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Decoupling Economic Growth From Carbon Dioxide Emissions in the EU Countries

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ABSTRACT

This paper aims to look at the long-run equilibrium relationship between CO_2 emissions and economic growth (the EKC hypothesis) in an asymmetric framework using the non-linear threshold cointegration. In order to avoid the problem of omitted variables bias, the dynamic relationship between pollutant emissions, economic development and energy consumption are also examined (the extended EKC model). The research hypothesis is that the economic growth decouples from CO_2 emissions growth, i.e. the EKC hypothesis holds. The empirical study is carried out for the European Union countries (EU-14) divided into three groups depending on a category of knowledge-advanced economies in order to explain the differences in the dynamic linkage between CO_2 emissions and economic growth, as well as in the energy consumption impact on this cointegrating relationship. We have found that the EKC hypothesis is valid for the most high-level and some middle-level knowledge advanced economies. The addition of energy consumption to the standard EKC model has improved the results in terms of the presence of linear or threshold cointegration for all low-level knowledge based economies. Moreover, the causality pattern between CO_2 emissions and income has changed after energy consumption adding to the EKC model and some similarities are found in the countries belonging to the same category of knowledge-advanced economies.

INTRODUCTION

The issues of global warming and climate changes caused by anthropogenic greenhouse gas emissions (GHG), as well as the harmful impact of air pollutants on human health have been becoming increasingly important over the past few decades. According to Intergovernmental Panel on Climate Change (IPCC), the future global warming effect will depend on the concentrations of greenhouse gases in the atmosphere and the natural climate variability. It is predicted that the global mean surface temperature will likely increase from 0.3°C to 0.7°C during the period 2016–2035 relative to 1986–2005, whereas the base period (1986–2005) was approximately 0.61°C warmer than the pre-industrial period (1850–1900). Moreover, the increase of the global mean surface temperature by the end of the 21st century (2081–2100) relative to the base period will likely be in the range either 0.3°C to 1.7°C (optimistic scenario) or 2.6°C to 4.8°C (pessimistic scenario) (IPCC, 2014). Such worrying forecasts of climate change cause the intensification of work over the improvement of air quality at the international scale.

Since the Kyoto Protocol (1997) most countries are becoming increasingly concerned about the excess amount of GHGs in the atmosphere and human influence on the climate system. Among the various GHGs contributing to global climate change, carbon dioxide excess is directly assigned to intensification of such human activities as fossil fuels combustion, transport activity, aviation, deforestation, clearing lands for agricultural purposes, cement production (Özocku and Özdemir, 2017). In particular, carbon dioxide accounted for 74.91% of the total GHG emissions in the EU-28 countries in 2012 (excluding LULUCF[1]), and respectively 71.41% in 1990. Therefore, all countries ought to encourage raising their environmental targets directed to GHG emissions reducing, especially CO_2 emissions. The European Union, as a party to the United Nations Framework Convention on Climate Change (UNFCCC), has intensified its activity leading to concluding a new agreement on the CO_2 emission abatement which would replace the Kyoto Protocol that expired in 2012 (UN Climate Conference in Doha 2012, Warsaw 2013, Lima 2014, Geneva 2015, Paris 2015). Finally, the agreement reached in Brussels in 2014, in which the common framework on climate and energy policy for the period 2020-2030 was determined, concerns three key issues. Namely, by the 2030 the EU-28 will have to reduce its greenhouse gas emissions by 40% with reference to the 1990 baseline, renewable energy will have to represent at least 27% of the European gross final energy consumption and the energy efficiency will have to reach the level of at least 27% (COM (2014) 15 final: A policy framework for climate and energy in the period from 2020 to 2030). The basic assumption of the EU's environmental policy is to achieve the reduction of GHG emissions in the process of socio-economic development leading to decouple the economic growth from the pollutants emissions. Then, the environmental improvement is not treated as contradictory to economic growth, but on the contrary, it may stimulate economic growth in the EU countries and strengthen their competitiveness through the transformation to the low-carbon economy and increase in the energy efficiency. For these reasons, the long-run equilibrium relationship between the GHG emissions, economic growth and gross final energy consumption has long attracted policy-makers attention.

The aim of our study is the investigation and explanation of the possible differences in the dynamic linkage between CO_2 emissions and economic growth, as well as in the energy consumption impact on this long-run relationship among three groups of the European Union countries (EU-14): high-, middle- and low knowledge-advanced economies. The implementation of threshold cointegration with asymmetric adjustment as well as Granger causality tests enables for detecting the changes in the non-linear pollutant-income relationship in the short-run and long-run. In consequence this approach allows to identify the non-linear causal linkages among CO_2 emissions, GDP and energy consumption in a more comprehensive way and formulate more reliable recommendations for energy policy.

The main contribution of the paper lies in testing the EKC hypothesis for the presence of threshold cointegration between per capita CO_2 emissions and per capita real GDP for the EU-14 countries using the methodology developed by Enders and Granger (1998), and Enders and Siklos (2001). This approach will allow for a different speed of adjustment to the long-run equilibrium depending on whether emissions of CO_2 are above or below the EKC curve. Additionally, energy consumption is added to test the robustness of the results. The standard EKC hypothesis and its extended version including energy consumption will be tested by means of Threshold Autoregressive (TAR) and Momentum-Threshold Autoregressive (MTAR) cointegration methods of Enders and

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[1] LULUCF abbreviation stands for Land Use, Land-Use Change and Forestry.

Siklos (2001). We will also concentrate on the short-run and long-run causal relationships between per capita CO_2 emissions, per capita GDP and per capita energy consumption using Threshold Error Correction Model (T-ECM) and Momentum-Threshold Error Correction Model (M-TECM). Such approach enables for detecting nonlinearities in the relationship among the variables and describing different dynamic behavior of the long-run relationship between CO_2 emissions and income in each regime. The cost of adjustment of the CO_2 emissions deviations toward the long-run equilibrium or policy interventions may invalid the assumption of linearity, therefore the linear cointegration techniques enables for capturing only average behavior across regimes (Esteve and Tamarit, 2012).

The second contribution of the paper is that it analyzes the EKC relationship for the 14 EU countries divided into three groups with regard to the Knowledge Economy Index (KEI) Ranking (2012) available on the World Bank website. The KEI is based on a simple average of sub-indexes which represent the four pillars of the knowledge economy: Economic Incentive and Institutional Regime, Innovation and Technological Adoption, Education and Training, Information and Communications Technologies Infrastructure. Hence, it is able to find similarities or differences in the dynamic linkage between CO_2 emissions, energy consumption and economic growth among the developed countries grouped according to the KEI index that captures typical decoupling factors, i.e. technological progress, innovations, productivity and efficiency gains.

The third contribution of the present paper is that it employs long time series data from 1960 to 2012 (World Bank data) what is very important as data covers the period in which the adoption of the Kyoto Protocol (1997) and the financial crisis (2008) took place. During this period many energy and climate policies have been implemented in the European countries. To improve energy efficiency and to reduce the human effects on climate change different measures have been proposed such as: the EU Emission Trading Scheme, the white certificates, financial incentives, voluntary agreements and legislative measures. Therefore the investigation as to economic growth decouples from GHG emissions levels can be helpful to measure the implementation status of environmental policy and to provide new information for policy-making (Annabelle, 2007). To the best of our knowledge, there is no such study that uses the threshold cointegration approach to identify possible nonlinearities in CO_2-GDP relationship for the EU-14 countries studied in this paper which are divided for three groups with regard to the level of knowledge advanced economy and are investigated on the basis of a long span of data at individual country levels.

The remainder of this paper is organized as follows: Section 2 reviews theoretical and empirical literature on the EKC hypothesis; Section 3 focuses on the econometric methodology presenting the steps for establishing the conceptual framework of our study; Section 4 describes the data employed in this study and provides the results of econometric modelling referring to the EKC validity and the occurrence of decoupling effect; finally, Section 5 sets out the main conclusions derived from empirical research.

1. LITERATURE REVIEW

Ambitious environmental targets and tightening the EU's climate policy are accompanied by growing concern about ensuring the economic growth particularly in low income countries. The relationship between GHG emissions and economic development has been the subject of theoretical and empirical studies over past two decades which focus on testing the validity of the Environmental Kuznets Curve (EKC) hypothesis. In the EKC hypothesis is assumed that environmental degradation increases with per capita income during the early stages of economic growth, and then declines with per capita income after passing beyond an income turning point (Stern, 2004). Hence, the relationship between economic development and environmental degradation resembles an inverted U-shaped curve. It is worth stressing that the EKC relationship does not mean that environmental degradation will fall in the long run automatically as income becomes sufficiently high. As Panayotou (1997) indicates the income level cannot be used "as a catch-all surrogate variable for all the changes that take place with economic development". Amongst a number of plausible explanations for the observed EKC as the main factors responsible for the downturn of the EKC are mentioned: the structural change (a shift in the composition of production from manufacturing to services), technological progress and the demand for environmental quality. Good overviews of the deeper understanding of the environment-income relationship were provided among others by Lieb (2003), Stern (2004), Dinda (2004), Luzzati and Orisni (2009). This hypothesis has become more and more popular after 1990 because of its promising finding that economic growth may be compatible with environmental improvement if appropriate policies are taken (Dinda, 2004). However, such environmental policies can be implemented only in countries with higher income level.

Standard EKC model is often modified by adding some explanatory variables such as energy use, population density, urbanization, trade openness, foreign direct investments, civil liberties in order to avoid omitted variable bias in the EKC testing procedure (Azam and Khan, 2016; Özocku and Özdemir, 2017). Since Ang (2007) work examining the dynamic relationship between pollutant emissions, energy consumption and economic growth under the integrated framework, this strand of the research has been intensively developed (Ang, 2007; Halicioglu, 2009; Apergis and Payne, 2009; Soytas and Sari, 2009, Acaravci and Ozturk, 2010; Özocku and Özdemir, 2017). Energy consumption is a key factor influencing economic growth being a fundamental input for both production and consumption of goods, thus it is shown that higher economic development requires more energy consumption (Menegaki, 2014). In turn, the increase in energy consumption is responsible for excessive GHG emissions in the case of countries with fossil fuels dominating in the structure of primary energy sources (Halicioglu, 2009). The mitigation of the GHG emissions through reduction of energy consumption may lead to slowdown in economic growth, especially in countries with lower income (Kais and Sami, 2016). On the other hand, more efficient use of energy in production processes, services and households, that is caused by technological progress, leads to the reduction in energy consumption and in consequences helps to reduce GHG emissions. However, better technology and structural shift towards information-intensive industries and services or “knowledge-based” economy may be possible in countries with higher income level because as Ang (2007) stated: “better economic performance may be a catalyst for energy efficiency”. The environmental benefits from this shift are rather questionable as heavy-polluting industries are taken over by countries with lower income (Ang, 2007). Thus there is a growing need to verify the EKC hypothesis validity and identification the causality relationship among CO_2 emissions, income and energy consumption in the homogeneous group of countries not only in terms of income (Azam and Khan, 2016), but above all in terms of knowledge-advanced economy.

Therefore such important issue is to achieve the sustainable economic growth mostly through boosting in energy efficiency and growing share of renewable energy consumption, what is in line with the EU's environmental policy. Researchers are interested in searching different measures that enable to capture some symptoms of sustainable economic growth such as decoupling effect. Decoupling is said to occur when environmental pressure is stable or decreasing while the economic driving force is increasing (Liobikienė and Butkus, 2017). In particular, absolute decoupling is observed when GHG emissions declines whilst the economy grows, what may be driven by innovations and technological progress leading to structural economy change and energy efficiency improvements. This effect is treated as clear and lasting symptom of sustainable economic growth (Pearce, 2003). Relative decoupling involves situation when emissions grows at a slower rate than economic growth what may be caused by manufacturing activity being outsourced to countries with less restricted environmental law and lower income, and does not improve the absolute amount of pollution globally (Stern, 2006). It is expected that evidence for the EKC hypothesis will be found only for those countries for which absolute decoupling occurred.

Finally, it is worth stressing that many critiques are addressed to the statistical properties of data and the econometric methodology used in the EKC validity testing because they have produced mixed results (Stern, 2004; Dinda, 2004; Kaika and Zervas, 2013). A time-series approach seems to be more appropriate to evaluate the impact of environmental policy, technological progress and energy efficiency on the environment-income relationship over time at individual country levels and therefore this direction of research should be developed in the future (Lieb, 2003; Nahman and Borghesi, 2005).

Our study follows this direction. Moreover, there is a wide stream of researches that have employed time series analysis deploying linear cointegration techniques to examine the relationship between some types of pollutants and per capita income, among others, Halicioglu (2009), Acaravci and Ozturk (2010), Azam and Khan (2016). However, empirical results are inconclusive and make impossible to give policy recommendations that can be applied in a given country. It has been suggested more recently that the adjustment of deviations toward the long-run equilibrium need not be symmetric, constant and reverting each period (Balke and Fomby, 1997; Enders and Granger, 1998; Enders and Siklos, 2001). To our knowledge, there are a very few studies that use non-linear (threshold) cointegration techniques for testing the EKC hypothesis, amongst few, e.g. Fosten et. al. (2012), Esteve and Tamarit (2012) and Piłatowska et. al. (2014). Building on the previous studies, we investigate the relationship between CO_2 emissions, income and energy consumption in the EU-14 countries over the period 1960-2012 based on time series analysis using threshold cointegration test, threshold error correction models and Granger causality test

2. METHODOLOGY

In the empirical study the long-run relationship is estimated between carbon dioxide and income in the framework of two EKC models, i.e. the standard EKC model and its extended version including energy consumption. The addition of this exogenous variable aims at examining the impact of changes in energy consumption on the nature of the CO_2 emissions-income relationship. These models are considered for the EU-14 countries divided into three groups depending on the level of knowledge advanced economy. The EKC models take the form:

- standard specification of long-run EKC: $CO2_t = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \mu_t,$ (1)
- extended specification of long-run EKC: $CO2_t = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \gamma E_t + \delta t + \mu_t,$ (2)

where: $CO2_t$ – CO_2 emissions per capita, GDP_t − real income per capita, E_t − energy consumption per capita, t –time trend, β_i (i= 0,1,2), γ, δ are estimated parameters, μ_t is the disturbance term that may be serially correlated.

Based on the parameter values we may conclude about the shape of environmental pollution and income linkage. If $\beta_1 > 0$ and $\beta_2 < 0$, an inverted U-shape describes the situation when the CO_2 emissions level increases as a country develops until this development reaches a turning point and after that the rising incomes are accompanied by decreasing environmental degradation. The turning point value GDP_{TP} is approximated by the following relation (Stern, 2004): $GDP_{TP} = \exp(-\beta_1/2\beta_2)$. The inverted U-shaped curve and existence of feasible turning point indicate the decoupling or delinking between environmental degradation and economic growth. Then, it is said that the EKC hypothesis is valid. It is worth noting that the EKC is a natural extension of delinking analysis, which has become increasingly popular in detecting and measuring improvements in environmental efficiency with regard to economic activity (Ru et al., 2012).

The first step in our cointegration analysis is to determine the order of integration for each variables by means of the Augmented Dickey-Fuller Generalized Least Squares (ADF-GLS) test (Elliot et al., 1996). If all variables are identified as integrated of first order through the ADF-GLS test, the cointegration test and the Error Correction Model (ECM) may be used. At the beginning we employ the threshold cointegration with asymmetric adjustment procedure of Enders and Siklos (2001) to allow for a different speed of adjustment to the long-run CO_2 emission-income relationship, depending on whether emissions are above or below the EKC. If the threshold cointegration is not found we proceeded with the linear cointegration with symmetric adjustment (Engle and Granger, 1987).

Threshold cointegration with asymmetric adjustment approach is a generalization of the two-stage residual-based cointegration procedure proposed by Engle and Granger (1987), which allows for nonlinearities capturing in the linkage between CO_2 emissions and income. In the first stage of Enders and Siklos procedure the long-run EKC model (1) or (2) is estimated by means of Ordinary Least Squares (OLS) method. The second stage focuses on the coefficient estimates of ρ_1 and ρ_2 in the following two-regime Threshold Autoregressive (TAR) model of the disequilibrium error (Enders and Siklos, 2001):

$$\Delta\mu_t = I_t\rho_1\mu_{t-1} + (1-I_t)\rho_2\mu_{t-1} + \sum_{i=1}^{r}\theta_i\Delta\mu_{t-i} + \varepsilon_t, \tag{3}$$

where: μ_t is the disturbance term extracted from (1) or (2), θ_i (i=1,2,...,r) are estimated parameters, ε_t is a white noise disturbance.

Term I_t is the Heaviside indicator function such that I_t=1 if $\mu_{t-1} \geq \tau$ and I_t=0 if $\mu_{t-1} < \tau$, where τ is the threshold value. If the Heaviside indicator depends not on levels but on changes of μ_{t-1}, then it is specified as I_t=1 if $\Delta\mu_{t-1} \geq \tau$ and I_t=0 if $\Delta\mu_{t-1} < \tau$. This model is termed the Momentum-Threshold Autoregressive (MTAR) model. The TAR model allows to examine whether the positive deviations ($\mu_t > 0$) or deviations above the threshold value τ from the long-run equilibrium have different effects on the behavior of emissions than the negative deviations ($\mu_t < 0$) or below the threshold value. The MTAR model allows to exhibit more "momentum" in one direction than the other, i.e. allows to display various amounts of autoregressive decay depending on whether the series is increasing or decreasing. The necessary and sufficient condition for μ_t to be stationary is: $\rho_1<0$, $\rho_2<0$, $(1+\rho_1)(1+\rho_2)<1$ for any threshold value τ. If these conditions are satisfied and threshold value τ is set to zero, $\mu_t = 0$ can be considered as the long-run equilibrium value of the sequence. If μ_t is higher than the long-run equilibrium value (τ), the adjustment is $\rho_1\mu_{t-1}$, but if μ_t is lower than the long-run equilibrium, the adjustment is $\rho_2\mu_{t-1}$ (Yau and Nieh, 2009). In general, the threshold value τ has to be estimated along with the values of adjustment parameters ρ_1 and ρ_2. In our studies we follow Enders and Siklos (2001) by employing Chan's methodology of searching the consistent estimates of threshold value (Chan, 1993). To select the best adjustment process (TAR or MTAR) we use the Bayesian Information Criterion (BIC).

Testing for threshold cointegration is performed in two steps. Firstly, the null hypothesis of no cointegration: $H_0:\rho_1=\rho_2=0$ is tested, and secondly, when it is rejected, then the null hypothesis of symmetric adjustment: $H_0:\rho_1=\rho_2$ is verified. To test the former hypothesis Enders and Siklos (2001) proposed the $\Phi\mu$ statistic which under the null hypothesis of no cointegration has a non standard distribution. The critical values for this non standard $\Phi\mu$ statistic are tabulated in Enders and Siklos (2001). The later hypothesis of symmetric adjustment is tested using the standard *F* statistic. Rejecting both the null hypotheses implies the existence of threshold cointegration with asymmetric adjustment (Enders and Siklos, 2001).

Given the threshold or linear cointegration is found, the next step proceeds with the Granger-causality test using Threshold Error Correction Model or Momentum-Threshold Error Correction Model (Enders and Granger, 1998; Enders and Siklos, 2001) or linear Error Correction Model (Engle and Granger, 1987). In case of threshold cointegration and depending on the specification of the long-run EKC (standard or extended), the TECM or M-TECM are expressed as follows (Yau and Nieh, 2009):

– standard specification of the long-run EKC:

$$\Delta Y_{jt} = \beta + \lambda_1 Z_{t-1}^{+} + \lambda_2 Z_{t-1}^{-} + \sum_{i=1}^{q_1}\delta_i\Delta CO2_{t-i} + \sum_{i=1}^{q_2}\theta_i\Delta GDP_{t-i} + \sum_{i=1}^{q_3}\gamma_i\Delta GDP_{t-i}^2 + v_t, \tag{4}$$

– extended specification of the long-run EKC:

$$\Delta Y_{jt} = \beta + \lambda_1 Z^{+}_{t-1} + \lambda_2 Z^{-}_{t-1} + \sum_{i=1}^{q_1}\delta_i \Delta CO2_{t-i} + \sum_{i=1}^{q_2}\theta_i \Delta GDP_{t-i} + \sum_{i=1}^{q_3}\gamma_i \Delta GDP^{2}_{t-i} + \sum_{i=1}^{q_4}\alpha_i \Delta E_{t-i} + v_t, \qquad (5)$$

where: $\Delta Y_{jt} = (\Delta CO2_t, \Delta GDP_t)$, $Z^{+}_{t-1} = I_t \hat{\mu}_{t-1}$ and $Z^{-}_{t-1} = (1 - I_t)\hat{\mu}_{t-1}$; $\hat{\mu}_{t-1}$ is obtained from the estimated long-run relationship (1) or (2); I_t – Heaviside indicator function depending on the levels of $\hat{\mu}_{t-1}$ (TECM specification) or changes of $\hat{\mu}_{t-1}$ (M-TECM specification); β, λ_1, λ_2, δ_i (i=1,2,...,q_1), θ_i (i=1,2,...,q_2), γ_i (i=1,2,...,q_3), α_i (i=1,2,...,q_4) are estimated parameters; and v_t is a white noise disturbance.

In the case of linear cointegration the ECM specifications are as follows:

– standard specification of the long-run EKC:

$$\Delta Y_{jt} = \beta + \lambda\, ECT_{t-1} + \sum_{i=1}^{q_1}\delta_i \Delta CO2_{t-i} + \sum_{i=1}^{q_2}\theta_i \Delta GDP_{t-i} + \sum_{i=1}^{q_3}\gamma_i \Delta GDP^{2}_{t-i} + v_t, \qquad (6)$$

– extended specification of the long-run EKC:

$$\Delta Y_{jt} = \beta + \lambda\, ECT_{t-1} + \sum_{i=1}^{q_1}\delta_i \Delta CO2_{t-i} + \sum_{i=1}^{q_2}\theta_i \Delta GDP_{t-i} + \sum_{i=1}^{q_3}\gamma_i \Delta GDP^{2}_{t-i} + \sum_{i=1}^{q_4}\alpha_i \Delta E_{t-i} + v_t. \qquad (7)$$

The equation (4)-(5) or (6)-(7) are estimated by the OLS method. The long-run causality is determined by the parameters λ_1 and λ_2 in TECM or M-TECM specification, i.e. the long-run Granger causality is tested by looking at the significance of the speed of adjustment towards the long-run equilibrium, depending on whether emissions are above (t-Student statistic for λ_1 parameter) or below (t-Student statistic for λ_2 parameter) the EKC. In the case of linear ECM (6) or (7), the above procedure is reduced to test only significance of λ parameter. The short-run causality (weak causality) is governed by the parameters δ_i, θ_i, γ_i, α_i and may come either from its own history of lagged dynamics or from the lagged effects of changes in real GDP (and square real GDP) and/or some additional explanatory variables (e.g. energy consumption). Then, the Wald F test for the joint significance of the coefficients on the lagged terms in the error correction models (in threshold or linear version) is applied. The following null hypothesises are tested in order to find the weak causality between the set of variables (Asafu-Adjaye, 2000):

- $H_0 : \delta_i = 0, (i = 1,2,...,q_1)$ or CO_2 emissions does not Granger cause economic growth in the short-run,
- $H_0 : \theta_i = 0, (i = 1,2,...,q_2), \gamma_i = 0, (i = 1,2,...,q_3)$, or GDP terms do not Granger cause CO_2 emissions in the short-run,
- $H_0 : \alpha_i = 0, (i = 1,2,...,q_4)$ or energy consumption does not Granger cause respectively economic growth or CO_2 emissions in the short-run.

It is also desirable to check for the strong Granger causality between CO_2 emissions, economic growth and energy consumption by providing the Wald F statistic for the interactive terms, i.e. the Error Correction Term (ECT) and the lagged explanatory variables (Piłatowska et al., 2014). The joint significance of both the coefficient associated with the ECT_{t-1} and the coefficients on the lagged terms, e.g. H_0: θ_i=λ_1=0, H_0: θ_i=λ_2=0 in equations (4) or (5) for the threshold cointegration case or H_0: θ_i=λ=0 in equations (6) or (7) for the linear cointegration case, gives the indication of which variables bear the burden of short-run adjustment to re-establish long-run equilibrium, given a shock to the system (Asafu-Adjaye, 2000).

3. EMPIRICAL RESULTS

3.1 Analysis of data and decoupling performance

The study is carried out for the 14 European Union countries grouped into the high-, middle- and low-level knowledge based economies according to the position in the KEI 2012 Ranking. To the high-level countries belong: Denmark, Finland, the Netherlands, Sweden; to middle-level countries: Austria, Belgium, France, Ireland, Spain, the United Kingdom; to low-level countries: Greece, Italy, Portugal. The data used in this study consist of CO_2 emissions ($CO2_t$; in metric tons per capita), real gross domestic product (GDP_t; constant 2005 US dollars per capita) and energy consumption (E_t; in kg of oil equivalent per capita) and are taken from the World Development Indicators (WDI) online database. The sample period runs from 1960 to 2012, with a total of 53 annual observations, according to data availability.

Before starting with the cointegration analysis we first describe the EU countries considered in the study in terms of the mix of energy consumption (in 2012) as the different energy sources imply an extremely different CO_2 emissions, e.g. the carbon emission factor for solid fossil fuels is much higher than for natural gas, and equal to null for wind and solar energy. Next the evolution of energy intensity (E/GDP) is considered as the environmental Kuznets curve (EKC) is merely the reflection of the peak theory of energy intensity (Sun, 1999) and then the decoupling performance of the EU countries is examined by reporting the growth rates of CO_2 emissions and GDP.

Table 1. The mix of gross inland energy consumption in 2012 in the EU-14 countries (in %) and the Knowledge Economy Index, KEI (2012 ranking)

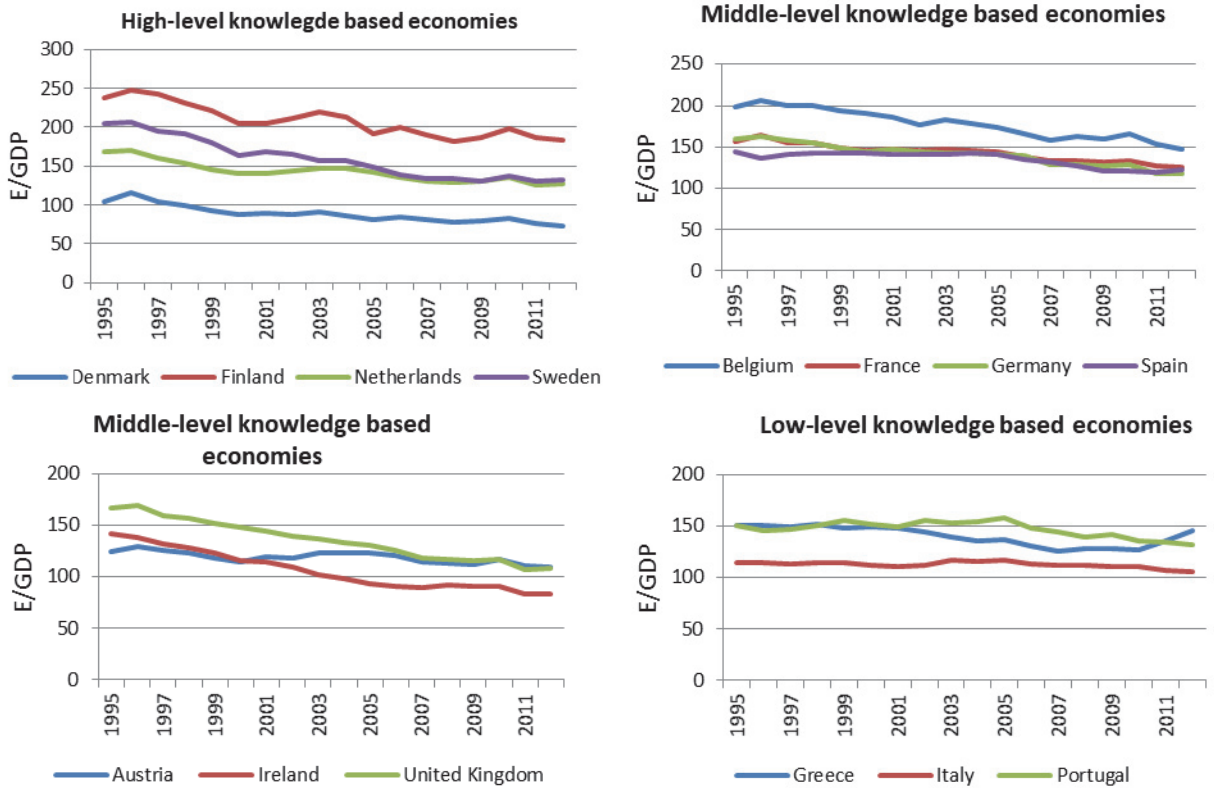
Country	Solid fuels	Crude oil	Gas	Renewables	Nuclear	**KEI 2012**
High-level knowledge based economies						
Sweden	4	25	2	34	33	9.43
Finland	13	26	9	29	17	9.33
Denmark	14	39	19	23	0	9.16
Netherlands	10	41	40	4	1	9.11
Middle-level knowledge based economies						
Germany	25	34	22	10	8	8.9
Ireland	17	47	29	6	0	8.86
UK	19	34	33	4	9	8.76
Belgium	5	39	26	6	18	8.71
Austria	10	36	22	30	0	8.61
Spain	12	42	22	13	12	8.35
France	4	31	15	8	42	8.21
Low-level knowledge based economies						
Italy	10	37	38	13	0	7.89
Portugal	13	45	18	20	0	7.61
Greece	29	48	13	9	0	7.51

Source: Eurostat database, Complete Energy Balance.

For most of the EU countries the mix of energy consumption in 2012 was the mixture from crude oil and gas as well renewables (Table 1). In Sweden and Finland 29%−34% of energy consumption came from renewables but also with the large nuclear share, while in Denmark crude oil share was dominant (40%) but renewables share was also high (23%). In the most of middle-level knowledge based economies crude oil contributed by far the largest share (34-47%), while in France nuclear power was dominant (42%) and in Austria renewables (30%) (mainly hydro and wind power) accounted for the noticeable share in total energy consumption. It is worth emphasizing that the share of solid fuels in the structure of energy consumption is significantly high in Germany (25%), the UK (19%) and Ireland (17%). Energy consumption in the low-level knowledge based economies was also the mixture from crude oil and a country specific energy source, i.e. renewables (20%) in Portugal, gas (38%) in Italy and fossil fuels (29%) in Greece. This variety of energy sources reflects the availability of different fossil fuel deposits and the potential for renewables among the EU countries and on the other hand different policy approach towards nuclear fuels and renewables.

Figure 1 shows that the energy intensity (E/GDP - gross inland consumption of energy divided by GDP; kg of oil equivalent per 1000 EUR) diminishes significantly for high and middle-level knowledge based economies during the period considered (except Austria for which energy intensity is rather stable). This suggests the energy peak has already occurred in those countries. For low-level knowledge based economies the situation is slightly decreasing and more or less stable since 2000. This means that the energy peak has not been reached yet in these countries.

Figure 1. Energy intensity in the EU-14 countries, 1995-2012 (unit: kg of oil equivalent per 1000 dollars at 2005 prices)



Source: Eurostat database (February 8th, 2017).

Table 2 presents GDP growth and the growth in emission of CO_2 in the EU-14 countries. It is seen that Belgium (since 2005), Denmark, Sweden, France, Germany and the UK report the absolute decoupling (emissions have declined in absolute terms), e.g. in the UK CO_2 emissions have fallen by 24% in 2012 over 1990 level, in Denmark - by 33%, in France - by 18%, all against a backdrop of steady economic growth. The results for Finland, the Netherlands, Austria, Ireland, Greece, Italy in recent years indicate evidence of relative decoupling (emissions growth rate is slower than GDP growth rate).

Table 2. GDP and CO_2 emission indices (1990=100%)

	CO_2 emission index					GDP index				
Country	1995	2000	2005	2010	2012	1995	2000	2005	2010	2012
High-level knowledge based economies										
Denmark	112	98	89	86	67	110	125	132	129	129
Finland	99	98	100	111	85	95	121	135	138	138
Netherlands	103	98	99	103	94	108	130	136	142	142
Sweden	103	92	94	92	78	100	119	133	139	140
Middle-level knowledge based economies										
Austria	100	103	120	108	94	108	124	132	138	142
Belgium	104	105	97	94	84	106	121	130	134	134
France	91	93	96	86	82	105	118	124	125	127
Germany	83	79	76	72	71	108	118	121	129	137
Ireland	103	122	118	99	89	122	187	221	210	214
Spain	109	130	144	103	105	106	127	138	137	131
UK	95	95	92	81	76	110	127	142	139	141
Low-level knowledge based economies										
Greece	101	115	122	106	101	102	119	141	138	117
Italy	103	107	111	93	86	106	117	121	116	113
Portugal	123	145	147	111	119	108	129	132	135	128

Source: Data calculation based on World Development Indicators (WDI) online database.

3.2 The standard and extended EKC model - cointegration and causality analysis

All analyzed variables are expressed in natural logarithms in order to reduce heteroscedasticity and to obtain the growth rate of relevant variables by taking their differenced logarithms during the investigation of Granger causality between CO_2 emissions, energy consumption and income (Acaravci and Ozturk, 2010). Before performing cointegration analysis, we use the Augmented Dickey-Fuller Generalized Least Squares (ADF-GLS) test to identify the order of integration for each variable (Elliot et al., 1996). We found that all series are integrated of first order, $I(1)$ (see Appendix). Next the long-run relationship is estimated between carbon dioxide and income in the framework of two EKC models, i.e. the standard EKC model and its extended version including energy consumption for the EU countries divided into three groups depending on the level of knowledge based economy. Parameters of the EKC models (1)-(2) are estimated by means of the ordinary least squares (OLS) method using the R software. Based on the disequilibrium errors μ_t from the long-run regression (1) and (2) we estimate parameters of the TAR and MTAR models (3) (both for $\tau=0$ and estimated τ according to the Chan's method) by the means of OLS method to test for threshold cointegration between the CO_2 emissions and income. Only for the Netherlands and Spain (standard EKC model) and also the Netherlands and Sweden (extended EKC model) both the null hypothesises of no cointegration (H_0: $\rho_1=\rho_2=0$) and symmetric adjustment (H_0: $\rho_1=\rho_2$) are rejected (see Table 3)[2].

The results in Table 3 show that the set of countries exhibiting the threshold cointegration between CO_2 emissions and income is different (except the Netherlands) in two versions of the EKC model. It is worth noting that in the case of standard EKC model the short-run adjustments towards the long-run equilibrium revert more quickly when the emissions show the momentum in the downwards direction ($|\rho_1|<|\rho_2|$) and tend to persist more when emissions show the momentum in the upwards direction. This means that emissions are rather 'sticky downwards', i.e. they are resistant to move down. In the case of the extended EKC model for Sweden (except the Netherlands) the speed of adjustments is opposite because $|\rho_1|>|\rho_2|$ what means that emissions are rather 'sticky upwards', i.e. they are resistant to move up. Taking into account different environ-

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[2] The rest of the results are omitted due to the space limit but they are available on request.

mental regulation introduced by the EU member countries this behavior of emissions to adjust quicker to equilibrium when they are above the long-run path might have been expected. These results indicate that the impact of energy consumption on the EKC relationship is relevant. For the set of the EU-14 countries for which the threshold cointegration between CO_2 emissions and income is not found, we conduct the linear cointegration test (see Table 4).

Table 3. Results of threshold cointegration test in the case of standard and extended EKC long-run relationship

Parameters/ Statistics	*Standard LR-EKC (1)*		*Extended LR-EKC (2)*	
	Netherlands	*Spain*	*Netherlands*	*Sweden*
	MTAR τ= -0.050	*MTAR* τ=-0.057	*MTAR* τ=0	*MTAR* τ=0
ρ_1	-0.117	-0.096	-0.115	-0.333***
	(-1.020)	(-1.210)	(-0.643)	(-3.444)
ρ_2	-0.610***	-0.598***	-0.906***	-0.083
	(-3.394)	(-3.407)	(-5.250)	(-0.814)
$\Phi\mu$	6.066*	6.537*	13.785***	6.261*
F	5.701**	11.988***	11.729***	8.788***
	[0.021]	[0.001]	[0.001]	[0.005]
Lag	1	0	1	0
BIC	-147.45	-148.94	-218.44	-155.67
LB(4)	0.74	3.86	4.72	1.24
	[0.946]	[0.425]	[0.317]	[0.871]

Note: (***), (**), (*) indicate significance at 1%, 5% and 10%. Critical values for $\Phi\mu$ statistic from Enders, Siklos (2001). *t*-statistic for ρ terms in parentheses. In brackets are *p*-values for Wald *F*-statistic and Ljung-Box statistic (LB(4)). The lag length is selected such that the BIC is minimized. The choice between the TAR and MTAR models for a given country is made using BIC criterion.

It is interesting that for all low-level knowledge based economies (Greece, Italy, Portugal) the evidence for linear cointegration is not found in the case of the standard EKC, but it is found in the case of the extended EKC (with energy consumption and/or time trend added[3]). Addition of energy consumption improved the long-run CO_2 emissions-income relationship for Sweden and Ireland in the terms of cointegration (Table 3 and 4), i.e. threshold and linear cointegration is found respectively, while in the framework of standard EKC model the CO_2 emissions and GDP were not cointegrated.

Having established threshold or linear cointegration in the long-run relation for CO_2 emissions, it is possible to analyse estimation results and what they mean for the EKC hypothesis. We can see (Tab. 4) that in terms of the β coefficients described in the EKC model, we have $\beta_0 < 0$, $\beta_1 > 0$, $\beta_2 < 0$ for Denmark, Finland, the Netherlands (high-level knowledge based economies), Austria, Belgium, France, Germany, Spain, the UK (middle-level knowledge based economies) what implies an inverted U-shape of the EKC relation (CO_2 emissions first rise with per capita GDP and after reaching the turning point start falling). The fitted values of CO_2 emissions per capita for the observed values of real GDP per capita are displayed in Fig. 2 (only for countries for which cointegration is found). These results show that there is strong evidence in favor of the EKC hypothesis (except Spain), i.e. there is one turning point in the observed range of GDP for CO_2 emissions and the inverted U-shape holds. This means that the decoupling of economic growth from CO_2 emissions appears (Azar et. al, 2002; Andreoni and Galmarini, 2012). In the case of Spain the signs of the β coefficients suggest an inverted U-shape, however there is no turning point in the observed range of GDP and therefore the EKC hypothesis is rejected. This means that the decoupling between CO_2

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[3] The energy consumption is added to all EKC models, and time trend only when it improves the properties of residuals in terms of stationarity.

emissions and GDP does not occur. For the UK the fitted EKC has only the monotonically falling branch and the feasible turning point but out of the observed range of GDP (the turning point is located before the beginning of sample period). This is a strong evidence that in the UK economic growth decouples from emissions growth.

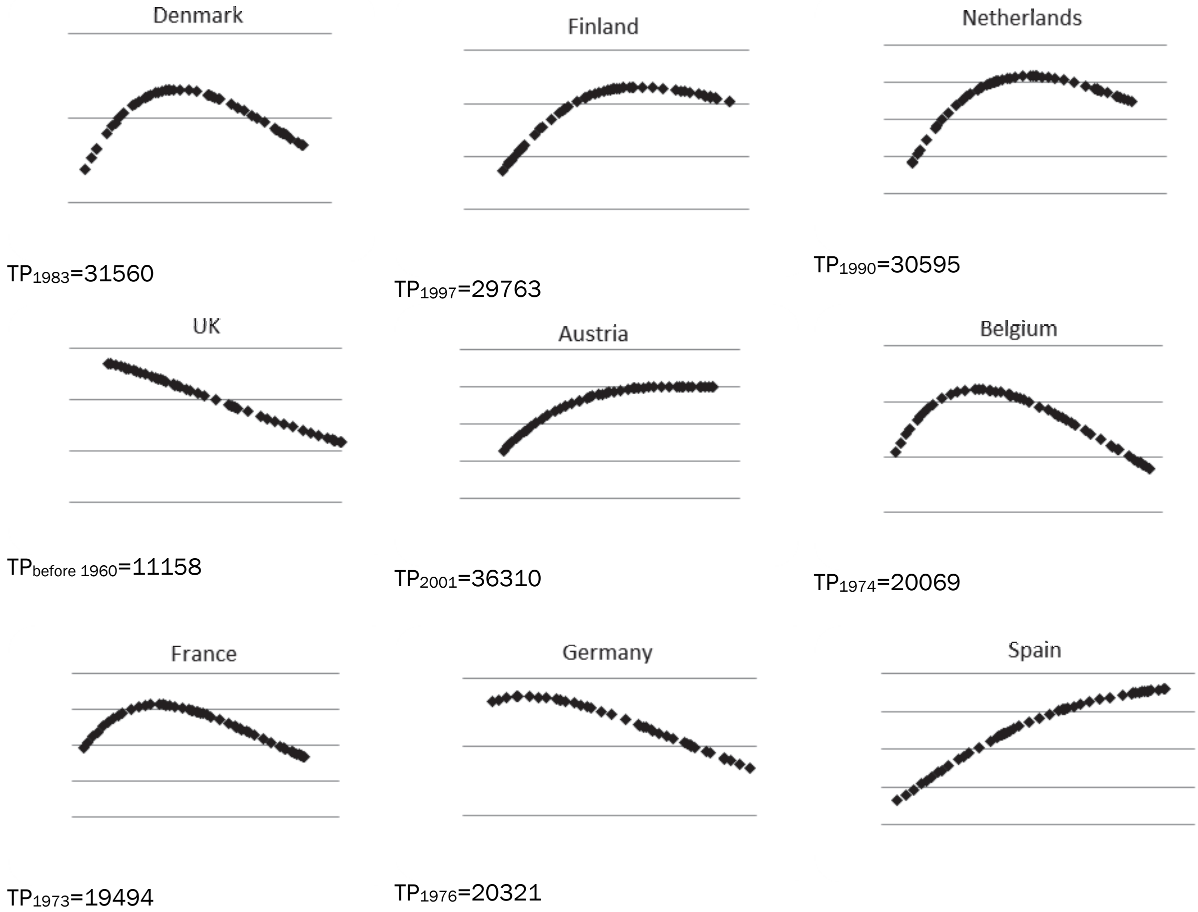
After adding energy consumption and/or time trend to the EKC model (Tab. 4) the coefficients of GDP_t and GDP_t^2 for most of countries are not correctly signed and are insignificant in comparison to the standard specification of the EKC (except France, Ireland, Italy and Portugal), i.e. now coefficients are signed like in the U-shape long-run relationship. This indicate that addition of energy consumption has affected the results and the EKC relation is not robust. On the other hand, the significance of coefficients of energy consumption can suggest that energy consumption is of great relevance in explaining CO_2 emissions in these countries.

Table 4. Estimated parameters of long-run EKC and results of linear cointegration test

Country	LR relation	Parameter estimates					ADF-GLS test
		Intercept	GDP_t	GDP_t^2	E_t	Time	
High-level knowledge based economy							
Denmark	(1)	-156.2***	30.62***	-1.478***			-1.68*
	(2)	-2.06	-1.237	0.092	0.956***	-0.019***	-2.47**
Finland	(1)	-108.7***	21.585***	-1.048***			-2.29**
	(2)	12.978	-5.445*	2.436*	2.385***	-0.014***	-1.73*
Netherlands	(1)	-90.4***	17.975***	-0.870***			threshold cointegration
	(2)	20.98**	-5.094***	0.247***	0.937***	-0.006**	threshold cointegration
Sweden	(1)	-106.8***	21.797***	-1.091***			-1.43
	(2)	4.95	-2.896	0.211	0.673*	-0.047***	threshold cointegration
Middle-level knowledge based economy							
Austria	(1)	-42.98***	8.582***	-0.409***			-1.85*
	(2)	10.83	-3.863**	0.193**	1.349***	-0.014***	-2.74***
Belgium	(1)	-56.86***	11.989***	-0.605***			-2.28**
	(2)	13.781	-3.841*	0.188*	1.024***	-0.015***	-3.02***
France	(1)	-110.2***	22.745***	-1.152***			-2.13**
	(2)	-75.70***	15.241***	-0.800***	0.658**	–	-1.96**
Germany	(1)	-105.3***	21.765***	-1.097***			-3.13***
	(2)	-0.609	-0.941	0.021	1.251***	–	-2.84***
Ireland	(1)	-20.16**	4.139**	-0.191*			-1.38
	(2)	-7.34	0.089	-0.007	1.187***	-0.004**	-2.66***
Spain	(1)	-63.46***	12.534***	-0.600***			threshold cointegration
	(2)	-2.08	-1.023	0.057	1.147***	-0.014***	-1.75*
UK	(1)	-14.89*	3.720**	-0.200**			-2.80***
	(2)	22.27***	-5.038***	0.23***	0.905***	–	-3.64***
Low-level knowledge based economy							
Greece	(1)	-49.29***	9.227***	-0.408***			-1.23
	(2)	-3.096	-0.410	0.010	1.061***		-2.98***
Italy	(1)	-97.21***	19.359***	-0.944***			-1.58
	(2)	-18.84***	2.445***	-0.106**	0.913***	-0.010***	-4.23***
Portugal	(1)	0.002	-0.983	0.118 **			-1.03
	(2)	-14.15***	1.904***	-0.120***	1.125***	–	-2.87***

Note: (***), (**), (*) indicate significance at 1%, 5% and 10% level.

Figure 2. The fitted values of the estimated EKC results and turning points (TP)



TP_{1983}=31560

TP_{1997}=29763

TP_{1990}=30595

$TP_{before\ 1960}$=11158

TP_{2001}=36310

TP_{1974}=20069

TP_{1973}=19494

TP_{1976}=20321

Given the cointegration (threshold or linear) results in Tab. 3 and 4, we proceed with the Granger causality test using the error-correction models both in linear and threshold version (4)-(7). The estimated error correction models (ECMs) displayed reasonable goodness-of-fit based on the R^2 and F statistic (not reported here) and passed most of the diagnostic tests including the Ljung-Box test for autocorrelation, the McLeod-Li test for autoregressive heteroscedasticity ARCH(4), the Jarque-Bera test for normality, the Breush-Pagan test for heteroscedasticity of residuals. In Table 5-8 we provide joint Wald F-statistic of the lagged differences of explanatory variables to test the significance of short-run causal effects. We also provide t-statistic for the coefficients of the ECTs which give an indication of long-run causal effects. Finally, we provide joint Wald F-statistic for the interactive terms, i.e. the ECTs and lagged differences of explanatory variables which give an indication of which variables bear the burden of short-run adjustment to re-establish long-run equilibrium, given a shock to the system. We compare the causality results for the standard and extended EKC relation to evaluate changes in causal pattern.

It can be seen in Table 5 and 6 that the Wald F-statistic for GDP terms in emissions equations is significant at least at 10% level for Denmark, Finland, France, the Netherlands and the UK (short-run effects), however none of F-statistic is significant in income equation. These results imply that, in the short-run, there is unidirectional Granger causality running from GDP to CO_2 emissions for these countries.

Table 5. The Granger causality results in the threshold error correction model - standard specification of the EKC

Dependent variable	*Short-run effects*		*Regimes*	*Long-run effect*	*Interaction terms*	
	$\Delta CO2_t$	$\Delta GDP_t, \Delta GDP_t^2$		*ECT* only	*ECT*, $\Delta CO2_t$	*ECT*, ΔGDP$_t$, ΔGDP_t^2
High-level knowledge based economy: Netherlands						
$\Delta CO2_t$	–	5.057**	I	-0.747	–	3.422**
			II	-3.621***	–	6.833***
ΔGDP_t	0.133	–	I	-1.206	0.754	–
			II	-2.523**	3.453**	–
Middle-level knowledge based economy: Spain						
$\Delta CO2_t$	–	1.385	I	-2.422**	–	3.924**
			II	-3.878***	–	5.792***
ΔGDP_t	1.836	–	I	-0.795	1.639	–
			II	-0.237	1.235	–

Note: (***), (**), (*) indicate significance at 1%, 5% and 10% level.

Table 6. The Granger causality results in the linear error correction model - standard specification of the EKC

Dependent variable	*Short-run effects*		*Long-run effect*	*Interaction terms*	
	$\Delta CO2_t$	ΔGDP_t, ΔGDP_t^2	*ECT* only	ECT, $\Delta CO2_t$	ECT, ΔGDP_t, ΔGDP_t^2
High-level knowledge based economy					
Denmark					
$\Delta CO2_t$	–	2.55*	-2.12*	–	4.14**
ΔGDP_t	2.75	–	-0.75	1.38	–
Finland					
$\Delta CO2_t$	–	4.21*	-2.56**	–	6.05***
ΔGDP_t	2.52	–	0.21	1.64	–
Middle-level knowledge based economy					
Austria					
$\Delta CO2_t$	–	3.42**	-2.04**	–	4.16**
ΔGDP_t	5.22**	–	-0.04	3.07*	–
Belgium					
$\Delta CO2_t$	–	1.88	-2.06*	–	2.95**
ΔGDP_t	2.72	–	-0.49	1.36	–
France					
$\Delta CO2_t$	–	4.376**	-0.585	–	3.480**
ΔGDP_t	0.137	–	-0.602	0.257	–
Germany					
$\Delta CO2_t$	–	0.741	-2.935***	–	4.013**
ΔGDP_t	0.134	–	-1.768*	1.768	–
UK					
$\Delta CO2_t$	–	3.596**	-1.775*	–	3.432**
ΔGDP_t	0.288	–	-2.183**	2.469*	–

Note: (***), (**), (*) indicate significance at 1%, 5% and 10% level.

In the case of Austria the emissions equation and income equation results indicate that both the GDP Granger-causes emissions and CO$_2$ emissions cause the GDP, therefore there may indicate bidirectional Granger causality between CO$_2$ emissions and GDP in the short-run. The results for Belgium, Germany and Spain indicate that there is no causality between emissions and GDP in the short-run because none of explanatory variables is significant.

Looking at the t-statistic, it can be seen that the coefficient of ECT is significant in the emissions equation but is not significant in the GDP equation, hence there is unidirectional long-run causality running from GDP to CO_2 emissions for Denmark, Finland, Austria, Belgium, Spain (in both regimes) and the Netherlands (only in the second regime). Moreover, the significance of interaction term (ECT, ΔGDP_t, ΔGDP_t^2) indicate that the long-run effect of GDP is strong. In the case of the UK and the Netherlands (only in the second regime) the significance of coefficient of ECT in both equations suggest that there is bidirectional causality between emissions and GDP (Table 5-6). This finding implies that both emissions and income contribute to short-run adjustment to re-establish the long-run equilibrium.

Table 7. The Granger causality results in the threshold error correction model - extended specification of the EKC

Dependent variable	*Short-run effects*			*Regimes*	*Long-run effect*	*Interaction terms*		
	$\Delta CO2_t$	ΔGDP_t, ΔGDP_t^2	ΔE_t		*ECT* only	*ECT*, $\Delta CO2_t$	*ECT*, ΔGDP_t, ΔGDP_t^2	ECT, ΔEt
High-level knowledge based economy								
Netherlands								
$\Delta CO2_t$	–	1.857	14.94***	I	-1.48	–	2.040	7.69***
				II	-4.33***	–	6.642***	16.91***
ΔGDP_t	0.505	–	2.08	I	0.01	0.321	–	1.09
				II	-0.40	0.278	–	1.13
Sweden								
$\Delta CO2_t$	–	3.534**	0.72	I	-0.89	–	3.172**	0.71
				II	-0.38	–	2.366*	0.43
ΔGDP_t	0.170	–	0.02	I	1.47	1.227	–	1.11
				II	0.56	0.266	–	0.17

Note: (***), (**), (*) indicate significance at 1%, 5% and 10% level.

Having included energy consumption and/or time trend and estimated error correction models both in linear and threshold version (4)-(7), the importance of energy consumption in restoring the long-run equilibrium has been exhibited in the case of Belgium, Germany, Spain, the UK, the Netherlands (in the first regime), Greece, Italy and Portugal due to the significance *ECT* term and interaction terms *ECT*, ΔE_t in CO_2 emissions equation (see Table 7-8). This means that energy consumption bears the burden of short-run adjustment to the EKC equilibrium path, given a shock to the system. Moreover, energy consumption influences economic growth in the case of the UK in the long-run due to the significance of both *ECT* term and interaction term *ECT*, ΔE_t in GDP equation. This implies that the GDP and energy consumption interact in the short-run to re-establish the long-run equilibrium after a change in CO_2 emissions.

In the short-run, the impact of energy consumption is revealed only for Finland and the Netherlands in emissions equation and for Germany and Portugal in the GDP equation. The addition of energy consumption to the CO_2 emissions-income relation changed the direction of causality in the case of Germany and the Netherlands, i.e. in the standard EKC model causality between the CO_2 emissions and income is bidirectional, and in the extended EKC model – unidirectional (the Wald F-statistic for the short-run effects).

Table 8. The Granger causality results in the linear error correction model - extended specification of the EKC

Dependent variable	*Short-run effects*			*Long-run effect*	*Interaction terms*		
	$\Delta CO2_t$	*ΔGDP_t, ΔGDP_t^2*	*ΔE_t*	*ECT* only	*ECT, $\Delta CO2_t$*	*ECT,ΔGDP_t, ΔGDP_t^2*	*ECT, ΔE_t*
			High-level knowledge based economy				
Denmark							
$\Delta CO2_t$	–	2.21	0.96	-0.22	–	1.58	0.59
ΔGDP_t	0.08	–	0.22	1.94	2.05	–	1.87
Finland							
$\Delta CO2_t$	–	6.52***	3.75*	-1.4	–	4.58***	2.21
ΔGDP_t	0.22	–	0.06	-0.39	0.14	–	0.15
			Middle-level knowledge based economy				
Austria							
$\Delta CO2_t$	–	3.72**	0.2	0.12	–	2.50*	0.11
ΔGDP_t	0.01	–	2.31	0.93	0.7	–	1.17
Belgium							
$\Delta CO2_t$	–	4.85**	0.01	-3.67***	–	6.05***	8.51***
ΔGDP_t	0.08	–	0.83	-1.19	0.73	–	1.19
France							
$\Delta CO2_t$	–	4.931**	0.07	-1.64*	–	3.971**	1.35
ΔGDP_t	0.018	–	0.16	-1.64*	1.393	–	1.69
Germany							
$\Delta CO2_t$	–	1.692	1.89	-2.24**	–	2.687*	2.51*
ΔGDP_t	0.193	–	3.62*	-1.58	1.271	–	1.97
Ireland							
$\Delta CO2_t$	–	5.178**	1.53	-0.43	–	3.466**	0.78
ΔGDP_t	0.632	–	0.04	0.58	0.823	–	0.31
Spain							
$\Delta CO2_t$	–	0.584	0.53	-2.49**	–	2.372*	4.60**
ΔGDP_t	0.795	–	0.41	-0.79	0.524	–	0.78
UK							
$\Delta CO2_t$	–	3.263**	0.08	-2.44**	–	4.185**	3.81**
ΔGDP_t	0.003	–	0.04	-2.65**	5.081**	–	4.89**
			Low-level knowledge based economy				
Greece							
$\Delta CO2_t$	–	0.54	1.96	-1.89*	–	1.44	5.2***
ΔGDP_t	0.2	–	1.25	0.11	0.16	–	0.74
Italy							
$\Delta CO2_t$	–	0.522	1.17	-2.58**	–	2.357*	3.41**
ΔGDP_t	0.956	–	0.15	-0.28	0.495	–	0.08
Portugal							
$\Delta CO2_t$	–	5.532***	0.14	-2.37**	–	6.378***	3.17*
ΔGDP_t	0.489	–	3.37**	-0.55	0.284	–	2.94**

Note: (***), (**), (*) indicate significance at 1%, 5% and 10% level.

Generally, the reaction of different knowledge based economies to the addition of energy consumption is diversified. For high-level knowledge based economies (Denmark, Finland, Sweden, the Netherlands) and some middle-level knowledge based economies (Austria, Germany) the addition of energy consumption has made causal links between CO_2 emissions and GDP weaken in the long-run (insignificance of ECT term), and for other middle-level knowledge based economies - strengthen (Belgium, Spain, the UK). On the other hand, for low-level knowledge based economies (Greece, Italy, Portugal) the addition of energy consumption enabled to reveal causal links in the long-run.

CONCLUSIONS

This paper has considered the long-run equilibrium relationship between CO_2 emission and economic growth (the standard EKC model) and the energy consumption impact on this long-run relationship (the extended EKC model) in an asymmetric framework using the non-linear threshold cointegration for the EU countries divided into three groups according to the level of knowledge advanced economies.

The major findings are as follows. First, in the most of cases in which the threshold cointegration is found, the short-run adjustments towards the long-run equilibrium revert more quickly when the CO_2 emissions show the momentum in the downwards direction. This is a rather surprising result taking into account that all analyzed countries have ratified the Kyoto Protocol and they have a commitment to reduce their emissions to a given level. Therefore, it is expected that CO_2 emissions adjust quicker to the EKC equilibrium when they are above the long-run path.

Second, we found that the EKC hypothesis is valid for the most high-level and some middle-level knowledge based economies. It is worth noting that evidence for the EKC hypothesis refers not only to those countries for which absolute decoupling occurred (Belgium, Denmark, France, Germany, the UK), but also to countries for which relative decoupling is observed (Finland, the Netherlands, Austria). Moreover, these countries are characterized by either decreasing trend in energy intensity or the diversified energy consumption mix with significant share of nuclear and renewable energy and also smaller share of solid fuels.

Confronting the shape of the fitted values of estimated EKC relation with the type of decoupling identified by comparing the GDP and CO_2 emission growth rates it is seen that for countries exhibiting absolute decoupling the falling branch of the EKC is longer or has the similar length as the raising branch, but for countries exhibiting relative decoupling the falling branch of the fitted EKC is shorter and flattened in comparison to the raising branch. The former is a strong evidence that economic growth decouples from emissions growth, so the EU's policy for reducing the GHG emissions seems to be efficient in these countries. The latter is rather a weak evidence that economic growth decouples from emissions growth permanently. Besides, it is an indication that policy aimed at the reduction of CO_2 emissions is not fully effective. Therefore this policy should be more directed into the introduction of such improvements (e.g. reduction in energy intensity, technological development, the increase of renewables share) which lead to reduce environmental pressure but not to hinder economic growth. Particularly, it seems to be important for the low-level knowledge based economies.

Third, the addition of energy consumption has affected the results and the EKC relationship in terms of the occurrence of cointegration, parameter significance and its signs, and also causality pattern depending on the level of knowledge based economies. In the framework of extended EKC the cointegration (threshold or linear) is found for all countries independently of the level of knowledge based economies, while in the standard version of EKC only for most of high- and middle-level knowledge based economies, but none of the low-level ones. This performance indicates that the EKC relation is not robust, but also that energy consumption is of great relevance in explaining CO_2 emissions in these countries. The addition of energy consumption has affected the causality results but mainly in the long-run and to lesser extent in the short-run. The importance of energy consumption in restoring the long-run equilibrium has been revealed in each group of knowledge based economies, i.e. the Netherlands, Belgium, Germany, the UK, Spain, Greece, Italy and Portugal. However the most symptomatic effect is registered for the low-level knowledge based economies for which the addition of energy consumption enabled to reveal causal links in the long-run.

The results obtained in the paper suggest that the EKC model needs to be estimated using an approach accounting for asymmetric adjustment and specified with the inclusion of different energy aspects, e.g. energy consumption or energy intensity. In further studies we will concentrate on re-examining the EKC relationship in the context of multivariate vector autoregressive model with asymmetric adjustment and then testing the long- and short-run Granger causality with respect to CO2 emission, energy consumption and income linkages.

REFERENCES

Acaravci, A., Ozturk, I. (2010), "On the relationship between energy consumption, CO_2 emissions and economic growth in Europe", *Energy*, Vol. 35, No. 12, pp. 5412-5420.

Andreoni, V., Galmarini, S. (2012), "Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption", *Energy*, Vol. 44, No. 1, pp. 682-691.

Ang, J. (2007), "CO2 Emissions, Energy Consumption, and Output in France", *Energy Policy*, Vol. 35, No. 10, pp. 4772–4778.

Annabelle, G. (2007), "A Discussion on Decoupling Economic rowth from the Emissions of Carbon Dioxide", *Environmental Waikato Technical Report*, available at: https://www.waikatoregion.govt.nz/assets/ PageFiles/6131/tr07-02.pdf (accessed 10 March 2017).

Apergis, N., Payne, J. E. (2009), "CO2 Emissions, Energy Usage and Output in Central America", *Energy Policy*, Vol. 37, No. 1, pp. 3282–3286.

Asafu-Adjaye, J. (2000), "The Relationship Between Energy Consumption, Energy Prices and Economic Growth: Time Series Evidence from Asian Developing Countries", *Energy Economics*, Vol. 22, No. 6, pp. 615–625.

Azam, M., Khan, A.Q. (2016), "Testing the Environmental Kuznets Curve hypothesis: A comparative empirical study for low, lower middle, upper middle and high income countries", *Renewable and Sustainable Energy Reviews*, Vol. 63, pp. 556-567.

Azar, C., Holmberg, J., Karlson, S. (2002), "Decoupling: past trends and prospects for the future", University of Götenberg, Department of Environmental Economics, Stockholm, May, pp. 1-63.

Balke, N. S., Fomby, T. B. (1997), "Threshold Cointegration*", International Economic Review*, Vol. 38, No. 3, pp. 627–645.

Chan, S.-L. (1993), "Consistency and limiting distribution of the least squares estimator of a threshold autoregressive model", *The Annals of Statistics*, Vol. 21, No. 1, pp. 520-533.

COM (2014) 15 final: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, "A policy framework for climate and energy in the period from 2020 to 2030", Brussels, January, available at: https://www.europarl.europa.eu/meetdocs/2009_2014/documents/nest/dv/depa_20140212_06/depa_20140212_06en.pdf (accessed 10 March 2017).

Dinda, S. (2004), "Environmental Kuznets Curve Hypothesis: a Survey", *Ecological Economics*, Vol. 49, No. 4, pp. 431–455.

Elliott, G. Rothenberg, T. J, and Stock, J. H. (1996), "Efficient Tests for an Autoregressive Unit Root", *Econometrica*, Vol. 64, No. 4, pp. 813–836.

Enders, W., Granger, C. W. J. (1998), "Unit-Root tests and asymmetric adjustment with an example using the term structure of interest rates", *Journal of Business Economics & Statistics*, Vol. 16, No. 3, pp. 304–311.

Enders, W., Siklos, P. L. (2001), "Cointegration and threshold adjustment", *Journal of Business and Economic Statistics*, Vol. 19, No. 2, pp. 166–176.

Engle, F. R., Granger, C. W. J. (1987), "Co-integration and error correction: representation, estimation, and testing", *Econometrica*, Vol. 55, No. 2, pp. 251–276.

Esteve, V. and Tamarit, C. (2012), "Threshold Cointegration and Nonlinear Adjustment Between CO_2 and Income: The Environmental Kuznets Curve in Spain, 1857-2007", *Energy Economics*, Vol. 34, No. 6, pp. 2148–2156.

Fosten, J., Morley, B., Taylor, T. (2012), "Dynamic misspecification in the environmental Kuznets curve: evidence from CO_2 and SO_2 emissions in the United Kingdom", *Ecological Economics*, Vol. 76, pp. 25–33.

Halicioglu, F. (2009), "An Econometric Study of CO_2 Emissions, Energy consumption, income and Foreign Trade in Turkey", *Energy Policy*, Vol. 37, No. 3, pp. 1156–1164.

IPCC (2014), "Climate Change 2014: Synthesis Report. Summary for Policymakers", *Cambridge University Press*, Cambridge, United Kingdom and New York, USA, available at: https//www.ipcc.ch/pdf/ assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (accessed 23 Jan. 2017).

Kaika, D., Zervas, E. (2013), "The Environmental Kuznets Curve (EKC) theory- Part A: Concept, causes and the CO_2 emissions case", *Energy Policy*, Vol. 62, pp. 1392–1402.

Kais, S. , Sami, H. (2016), "An econometric study of the impact of economic growth and energy use on carbon emissions: panel data evidence from fifty-eight countries", *Renewable and Sustainable Energy Reviews*, Vol. 59, pp. 1101-1110.

Lieb, C. M. (2003), "The Environmental Kuznets Curve – A survey of the Empirical Evidence and of Possible Causes", *Discussion Paper Series* No 391, University of Heidelberg – Department of Economics, Heidel-berg, April.

Liobikienė, G., Butkus, M. (2017), "Environmental Kuznets Curve of greenhouse gas emissions including technological progress and substitution effects", *Energy*, Vol. 135, pp. 237-248.

Luzzati, T., Orsini, M. (2009), "Investigating the Energy-Environmental Kuznets Curve", *Energy*, Vol. 34 No 3, pp. 291–300.

Menegaki, A. N. (2014), "On energy consumption and GDP studies: A meta-analysis of the last two decades", *Renewable and Sustainable Energy Reviews*, Vol. 29, pp. 31-36.

Nahman, A., Borghesi, S. (2005), "The environmental Kuznets curve: a literature survey", *South African Journal of Economics*, Vol. 73, No. 1, pp. 105-120.

Özocku, S., Özdemir, Ö. (2017), "Economic growth, energy, and environmental Kuznets curve", *Renewable and Sustainable Energy Reviews*, Vol. 72, pp. 639-647.

Panayotou, T. (1997), "Demystifying the environmental Kuznets curve: turning a black box into a policy tool", *Environment and Development Economics*, Vol. 2, No. 4, pp. 465-484.

Pearce, D. (2003), *Conceptual framework for analyzing the distributive impacts of environmental policies*, OECD Environment Directorate Workshop on the Distribution of Benefits and Costs of Environmental Policies, Paris.

Piłatowska, M., Włodarczyk, A., Zawada M. (2014), „The Environmental Kuznets Curve in Poland – Evidence from Threshold Cointegration Analysis", *Dynamic Econometrics Models*, Vol. 14, pp. 51-70.

Ru, X., Chen, S. and Dong, H. (2012), "An empirical Study on Relationship between economic Growth and Carbon Emissions Based on Decoupling Theory", *Journal of Sustainable Development*, Vol. 5, No. 8, pp. 43-51.

Soytas, U., Sari, R. (2009), "Energy Consumption, Economic Growth and Carbon Emission: challenges Faced by an EU Candidate Member", *Ecological Economics*, Vol. 68 No 6, pp. 1667–1675.

Stern, D. (2004), "The Rise and Fall of the Environmental Kuznets curve", *World Development*, Vol. 32, No. 8, pp. 1419–1439.

Stern, N. (2006), *The Economics of Climate Change: the Stern Review*, HM Treasury, Cabinet Office, London.

Sun, J. W. (1999), "The nature of CO2 emission Kuznets curve", *Energy Policy*, Vol. 27, pp. 691-694.

World Bank: Knowledge Economy Index (KEI) 2012 Ranking, available at: https://knowledgepolicy.wordpress.com/2012/06/22/world-bank-knowledge-economy-index-kei-2012-rankings/ (accessed 12 February 2017).

Yau, H-Y., Nieh, C-C. (2009), "Testing for cointegration with threshold effect between stock prices and exchange rates in Japan and Taiwan", *Japan and World Economy*, Vol. 21, pp. 292–300.

Appendix I

Table 1. The results of the ADF-GLS unit root tests for the EU-14 countries

Country	*Levels (c+t)*				*First differences (c)*			
	CO2$_t$	GDP$_t$	GDP$_t^2$	E$_t$	CO2$_t$	GDP$_t$	GDP$_t^2$	E$_t$
High-level knowledge based economy								
Denmark	-1.323 (0)	-0.599 (0)	-0.635 (0)	-1.261 (0)	-7.364*** (0)	-4.388*** (0)	-4.549*** (0)	-5.675*** (0)
Finland	-1.100 (0)	-1.680 (1)	-1.922 (1)	-0.772 (0)	-6.005*** (0)	-3.756 (0)	-3.962*** (0)	-6.703*** (0)
Netherlands	-1.422 (0)	-1.698 (1)	-1.780 (1)	-0.974 (0)	-7.202*** (0)	-3.273*** (0)	-3.302*** (0)	-5.274*** (0)
Sweden	-1.579 (0)	-1.840 (1)	-1.978 (1)	-1.006 (0)	-6.784*** (0)	-4.073*** (0)	-4.298*** (0)	-7.520*** (0)
Middle-level knowledge based economy								
Austria	-1.339 (0)	-0.338 (0)	-0.404 (0)	-1.214 (0)	-7.742*** (0)	-1.647* (2)	-4.944*** (0)	-6.446*** (0)
Belgium	-1.607 (0)	-0.305 (0)	-0.330 (0)	-0.900 (0)	-7.187*** (0)	-2.546** (1)	-2.777*** (1)	-5.519*** (0)
France	-1.337 (0)	-0.596 (1)	-0.605 (1)	-0.570 (0)	-6.776*** (0)	-3.422*** (0)	-3.653*** (0)	-5.751*** (0)
Germany	-2.087 (0)	-1.669 (0)	-1.779 (0)	-1.204 (3)	-6.888*** (0)	-5.314*** (0)	-5.423*** (0)	-3.953*** (2)
Ireland	-0.671 (0)	-1.834 (1)	-1.874 (1)	-0.888 (0)	-5.442*** (0)	-2.980*** (0)	-2.903*** (0)	-1.740* (1)
Spain	-1.158 (2)	-0.714 (1)	-0.804 (1)	-1.721 (3)	-2.511** (1)	-3.092* (0)	-3.158* (0)	-2.271** (1)
UK	-0.790 (0)	-2.823 (1)	-2.872 (1)	-0.790 (0)	-7.065*** (0)	-4.690*** (0)	-4.651*** (0)	-7.065*** (0)
Low-level knowledge based economy								
Greece	-0.961 (4)	-0.689 (1)	-0.772 (1)	-0.639 (1)	-2.931* (3)	-2.549** (0)	-2.655*** (0)	-3.215*** (0)
Italy	-0.755 (3)	0.170 (1)	0.442 (0)	-0.602 (0)	-3.467** (1)	-6.240*** (0)	-6.291*** (0)	-2.904* (2)
Portugal	-1.734 (7)	-0.858 (1)	-0.901 (1)	0.257 (0)	-7.183*** (0)	-3.811*** (0)	-3.895*** (0)	-6.786*** (0)

Note: (***), (**), (*) in ADF-GLS test indicate the rejection of the null hypothesis that series has a unit root at 1%, 5% and 10% levels of significance. The optimum lag lengths (given in parenthesis) were determined using BIC. *c* means the constant term, *c+t* means the constant term and trend.