	– 3.322*
Energy Cons.	– 1.994	– 4.726***	– 2.458	– 4.645***	– 2.167	– 4.618***	– 2.696	– 4.527***

Values presented are those of the statistical test results. ***, **, * denotes statistical significance at 1 per cent, 5% and 10%, respectively. The optimal lag length for the Augmented Dickey-Fuller unit root test is selected using the Akaike Information Criteria (AIC), while the bandwidth for the Philips-Perron stationary tests is selected using Newey-West Barlett kernel with these being common in both countries: textile and leather, paper and printing, nonmetallic minerals and transport equipment. Both Tables 3 and 4 validate the existence of stationarity in the variables at their first differences.

In order to confirm the stationarity tests performed and presented in Tables 3, 4, Table 5, 6 presents (5 for Portugal and 6 for Spain) the Zivot-Andrews structural break unit root tests for Portugal and Spain by economic activity sector. Results reveal different breaks in different time periods in different economic activity sectors.

Additionally, we present the Clemente Montanes Reyes structural break unit root test results in Tables 7 and 8, with mean drift for Portuguese and Spanish economic activity sectors respectively. Using this type of test it can be noticed that variables are stationary at levels. Still, we have different significance levels for variables depending in the country and sector; they are not consistent and make it impossible to generalize stationarity for all variables, as occurs with the variable energy consumption, mostly noticed within the Zivot-Andrews structural break unit root test. It is also noticed from the results presented in Tables 5, 6, 7, and 8 that different time breaks are identified over sectors depending on the test implemented, not allowing a common pattern to be established.

4.2 Results of cointegration tests

We start this section by presenting the results for the Gregory-Hansen test for cointegration which considers regime shifts. Table 9 reports the results for Portuguese sectors and Table 10 for Spanish sectors. For Portugal, cointegration is only validated for sector 3 using break regime and trend (valid for sectors 8, 10, 11 and 12 also). Considering the break regime solely, sectors 8, 10, 11 and 12 reveal cointegration among the variables under study to validate the EKC hypothesis. For Spain the situation is different, where we only find evidence of cointegration in sector 4, considering the break regime and trend. Sectors 6, 8 and 10 reveal cointegration among variables under study considering both break regime and break regime and trend.

To confirm the results obtained in Tables 9, 10, Tables 11 and 12 present the results of the ARDL bounds test for Portugal and Spain, respectively. Critical values reported in Table 11 and 12 for F-statistic and t-statistic are validated with significance and we are only able to confirm the existence of long-run relationships in 6 sectors in Portugal and only for four in Spain. The null hypothesis for all the tests is the existence of no cointegration. In the EKC hypothesis in the quadratic formulation and considering the tested relations proposed, the null hypothesis of no cointegration among the variables for the economic activity sectors sample in Portugal and Spain was not always rejected with a level of 5% of significance.

According to the ADRL bounds tests presented in Table 11 (Portugal), cointegration results are not conclusive at 10% for food and beverage and other industries. However, for the sectors of textiles and leather, paper and printing, chemical and petrochemical, nonmetallic minerals, transport equipment and construction the results are in favor of cointegration.

For the Spanish economic sectors, the results presented in Table 12 evidence cointegration for all four sectors at the 1% significance level: textiles and leather, paper

Table 5 Zivot–Andrews structural break unit root test—Portuguese economic activity sectors

Spain sector 4/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
CO_2	– 1.464	1989	– 9.711***	1989
GVA	– 5.222**	1990	– 5.163**	1984
GVA^2	– 5.180**	1990	– 5.374***	1984
Energy cons.	– 4.622**	1996	– 6.227***	2004
Portugal sector 4/variables				
CO_2	– 3.797	1991	– 7.161***	2004
GVA	– 4.159*	1990	– 4.312*	1994
GVA^2	– 4.251*	1990	– 4.205*	2000
Energy cons.	– 3.176	1989	– 5.748***	2005
Portugal sector 6/variables				
CO_2	– 4.021*	2000	– 6.402***	1993
GVA	– 4.166*	1997	– 7.316***	1988
GVA^2	– 3.762	1997	– 7.671***	1988
Energy cons.	– 2.687	1998	– 6.290***	1991
Portugal sector 7/variables				
CO_2	– 3.681	2006	– 8.114***	2006
GVA	– 3.099	1990	– 6.831***	1994
GVA^2	– 3.102	1990	– 6.667***	1994
Energy cons.	– 2.350	2006	– 7.380***	2003
Portugal sector 8/variables				
CO_2	– 2.889	2003	– 6.835***	2006
GVA	– 3.415	2006	– 4.722**	1999
GVA^2	– 2.806	2006	– 4.792**	1998
Energy cons.	– 2.306	2006	– 6.568***	2000
Portugal sector 10/variables				
CO_2	– 3.126	2001	– 6.558***	1998
GVA	– 2.665	1984	– 4.449**	1997
GVA^2	– 2.664	1984	– 4.828**	1997
Energy cons.	– 2.330	2002	– 5.487***	1998
Portugal sector 11/variables				
CO_2	– 4.420**	2006	– 6.999***	2000
GVA	– 3.502	2006	– 6.401***	1982
GVA^2	– 3.066	2006	– 6.188***	2005
Energy cons.	– 4.343*	2006	– 7.033***	2006
Portugal sector 12/variables				
CO_2	– 2.916	2006	– 9.779***	1996
GVA	– 3.503	2002	– 5.343***	1999

Table 5 continued

Spain sector 4/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
GVA^2	− 3.312	2002	− 5.540***	1999
Energy cons.	− 3.013	2003	− 3.706	1996

The level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and at 10% by *. The critical value at 1% is − 5.34, at 5% is − 4.80 and 10% is − 4.58. The maximum lag order is 4. The unit root test has a structural break in the intercept

Table 6 Zivot –Andrews structural break unit root test—Spanish economic activity sectors

Spain sector 4/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
CO_2	− 5.481***	1984	− 9.350***	2001
GVA	− 3.742	2003	− 6.242***	2006
GVA^2	− 3.787	2003	− 6.054***	2006
Energy cons.	− 3.073	1993	− 11.613***	2001
Spain sector 6/variables				
CO_2	− 3.769	1984	− 7.052***	1989
GVA	− 1.743	1997	− 6.089***	1986
GVA^2	− 2.966	2000	− 5.459***	2006
Energy cons.	− 2.446	1999	− 1.007	2006
Spain sector 8/variables				
CO_2	− 3.375	2000	− 7.756***	1995
GVA	− 3.005	1999	− 5.018**	1986
GVA^2	− 3.265	1999	− 4.493	1997
Energy cons.	− 3.845	2000	− 8.446***	2006
Spain sector 10/variables				
CO_2	− 4.718*	1998	− 7.962***	1997
GVA	4.150	1997	− 6.384***	1994
GVA^2	− 4.041	1997	− 5.985***	1994
Energy cons.	− 3.268	1997	− 5.063**	2004
Spain sector 11/variables				
CO_2	− 4.026	2004	− 7.232***	2006
GVA	− 3.050	1995	− 4.357	2001
GVA^2	− 3.626	1997	− 4.313	2002
Energy cons.	− 4.039	1989	− 4.653*	1989

The level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and at 10% by *. The critical value at 1% is − 5.34, at 5% is − 4.80 and 10% is − 4.58. The maximum lag order is 4. The unit root test has a structural break in the intercept

Table 7 Clemente Montanes Reyes structural break unit root test with mean shift: Portuguese economic activity sectors

Portugal sector 3/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
CO_2	8.448***	1986	– 1.338	2004
GVA	2.201**	2005	– 2.155**	1980
GVA^2	2.213**	2005	– 1.968*	1980
Energy cons.	10.973***	1993	– 0.676	2000
Portugal sector 4/variables				
CO_2	11.259***	1986	– 1.373	1991
GVA	5.434***	1987	– 5.152***	1989
GVA^2	5.417***	1987	– 4.739***	1991
Energy cons.	6.858***	1983	– 0.440	2003
Portugal sector 6/variables				
CO_2	11.629***	1988	– 1.490	1997
GVA	12.404***	1987	– 1.603	1993
GVA^2	12.514***	1987	– 1.505	1994
Energy cons.	15.283***	1991	0.703	1988
Portugal sector 7/variables				
CO_2	6.623***	1983	– 1.754*	2008
GVA	2.296**	1987	– 1.663*	1991
GVA^2	2.115**	1987	– 1.469	1991
Energy cons.	4.632***	1995	– 1.333	2003
Portugal sector 8/variables				
CO_2	10.115***	1993	– 1.611	2001
GVA	12.364***	1992	– 2.667**	2010
GVA^2	10.412***	1998	– 2.634**	2010
Energy cons.	12.465***	1995	– 0.942	2005
Portugal sector 10/variables				
CO_2	11.301***	1994	– 0.087	1995
GVA	12.567***	1997	1.336	1994
GVA^2	12.863***	1997	1.286	1994
Energy cons.	12.582***	1994	0.382	1995
Portugal sector 11/variables				
CO_2	4.588***	2000	– 0.421	1994
GVA	7.500***	1991	– 1.032	1991

Table 7 continued

Portugal sector 3/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
GVA^2	9.331***	1998	– 0.774	1991
Energy cons.	– 0.571	1992	– 0.482	1990
Portugal sector 12/variables				
CO_2	13.798***	1992	– 1.595	2004
GVA	11.632***	1994	– 2.043	2001
GVA^2	12.089***	1994	– 1.199	1999
Energy cons.	13.779***	1991	– 1.680	2000

The level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and at 10% by *. The maximum lag order is 4. The unit root test has a structural break in the intercept

and printing, nonmetallic minerals, transport equipment and other industries. The nonmetallic minerals sector in Spain is considered cointegrated if we take the significance level of 5% into account. Even so, at the limit we can say that we have four common sectors among the two countries where cointegration is found, and we will consider both as important for Spain in the following estimations.

Considering the reported F-statistic, if values are higher than the upper critical bounds generated by Pesaran et al. (2001a, b), the results for the Portuguese and Spanish economic sectors validate the EKC approach and favor cointegration for the variables CO_2 emissions, GVA, GVA quadratic and energy consumption included in the specification.

Estimations in Tables 13 and 14 present the ADRL unrestricted error correction model estimation results, following Menegaki (2019), for Portuguese economic activity sectors. Table 13 reports the short- and long-run parameters of the EKC approach for the cointegrated sectors in Portugal and Spain. The EKC hypothesis states that as GVA increases, CO_2 emissions will also increase until a certain level of GVA and after that level they are supposed to decline. Our results follow this hypothesis, as expected. To verify the shape of the EKC, we must observe the coefficient sign attained (Dinda 2004).

The simplified log linear relationship between the variables is specified as: $\ln CO_{2t} = \beta_0 + \beta_1 .\ln Y_t + \beta_2 .\ \mathrm{Ln}\ Y_t^2 + \beta_3 .\ln EC_t + \varepsilon_t$ (the error term being normally distributed in time period t and β_0 being a constant term). If β_1 is significantly positive and β_2 significantly negative, we obtain an inverted U-shaped function. Otherwise, if β_1 is significantly negative and β_2 significantly positive, the result is a U-shaped function. For the Portuguese sector specification that estimates the EKC hypothesis, we can verify that GVA and energy consumption variables have a positive effect upon CO_2 emissions and are both statistically significant at 1% only in the nonmetallic minerals. Therefore, we can only validate the EKC hypothesis in this sector and we found no U-shaped relationship for the rest of the cointegrated sectors in the long run. Energy consumption effect over CO_2 emissions is significant for all economic activity sectors where cointegration was found and has the expected positive sign, except in paper

Table 8 Clemente Montanes Reyes structural break unit root test: Spanish economic activity sectors

Spain sector 4/variables	At level		At 1st difference	
	t-statistic	Time-break	t-statistic	Time-break
CO_2	4.689***	1994	0.421	1979
GVA	– 8.764***	2003	1.517	2008
GVA^2	– 8.426***	2003	1.416	2008
Energy cons.	11.252***	1992	– 0.763	1998
Spain sector 6/variables				
CO_2	10.808***	1999	– 1.142	1986
GVA	10.594***	1993	– 2.214**	2007
GVA^2	12.678***	1997	– 2.255**	2007
Energy cons.	10.174***	1996	– 3.820***	2009
Spain sector 8/variables				
CO_2	12.290***	2002	1.788	1995
GVA	10.637***	1994	– 3.484***	2008
GVA^2	9.097***	2002	– 2.956***	2007
Energy Cons.	10.732***	1997	– 0.808	2004
Spain sector 10/variables				
CO_2	15.001***	1997	– 0.056	1998
GVA	14.616***	1996	– 0.080	1995
GVA^2	14.699***	1996	0.058	1995
Energy cons.	11.039***	1997	– 3.045***	2010
Spain sector 11/variables				
CO_2	9.817***	2001	1.857*	1990
GVA	13.721***	1996	– 1.921*	2007
GVA^2	15.663***	1996	– 1.790*	2007
Energy cons.	4.387***	1991	– 0.152	2004

The level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and at 10% by *. The maximum lag order is 4. The unit root test has a structural break in the intercept

and printing. For the five cointegrated sectors in Spain, GVA is always statistically except in transport equipment and significant, although negative, in textiles and leather, nonmetallic minerals and other industries (Table 14).

The results for the Spanish sector paper and printing reveal the validity of the EKC hypothesis. However, a U-shaped relationship is found for the sectors textiles and leather and other industries in Spain considering the long-run. As such, pollution increases in Spain as the sectors textiles and leather and other industries develop (GVA decreases once the threshold GVA is reached and it begins to increase afterwards, once the GVA of the sector starts a growth trajectory).

Therefore, we were able to find only one inverted U-shaped relationship for one cointegrated sector in each country in the long run. This means that the GVA levels are very high, initially increasing CO_2 emissions and reduce them as the sector matures.

Table 9 Gregory–Hansen test for cointegration with regime shifts at sectoral level for Portugal

Portugal—sector 3	Break regime		Break regime and trend	
	Zt statistic	Time-break	Zt statistic	Time-break
CO_2, GVA, GVA Quad, Energy cons.	– 4.82	1984	– 6.50**	1990
Portugal—sector 4				
CO_2, GVA, GVA Quad, Energy cons.	– 5.54	1984	– -5.21	1988
Portugal—sector 6				
CO_2, GVA, GVA Quad, Energy cons.	– 5.04	2006	– 5.21	2003
Portugal—sector 7				
CO_2, GVA, GVA Quad, Energy cons.	– 5.35	1984	– 5.02	1990
Portugal—sector 8				
CO_2, GVA, GVA Quad, Energy cons.	– 7.70***	1995	– 7.60***	1994
Portugal—sector 10				
CO_2, GVA, GVA Quad, Energy cons.	– 5.92*	1984	– 6.48**	1990
Portugal—sector 11				
CO_2, GVA, GVA Quad, Energy cons.	– 6.78***	1984	– 8.07***	1990
Portugal—sector 12				
CO_2, GVA, GVA Quad, Energy cons.	– 5.94**	2004	– 6.73**	1982

The level of statistical significance of 1% is denoted by *** 5% is denoted by ** and 10% is denoted by *. The maximum lag order is 4. The cointegration test has a structural break in the intercept

Table 10 Gregory–Hansen test for cointegration with regime shifts at sectoral level for Spain

Spain—sector 4	Break regime		Break regime and trend	
	Zt statistic	Time-break	Zt statistic	Time-break
CO_2, GVA, GVA Quad, Energy cons.	– 4.03	1988	– 6.78**	1995
Spain—sector 6				
CO_2, GVA, GVA Quad, Energy cons.	– 6.30**	1999	– 6.51**	1989
Spain—sector 8				
CO_2, GVA, GVA Quad, Energy cons.	– 5.90*	2004	– 6.87***	1992
Spain—sector 10				
CO_2, GVA, GVA Quad, Energy cons.	– 6.65***	2003	– 6.76**	2003
Spain—sector 11				
CO_2, GVA, GVA Quad, Energy cons.	– 5.47	1984	– 6.01	1990

The level of statistical significance of 1% is denoted by *** 5% is denoted by ** and 10% is denoted by *. The maximum lag order is 4. The cointegration test has a structural break in the intercept

The overall adjustment of the models for both countries is high (R^2 and adjusted R^2) and in most economic activity sectors (sector 4 in Portugal is an exception with values lower than 50%).

For Portugal, transport equipment and construction and transport equipment in Spain have coefficient signs evidencing an inverted U-shaped relationship, although

Table 11 ARDL bounds test for investigating long run equilibrium relationships for Portugal

Sectors	ARDL specification	F-statistic	K	Case	t-statistic	Cointegration decision
Sector 3	ARDL (1, 0, 0, 0)	3.256	3	3	– 3.472*	Non conclusive
Sector 4	ARDL (1, 0, 0, 0)	4.488**	3	3	– 3.954**	Yes
Sector 6	ARDL (4, 3, 3, 4)	6.334***	3	3	– 4.468***	Yes
Sector 7	ARDL (2, 0, 0, 0)	7.757***	3	3	– 4.491***	Yes
Sector 8	ARDL (1, 1, 1, 1)	5.852***	3	3	– 4.639***	Yes
Sector 10	ARDL (1, 0, 0, 0)	7.979***	3	3	– 4.929***	Yes
Sector 11	ARDL (4, 2, 4, 2)	3.612	3	3	– 2.676	Non conclusive
Sector 12	ARDL (4, 4, 4, 4)	6.181***	3	3	2.031***	Yes

For the bounds test, the asymptotic critical value bounds are taken from Pesaran et al. (2001a, b), with unrestricted intercept and no trend with max lags k in dependent variable and regressors equal to 4. *, **, *** statistically significant at 10%, 5% and 1%, respectively

Table 12 ARDL bounds test for investigating long run equilibrium relationships for Spain

Sectors	ARDL specification	F-statistic	K	Case	t-statistic	Cointegration decision
Sector 4	ARDL (1, 0, 0, 0)	23.884**	3	3	– 9.791***	Yes
Sector 6	ARDL (1, 3, 0, 1)	6.380***	3	3	– 4.361***	Yes
Sector 8	ARDL (2, 4, 3, 3)	4.977**	3	3	– 4.387**	Yes
Sector 10	ARDL (1, 3, 1, 2)	7.453***	3	3	– 4.493***	Yes
Sector 11	ARDL (1, 3, 3, 4)	5.522***	3	3	– 4.282***	Yes

For the bounds test, the asymptotic critical value bounds are taken from Pesaran et al. (2001a, b), with unrestricted intercept and no trend with max lags k in dependent variable and regressors equal to 4. *, **, *** statistically significant at 10%, 5% and 1%, respectively

not statistically significant. This happens in the long run, providing evidence of the existence of an EKC curve only in two of the sectors and one for each country (sector 8 in Portugal and 6 in Spain, nonmetallic minerals and paper and printing, respectively).

The cointegration form of the autoregressive distributed lag model is statistically significant at the 1% level and has the correct and expected sign, although not in all sectors (it is not the case in Portugal for sector 12 and in sectors 8 and 10 in Spain). Being negative means that the variables will converge towards long-run equilibrium. The error correction mechanism is of statistical significance, which means that if the system is exposed to a shock, the speed of adjustment to a long-run equilibrium occurs with a relatively high convergence speed. For example, in the textile and leather sector, the values of the term ECT_{t-1} for Portugal (– 0.5181) and for Spain (– 1.0825), implies that the CO_2 emissions value is corrected by 52% and 108% each year, respectively, due to the adjustment from the short towards the long run.

Subsequently, all the familiar regress post-estimation results are presented in Table 15 for both countries. The heteroscedasticity test was performed by Breusch-Pagan/Cook Weisberg test (BP/CW Test) and White test and we can see that we cannot reject H0 of no serial correlation in all sectors/countries were cointegration was found. The same happens with the normality test where Cameron and Trivedi's decomposition of normality including heteroscedasticity, Skewness and Kurtosis tests were

Table 13 Estimation results for the ADRL unrestricted ECM estimation results for Portugal

Short run	Sector 4	Sector 6	Sector 7	Sector 8	Sector 10	Sector 12
D1 CO_2		– 1.05798***				
LD CO_2		0.47478**	– 0.21491***			– 1.54320***
LD2 CO_2		0.47157*				– 1.73018***
LD3 CO_2						– 1.1459***
D1 GVA		– 2.65186		– 7.35466	– 0.02343	– 0.030261*
LD GVA		6.9067			0.06567*	0.37032**
LD2 GVA		– 15.449***				– 0.148199
LD3 GVA						0.63617***
D1 GVA^2		0.000346		0.002665*		0.000033**
LD GVA^2		-0.002870				-0.000521***
LD2 GVA^2		0.006102***				0.000016
LD3 GVA^2						– 0.00008***
D1 Energy C		0.195515		– 1.12294		5.2611***
LD Energy C		– 0.27056				6.01464***
LD2 Energy C		0.024630*				6.39242***
LD3 Energy C		– 0.664687				3.72504***
ECt-1	– 0.5181***	– 1.35908***	– 0.4564***	– 1.0452***	– 0.5958***	0.47844**
Long run	**Sector 4**	**Sector 6**	**Sector 7**	**Sector 8**	**Sector 10**	**Sector 12**
GVA	– 1.04329	– 4.884538	– 15.6394	4.85117***	0.179079	0.407484
GVA^2	0.000254	0.002681	0000641***	– 0.0019***	– 0.000130	– 0.00006*
Energy Cons.	2.60063***	– 0.07754	4.97892***	3.43959***	4.9164***	4.2439***
R^2	0.3824	0.7858	0.553	0.6312	0.6834	0.9682
Adjust R^2	0.2972	0.5582	0.474	0.5319	0.6131	0.9250

*, **, *** mean statistically significance at 10%, 5%, and 1%, respectively. ECT (-1) is the one period lagged cointegrating error term

Table 14 Estimation results for the ADRL unrestricted ECM estimation results for Spain

Short run	Sector 4	Sector 6	Sector 8	Sector 10	Sector 11
D1 CO_2					
LD CO_2			0.42272*		
LD2 CO_2					
LD3 CO_2					
D1 GVA	9.7387***	– 0.7855***	6.05865**	– 0.3298*	1.687891
LD GVA	8.5710***	– 0.6121**	6.66050**	– 0.1510**	3.92590*
LD2 GVA	2.729567*	– 0.43527*	7.62896**	– 0.13417**	3.021172
LD3 GVA	4.79159***		1.59693*		
D1 GVA 2	– 0.00075***		– 0.0005***	0.000012	-0.000117
LD GVA 2	– 0.00066***		– 0.00059**		– 0.00029**
LD2 GVA 2	– 0.000233*		– 0.00058**		– 0.000204*
LD3 GVA 2	– 0.000374***				
D1 Energy C		0.610897*	– 0.2583	– 0.29095	– 0.96647*
LD Energy C			– 0.79665	– 0.56073	– 1.30753***
LD2 Energy C			0.555456		– 0.955954**
LD3 Energy C					– 0.524514*
ECt-1	– 1.0825***	– 0.8249***	1.284***	0.7494***	– -0.9648***
Long Run	**Sector 4**	**Sector 6**	**Sector 8**	**Sector 10**	**Sector 11**
GVA	– 10.117***	1.1786***	– 4.6728***	0.35579	– 6.3964***
GVA 2	0.000789***	– 0.0001***	– 0.0004***	– 0.81e–06	0.00036***
Energy C	2.64449***	– 0.112967	0.99074**	0.883078	2.1269***
R^2	0.8642	0.6299	0.7880	0.6797	0.7481
Adjust R^2	0.7907	0.5114	0.6113	0.5405	0.5625

*, **, *** mean statistically significance at 10%, 5%, and 1%, respectively. ECT (– 1) is the one period lagged cointegrating error term

used. We were unable to reject the null hypothesis for all sectors. Serial correlation was tested by Durbin's alternative test and Breusch–Godfrey test, and in all sectors we reject H0 except in 8 and 12 in Portugal. Finally, the structural breaks testing was used by cumulative sum test for parameter stability (SBcusum) and here for both Portugal (in all except 4) and Spain (in 6, 8 and 10) we are unable to reject H0.

In the next section we present the results of the Toda-Yamamoto causality tests by using the ECM specification for all cointegrated sectors and all sectors where causality was found or not (8 in Portugal and 6 in Spain).

Ahmad et al. (2017) state that negative and significant error correction will confirm the long-run relation among variables. Once the long-run relation has been confirmed, the next step is to estimate VECM. Our long-run results confirm the existence of the EKC hypothesis for two sectors, one for each country. ARDL, although useful for testing co-integration and the validity of the EKC hypothesis, does not explain causality between variables and Toda Yamamoto can help to show which variable is responsible for causing which (see Sect. 3.4).

Table 15 Results of sectoral regression post estimation for Portugal (Panel A) and Spain (Panel B)

Panel A	Sector 4	Sector 6	Sector7	Sector 8	Sector 10	Sector 12
Bresch-P Test	0.26	3.84**	0.53	16.79***	1.30	15.71***
White test	10.84	8.82	3.07	25.29***	7.35	7.30
Skewness	3.33	1.78	2.53	10.21**	1.23	3.81
Kurtosis	1.17	1.31	1.31	1.14	1.88	1.88
Durbin	5.482**	6.155**	4.873**	0.277	4.108**	1.339
BGodfrey	5.413**	5.974**	4.889**	0.316	4.207**	1.482
SBcusum	1.4317**	0.484	0.8236	0.7865	0.6717	0.599

Panel B	Sector 4	Sector 6	Sector 8	Sector 10	Sector 11
BP/CW Test	0.13	1.05	5.25***	0.37	6.35**
White test	6.24	11.88	15.70***	15.96**	18.82**
Skewness	2.73	0.73	5.34	8.82**	5.92
Kurtosis	0.02	0.70	2.05	0.99	2.20
Durbin	15.308***	3.454**	17.22**	13.973***	33.191***
BGodfrey	12.042***	3.601**	13.03***	11.304***	19.055***
SBcusum	1.1475***	0.3731	0.6586	0.3117	0.9738**

For the results of sectoral regressions post estimation we follow Kripfganz and Schneider (2018).The level of statistical significance of 1% is denoted by *** of 5% is denoted by **and of 10% is denoted by *. The heteroscedasticity test was performed by Bresch-Pagan/Cook Weisberg test (BP/CW test) and White test. Normality was tested by Cameron & Trivedi's decomposition of Normality including Heteroscedasticity, Skewness and Kurtosis tests. Serial correlation was tested by the Durbin´s alternative test and Breusch-Godfrey test. Finally, the structural breaks testing was used by Cumulative sum test for parameter stability (SBcusum)

4.3 Results of causality tests

The existence of a long-run relationship between the variables in some economic activity sectors in Portugal and Spain suggests that there must be causality in at least one direction. Toda and Yamamoto (1995) propose a simple procedure when economic time series are integrated of different orders, non-cointegrated, or when we have both cases. This approach is known as the Toda and Yamamoto augmented Granger causality procedure, which allows testing for causality between integrated variables based on asymptotic theory. This procedure requires the estimation of an "augmented" VAR, which guarantees the asymptotic distribution of the Wald statistic, namely an asymptotic χ^2 distribution, since the testing procedure is robust to the integration and cointegration process properties (Toda and Yamamoto 1995; Dritsaki 2017). Tables 16 and 17 present the Toda-Yamamoto causality test results for non-cointegrated (Table 16) and cointegrated (Table 17) economic activity sectors in Portugal. Tables 18 and 19 evidence the same results, respectively but considering the same 13 economic activity sectors in Spain. In each column we have the *dependent* variables and in each row we have the *independent* ones.

Among non-cointegrated sectors in Portugal there seem to exist bidirectional causalities between energy consumption and CO_2 emissions in sector 1, 2, 9 and 13. There

Table 16 Toda-Yamamoto causality test results for non-cointegrated sectors in Portugal

Sector 1	CO_2	GVA	GVA 2	Energy C.	Sector 2	CO_2	GVA	GVA 2	Energy C.
CO_2		5.7652	5.8197	11.166**	CO_2		2.2475	4.0719	27.195***
GVA	2.5659		3.2999	2.7614	GVA	95935**		9.7524**	6.7965
GVA 2	2.6009	3.401		2.875	GVA 2	8.9859*	9.6715**		9.6456**
Energy C.	10.546**	5.5606	5.6333		Energy C.	26.76***	1.1147	1.8648	
Sector 3	**CO_2**	**GVA**	**GVA 2**	**Energy C.**	**Sector 5**	**CO_2**	**GVA**	**GVA 2**	**Energy C.**
CO_2		3.0996	3.0613	9.9805**	CO_2		5.3991	6.149	12.767***
GVA	7.7085*		10.335**	3.2497	GVA	4.1895		8.194*	7.886*
GVA 2	8.1489*	10.536**		3.272	GVA 2	5.3543	7.216		10.203**
Energy C.	5.3439	3.9199	3.8921		Energy C.	6.3941	1.6507	2.4959	
Sector 9	**CO_2**	**GVA**	**GVA 2**	**Energy C.**	**Sector 11**	**CO_2**	**GVA**	**GVA 2**	**Energy C.**
CO_2		7.2422	6.808	11.093**	CO_2		6.1078	8.9484*	2.2248
GVA	18.247***		5.5989	8.291*	GVA	7.8676*		1.6069	9.2166*
GVA 2	18.388***	4.8285		7.8432*	GVA 2	5.8625	2.6917		7.5055
Energy C.	8.9765*	9.0346*	11.017**		Energy C.	5.8128	8.4597*	43.913***	
Sector 13	**CO_2**	**GVA**	**GVA 2**	**Energy C.**					
CO_2		2.0945	3.752	24.908***					
GVA	13.243***		8.1117	7.3789					
GVA 2	25.006***	6.9564		14.003***					
Energy C.	30.135***	6.7399	12.455**						

Modified Wald Chi square statistics are displayed. *, ** and *** indicate statistical significance at 10, 5, and 1% levels, respectively

Table 17 Toda-Yamamoto causality test results for cointegrated sectors in Portugal

Sector 4	CO_2	GVA	GVA^2	Energy C.	Sector 6	CO_2	GVA	GVA^2	Energy C.
CO_2		5.4589	0.143	9.0336*	CO_2		3.3966	4.0719	9.2188**
GVA	0.20395		11.048**	16.615***	GVA	19.972***		16.497***	4.9777
GVA^2	0.42567	8.1659*		16.309***	GVA^2	23.443***	13.365***		3.5678
Energy C.	4.3879	5.2783	4.1367		Energy C.	7.3862	16.988***	21.808***	4.3253
Sector 7	CO_2	GVA	GVA^2	Energy C.	Sector 8	CO_2	GVA	GVA^2	Energy C.
CO_2		8.9602*	8.7648*	17.064***	CO_2		7.879*	15.948***	53793***
GVA	4.4245		5.8696	7.7535*	GVA	7.879*		5.3056	35233***
GVA^2	3.9035	7.3375		7.7659*	GVA^2	9.7447**	5.007		43.165***
Energy C.	9.6557**	4.0472	3.906		Energy C.	7.9318*	32.822***	49.808***	
Sector 10	CO_2	GVA	GVA^2	Energy C.	Sector 12	CO_2	GVA	GVA^2	Energy C.
CO_2		13.106***	11.835**	20.96***	CO2		14.547***	19.622***	40.962***
GVA	11.229**		32.162***	26.324***	GVA	7.0794		3.3385	7.3831
GVA^2	8.8056*	21.54***		22.967***	GVA^2	10.591**	4.7827		12.294**
Energy C.	9.0728*	3.5097	5.5887		Energy C.	26.167***	31.437***	43.913***	

Modified Wald Chi square statistics are displayed. *, ** and *** indicate statistical significance at 10, 5, and 1% levels respectively

Table 18 Toda-Yamamoto causality test results for non-cointegrated sectors in Spain

Sector 1	CO_2	GVA	GVA^2	Energy C.	Sector 2	CO_2	GVA	GVA^2	Energy C.
CO_2		10.31**	10.292**	13.261***	CO_2		17.919***	14.625***	3.2483
GVA	5.5523		2.4331	3.0271	GVA	1.8589		30.454***	5.6426
GVA^2	5.5824	2.5726		2.8993	GVA^2	1.1535	32.351***		7.9045*
Energy C.	8.3317*	10.313**	10.313**		Energy C.	5.2977	32.565***	30.358***	
Sector 3	CO_2	GVA	GVA^2	Energy C.	Sector 5	CO_2	GVA	GVA^2	Energy C.
CO_2		9.9162**	11.623**	16.129***	CO_2		11.364**	12.715**	10.328**
GVA	1.8866		32.547***	10.192**	GVA	3.0591		6.4996	7.7988*
GVA^2	1.8122	30.394***		11.28**	GVA^2	2.3933	4.4347		8.8578**
Energy C.	12.644**	9.8506**	11.142**		Energy C.	16.169***	15.65***	15.619***	
Sector 7	CO_2	GVA	GVA 2	Energy C.	Sector 9	CO_2	GVA	GVA 2	Energy C.
CO_2		3.9672	0.69815	26.022***	CO_2		5.1279	2.2763	6.3828
GVA	31.329***		10.409**	22.316***	GVA	7.1134		1.3662	22.405***
GVA^2	27.471***	10.982**		23.528***	GVA^2	6.988	2.9621		26.28***
Energy C.	7.1231	29.081***	38.096***		Energy C.	4.261	4.0884	4.9856	
Sector 12	CO_2	GVA	GVA 2	Energy C.	Sector 13	CO_2	GVA	GVA 2	Energy C.
CO_2		4.7356	6.5081	10.247**	CO_2		15.456***	16.897***	1.3612
GVA	17.245***		66.589***	21.058***	GVA	11.392**		49.833***	12.688**
GVA^2	9.9583**	92.2***		21.396**	GVA^2	23.529***	107.54***		28.256***
Energy C.	11.328**	33.085***	51.579***		Energy C.	48.221***	128.80***	148.76*****	

Modified Wald Chi square statistics are displayed. *, ** and *** indicate statistical significance at 10, 5, and 1% levels, respectively

Table 19 Toda-Yamamoto causality test results for cointegrated sectors in Spain

Sector 4	CO_2	GVA	GVA^2	Energy C.	Sector 6	CO_2	GVA	GVA^2	Energy C.
CO_2		6.2599	6.4791	10.832**	CO_2		4.733	7.6178*	6.2661
GVA	33.491***		13.585***	4.4231	GVA	5.6015		24.749***	6.2703
GVA^2	33.499***	11.441**		4.5933	GVA^2	6.377	15.576***		13.596***
Energy C.	36.512***	15.594***	16.627***		Energy C.	4.1777	35.430***	53.139***	
Sector 8	CO_2	GVA	GVA^2	Energy C.	Sector 10	CO_2	GVA	GVA^2	Energy C.
CO_2		18.261***	26.749***	22.282***	CO_2		5.6809	5.2393	7.2348
GVA	15.322***		4.6257	3.6531	GVA	1.8828		2.1648	8.650*
GVA^2	18.633***	3.8874		7.1534	GVA^2	1.3251	3.5258		12.719**
Energy C.	18.215***	10.140**	21.451***		Energy C.	6.0973	11.372**	9.929**	
Sector 11	CO_2	GVA	GVA^2	Energy C.					
CO_2		9.0833**	10.365**	2.1539					
GVA	21.770***		7.2085	18.464***					
GVA^2	22.931***	4.7985		20.869***					
Energy C.	5.6937	11.597**	14.887***						

Modified Wald Chi square statistics are displayed. *, ** and *** indicate statistical significance at 10, 5, and 1% levels, respectively

are bidirectional causality effects between GVA and its squared values in sector 2, as well as bidirectional causality effects between GVA and EC in 9 and 11. Finally, there are bidirectional causality effects between GVA squared and EC for sectors 9 and 13. Regarding cointegrated sectors in Portugal (Table 17), we are able to identify bidirectional causality between GVA and its squared values in sector 6. A bidirectional causality relationship is found between energy consumption and CO_2 emissions in the sectors chemical and petrochemical, nonmetallic minerals, transport equipment and construction. A bidirectional causality effect is also found between CO_2 emissions and GVA in the sector transport equipment, and bidirectional causality effects between CO_2 emissions and GVA squared in nonmetallic minerals, transport equipment and construction. Identifying these strong bidirectional causalities allows us to assume that both variables have the ability to predict each other in the future.

In the sectors paper and printing and nonmetallic minerals in Portugal we have a unidirectional causality running from gross value added to CO_2 emissions. In the other direction, we have unidirectional causality from CO_2 emissions to GVA in chemical and petrochemical, nonmetallic minerals and construction in Portugal. Thus we cannot validate the hypothesis that increases in GVA will reduce pollution emissions in the long run for all sectors at once (only 6 and 8 in Portugal and 4 of textiles and leather in Spain). Thus the EKC hypothesis cannot be entirely validated for all of these sectors, considering Toda-Yamamoto causality relations.

However, we observe a bidirectional causality between economic growth and CO_2 emissions confirming that increases in gross value added will reduce pollution emissions, but only in nonmetallic minerals and other industries in Spain, allowing the sectors to grow with no expense of emission increases.

Comparing the Portuguese results with those for the Spanish economic activity sectors presented in Table 18, we realize that there are bidirectional causality between CO_2 emissions and energy consumption in the non-cointegrated sectors 1, 3, 5 and 12. This is also the case between GVA and its squared values in sectors 2 and 12, between GVA and EC in sector 3, 5, 7, 12 and 13, and between GVA squared and energy consumption in sectors 3, 5, 7, 12 and 13. Regarding the cointegrated sectors (Table 19) in Spain, we were able to find bidirectional causalities between CO_2 emissions and energy consumption only in textiles and leather, but bidirectional causalities between GVA and CO_2 emissions in nonmetallic minerals and other industries. Bidirectional causalities between GVA, its square and energy consumption are identified in the transport equipment sector and in the other industries sector in Spain.

Evidence of the EKC hypothesis was identified in the cointegrated sectors of nonmetallic minerals (8) in Portugal and paper and printing (6) in Spain. Only in Portugal is a bidirectional causality confirmed between CO_2 emissions and economic growth in the sector. In Spain we only found a unidirectional causality and running from CO_2 emissions to GVA squared. The observation of a bidirectional causality between economic growth and CO_2 emissions confirms that increases in gross value added will reduce pollution emissions, but only in nonmetallic minerals in Portugal, allowing the sector to grow with no expense of emission increases. But for Spain we cannot argue that even in the paper and printing sector. These results evidence the need for urgent intervention in specific economic activity sectors, since the validation of the EKC hypothesis is clearly dependent on the economic activity sector we are analyzing; our results make clear the need to analyze these in an individual way.

5 Conclusion and policy implication

Our study tests the existence of the EKC hypothesis in 13 activity sectors in Portugal and Spain for the period between 1975 and 2012, using the cointegration approach. Cointegration is found in six Portuguese sectors. For Spain, the results of cointegration tests provided by ADRL show evidence of cointegration for five sectors. Those common to both countries are only four, namely textiles and leather, paper and printing, nonmetallic minerals and transport equipment. All the results for the short- and long-run EKC hypothesis approach have an overall satisfactory fit and are statistically significant with levels of 1 and 5 percent. The results for the Portuguese nonmetallic minerals present an inverted U-shaped curve favoring the EKC hypothesis, while in Spain there was only evidence of the EKC hypothesis in the sector paper and printing. Very few in each country reveal the existence of a U-shaped relationship, and there are others in which, despite the fact that coefficients signs point for the existence of the EKC hypothesis, the results cannot be validated as there is no statistical significance.

We further studied the causality relationship between the variables CO_2 emissions, gross value added and (gross value added squared) energy consumption by economic activity sector using Toda-Yamamoto causality after the ECM model has been applied. The results reached with respect to the error correction term confirm that there exists a long-run relationship between the variables under analysis, and we were able to identify unidirectional and bidirectional causality relationships for some sectors in both countries, running from CO_2 emissions to GVA, and the other way around.

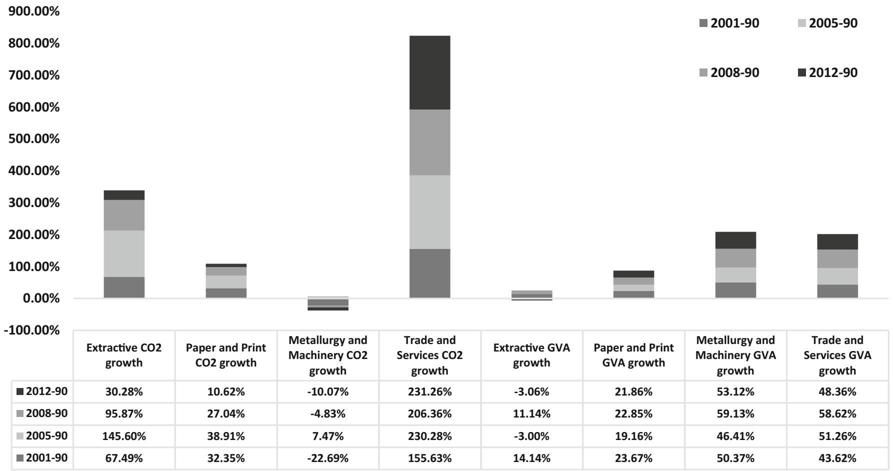
The EKC hypothesis represents the observation that the EKC relationship in the Portuguese and Spanish economic activity sectors observed in this study are mainly caused by economic structure changes rather than by technical changes or economies of scale. These results are corroborated by Fujii and Managi (2013); while estimating the EKC hypothesis, they separately controlled for economic scale and technology in accordance to the type of industry. Therefore, our results in the first econometric step performed (ARDL) imply that for one Portuguese sector, in the short run, CO_2 emissions can be reduced at the cost of gross value added growth, while in the long run, higher GVA can be achieved by condensing CO_2 emissions. As such, there are some economic sectors where we cannot observe the EKC hypothesis in Portugal and in Spain, and there is evidence of structural changes in the data if we directly control for effects from economic sectoral structure change. This lack of evidence of the EKC hypothesis has also been reached for other countries as in Al-Mulali et al. (2015), Mrabet and Alsamara (2017) and Mrabet et al. (2017) but also for sectors, as in Pablo-Romero et al. (2017) for the transport sector and Fujii and Managi (2016) for industry, but not including all industries. Fujii and Managi (2013) only found evidence of the EKC hypothesis in the industries of paper, wood and construction, Jebli and Youssef (2017) found no EKC hypothesis for the agriculture sector and Moutinho et al. (2017) did not find evidence for the EKC hypothesis in all sectors, considering both the quadratic as well as the cubic function, nor even with demeaned variables.

Surprisingly, and according to the ADRL bounds tests, cointegration results are not conclusive for textiles, transport equipment and other manufacturing industries, which are key economic activity sectors with a high share of CO_2 emissions. One interpretation of this result is that air pollution emissions resulting from the energy consumption depend greatly on the method of power generation of the type of the energy consumed. It is possible that CO_2 emissions are issued from thermal power generation, but little of CO_2 emissions are emitted from hydro and nuclear power generation. So, the energy storage and energy generation portfolios are diverse in our sample of economic activity sectors and are more strongly affected by the characteristics of the geography, resources, and disaster conditions than exactly by the economic development stage. Moreover, these sectors are notably responsible for a significant increase in CO_2 emissions experienced during recent years, according to Alcantara and Padilla (2009), and additionally the authors argue that these sectors received very little attention during the design of policies aimed at reducing CO_2 emissions.

In the second step carried out by the econometric approach, the Toda-Yamamoto causality results show statistical and significant evidence to support the unidirectional causality from economic growth to energy consumption, namely the conservation hypothesis. It implies that the energy reduction policy will not negatively affect economic growth, since economic growth of an economic activity sector does not depend on energy. Therefore, it implies that an increase in GVA leads to an increase in energy consumption. This unidirectional causality between GVA and energy consumption means that energy saving would not harm gross value added which is also observed by Lise and Montfort (2007), Altunbas and Kapusuzoglu (2011) in the short run, Shahbaz et al. (2014) and Zambrano-Monserrate et al. (2016).

Conversely, a unidirectional causality from energy consumption to economic growth, the so-called growth hypothesis, is also found in some economic activity sectors. Here, energy consumption plays a significant role (positive or negative) in economic growth, directly or indirectly, through a production process as a complement to labor and capital. The policy implication of this hypothesis suggests that the orientation to save energy could have a negative impact on economic growth. These findings are corroborated by other studies carried out, among others researches, by Shahbaz et al. (2014), for Indonesia and India by Asafu-Adjaye (2000), by Apergis and Payne (2009) for Central America, and by Soytas and Sari (2003) in Turkey, France, Germany and Japan, where all authors state that energy conservation may harm economic growth.

Finally, the causality between these two variables (economic growth and energy consumption), shows statistical and significant evidence to support the existence of the neutrality hypothesis. This view supports the idea that energy consumption represents a small share of GVA in these sectors so it does not have a significant effect on gross value added growth. Furthermore, an energy policy based on savings will not have a negative effect on GVA. For the UK, Altunbas and Kapusuzoglu (2011) found no long-run relationship between energy consumption and GDP. Asafu-Adjaye (2000) also found neutrality in the short run for Indonesia and India. Huang et al. (2008) found no causal relationship between energy consumption and economic growth for the low-income group of countries, whereas in the middle-income groups they found that GDP leads to a reduction in energy consumption, implying that in this last group



	Extractive CO2 growth	Paper and Print CO2 growth	Metallurgy and Machinery CO2 growth	Trade and Services CO2 growth	Extractive GVA growth	Paper and Print GVA growth	Metallurgy and Machinery GVA growth	Trade and Services GVA growth
■ 2012-90	30.28%	10.62%	-10.07%	231.26%	-3.06%	21.86%	53.12%	48.36%
■ 2008-90	95.87%	27.04%	-4.83%	206.36%	11.14%	22.85%	59.13%	58.62%
■ 2005-90	145.60%	38.91%	7.47%	230.28%	-3.00%	19.16%	46.41%	51.26%
■ 2001-90	67.49%	32.35%	-22.69%	155.63%	14.14%	23.67%	50.37%	43.62%

Fig. 1 Portuguese sectors growth rate for 4 periods with respect to 1990 levels: the case of CO_2 emissions versus GVA

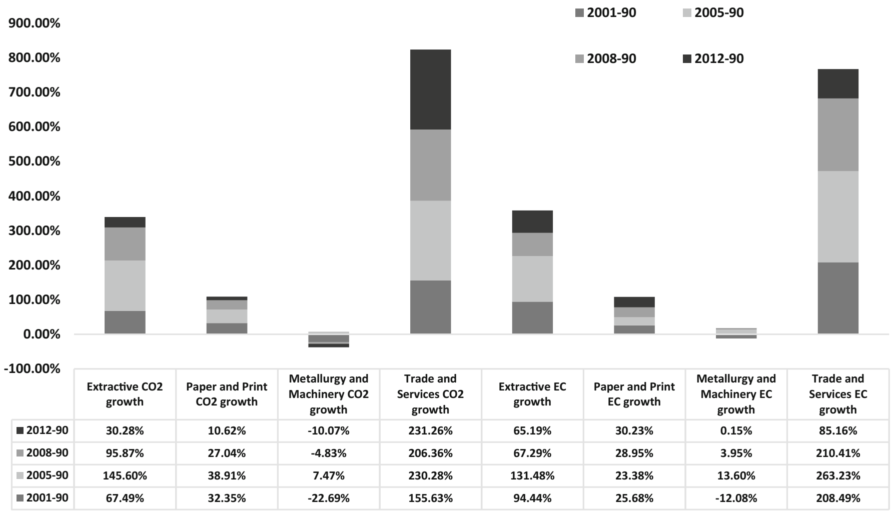
there is great environmental improvement as a result of more efficient energy use and reduction in the release of CO_2. Since Huang et al. (2008) found no evidence that energy consumption leads economic growth in any of the income groups, they recommend pursuing a stronger energy conservation policy in all countries.

For a deeper understanding of the resulting empirical evidence, considering these mixed results, to corroborate the EKC hypothesis, and in accordance with commitment to some policies (see EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources, and the amending and subsequently repealing directives 2001/77/EC and 2003/30/EC; 2009), we next analyze the evolution of the growth rate of CO_2 emissions, GVA and energy consumption with respect to the 1990 target values.

According to Figs. 1 and 2, in Portugal the trade and services sector emits the highest level of CO_2. As such, strategies to reduce CO_2 must consider a wider understanding of that particular sector, an understanding that reflects wholesale and retail trade, transportation, real estate, hotels and restaurants, the tourism industry and other service sub-sectors. The economic activity sector that shows the best performance in Portugal is the metallurgy and machinery sector, where the largest reduction in CO_2 emissions and energy consumption was registered, the evolution of which may be associated with greater increases in the GVA indicator.

According to Fig. 2, in Portugal, the paper and print sector emits the highest level of CO_2 and evidences higher energy consumption with respect to 1990 levels, while the rate of growth in GVA shows a high increase in that economic sector. The economic activity sector metallurgy and machinery shows better performance, where the greatest change in the magnitude of the CO_2 growth rate can be observed.

It is evident that there was a clear reduction in CO_2 emissions in almost all years as compared to 1990 levels and energy consumption has also decreased in this sector in 2001 when compared to 1990. That behavior can be associated with the major positive



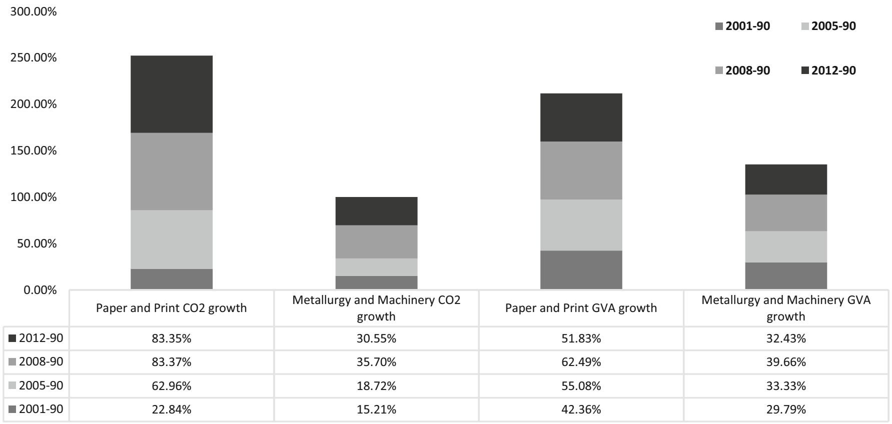
	Extractive CO2 growth	Paper and Print CO2 growth	Metallurgy and Machinery CO2 growth	Trade and Services CO2 growth	Extractive EC growth	Paper and Print EC growth	Metallurgy and Machinery EC growth	Trade and Services EC growth
2012-90	30.28%	10.62%	-10.07%	231.26%	65.19%	30.23%	0.15%	85.16%
2008-90	95.87%	27.04%	-4.83%	206.36%	67.29%	28.95%	3.95%	210.41%
2005-90	145.60%	38.91%	7.47%	230.28%	131.48%	23.38%	13.60%	263.23%
2001-90	67.49%	32.35%	-22.69%	155.63%	94.44%	25.68%	-12.08%	208.49%

Fig. 2 Portuguese sectors growth rate for 4 periods with respect to 1990 levels: the case of CO_2 emissions versus energy consumption

change in GVA growth in all years in that sector when compared to the 1990 baseline. In fact, our results do not corroborate the existence of the EKC hypothesis exactly in the metallurgy and machinery sector in Portugal and in the trade and services sector. However, in the latter we still observe high levels of CO_2 emissions, even if energy consumption decreased in 2012 when compared to 1990 as did the values reported in the previous years in terms of growth rates (2001, 2005 and 2008).

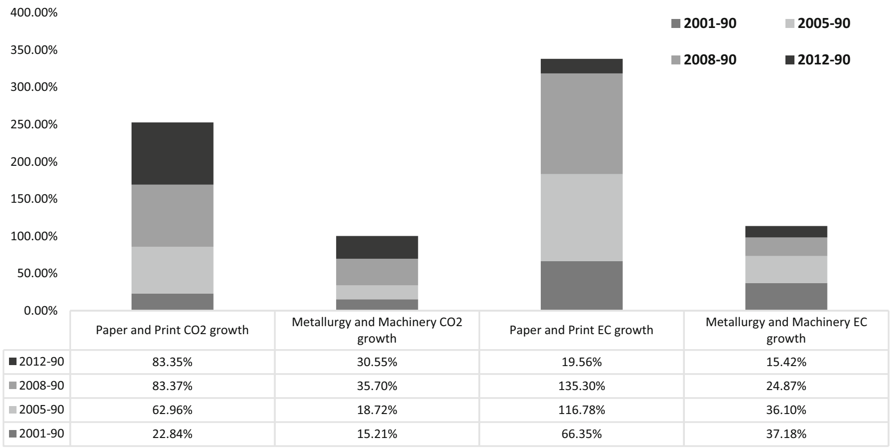
Attending to Figs. 3 and 4 for the sectors analyzed in terms of cointegration in Spain, the indication is that in none of the sectors do we have a negative growth rate of CO_2 emissions. In percentage terms, the growth rate of CO_2 emissions is lower in 2012 (with respect to the year 1990) than it was in 2008 when compared to 1990 levels. Also the GVA growth rate and energy consumption decreased, which may mean that lower CO_2 emissions are in fact due to both decreases and in reality could not be clearly attributed to the effectiveness of policies being implemented at the sector level, more specifically in the metallurgy and machinery sector. This because in the paper and printing sector in Spain we have an almost unchanged growth rate in CO_2 emissions despite the huge decrease which occurred in energy consumption in 2012 when compared to 1990 levels.

The four selected figures, which show different relationships between economic development and pollution emission trends in Portuguese and Spanish specific sectors, show us the importance of establishing the emission targets of CO_2 emissions and of creating a system to achieve sustainable development at the sector level. Evaluating CO_2 emissions behavior due to economic development may be good for estimating the potential magnitude of environmental problems. The identification of previous economic development conditions leading to increased air pollution allows emission sources to be treated earlier and at a lower cost. The production process is more dependent on one particular type of energy, such as the case of trade and services in



	Paper and Print CO2 growth	Metallurgy and Machinery CO2 growth	Paper and Print GVA growth	Metallurgy and Machinery GVA growth
■ 2012-90	83.35%	30.55%	51.83%	32.43%
■ 2008-90	83.37%	35.70%	62.49%	39.66%
■ 2005-90	62.96%	18.72%	55.08%	33.33%
■ 2001-90	22.84%	15.21%	42.36%	29.79%

Fig. 3 Spanish sectors growth rate for 4 periods with respect to 1990 levels: the case of CO_2 emissions versus GVA



	Paper and Print CO2 growth	Metallurgy and Machinery CO2 growth	Paper and Print EC growth	Metallurgy and Machinery EC growth
■ 2012-90	83.35%	30.55%	19.56%	15.42%
■ 2008-90	83.37%	35.70%	135.30%	24.87%
■ 2005-90	62.96%	18.72%	116.78%	36.10%
■ 2001-90	22.84%	15.21%	66.35%	37.18%

Fig. 4 Spanish sectors growth rate for 4 periods with respect to 1990 levels: the case of CO_2 emissions versus energy consumption

Portugal and the paper and printing sector in Spain. These selected sectors demonstrate some difficulty in significantly reducing their carbon emission levels with respect to 1990 levels (fossil fuels as crucial inputs in their process), and there are restrictions for fuel switching.

The use of potential energy saving measures and prioritizing the implementation of energy efficiency are necessary for all companies that operate in these sectors. It is also necessary to strengthen existing political, economic, and institutional and media instruments to improve their performance and achieve the objectives of mitigating the pollutant levels generated by Portuguese and Spanish economic sectors. Simultaneously, there should be an increase in the share of renewable energy in the Iberian energy mix, following the EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Additionally, policies may help to follow the right path and make the most from these causal relationships. In April 2011 the European Commission presented a proposal with two main goals: (i) to contribute to growth and employment by shifting taxation from labor to consumption; (ii) to promote energy efficiency and consumption of more environmentally friendly products. Furthermore, the proposal aims to complement the existing European Union Emission Trade System (EU ETS) by applying a CO_2 tax on sectors that are out of its present scope (transport, households, agriculture and small industries). If approved, this will result in a sort of hybrid regulation system for CO_2 emissions. Moreover, to increase the contribution in terms of the validity of the general EKC hypothesis, it is necessary to consider some industrial characteristics for inducing new environmental foundations in accordance with the sectoral crediting mechanism (SCM), which focuses on the industrial characteristics of CO_2 emissions (see Cai et al. 2012, for example).

The inexistence of an identified unidirectional causality from economic growth to CO_2 emissions does not allow us to validate that increases in gross value added reduce pollution emissions, thus not validating the EKC hypothesis. However, when considering the multivariate Granger causality we validate this result only in the paper and print sector in Portugal (bidirectional causality between CO_2, GVA, GVA^2 and EC) and in the metallurgy and machinery sector in Spain. Overall, the results evidence the need to direct targeted policies to each of the sectors since each has different energy consumption needs and in some we may reach lower emission levels than in others just by adjusting their energy needs to the production process and the gross value added produced.

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Compliance with ethical standards

Conflict of interest The authors declare that have no conflict of interest.

Consent for publication We declare that the manuscript is your own original work, and does not duplicate any other previously published work, including our own previously published work. The manuscript has been submitted only to the Environmental and Ecological Statistics; it is not under consideration or peer review or accepted for publication or in press or published elsewhere. The manuscript contains nothing that is abusive, defamatory, libelous, obscene, fraudulent, or illegal.

References

Abdallah KB, Belloumi M, De Wolf D (2013) Indicators for sustainable energy development: a multivariate cointegration and causality analysis from Tunisian road transport sector. Renew Sust Energy Rev 25:34–43. https://doi.org/10.1016/j.rser.2013.03.066

Ahmad N, Du L, Lu J, Wang J, Li H-Z, Hashmi MZ (2017) Modelling the CO_2 emissions and economic growth in Croatia: is there any environmental Kuznets curve? Energy 123:164–172. https://doi.org/10.1016/j.energy.2016.12.106

Ahmad M, Zhao Z-Y, Li H (2019) Revealing stylized empirical interactions among construction sector, urbanization, energy consumption, economic growth and CO$_2$ emissions in China. Sci Total Environ 657:1085–1098

Alcantara V. (2007) Análisis Input-Output y emisiones de CO$_2$ en España: un primer análisis para la determinación de sectores clave en la emisión, Document de treball 07.02, Departament d´Economia Aplicada, Universitat Autònoma de Barcelona

Alcantara V, Duro JA (2004) Inequality of energy intensities across OECD countries: a note. Energy Policy 32(11):1257–1260. https://doi.org/10.1016/S0301-4215(03)00095-8

Alcantara V, Padilla E (2009) Input-output subsystems and pollution: an application to the service sector and CO$_2$ emissions in Spain. Ecol Econ 68(3):905–914. https://doi.org/10.1016/j.ecolecon.2008.07.010

Ali W, Abdullah A, Azam M (2017) Re-visiting the environmental Kuznets curve hypothesis for Malaysia: fresh evidence from ARDL bounds testing approach. Renew Sustain Energy Rev 77:990–1000. https://doi.org/10.1016/j.rser.2016.11.236

Al-Mulali U, Saboori B, Ozturk I (2015) Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76:123–131. https://doi.org/10.1016/j.enpol.2014.11.019

Al-Mulali U, Solarin SA, Ozturk I (2016) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat Hazard 80(3):1729–1747. https://doi.org/10.1007/s11069-015-2050-x

Alshehry AS, Belloumi M (2017) Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia. Renew Sustain Energy Rev 75:1339–1347. https://doi.org/10.1016/j.rser.2016.11.122

Altunbas Y, Kapusuzoglu A (2011) The causality between energy consumption and economic growth in United Kingdom. Econ Res-Ekonomska Istraživanja 24(2):60–67. https://doi.org/10.1080/1331677X.2011.11517455

Apergis N, Payne JE (2009) Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model. Energy Econ. 31(2):211–216. https://doi.org/10.1016/j.eneco.2008.09.002

Asafu-Adjaye J (2000) The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries. Energy Econ. 22(6):615–625. https://doi.org/10.1016/S0140-9883(00)00050-5

Aslan A, Destek MA, Okumus I (2018) Sectoral carbon emissions and economic growth in the US: further evidence from rolling window estimation method. J Clean Prod 200:402–411. https://doi.org/10.1016/j.jclepro.2018.07.237

Benavides M, Ovalle K, Torres C, Vinces T (2017) Economic growth, renewable energy and methane emissions: is there an Environmental Kuznets curve in Austria? Int J Energy Econ Policy 7(1):259–267

Bento JPC, Moutinho V (2016) CO$_2$ emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. Renew Sustain Energy Rev 55:142–155. https://doi.org/10.1016/j.rser.2015.10.151

Cai W, Wang C, Chen J, Wang S (2012) Sectoral crediting mechanism: how far China has to go. Energy Policy 48:770–778. https://doi.org/10.1016/j.enpol.2012.06.012

Charfeddine L (2017) The impact of energy consumption and economic development on Ecological Footprint and CO$_2$ emissions: evidence from a Markov Switching Equilibrium Correction Model. Energy Econ. 65:355–374. https://doi.org/10.1016/j.eneco.2017.05.009

Chiu Y-B (2017) Carbon dioxide, income and energy: evidence from a non-linear model. Energy Econ 61:279–288. https://doi.org/10.1016/j.eneco.2016.11.022

Clemente J, Montanes A, Reyes M (1998) Testing for a unit root in variables with a double change in the mean. Econ Lett 59:175–182

Congregado E, Feria-Gallardo J, Golpe AA, Iglesias J (2016) The environmental Kuznets curve and CO2 emissions in the USA: is the relationship between GDP and CO$_2$ emissions time varying? Evidence across economic sectors. Environ Sci Pollut Res 23(18):18407–18420. https://doi.org/10.1007/s11356-016-6982-9

del Pablo-Romero M, Sánchez-Braza PA (2017) Residential energy environmental Kuznets curve in the EU-28. Energy 125:44–54. https://doi.org/10.1016/j.energy.2017.02.091

Dickey D, Fuller W (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366):427–431

Dinda S (2004) Environmental Kuznets curve hypothesis: a survey. Ecol Econ 49(4):431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Dritsaki C (2017) Toda-Yamamoto causality test between inflation and nominal interest rates: evidence from three countries of Europe. Int J Econ Financ Issues 7:120–129

Esmaeilpour Moghadam H, Dehbashi V (2018) The impact of financial development and trade on environmental quality in Iran. Emp Econ 54:1777–1799

Eurostat (2016) Greenhouse gas emissions by industries and households. http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emissions_by_industries_and_households#Further_Eurostat_information. Accessed 5 Oct 2017

Fuinhas JA, Marques AC (2019) The extended energy-growth nexus: theory and empirical applications. 1st ed. Elsevier, Academic Press, p 332. ISBN-9780128157190

Fujii H, Managi S (2013) Which industry is greener? An empirical study of nine industries in OECD countries. Energy Policy 57:381–388. https://doi.org/10.1016/j.enpol.2013.02.011

Fujii H, Managi S (2016) Economic development and multiple air pollutant emissions from the industrial sector. Environ Sci Pollut Res 23(3):2802–2812. https://doi.org/10.1007/s11356-015-5523-2

Ganda F (2019) Carbon emissions, diverse energy usage and economic growth in South Africa: investigating existence of the environmental Kuznets curve (EKC). Environ Prog Sustain Energy 38(1):30–46

Ghosh S (2002) Electricity consumption and economic growth in India. Energy Policy 30(2):125–129. https://doi.org/10.1016/S0301-4215(01)00078-7

Gokmenoglu KK, Taspinar N (2018) Testing the agriculture-induced EKC hypothesis: the case of Pakistan. Environ Sci Pollut Res 25(23):22829–22841. https://doi.org/10.1007/s11356-018-2330-6

Granger CWJ (1969) Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37:424–438. https://doi.org/10.2307/1912791

Granger CWJ (1986) Developments in the study of cointegrated economic variables. Oxford Bull Econ Stat 48:213–228

Gregory A, Hansen B (1996) Residual-based tests for cointegration in models with regime shifts. J Economet 70:99–126

Hanif I, Raza SMF, Gago-de-Santos P, Abbas Q (2019) Fossil fuels, foreign direct investment, and economic growth have triggered CO_2 emissions in emerging Asian economies: some empirical evidence. Energy 171:493–501

Harris RI, Sollis R (2003) Applied time series modelling and forecasting. Wiley, Chichester

Huang B-N, Hwang MJ, Yang CW (2008) Causal relationship between energy consumption and GDP growth revisited: a dynamic panel data approach. Ecol Econ 67(1):41–54. https://doi.org/10.1016/j.ecolecon.2007.11.006

Huntington HG (2010) Structural change and U.S. energy use: recent patterns. Energy J 31:25–39. https://www.jstor.org/stable/41323292

Jalil A, Mahmud SF (2009) Environment Kuznets curve for CO_2 emissions: a cointegration analysis for China. Energy Policy 37(12):5167–5172. https://doi.org/10.1016/j.enpol.2009.07.044

Jebli MB (2016) On the causal links between health indicator, output, combustible renewables and waste consumption, rail transport, and CO_2 emissions: the case of Tunisia. Environ Sci Pollut Res 23(16):16699–16715. https://doi.org/10.1007/s11356-016-6850-7

Jebli MB, Belloumi M (2017) Investigation of the causal relationships between combustible renewables and waste consumption and CO_2 emissions in the case of Tunisian maritime and rail transport. Renew Sustain Energy Rev 71:820–829. https://doi.org/10.1016/j.rser.2016.12.108

Jebli MB, Youssef SB (2015) The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. Renew Sustain Energy Rev 47:173–185. https://doi.org/10.1016/j.rser.2015.02.049

Jebli MB, Youssef SB (2017) Renewable energy consumption and agriculture: evidence for cointegration and Granger causality for Tunisian economy. Int J Sustain Develop World Ecol 24(2):149–158. https://doi.org/10.1080/13504509.2016.1196467

Johansen S (1988) Statistical analysis of cointegration vectors. J Econ Dyn Control 12:231–254. https://doi.org/10.1016/0165-1889(88)90041-3

Kharbach M, Chfadi T (2017) CO_2 emissions in Moroccan road transport sector: Divisia, Cointegration, and EKC analyses. Sustain Cities Soc 35:396–401. https://doi.org/10.1016/j.scs.2017.08.016

Kripfganz S, Schneider DC (2018) ARDL: estimating autoregressive distributed lag and equilibrium correction models. In: Proceedings of the 2018 London Stata Conference

Lima F, Nunes ML, Cunha J, Lucena AFP (2017) Driving forces for aggregate energy consumption: a cross-country approach. Renew Sustain Energy Rev 68:1033–1050. https://doi.org/10.1016/j.rser.2016.08.009

Lise W, Montfort KV (2007) Energy consumption and GDP in Turkey: is there a co-integration relationship? Energy Econ 29(6):1166–1178. https://doi.org/10.1016/j.eneco.2006.08.010

Liu C, Jiang Y, Xie R (2019) Does income inequality facilitate carbon emission reduction in the US? J Clean Prod 217:380–387

Ma M, Cai W (2019) Do commercial building sector-derived carbon emissions decouple from the economic growth in Tertiary Industry? A case study of four municipalities in China. Sci Total Environ 650:822–834

Marrero GA, Ramos-Real FJ (2008) La Intensidad Energética en los Sectores Productivos en la UE-15 durante 1991 y 2005: ¿Es el caso Español Diferente? Economic Reports, 08-2008. Fundación de Estudios de Economía Aplicada, FEDEA, Madrid

Marrero GA, Ramos-Real FJ (2013) Activity sectors and energy intensity: decomposition analysis and policy implications for European Countries (1991–2005). Energ 6:2521–2540. https://doi.org/10.3390/en6052521

Mello M, Nell KS, (2001) The forecasting ability of a cointegrated VAR demand system with endogenous vs. exogenous expenditure variable. In: Working Papers nº109 Julho. Faculdade de Economia da Universidade do Porto

Mendiluce M, Pérez-Arriaga I, Ocaña C (2010) Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different? Energy Policy 38:639–645. https://doi.org/10.1016/j.enpol.2009.07.069

Menegaki A. (2018) The economics & the econometrics of the energy-growth nexus. 1st ed. Elsevier, Academic Press, p 402. ISBN: 9780128127469. https://doi.org/10.1016/C2016-0-03900-1

Menegaki A (2019) The ARDL method in the energy-growth nexus field: best implementation strategies. Economies 7(4):1–16

Menegaki AN, Tsagarakis KP (2015) Rich enough to go renewable but too early to leave fossil energy? Renew Sustain Energy Rev 41(C):1465–1477. https://doi.org/10.1016/j.rser.2014.09.038

Moutinho V, Varum C, Madaleno M (2017) How economic growth affects emissions? An investigation of the environmental Kuznets curve in Portuguese and Spanish economic activity sectors. Energy Policy 106:326–344. https://doi.org/10.1016/j.enpol.2017.03.069

Mrabet Z, Alsamara M (2017) Testing the Kuznets Curve hypothesis for Qatar: a comparison between carbon dioxide and ecological footprint. Renew Sustain Energy Rev 70:1366–1375. https://doi.org/10.1016/j.rser.2016.12.039

Mrabet Z, AlSamara M, Jarallah SH (2017) The impact of economic development on environmental degradation in Qatar. Environ Ecol Stat 24(1):7–38. https://doi.org/10.1007/s10651-016-0359-6

Newey WK (1987a) Interval moment estimation of the truncated regression model. Department of Economics (MIT), presented at the 1987 Summer Meeting of the Econometric Society

Newey WK (1987b) Efficient estimation of limited dependent variable models with endogenous explanatory variables. J Econometrics 36(3):231–250. https://doi.org/10.1016/0304-4076(87)90001-7

Ouyang X, Lin B (2017) Carbon dioxide (CO_2) emissions during urbanization: a comparative study between China and Japan. J Clean Prod 143:356–368

Özcan B, Öztürk I (2019) The environmental Kuznets Curve: A manual. 1st ed. Elsevier, Academic Press, p 162. ISBN-13: 978-0128167977. DOI: https://doi.org/10.1016/C2018-0-00657-X

Özokcu S, Özdemir Ö (2017) Economic growth, energy, and environmental Kuznets curve. Renew Sustain Energy Rev 2:639–647. https://doi.org/10.1016/j.rser.2017.01.059

Pablo-Romero MP, Cruz L, Barata E (2017) Testing the transport energy-environmental Kuznets curve hypothesis in the EU27 countries. Energy Econ 62:257–269. https://doi.org/10.1016/j.eneco.2017.01.003

Pal D, Mitra SK (2017) The environmental Kuznets curve for carbon dioxide in India and China: growth and pollution at crossroad. J. Policy Model 39(2):371–385. https://doi.org/10.1016/j.jpolmod.2017.03.005

Pesaran M, Shin Y, Smith R (2001a) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Pesaran MH, Shin Y, Smith R (2001b) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16:289–326. https://doi.org/10.1002/jae.616

Phillips P, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346

Raza SA, Shah N, Khan KA (2019) Residential energy environmental Kuznets curve in emerging economies: the role of economic growth, renewable energy consumption, and financial development. Sci Pollut Res Online, Environ. https://doi.org/10.1007/s11356-019-06356-8

Saboori B, Sulaiman J, Mohd S (2012) Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the Environmental Kuznets Curve. Energy Policy 51:184–191. https://doi.org/10.1016/j.enpol.2012.08.065

Samargandi N (2017) Sector value addition, technology and CO_2 emissions in Saudi Arabia. Renew Sustain Energy Rev 78:868–877. https://doi.org/10.1016/j.rser.2017.04.056

Sarkodie SA, Ozturk I (2020) Investigating the environmental Kuznets curve hypothesis in Kenya: a multivariate analysis. Renew Sustain Energy Rev 117:109481. https://doi.org/10.1016/j.rser.2019.109481

Sarkodie SA, Strezov V (2019) A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. Sci Total Environ 649:128–145. https://doi.org/10.1016/j.scitotenv.2018.08.276

Sasana H, Aminata J (2019) Energy subsidy, energy consumption, economic growth, and carbon dioxide emission: Indonesian case studies. Int J Energy Econ Policy 9:117–122

Seker F, Ertugrul HM, Cetin M (2015) The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey. Renew Sustain Energy Rev 52:347–356. https://doi.org/10.1016/j.rser.2015.07.118

Shahbaz M, Sinha A (2019) Environmental Kuznets curve for CO2 emissions: a literature survey. J Econ Stud 46(1):106–168

Shahbaz M, Lean HH, Shabbir MS (2012) Environmental Kuznets Curve hypothesis in Pakistan: cointegration and Granger causality. Renew Sustain Energy Rev 16:2947–2953. https://doi.org/10.1016/j.rser.2012.02.015

Shahbaz M, Khraief N, Uddin GS, Ozturk I (2014) Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia. Renew Sustain Energy Rev 34:325–336. https://doi.org/10.1016/j.rser.2014.03.022

Shahbaz M, Shafiullah M, Papavassiliou VG, Hammoudeh S (2017) The CO_2–growth nexus revisited: a nonparametric analysis for the G7 economies over nearly two centuries. Energy Econ 65:183–193. https://doi.org/10.1016/j.eneco.2017.05.007

Shahbaz M, Mahalik MK, Shahzad SJH, Hammoudeh S (2019) Testing the globalization-driven carbon emissions hypothesis: international evidence. Int Econ 158:25–38

Sheldon TL (2017) Carbon emissions and economic growth: a replication and extension. Energy Econ. https://doi.org/10.1016/j.eneco.2017.03.016

Soytas U, Sari R (2003) Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. Energy Econ 25(1):33–37. https://doi.org/10.1016/S0140-9883(02)00009-9

Talbi B (2017) CO_2 emissions reduction in road transport sector in Tunisia. Renew Sust Energy Rev 69:232–338. https://doi.org/10.1016/j.rser.2016.11.208

Tiwari AK, Shahbaz M, Hye QMA (2013) The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. Renew Sustain Energy Rev 18:519–527. https://doi.org/10.1016/j.rser.2012.10.031

Toda HY, Yamamoto T (1995) Statistical inference in vector auto regressions with possibly integrated processes. J Economet 66:225–250

Turner P (2006) Response surfaces for an F-test for cointegration. Appl Econ Lett 13:479–482. https://doi.org/10.1080/13504850500401726

Ullah A, Khan D (2020) Testing environmental Kuznets curve hypothesis in the presence of green revolution: a cointegration analysis for Pakistan. Sci Pollut Res Online, Environ. https://doi.org/10.1007/s11356-020-07648-0

Xu B, Lin B (2016) Reducing CO_2 emissions in China's manufacturing industry: evidence from nonparametric additive regression models. Energy 101:161–173

Xu B, Lin B (2017) Assessing CO_2 emissions in China's iron and steel industry: a nonparametric additive regression approach. Renew Sustain Energy Rev 72:325–337

Zafeiriou E, Sofios S, Partalidou X (2017) Environmental Kuznets curve for EU agriculture: empirical evidence from new entrant EU countries. Environ Sci Pollut Res 24(18):15510–15520. https://doi.org/10.1007/s11356-017-9090-6

Zambrano-Monserrate MA, García-Albán FF, Henk-Vera KA (2016) Bounds testing approach to analyse the existence of an environmental Kuznets curve in Ecuador. Int J Energy Econ Policy 6(2):159–166

Zhang L, Pang J, Chen X, Lu Z (2019a) Carbon emissions, energy consumption and economic growth: evidence from the agricultural sector of China's main grain-producing areas. Sci Total Environ 665:1017–1025

Zhang Y, Chen X, Wu Y, Shuai C, Shen L (2019b) The environmental Kuznets curve of CO2 emissions in the manufacturing and construction industries: a global empirical analysis. Environ Impact Assess Rev 79:106303. https://doi.org/10.1016/j.eiar.2019.106303

Zivot E, Andrews D (1992) Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. J Bus Econ Stat 10(3):251–270

Zoundi Z (2017) CO_2 emissions, renewable energy and the environmental Kuznets curve, a panel cointegration approach. Renew Sustain Energy Rev 72:1067–1075. https://doi.org/10.1016/j.rser.2016.10.018

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