Convergence of Energy Efficiency, Energy Intensity and Carbon Dioxide Emissions in the European Union

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ABSTRACT

Energy is a vital source for production, as well as for economic growth. Energy use in production process is in turn responsible for environmental degradation and climate change. Energy use in production is estimated to grow by 56 percent within twenty years. Accordingly, anthropogenic greenhouse gas emissions are foreseen to increase more than 1.5 times by 2030. Therefore, efficient energy consumption has gained attention in energy-environment-economic growth literature due to the gap in demand for energy supply and its effects on climate change. Moreover, energy efficiency plays a vital role for both increasing economic performance, and ensuring energy security as well as creates environmental sustainability. Therefore, it is important to increase energy efficiency by reducing energy intensity and apply effective strategies in order to minimize the negativity of energy use that contribute to environmental degradation and climate change.

To do this, in this study, we focus on energy intensity convergence in European union member states, that is one of the highest energy consumer regions in the world. On the other hand, using newly established club convergence technique we try to identify heterogeneous structure within apparently homogenous group of countries in order to help policy makers, legislators and environmentalists to generate effective strategies. In addition to the EU-28 members, EU-15 and the new EU members joined after 2004 are analysed as distinct groups for the periods 1990–2016, 1990–2004 and 2005–2016. Our results show convergence amongst the EU countries during the full and two subsample periods considered. However, the convergence takes place within clusters and there is no evidence of all members converging to a single club.

On the other hand, in another chapter of this study, we use the same technique and try to identify heterogeneous clubs in case of CO2 intensity in EU-28 region for the same group of countries and same time periods. The estimation results show important evidences of different clubs for investigated time periods.

Finally, in the last chapter, we try to observe how energy efficiency and CO2 emissions affect the economic growth for the newly membered country, namely Romania.Moreover, their long run relationship was investigated by using an autoregressive distributive lag model (ARDL) in cooperating with renewable energy consumption and the direction of causality was achieved via the Toda-Yamamoto model for the period between 1990 and 2014 on a quarterly basis. The results provide the evidence of cointegration among the variables under consideration. The causality results show feedback causality between energy intensity and economic growth while unidirectional causality is seen running from renewable energy consumption to economic growth.

Keywords: Club Convergence; Carbon Intensity; Economic Growth; Energy Intensity; European Union; Renewable Energy

ÖZ

Enerji, üretimin yanı sıra ekonomik büyüme için de hayati bir kaynaktır. Üretim sürecinde enerji kullanımı, çevresel bozulma ve iklim değişikliğine neden olmaktadır. Üretimde enerji kullanımının yirmi yıl içinde yüzde 56 oranında artacağı tahmin edilmektedir. Buna bağlı olarak, antropojenik sera gazı emisyonlarının 2030 yılına kadar 1,5 kattan fazla artacağı öngörülmektedir. Bu nedenle, enerji arzı talebindeki boşluk ve bunun iklim değişikliğine etkileri nedeniyle enerji-çevre-ekonomik büyüme literatüründe etkin enerji tüketimi dikkat çekmektedir. Dahası, enerji verimliliği hem ekonomik performansı artırmak hem de enerji güvenliğini sağlamak ve çevresel sürdürülebilirlik için hayati önem taşımaktadır. Bu nedenle, enerji yoğunluğunu azaltarak enerji verimliliğini artırmak ve çevresel bozulmaya ve iklim değişikliğine katkıda bulunan enerji kullanımındaki olumsuzluğu en aza indirgemek için etkili stratejiler uygulamak önemlidir.

Bu maksatla, bu çalışmada, dünyanın en yüksek enerji tüketici bölgelerinden biri olan Avrupa Birliği üyesi devletlerde, enerji yoğunluğu yakınsaması incelenmeye çalışılmıştır. Öte yandan, yeni kurulan kulüp yakınsama tekniğini kullanarak, politika yapıcıların, yasa koyucuların ve çevrecilerin etkili stratejiler üretmelerine yardımcı olmak amacıyla, görünüşte homojen bir ülke grubu içinde heterojen yapıyı tespit etmeye çalışıyoruz. AB-28 üyelerine ek olarak, AB-15 ve 2004'ten sonra katılan yeni AB üyeleri, 1990–2016, 1990–2004 ve 2005–2016 dönemleri için ayrı gruplar olarak analiz edildi. Sonuçlarımız, incelenen dönemler boyunca AB ülkeleri arasında yakınsama göstermektedir. Ancak, yakınsama kümeler halinde gerçekleşmekte ve tüm üyelerin tek bir kulüp olarak yakınsamadığı gözlemlenmektedir.

Ayrıca, bu çalışmanın başka bir bölümünde, aynı tekniği kullanarak aynı grup ülkelerde ve aynı zaman dilimleri için AB-28 bölgesinde CO2 yoğunluğu gözlemlenerek heterojen kulüpler tanımlamaya çalışılmıştır. Tahmin sonuçları, incelenen zaman dilimleri için farklı kulüplerin olduğuna dair önemli kanıtlarını göstermektedir.

Son olarak, son bölümde, enerji verimliliğinin ve CO2 emisyonlarının yeni AB üyesi olan ülkenin, Romanya, ekonomik büyümesini nasıl etkilediği gözlemlemeye çalışılmıştır. Ayrıca, bu değişkenlere ek yenilenebilir enerji tüketimi değişkeni de kullanılarak ARDL modeli ile uzun dönem ilişkileri araştırılmış ve 1990 ile 2014 arası dönemler için üçer aylık dönemlerde Toda-Yamamoto modeli ile bu değişkenlerin nedensellikleri incelenmiştir. Sonuçlar, incelenen değişkenler arasında uzun dönem ilişkisinin olduğunu göstermektedir. Nedensellik sonuçları, enerji yoğunluğu ve ekonomik büyüme arasındaki çift yönlü nedenselliğini gösterirken, yenilenebilir enerji tüketiminden ekonomik büyümeye tek yönlü nedensellik gözlemlenmiştir.

Anahtar Kelimeler: Kulüp yakınsaması; Karbondioksit yoğunluğu; Ekonomik Büyüme; Enerji Yoğunluğu; Avrupa Birliği; Yenilenebilir Enerji

To my unique love… MOM

To my Star… DAD

To my confidant… Brother

To My Family…

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey-Fuller Test
AIC	Akaike Information Criterion
ARDL	Autoregressive Distributed Lag Model
CDM	Clean Development Mechanism
CEE	Central and Eastern European Countries
CO2	Carbon Dioxide Emissions
CUSUM	Cumulative Sum of Recursive Residual
CUSUMSQ	Cumulative Sum of Recursive Residual Squares
DOLS	Dynamic Ordinary Least Squares Technique
EKC	Environmental Kuznets Curve method
ENINT	Energy Intensity
ETS	Emission Trading System
EU	European Union
EU-15	European Union 15 Countries
EU-28	European Union 28 Countries
EU-new	European Union New Member Countries (after2004)
F-gases	Fluorinated Green House Gasses
FMOLS	Fully Modified Ordinary Least Square Technique
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GHG	Green House Gasses
GMM	Generalized Method of Moments
HAC	Heteroscedasticity and Autocorrelation Consistent

JI	Joint Implementation
N2O	Nitrous Oxide
OECD	Organization for Economic Co-operation and Development Countries
PP	Phillips –Perron Unit Root Test
PPP	Purchasing Power Parity
PS	Phillips and Sul (2009) Method
RECONS	Renewable Energy Consumption
RGDP	Real Gross Domestic Product
TY	Toda-Yamamato Causality Test
US	United States
VAR	Vector Auto Regression
VECM	Vector Error Correction Model
WDI	WorldBank World Development Indicators

Chapter 1

INTRODUCTION

This study examines the dynamics of the energy intensity convergence as the indicator of energy efficiency in the European Union (EU) -28 countries using panel data for the period from 1990 to 2016. We use Phillips and Sul's (PS) (2007) approach to test for the energy intensity convergence and identify convergence clusters. In addition to the EU-28 members, EU-15 and the new EU members joined after 2004 are analysed as distinct groups for the periods 1990–2016, 1990–2004 and 2005–2016. Our results show convergence amongst the EU countries during the full and two subsample periods considered. However, the convergence takes place within clusters and there is no evidence of all members converging to a single club. Indeed, after the expansion of the EU, and depending on the decoupling of energy intensity levels amongst EU countries, convergence became more common and diverse.

On the other hand, another chapter of this study examines the convergence properties of energy related carbon dioxide emission intensity in EU-28 countries, using panel data for the period 1990 to 2016. Same as the first chapter, we use Phillips and Sul's (2007) approach to test for CO_2 intensity convergence and identify convergence clubs. Our results show no convergence to a single group among the EU countries during the full and two subsample periods. However, the convergence takes place within five to seven clubs for the EU-28 and within three to five clubs for the EU-15 and EU-new. There is no evidence of all members converging to a single club in either group or the three sub-periods examined. This study highlights the need for adopting new strategies considering club properties and for sustainable growth, which meets the EU-28 environmental regulation standards.

Finally, this study empirically examines the relationship between energy intensity, carbon emissions, renewable energy consumption, and economic growth for the case of new member country that is Romania; to observe how energy intensity and carbon dioxide emissions affect the economic growth. To this end, our study employs an autoregressive distributive lag model (ARDL) for cointegration, while direction of causality was achieved via the Toda-Yamamoto model for the period between 1990 and 2014 on a quarterly basis. Empirical findings reveal cointegration among the variables under consideration. The causality results show feedback causality between energy intensity and economic growth while unidirectional causality is seen running from renewable energy consumption to economic growth. Thus, this study affirms the energy-led growth hypothesis. Therefore, our study corroborates with the current success story of Romania attaining her energy targets within two decades. However, there is need to sustain this milestone by further diversification of her energy portfolio into other cleaner energy sources.

In order to have the compatibility in the thesis, each chapter has its own structure.

Chapter 2

THE DYNAMICS OF ENERGY INTENSITY CONVERGENCE IN THE EU-28 COUNTRIES

2.1 Introduction

Energy intensity is an area of study that has attracted the attention of many researchers. Numerous studies have described the impacts of energy use, energy intensity and greenhouse gas emissions (GHG) on several countries in the European Union (EU). Regardless, there has been little discussion on transitioning patterns, the heterogeneity of the inter-temporal dynamics of energy intensity or the detection of different steady state levels that depend upon distinct energy intensity patterns.

For developed and developing countries, energy consumption is considered to be vital to industrialization and the development of infrastructure. Thus, energy use is a necessary function of a country’s economic growth. Halıcıoğlu (2008) emphasized that energy output and economic development are connected because economic growth is associated with energy use and the efficient use of energy is required to achieve higher economic development. Moreover, a higher level of economic development is needed for ‘more efficient energy use’.

During the initial stages of economic growth, energy use tends to be excessive. In other words, the income elasticity of energy use is frequently low. The traditional belief is that energy is both a consumed good and an intermediate good, a type of good which is fundamental to technological improvement. Thus, the excessive energy use is one of the key drivers of economic growth. This concept can be evaluated using the intensity of use method. Energy intensity is the intensity of energy that is used during production, which is defined as the amount of energy that is needed to produce a unit of output. It can be calculated by dividing a country's energy use by its gross domestic product (GDP). In order to maintain sustainable, long-term economic growth, energy economists, environmentalists and policymakers have argued to reduce the levels of energy intensity. Accordingly, several energy economists have worked on energy use, attempting to investigate the determinants of energy intensity and its convergence by way of varied empirical estimation techniques on data sets from the firm, sectoral, national and territorial levels (Sinton and Levine; 1994; Borozan, 2017; Mishra and Smyth, 2017; Feng *et al.*, 2017; Parker and Liddle, 2017; Bhattacharya *et al.*, 2018).

While economic growth is stimulated by increases in energy consumption, it can also result in the emission of GHG. As such, several researchers have investigated the relationship between energy consumption, GHG and economic growth (Mercan and Karakaya, 2015; Zhang and Cheng, 2009). In particular, some existing studies have focused on the energy-growth nexus of GHG, environmental pollutants and environmental sustainability (See Table A.1 Part A in the Appendix). In this respect, the environmental Kuznets curve theory was developed and has since seen wide use in economics literature. It suggests that when an economy grows and a certain level of income has been achieved, the emission of environmental pollutants is expected to decrease. Parallel to these studies, and in an effort to achieve economic and environmental sustainability over the last several decades, the effect of anthropogenic GHGs on global warming and environmental degradation has undergone significant consideration. From this, the importance of environmental degradation awareness has increased considerably in recent years. Global warming and GHG emissions, especially carbon dioxide emissions (CO2), are considered to be the primary sources of worldwide environmental degradation. Solutions for global warming and environmental degradation include increase in energy efficiency and reductions to anthropogenic GHGs. In this respect, environmental scientists, policymakers and scientific entities have attempted to design common international policies to mitigate global warming and environmental degradation. The importance of these common policies have been emphasized in the signings of the Kyoto Protocol in 1997, the Copenhagen Agreement in 2010, the Durban Agreement in 2011, the Warsaw Agreement in 2013 and the Paris Agreement in 2015. These common international agreements were signed with the intent to reduce global GHGs and increase energy efficiency through the reduction of energy intensity.

As a whole, the countries in the EU are some of the largest energy consumers and GHG emitters in the world. Because of this, the EU has seriously committed to establishing common energy and economic policies for itself. This commitment has acted as the cornerstone for the union’s energy efficiency and sustainable economic development. The EU has set inclusionary targets to reduce GHGs and environmental degradation that is associated with increased energy efficiency. It has also set goals to find and use alternative green energy sources by the years 2020, 2030 and 2050. Although the EU strongly encourages each of its members to implement energy, economic and environmental policies under a common umbrella, each country’s reflection of these policies is quite different. Indeed, income inequality, divisions between the north and south and differences between GDP, economic structure and levels of energy efficiency illustrate the EU’s diversity. For effective policy design to be achieved, it is therefore fundamental that each EU country learns about the concepts and heterogenic natures of energy efficiency, GHG emissions and economic growth. The current state of global integration and the asymmetric structure of energy efficiency within economies should also be considered.

A vast number of studies have analysed the sources of intensity for energy consumption and inequality in energy efficiency amongst EU nations. In addition, most of these studies have used time series models to test the dynamics of causal and cointegrating relationships, primarily by using economic and environmental variables within a bivariate or trivariate econometric framework.(El-Montasser *et al.*, 2015) Early studies focused on observing the pattern of energy intensity and its effectiveness on the environment and the economies of individual countries. For instance, Yu and Choi (1985) used time series data from 1963 to 1976 to analyse the stability of the energy intensity in developed and developing countries. They observed that the energy intensity levels of these countries were erratic. In turn, the volatile nature of these patterns revealed the uselessness of the energy-GDP ratio for forecasting purposes. By comparison, while Adelman (1980) supported this unstable and confusing description of the energy-GDP ratio, he also pursued the argument that ‘the energy-GDP ratio is still a viable and useful indicator for economic growth’. (See also Feng *et al.*, 2017; Fu, 2018)

Jones (1991) and Sinton and Levine (1994) also attempted to investigate the reasons behind varied energy intensities for different countries over several time periods. They claimed that the climatic conditions and economic conditions (*e.g.*, production activities, *etc.*), urbanization, energy prices, the extent of capital formation and energy substitutions acted as the primary sources of energy intensity. (See also Berk *et al.*, 2018; Borozan, 2017; Kempa and Haas, 2016). Subsequent researchers continued the evaluation of energy intensity in long-term convergence studies that used different methods, such as absolute, conditional beta (β), sigma (σ), gamma (ϒ) and stochastic convergence or alternative econometric approaches (Orubu and Otomor, 2011; Onafowora and Owoye, 2014; Cho *et al.*, 2014; Farhani *et al.*, 2014; Bilgili *et al.*, 2016; Youssef *et al.*, 2016; Apergis,2016). In one of the first studies to assess energy intensity, Nilsson (1993) investigated the convergence of energy intensity amongst 31 developed and developing countries by using graphical analyses from 1950–1988. Later, Markandya *et al.* (2006) used a panel estimation technique (in the form of beta convergence), determining that the energy intensity levels of 12 Eastern European countries were converging towards the energy intensity levels of the EU. By contrast, when Le Pen and Sevi (2010) worked on a sample of 97 countries to examine energy intensity convergence, applying the method suggested by Pesaran (2007), they found evidence of global divergence, with some evidence of regional convergence in OECD and Middle Eastern countries.

By employing non-parametric methods, Ezcurra (2007) examined the convergence of energy intensity amongst 98 countries between 1971 and 2001. Later, this paper was expanded upon by Liddle (2010), who collected a sample of 134 countries between 1990 and 2006. Liddle concluded that there were convergences amongst several groups of countries. Moreover, Herrerias (2013) followed Ezcurra’s (2007) technique to examine the convergence behaviours of energy intensity levels under contrasting scenarios for 83 countries. Using the weighted vector technique in kernel measurements, Herrerias (2013) tested the intensity levels of fossil fuels in 73 countries and the nuclear and alternative energy intensity levels for 71 countries, determining that while developing economies converged at higher levels of energy intensity; developed economies converged at lower levels of energy intensity.

In short, the studies above used several methods to investigate cross-country convergence and the Energy-GDP ratio. While each method investigated the existence of several kinds of convergence, none of these studies were able to capture the diversity of the inter-temporal dynamics of energy intensity or transitioning patterns, nor were they able to detect the various steady-state levels that depend on distinct energy intensity patterns.(See also Table A.1 Part B in the Appendix)

The questions that follow have largely gone unanswered during examinations of the energy intensity distribution in the 28 EU countries: 1) Although the distribution of energy intensity in the EU has trended downwards in recent years, why does each EU country show different levels of improvement in energy intensity; in the future, will these countries unify in terms of energy efficiency? 2) Depending on the heterogeneous features of income levels, economic structures and technological improvements, would the impact of common policies be the same if all EU countries were to comply with the same policies, or would these policies influence each country differently? and 3), What sources of inequality contribute to the effectiveness of common policies that have been developed to control the production of energy intensity in each country? As these sources are not in the content of our work, it would greatly contribute future research if they were to be analysed and explained.

The newly developed and regression-based club convergence technique (Phillips and Sul, 2007) will be employed to compile EU countries flexibly according to their energy intensity features so that the existence of unique or differing equilibriums can be investigated. This approach will enable us to measure the inter-temporal dynamics of the energy intensity convergence process and account for cross-section dependence within a framework of common factor analysis. In this context, the inter-temporal dynamics of the energy intensity convergence process will be examined in three different groups of countries, 28 EU countries (EU-28), 15 EU countries (EU-15) and new EU countries, over three different periods of time, 1990–2016, 1990–2004 and 2005–2016. The complete sample period (1990–2016) will be divided for the reasons that follow: 1) to calculate the number of observations for each period that it took to obtain convergence dynamics, and 2) to test whether convergence dynamics changed after the fifth expansion of the EU. In particular, by testing for convergence and searching for possible group-specific features, we hope to enable policymakers to create separate policies for each group and depending on each group's economic features, reduce energy intensity levels so that they can achieve sustainable economic growth.

The remainder of this study will be organized as follows: section two will explain the work's data and sources, section three will briefly inform readers about the applied econometric method, section four will comment on the results and the final section will provide closing interpretations and conclusions.

2.2 Data

Data on energy intensity were gathered from the World Bank World Development Indicators database and included works that were published between 1990 and 2016. Energy intensity is calculated by the division of a country's energy consumption by its GDP. We considered 28 EU countries that had moved towards their energy intensity-clustering target. Table 1 displays descriptive statistics of the energy intensity levels of EU-28 at the beginning and the end of the indicated period. In 1990, the levels of energy intensity amongst all countries were high. However, after awareness of energy efficiency and environmental stability issues grew with the signings of common agreements, energy intensity levels decreased, albeit at different rates for each country. While certain Scandinavian countries, in addition to core members of the EU, have had the highest ratings for energy efficiency, newer EU members, especially Central and Eastern European (CEE) countries, have had the lowest ratings for energy efficiency. Several factors contribute to these differences, such as variety in economic structure and degrees of environmental awareness and involvement. In turn, new EU members are considered to be the least energy efficient due to their economic activities and technological improvements. Moreover, their adaptions to common policies are more recent than those of core EU members.

Table 1: Energy intensity levels of EU-28 countries

Countries	1990	2016
Austria	3.28	2.79
Belgium	4.01	2.99
Bulgaria	7.92	3.21
Cyprus	2.67	1.91
Croatia	3.09	2.54
Czech Republic	6.83	3.32
Denmark	3.20	2.15
Estonia	11.38	3.32
Finland	6.26	5.29
France	3.18	2.81
Germany	3.75	2.54
Greece	2.75	2.17
Hungary	4.47	2.09
Ireland	3.93	2.01
Italy	2.60	2.39
Latvia	7.32	3.67
Lithuania	6.86	2.68
Luxembourg	5.38	3.20
Malta	1.82	1.05

Netherlands	3.60	3.01
Poland	6.35	2.73
Portugal	2.45	2.03
Romania	6.77	2.27
Slovak Republic	7.32	2.15
Slovenia	4.19	3.61
Spain	2.50	2.04
Sweden	5.02	3.16
United Kingdom	3.88	2.29

Although energy intensity levels decreased over 1990–2016, disparities in energy intensity between the EU-28 countries remained throughout that entire period. Therefore, future policies should aim to reduce regional economic disparities, decouple energy intensity levels between EU countries and enhance energy efficiency by considering each country’s economic structures, income levels, *etc*. From 1990 to 2004, a relative decoupling of energy intensity levels was observed in the 28 EU countries. While economic growth for each country had increased more than the rate of energy consumption, there was no evidence of unity. After the fifth expansion of the EU, the speed of convergence increased and energy consumption decreased by more than 12%. There was also more than a 7.5% increase in economic growth during this period. Furthermore, within the period of 1990–2016, the energy intensity level of EU-28 fell by almost 2% on average per annum. This level was recorded by almost 2.5% of the EU-28 countries between 2005 and 2016. In 2016, the energy intensity levels of the EU-28 countries were approximately 35% lower than they were in 1990 (Figure 1). While the energy intensity levels of Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, Germany, Hungary, Italy, Latvia, Lithuania, Poland, Romania, Slovakia and the United Kingdom decreased during this period, their economies grew. Furthermore, although Austria, Belgium, Cyprus, Finland, France, Greece, Ireland, Luxembourg, Malta, the Netherlands, Portugal, Slovenia, Spain and Sweden also experienced economic growth at this time, they did so at lower rates of energy intensity growth. During this period, the largest decreasing rates were observed in Central and Eastern European (CEE) countries due to an increase in renewable energy and structural changes within their economies.

2.3 Econometric Methodology

Phillips and Sul's (PS) (2007) econometric approach attempts to test the hypothesis of convergence and identify convergence clusters. With this approach, PS adopted a non-linear time-varying factor model to ensure that the framework modelled irregular dynamics and long-term performances. In order to analyse the convergence of multiple variables, PS constructed this methodology under the framework of statistics. As such, it can easily be employed to test for several economic variables and their corresponding steady states.

This model also recommends a time-varying common factor representation for the cross-sectional data series Y_{it}, which is a variable of country i. In addition, it suggests that this common factor can be reduced into a systematic component (g_{it}) and transitory component (a_{it}) for all cross-sectional units (i) and time periods (t).

$$y_{it}=g_{it}+a_{it} \quad (1)$$

Equation (1) can also be transformed into the following representation:

$$y_{it}=\delta_{it}\mu_{it} \text{ where } \delta_{it}=\left(\frac{g_{it}+a_{it}}{\mu_t}\right) \quad (2)$$

Here, μ_{it} represents the common component, and δ_{it} stands for the time-varying idiosyncratic component. Furthermore, δ_{it} reflects the deviation of Y_{it} from the common component specified by μ_t. Within this scope, if the idiosyncratic component (δ_{it}) converges to a constant δ, then convergence occurs for all n economies. In other words, whether countries are close to a steady state or in transition, if $\lim_{k\to\infty}\delta_{it+k}=\delta$ for all cross-sectional countries (I =1,2,….N), then all N economies will converge at certain steady state points in the future.

Through over-parameterization, δ_{it} cannot be estimated directly by using equation (1). Hence, PS eliminated μ_t by introducing the transition coefficient.

$$h_{it}=\frac{y_{it}}{\frac{1}{N}\sum_{i=1}^{N}\delta_{it}}=\frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N}\delta_{it}} \qquad (3)$$

This relative parameter (e.g., h_{it}) seizes the transition path that relates to the cross-sectional average. As such, when δ_{it} converges to a constant, the transition parameter (e.g., h_{it}) converges to the representation for unity. Furthermore, the transition parameter variance, $H_t=\frac{1}{N}\sum_{i=1}^{N}(h_{it}-1)^2$, converges to zero when $t\to\infty$ over the long term.

To define the statistical and econometric approaches of convergence and EU country convergence, suppose that the hypothesis for the semi-parametric general form for the time- varying idiosyncratic coefficients (δ_{it}) are as follows:

$$\delta_{it}=\delta_i+\sigma_{it}\xi_{it} \qquad (4)$$

where ξ_{it}~iid(0,1) over i is also weakly dependent over time (t). Moreover, σ_{it} can be defined as $\sigma_{it}=\frac{\sigma_i}{L(t)t^{\alpha}}$, where σ_{it}>0, t≥0, in which named as an idiosyncratic scale parameter. Herein, α is the decay rate or speed of convergence, and L(t) (e.g., the logarithm of time) is the slowly varying function, which increases and diverges over the long term. Based on the specified form of δ_{it}, the null hypothesis of convergence is set as H_0: $\delta_i = \delta$ and $0 \leq \alpha$; however, for some countries, an alternative hypothesis can take on the form of non-convergence as H_A: $\delta_i \neq \delta$ for all i or $0 < \alpha$. The non-convergence hypothesis, H_A, can also be formed to test the convergences or divergences for the variables of the countries and a subset of provinces.

PS illustrated convergence analysis within the framework of logarithmic regression as follows:

$$\log(\frac{H_1}{H_T}) - 2\log(L(t)) = \hat{c} + \hat{b}\log(t) + u_t \tag{5}$$

For t=[rT],[rT+1],…., T and [rT] stand for the integer part of rT, where r is greater than 0 and PS's default of 0.3. PS used b as a parameter, which can be calculated as 2α (e.g. the convergence estimate). Under the current circumstances, the assumption of the convergence could be evaluated by using the inequality t-test, where H_0 indicates that the dependent variable diverges at α and is greater than or equal to 0. The statistics of one-sided t-tests follow standardized normal distribution asymptotically and are obtained by using heteroskedasticity and autocorrelation consistent (HAC) standard errors. The H_0 is not accepted at a 5% significance level if t_b is less than -1.65. The one-sided t-test is called the log (t) test, which PS based on the log (t) regressor in equation (5).

On the other hand, log (t) is analogous with the conditional σ-convergence test, which examines reductions in the cross-sectional diffusion of data, $Y_{it,}$ over time. Since it relies on the model of the general non-linear time-varying factor, this test authorizes the potential for transitional heterogeneity or transitional decoupling. For convergence, the traditional time series methods, which rely on unit root and cointegration tests, may not be appropriate for the calculation of heterogeneity. It may also prove insufficient for smaller samples. The legitimization of PS's econometric method depends on asymptotic co-integration. This indicates that convergence is most likely to occur when a series of divergences take place within the observed selected data. However, as a result of PS's convergence test, this method enables convergence to be tested in subgroups, which can be assessed even when divergence occurs within a full sample. Moreover, PS recommended a simple algorithm to classify countries and/or variables into convergence clusters.

2.3.1 Simple Algorithm

Early empirical studies have often classified districts into subgroups. These classifications have primarily been made on the basis of economic or geographical characteristics. Unfortunately, these classification criteria are often arbitrary or made without sufficient support. As such, PS recommended an empirical algorithm that weakens the need for arbitrary identifications and instead demonstrably detects convergent countries according to statistical convergence methods. Rather than rely on some pre-determined criteria, this simple algorithm enables researchers to identify separate points of equilibrium (steady states) for different countries. In turn, this allows for the identification of each country's specific patterns and characteristics. Therefore, this algorithm helps researchers to identify and understand the mechanisms of convergence and to obtain detailed information about the patterns and characteristics of specific groups/countries.

Moreover, the clustering process of the log (t) test contains several detailed instructions. First, suppose that there is a core convergence group where G_k has a k number of members. Given the core convergence group, a new addition to the group would be represented by the figure (k+1).Following this, equation (5) would be employed to determine if the new country results in any divergences. In addition, the resulting statistic would not be significant if the newly added member belonged to the cluster. This clustering procedure is summarized in the steps below.

Step 1: Last observation ordering. To help clarify the points of convergence during final observations, the ordering of panel members will depend on these observations.

Step 2: Forming all possible core clusters. To form the optimal core cluster size, which is denoted as k*, PS determined the level of k* by maximizing the log (t) statistic t_k= t (G_K), where k is in between 2 and N ($N > k \geq 2$). G_k represents the subgroup and involves the highest number of k individuals. Moreover, on the conditional basis that min (t_k) is greater than -1.65, then k*=argmax(t_k) will be set as the criteria. If this condition is not recognized, the last country to join a cluster will be eliminated and a new group will be formed. This process will continue until the core cluster has been identified.

Step 3: Filtering individual countries for group membership. Once the core cluster has been identified, the remaining countries will be eliminated so that they may join the core cluster through repetition of the log (t) test. To get t_s for membership and the formula of t_s>c*, where c* is the critical value, the log (t) test will be employed and one new country will be added to the cluster at a time. PS recommended that when the size of a sample is no greater than or equal to 50, than the value for c* should be set to 0. Therefore, after the first cluster is defined, the log (t) test will be enforced to the cluster so that condition t_b is always greater than -1.65. Otherwise, the critical value of c (e.g., c*) will be needed to be increased.

Step 4: Terminating procedure. By following the procedures above, individual countries that were not added to the first cluster of convergence will be processed into other clusters. In sum, in order to determine further convergence clusters, these steps need to be repeated as many times as necessary. The log (t) test also allows for certain convergence clusters and divergent group member to co-exist.

The steps above provide the flexibility to identify the clusters of all possible configurations. These can include, but are not limited to, overall convergence/divergence clusters, converging subgroups and single diverging units.

2.4 Results

This section summarizes the main outcomes of the convergences of the full panel sample of EU-28 and other assorted country subgroups (*e.g.* EU-15 and new EU countries) on, before and after the EU's fifth expansion.

2.4.1 Full panel convergence

The log (t) test was employed to test the convergence of energy intensity for the EU-28 countries. This method tested for conditional σ-convergence between the evaluated countries. Table 2 presents the estimated values of the convergence coefficients and the corresponding t-stats for different timespans. For example, in Panel A, the estimated value of the coefficient (b) was calculated as -0.997, and the t-stat revealed that the parameter was significantly less than zero, indicating the full sample panel's diversity. In other words, unlike previous studies, these results revealed no unified convergences between the full panel sample.

Table 2: Full sample convergence tests

	TIME SPAN	**Panel A 1990–2016**	**Panel B 1990–2004**	**Panel D 2005–2016**
Log(t) test	**b**	-0.997	-0.639	-1.446
	t-stat	-24.598	-51.311	-75.767

As such, equation (3) (e.g., h_{it}) was employed to obtain the relative path of transition for each country, enabling us to examine the energy intensity behaviour of country i in relation to the total sample average. The convergence theory suggests that the relative path of transition often adheres to a single steady state level for all selected countries. However, this method also indicates that the relative transition paths of each country converge at various steady states. Figure 1 provides a visual representation of the divergences and relative transition paths of the EU-28 countries, revealing that not all EU countries converged at a united point. However, because the full sample did not converge at the same equilibrium during any of the determined timespans, the algorithm presented in section 3.1 was employed to investigate if any specific groups of countries had different equilibriums. Thus, we investigated the inter-temporal dynamics of the energy intensity levels in the EU-28 countries by repeating our analysis over two different timespans. We also assessed the countries' paths of transition for any significant changes after the fifth expansion of the EU. The first period that was investigated took place from 1990–2004, and the second period that was investigated took place from 2005–2016. Thus, the results presented in Table 3 indicate the existence of subgroups and non-converging groups of countries during the evaluated periods of time.

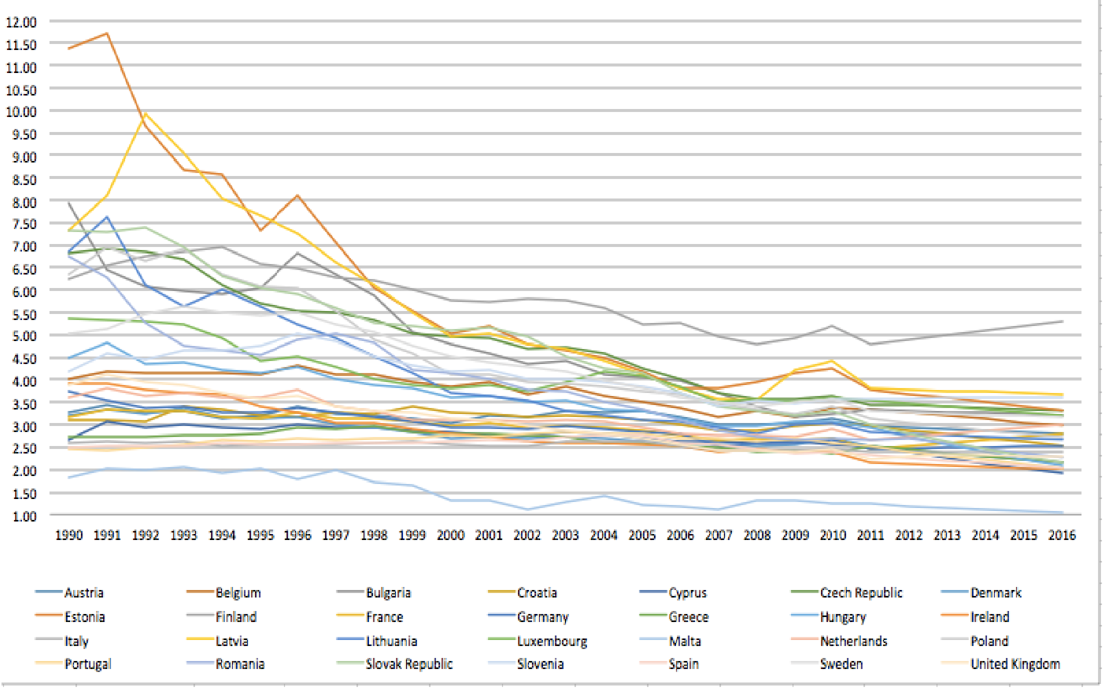

Figure 1: Energy intensity levels of EU-28
Source: Authors' Computation on WDI Data

Table 3: Classifications of convergence groups

Period	1990–2016	1990–2004	2005–2016
Number of Groups	2	2	7
Group no. 1	**Logt(-0.106)** **t-stat(-1.487)** Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden	**Logt(0.244)** **t-stat(2.352)** Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, France, Greece, Hungary, Italy, Latvia, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden	**Logt(0.286)** **t-stat(1.467)** Latvia, Slovenia
Group no. 2	**Logt(0.472)** **t-stat(7.667)** Cyprus, Hungary, Ireland, Romania, United Kingdom	**Logt(0.654)** **t-stat(4.487)** Denmark, Germany, Ireland, Lithuania, United Kingdom	**Logt(0.762)** **t-stat(3.352)** Belgium, Czech Republic, Luxembourg, Netherlands
Group no. 3			**Logt(-0.605)** **t-stat(-0.160)** Bulgaria, Sweden
Group no. 4			**Logt(0.438)** **t-stat(3.506)** Austria, Croatia, France, Germany, Lithuania, Poland
Group no. 5			**Logt(2.685)** **t-stat(5.618)**

			Denmark, Greece, Hungary, Italy, Romania, Slovak Republic, United Kingdom
Group no. 6			**Logt(0.043)** **t-stat(0.209)** Portugal, Spain
Group no. 7			**Logt(1.497)** **t-stat(2.656)** Cyprus, Ireland
Group with no convergence	**Logt(-1.518)** **t-stat(-113.057)** Finland, Malta	**Logt(-1.781)** **t-stat(-57.869)** Finland, Malta	**Logt(-1.223)** **t-stat(-174.408)** Estonia, Finland, Malta

While the results of the full panel's data (1990–2016) revealed that Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, France, Germany, Greece, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain and Sweden converged to the same steady state, they also indicated that Cyprus, Hungary, Ireland, Romania and the United Kingdom converged to a separate equilibrium with lower convergence speeds than the first group. In addition, Malta and Finland were also recorded as non-converging members of the EU due to their energy intensity patterns, with Malta showing the lowest levels of energy intensity compared to the other countries and Finland showing the highest levels of energy intensity compared to the other countries (Figure 1). In addition, the path of transition for CEE countries varied depending on the recorded time period (1990–2004 and 2005–2016)and on the years in which they were integrated into the EU. After the EU's fifth expansion and integration of high-energy intensive countries from CEE, which also compelled these countries to apply the EU's policies, the EU-28's structure grew more diverse due to the new countries' wide-ranging energy intensity levels, technological differences and varied economic structures/activities. While the EU's first group, which was formed from 1990–2004, was comprised of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, France, Greece, Hungary, Italy, Latvia, Luxembourg, the Netherlands, Poland, Portugal, Romania, the Slovak Republic, Slovenia, Spain and Sweden, its second group was comprised of Denmark, Germany, Ireland, Lithuania and the United Kingdom. However, after the EU expanded in 2004, the relationships between these countries changed and the heterogeneous structure of the EU increased. Since 1990, the number of groups in the EU has grown from two to seven. It should also be noted that while the speed of the convergence coefficient (b) was negative for some groups, their t-stats demonstrated that their estimates were statistically equal to zero, suggesting a certain degree of convergence amongst all of the EU's groups.

Once again, the tendency for unity convergence was observed amongst the full sample panel. All the same, Figure 1 presents the possibility of convergence amongst the various groups. Thus, the log (t) test was applied to check the merging of the groups or the transition of certain countries from one group to another. Although Table 4 reports the results on the groups that merged during the identified periods, there was no evidence of any mergers during the full timespan (1990–2016). In other words, because of each group's varied economic structures/activities, sources of energy intensity and other irreconcilable gaps, the unity of convergence was not achieved amongst the full panel for the period of 1990–2016. Regardless, analysis of the results before and after the EU's expansion process show evidence of transitioning amongst two converging groups and the tendency for certain countries to move between groups. Therefore, by employing the clustering algorithm for the periods of 1990–2004 and 2005–2016 periods, the unity of convergence was observed between the EU-28 countries for the period of 1990–2004, with Finland and Malta categorized as countries that did not converge. In the more recent period

(2005–2016), the number of converging groups decreased from seven to four and consisted of two, six, six and eleven countries, respectively. In addition, Estonia, Finland and Malta were identified as non-converging countries within this sample. In closing, these results provide evidence that the convergence speed of the first two groups were higher than the convergence speeds of the third and fourth groups.

Table 4: Groups after merging

Period	1990–2016	1990–2004	2005–2016
No of Groups	0	1	4
Groups no.1	**Logt(-0.439)** **t-stat(-5.802)** No groups could be merged.	**Logt(0.010)** **t-stat(0.137)** Australia, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom	**Logt(0.286)** **t-stat(1.467)** Latvia, Slovenia
Group no.2			**Logt(0.802)** **t-stat(3.489)** Belgium, Bulgaria, Czech Republic, Luxembourg, Netherlands, Sweden
Group no.3			**Logt(0.438)** **t-stat(3.506)** Austria, Croatia, France, Germany, Lithuania, Poland
Group no.4			**Logt(-0.074)** **t-stat(-0.514)** Cyprus, Denmark, Greece, Hungary, Ireland, Italy, Portugal, Romania, Slovak Republic, Spain, United Kingdom
Group with no convergence		**Logt(-1.781)** **t-stat(-57.869)** Finland, Malta	**Logt(-1.223)** **t-stat(-174.408)** Estonia, Finland, Malta

2.4.2 Convergence within EU-15 and new EU countries

In this section, the convergence paths of the countries that implemented common economic policies are investigated based on their membership status before and after the EU's expansion. More specifically, this section explores the impacts that convergence had on the EU-15 countries. This section also evaluates the convergence of new EU countries and how their dynamics changed before and after their inclusion in the EU. After the fifth expansion of the EU in 2004, common policies and obligations amongst the countries were implemented. In addition, shifts in policy and economic structures that resulted from the expansion caused the behaviours of certain paths of transition and energy intensity levels to change. In other words, the energy intensity and steady state levels of the EU's countries become more diverse. Thus, the number of groups and countries that were not converging expanded for both the EU-15 and new EU countries after 2004. During the 1990–2014 period, the EU-15 was comprised of five countries in group one and eight countries in group two. However**,** after the EU's expansion, the number of groups in the EU-15 increased to four with four, two, three and two countries, respectively. Moreover, while Finland and Ireland were recorded as non-convergent countries during the first period, Germany and Italy were added to this group during the second period. Although there is evidence of merging amongst the first and second groups after the EU's fifth expansion, the tendency for countries to transition between converging groups indicates that no groups or countries merged prior to the EU's expansion. Thus, due to the frequent movement of countries from one group to the other, the number of groups was reduced to three with six, three and two countries, respectively, and the four non-convergent countries of Finland, Germany, Ireland and Italy. Nonetheless, because the estimated log(t) coefficient (b) was found to be statistically no different than zero, the speed of convergence between the merged countries was also low. In addition, although new EU countries, like Malta and Lithuania, were unified in terms of energy intensity levels before the EU's expansion, they were ultimately recorded as non-convergent countries. After becoming members of the EU and implementing its common policies, the inter-temporal dynamics of most new EU countries' energy intensities diversified, and the clustering algorithm initially assorted them into three groups (Table 4). However, Bulgaria, Cyprus, the Czech Republic, Estonia and Malta showed different transitioning paths of energy intensity and were recorded as non-convergent countries when they were compared to their counterparts. Furthermore, no groups merged during the periods before or after the EU's expansion. In short, the identification of the inter-temporal dynamics in the patterns of the new EU countries' energy intensity levels revealed that the countries' initial unity of convergence during the first period was later segregated into three clubs.

Upon consideration of the full time period, the algorithm in section 3.1 was used to classify three convergence groups with six, two and four countries, respectively, and one non-convergent country. Furthermore, because the log (t) parameter equalled0.153 and was found to be statistically no different than zero, a transitional period between the convergence groups was observed. As such, the number of groups was reduced to two with six and six members, respectively, and one non-convergent country. Table 5 illustrates evidence of the merging histories for the EU-15 and new EU countries.

Table 5: EU-15 and new EU convergence groups before and after merging.

EU15-Convergence Groups Before Merging				**New EU Convergence Groups Before Merging**		
Periods	1990–2016	1990–2004	2005–2016	1990–2016	1990–2004	2005–2016
No. of Groups	2	2	4	3	1	3
Group no. 1	**Logt(0.245)** **t-stat(6.127)** Austria, Belgium, France, Italy, Luxembourg, Netherlands, Sweden	**Logt(0.278)** **t-stat(2.401)** Austria, Belgium, Luxembourg, Portugal, Sweden	**Logt(0.855)** **t-stat(3.428)** Belgium, Luxembourg, Netherlands, Sweden	**Logt(0.330)** **t-stat(3.514)** Bulgaria, Croatia, Czech Republic, Estonia, Latvia, Slovenia	**Logt(0.277)** **t-stat(2.826)** Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Poland, Romania, Slovak Republic, Slovenia	**Logt(0.286)** **t-stat(1.467)** Latvia, Slovenia
Group no. 2	**Logt(0.982)** **t-stat(3.553)** Denmark, Greece, Portugal, Spain, United Kingdom	**Logt(0.958)** **t-stat(6.609)** Denmark, France, Germany, Greece, Italy, Netherlands, Spain, United Kingdom	**Logt(0.874)** **t-stat(3.067)** Austria, France	**Logt(0.191)** **t-stat(0.649)** Lithuania, Poland		**Logt(1.818)** **t-stat(4.924)** Croatia ,Lithuania, Poland
Group no. 3			**Logt(4.070)** **t-stat(2.771)** Denmark, Greece, United Kingdom	**Logt(1.744)** **t-stat(12.334)** Cyprus, Hungary, Romania, Slovak Republic		**Logt(2.438)** **t-stat(2.346)** Hungary, Romania, Slovak Republic
Group no. 4			**Logt(0.043)** **t-stat(0.209)** Portugal, Spain			
Not Convergence Group	**Logt(-1.554)** **t-stat(-71.583)** Finland, Germany, Ireland	**Logt(-1.756)** **t-stat(-180.591)** Finland, Ireland	**Logt(-1.485)** **t-stat(-423.779)** Finland, Germany, Ireland, Italy	**Logt(-1.136)** **t-stat(-116.609)** Malta	**Logt(-1.628)** **t-stat(-33.582)** Lithuania, Malta	**Logt(-1.267)** **t-stat(-275.603)** Bulgaria, Cyprus, Czech Republic, Estonia, Malta
EU-15 Convergence Clubs After Merge				**EU-new members Convergence Clubs After Merge**		
No. of Clubs	No clubs can be merged.	No clubs can be merged.	3	2	No clubs can be merged.	No clubs can be merged.

Club no.1			**Logt(-0.015)** **t-stat(-0.142)** Austria, Belgium, France, Luxembourg, Netherlands, Sweden	**Logt(0.330)** **t-stat(3.514)** Bulgaria, Croatia, Czech Republic, Estonia, Latvia, Slovenia		
Club no.2			**Logt(4.070)** **t-stat(2.771)** Denmark, Greece, United Kingdom	**Logt(0.866)** **t-stat(0.153)** Cyprus, Hungary, Lithuania, Poland, Romania, Slovak Republic		
Club no.3			**Logt(0.043)** **t-stat(0.209)** Portugal, Spain			
Not Convergence Group			**Logt(-1.485)** **t-stat(-423.779)** Finland, Germany, Ireland, Italy	**Logt(-1.136)** **t-stat(-116.609)** Malta		

2.5. Conclusions and Policy Recommendations

Energy intensity is measured by the quantity of energy required per unit output or activity, and reductions in energy intensity are used as the proxies of higher energy efficiency. Thus, environmentalist, energy and environmental economists and policymakers moved towards determining the sources for energy intensity and in identifying methods that may decrease it across countries and regions alike. There have been clear declining trends of energy intensity and significant regional decoupling in the EU-28 over the past several decades. Thus, this study examined the energy intensity convergences of a phenomenologically homogenous sample of countries that depended upon the evaluation of unity convergence and/or the existence of various steady states. By using PS’s recently developed method (2007), we demonstrated that there was no unity between EU countries for the periods of

1990–2016, 1990–2004 and 2005–2016. We also examined the inter-temporal dynamics of the energy intensity convergence process for two different groups of countries, the EU-15 and new EU countries, over two different periods of time (1990–2004 and 2005–2016). This division of time was applied for two reasons: first, to obtain a reasonable number of observations on any convergence dynamics for each period, and second, to test if the convergence dynamics changed after the fifth expansion of the EU.

Moreover, these results indicate likelihood for disparities or different equilibriums between different EU countries. In other words, a large variety of steady states were observed between EU-28 countries, especially after the integration of CEE countries into the EU. Following this integration, these countries saw large reductions in energy intensity due to their increased use of renewable energy for power and structural changes to their economies. Through some simple analysis and descriptive statistics, we determined that the speed of convergence in EU countries increased and that their levels of energy consumption decreased by more than 12% after the EU's expansion in 2016. During this period, these countries also experienced economic growth of more than 7.5%. Therefore, the energy intensity levels of the EU-28 fell in this period (1990–2016) by an average of almost 2% per annum.

The results of this study also revealed evidence of convergence amongst the EU countries during the full sample period. Indeed, after the expansion of the EU, and depending on the decoupling of energy intensity levels amongst EU countries, convergence became more common and diverse. Thus, contrary to existing literature, our study shows evidence of the convergence of many EU countries around different steady states due to their economic structures, environmental awareness and economic advances. Furthermore, the existence of merging was examined within two or more groups to assess if convergence was achieved as a result of the various countries’ transitional energy intensity patterns, revealing that certain groups merged within the three selected periods of time. Thus, in order to increase energy efficiency and decrease environmental degradation through the improvement of environmental awareness, policy designers, environmentalists and other authorities should consider developing country-specific, or more precisely, group-specific policies to reduce decoupling levels between EU countries. They should also consider the development of economic and strategic structures for energy efficiency and environmental development within each country. At the same time, they should allocate resources for economic advancements to equalize economic performance and to achieve dynamic convergence in energy efficiency between the EU-28 countries.

Chapter 3

INEQUALITY IN CARBON INTENSITY IN EU-28: ANALYSIS BASED ON CLUB CONVERGENCE

3.1 Introduction

The most crucial factors for life sustainability are energy and environment. Therefore, energy economists, governmental and non-governmental organizations, and ecologists, have long debated the relationship between environmental quality, energy use, and economic growth, with inconclusive results. Particularly, legislators and ecologists argue that working on reducing CO_2 pollution for better environment hampers the economic growth of countries. However, their opposites argue that policies to reduce the level of irremediable global damage due to anthropogenic emissions of greenhouse gasses are strictly necessary. Therefore, the causal relationship between economic growth and CO_2 emissions were analyzed to determine whether policies—applied or applicable—might slow down sustainability in economic growth. Moreover, greenhouse gas emissions (GHG) from human activities are the primary drivers of economic growth and environmental degradation. Therefore, the increasing threats of climate change and anthropogenic GHG, of which carbon dioxide emissions (CO_2) are the most significant, have been a serious, global, and ongoing concern for several decades. Unfortunately, global GHG shows fluctuations and a pattern of sharp increases in the last two decades. Economic structure and activities as well as energy intensities are claimed to be the key factors of increased GHG globally. Furthermore, increasing global integration and asymmetries between economies boost global GHG emissions and worsen environmental degradation and global climate change. Therefore, it is of utmost importance to develop policies that focus on environmental, social, and economic differences to mitigate economic asymmetries and anthropogenic GHG, while simultaneously, increasing energy efficiency. To this end, environmental scientists, policymakers, and scientific bodies, attempt to design common international policies to mitigate the pace of global climate change and global warming. The signing of the Kyoto Protocol in 1997, Copenhagen Agreement in 2010, Durban Agreement in 2011, Warsaw Agreement in 2013, and the Paris Agreement in 2015 have emphasized the importance of these common policies. These common international agreements aimed to reduce global greenhouse gasses and increase energy efficiency.

According to the European Environment Agency database (2016), the European Union (EU) is one of the largest GHG emitters and biggest energy consumers in the world. Its carbon emissions in 2014 were recorded at 81% of world emissions, followed by methane, N_2O and F-gasses at 10.6%, 5.6%, and 2.9%, respectively. On the other hand, fuel combustion, transportation, industrial process and product use, agricultural activities and waste management are listed as the top sources of emissions with 55.1%, 23.2%, 8.5%, 9.9%, and 3.3%, respectively (Eurostat, 2016). Hence, EU policy makers consider energy efficiency and climate change policies as the cornerstones for economic growth and sustainable economic development. Thereby, besides signing and obeying all common protocols, for example, the Kyoto Protocol, the EU introduced three systems to meet its commitments to the common policies and its carbon mitigation objectives, that is, the Emission Trading Systems (ETS), Clean Development Mechanism (CDM), and Joint Implementation (JI). EU-ETS is an EU flagship tool to meet the abatement target of CO_2 in relation to the balance with economic objectives, innovation impacts, investment and price, and profit impact. On the other hand, the EU set inclusionary targets for reducing greenhouse gasses and environmental degradation associated with increasing economic competitiveness, energy efficiency, and the use of renewable energy sources to be accomplished by 2020, 2030, and 2050. The European Commission adopted a new 10-year action plan after the 2020 target to mitigate GHG emissions by 85%–95% by 2050, compared to 1990 levels. Depending on ongoing targets and action plans, the European Commission aimed to decrease the level of CO_2 emissions by 40% and 60% by 2030 and 2040, respectively. However, Korban and Manowska (2011) predictions indicates that asymmetries between economic and social structures will not allow the directives and common policies of the EU to mitigate CO_2 emissions by 20% compared to 1990 levels. Although the European Union pressures each member country to implement the same directives of energy and carbon abatement, its impact on each country is quite different. For instance, Germany, United Kingdom, France, Italy, Poland, and Spain were listed as top emitters compared to the EU-28 member countries. The aggregated share of GHG emissions of the listed countries is 70% of the total EU-28 member countries. Among these countries, the new member countries, Romania (56%) and the Czech Republic (approximately 37%) achieved significant reduction in CO_2 emissions by changing their economic structures while Spain (15%), Portugal (6.4%), and Ireland (3.7%) showed an increasing pattern of emissions. The North–South division within member countries, income inequality, and the difference in Gross Domestic Product (GDP), economic structure, and the level of energy efficiency, reveal a heterogeneous picture among EU-28 member countries for the sources of environmental degradation and global warming. Consequently, the determination of the distribution of state-level CO_2 emissions and its dynamics over time, require inspection. Moreover, an investigation of EU-28 CO_2 emissions necessitates the following questions. Do the country-specific differences in CO_2 emission levels tend to disappear or increase over time? If the observed diminishing disparities in CO_2 emissions level minimized, should the legislators not be worried about the current mitigation scheme? If the disparities tend to continue over time, should the legislators implement strict rules to mitigate the disparities between EU-28 countries and CO_2 emissions to reduce global warming? Are the common policies adequate for achieving the target? Do these policies give the intended reduction in CO_2 emissions for each country?

Notably, a developing country, China, was placed as the top CO_2 emitter, followed by the United States, India, Russia, Japan, Germany, Korea, Canada, Iran, and Saudi Arabia; the CO_2 emissions of these countries represent 75% of global CO_2 emissions. This study analyzes the patterns and inter-temporal dynamics of CO_2 emissions EU-28 countries, and classifies them into homogenous groups. To this end, we employed the club convergence method (PS) by Phillips and Sul (2007) to assort member countries depending on country-specific CO_2 features to investigate the existence of unique or different equilibriums. The PS method accounts for cross-section dependence through common factor analysis and evaluates the convergence process depending on the inter-temporal dynamics of GHG emissions of each member country. Consequently, we evaluated the convergence dynamics of EU-28, EU-15, and EU-new member countries for three different periods as follows: 1990-2016, 1990-2004, and 2005-2016. We divide the full sample period (1990-2016) into two different periods as per the number of observations for each period, to obtain convergence dynamics, and test whether the convergence dynamics changed after the fifth enlargement process of the EU. In particular, by testing for convergence and searching for possible club-specific features, we hope to help policymakers develop separate policies for each club to minimize their energy intensity levels for sustainable economic growth, depending on each club's economic features.

This study makes a three-fold contribution to the existing literature: (i) It attempts to classify the EU-28 members into different clubs as per their inter-temporal dynamics of CO_2 emissions intensities and find the different steady state levels for EU-28, EU-15, and EU-new members for the identified time periods (1990-2016, 1990-2004, 2005-2016). This may lead to different club-specific policies to unify all countries in the long run, and achieve environmental and energy targets in 2030 and 2050. (ii) The methodology employed helps account for spatial heterogeneity in the series, focusing on different steady state levels for countries with the same characteristics in terms of CO_2 intensity, and gives robust results in the presence of heterogeneity and non-stationary. Lastly, it emphasizes the asymmetric reductions in CO_2 emission intensity levels, the magnitude of the effect of common policies, their contributions to the EU 10-year targets, and the diversity between the founding members and newly participating countries.

The rest of this study is organized as follows: Section-II discusses key related studies and Section-III presents the data and econometric method. Section-IV comments on empirical results, while Section-V concludes.

3.2 Literature Review

Recently, global warming and global climate change have become the most important topic in all developed and developing countries, with considerable discussion on GHG emissions and its environmental effects in energy and environmental economics. Many studies have attempted to find the drivers of these anthropogenic GHGs, particularly for CO_2 emissions. Popular studies in this field examine causality issues and use the Environmental Kuznets curve (EKC) model to test the direct relationship between gross domestic product and pollutant emissions (Haseeb *et al*., 2018; Park *et al.,* 2018; Montasser *et al*., 2018; Huang, 2018; Farhani and Ozturk, 2015; Begum *et al.*, 2015; Heidari *et al.*, 2015; Ozcan 2013). This motivated energy and environmental economists and policymakers to focus on the convergence of these pollutants (see Li and Lin, 2013; Yavuz and Yilanci, 2013; Criado and Grether, 2011). All these studies have relied on the conventional stationarity of GHGs emissions (time series and/or panel) by employing unit root tests such as beta, sigma, and stochastic convergence techniques. These tests also captured the "catch up effect," and were later classified in relative (conditional) and absolute (unconditional) terms. An important issue in these analyses is judging whether the shocks in pollutant emission patterns are permanent. Thus, by studying the behavior of the series (stationary or non-stationary/convergence or divergence), policymakers, and environmental and energy economists can provide country-specific guidance and policies to reduce environmental degradation and overcome global warming under the rules and regulations of the common policies, *e.g.*, the Kyoto Protocol (see Lee and Chang, 2008; Solarin, 2014). Therefore, to design appropriate policies, it is necessary to examine and understand the trends in and behavior of pollutants although a large number of studies on convergence or divergence are ultimately inconclusive. For example, Aldy (2006) provided evidence of divergence in terms of per capita CO_2 emissions among 88 countries during the 1960-2000 period. Nguyen-Van (2005) also investigated the per capita CO_2

emissions and presented mixed results for a sample of hundred industrialized countries. Moreover, Barassi *et al.* (2008) reached the same conclusion for OECD countries during the period 1950-2002. Ezcura (2007) examined the regional distribution of CO_2 emissions for 87 selected countries and concluded that the regional disparities of these countries were increasing over the period 1960-1999. Furthermore, Camarero *et al.* (2013) generated a new index, called the carbonization index, and showed that there is no single steady-state level for the countries considered in his study.

In contrast, Strazicich and List (2003) employed stochastic and conditional convergence techniques and examined 21 OECD countries' CO2 emissions. They found strong evidence of convergence for the period of 1960-1997. Similarly, Westerlund and Basher (2008) examined 16 industrialized countries and found strong support for stochastic conditional convergence for the period 1870-2002. Furthermore, Romero-Avila (2008) found evidence in support of convergence among 23 industrialized countries for the 1960-2002 period by using panel unit root tests, while Herrerias (2012) reached the same conclusion for the selected 25 EU countries for the 1920-2007 period. Likewise, Jobert *et al.* (2010) examined the same issue for selected EU countries and focused on the absolute convergence in terms of per capita CO_2 emissions using data for the period of 1971-2006. They documented that the speed of convergence differs across the members and, thus, they suggested to identify different groups within studied EU member states. Moreover, Yavuz and Yilanci (2013) (G7 countries), Christidou *et al.* (2013) (selected 36 countries), Acaravci and Erdogan (2016) (World's 7 region) and Acaravci and Lindmark (2017) (OECD countries) employed several methods and obtained evidence in support of the convergence of CO_2 emissions across different selected countries over their different study periods. In the same line, Acar and Lindmark (2016), Nguyen-Van (2005) and Stegman (2005) obtained evidence both on the divergence and convergence of CO_2 emission on various countries.

There are several reasons for these mixed findings, for instance, the use of different time spans and/or different conventional econometric techniques, and ignoring the behavior of the series. Thus, the findings may provide inconsistent and specious results about the hypothesis of convergence. Therefore, Quah (1993, 1996, 1997) and later Durlauf *et al*. (2005) have both cogently criticized the econometric methods used in the literature and argue that there is no single steady state level as suggested in the neoclassical theory. Furthermore, they also argue that the neoclassical-based approaches ignore the fact that several countries may modify their positions over time. Thus, expecting single steady-state convergence may lead to the ignorance of country spillover effects such as environmental degradation or GHG emissions depending on the diversity within countries and regions that have different growth processes, different energy production compositions of renewable and non-renewable forms, and different composition of energy use. Therefore, many studies investigating the convergence-divergence issue employ the Phillips and Sul (2009) methodology that considers the convergence issue among countries and the homogeneity/heterogeneity of them. For instance, Panopolou and Pantelis (2009) investigated the convergence of CO_2 emission for a total of 128 countries. They found two separate convergence clubs spanning the period of 1960-2003. Moreover, they argue that, there is an evidence of transitions across the two clubs with a tendency of the countries to move from one club to another. Moreover, Herrerias (2013) investigated the convergence issue for 162 countries over 1980-2009 and presented the strong evidence of club convergence. Wang *et al.* (2014) analyzed CO_2

emissions convergence depending on the diversity in China provinces. They found different steady-state points for the period of 1995-2011. Similarly, Burnet (2016) applied the same approach for per capita aggregate CO_2 emissions for the states of the US over the 1960-2010 period and identified 23 states that comprised 3 clubs and 25 diverging states, while Apergis and Payne (2017) investigated 3 homogenous clubs within the states of the US with respect to CO_2 emissions intensity. Additionally, Ulucak and Apergis (2018) confirmed convergence of the per capita ecological footprint by using club-clustering approach in the EU countries spanning the period from 1961 to 2013. The findings show significant evidence of different convergence clubs. Recently, Yu *et al.* (2018) and Liu *et al. (*2018) found evidence of multiple homogenous clubs in terms of CO_2 emissions convergence for 24 industrial sectors and 285 cities in China.

This study assorts the behavior and inter-temporal dynamics of EU-28 CO_2 emissions, as well as the “catch up effect” of the series, into separate clubs that follow the same common environmental targets and convene at different steady state points. Accordingly, this study employed the newly developed PS methodology, which deliberates that some countries, regions, states, or sectors belong to a club, moving from a position of disequilibrium to their club-specific equilibrium level.

3.3 Data and Empirical Methodology

We obtained the annual data for CO_2 emissions intensity from the World Bank World Development Indicators for European Union-28 member countries, spanning 1990 to 2016. The period of the data is restricted by the availability. The selected countries under investigation are as follows: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Spain, Slovakia, Slovenia, Sweden, and the United Kingdom. We chose to investigate the EU-28 countries due to their high environmental standards globally and their common policies. Carbon dioxide emission intensity refers to the kilogram of emitted CO_2 gasses per kilogram of oil equivalent energy use for production. In other words, it is an emission rate of CO_2 relative to the intensity of a specific activity, or an industrial production process. The concept of convergence, in terms of CO_2, means becoming equal in terms of the level of environmental degradation, while divergence implies decoupling among countries. Here, it is important to consider the behavior and dynamics of the CO_2 emissions pattern of each country as well as their geographical factors, volume of economic activities, and energy use and resources. Therefore, countries may diverge overall but can converge into clubs or attain certain equilibrium. Therefore, the common environmental policies of the EU for achieving the EU-2020, 2030, and 2050 targets may fail. Therefore, Phillips and Sul (2009) recommended the club convergence technique to avoid a single equilibrium level and checking different equilibriums for investigated samples. In other words, PS classifies the countries, states, industries, or regions for different groups or clubs. Moreover, PS has several advantages as follows:

1. It considers the full sample average and measures its relative convergence.
2. PS considers gradually converging series and gradual changes in series, while panel unit root tests do not.
3. PS accounts for the presence of slowly approaching series in the long run equilibrium, while indicates a nonlinear process.

4. PS does not rely on stationarity or panel unit root testing (Apergis and Payne, 2017).
5. PS allows country specific heterogeneity and gives robust results in the presence of heterogeneity and non-stationarity (Burnett, 2016).
6. It is formulated as a nonlinear time varying factor model and named as log t-test.

The first step in the log t-test is to decompose panel data variable into two time varying components.

$$y_{it} = r_{it} u_t \tag{1}$$

Where y_{it} denotes the panel data variable, for$N$, $i = 1,2,3, \dots N$, number of countries and T, $t = 1,2,3, \dots T$, is the time dimension. Here, u_t indicates the common factor across identified countries and represents the aggregate common movements of the panel data variable, which is CO_2 emission intensity. Moreover, r_{it} is the idiosyncratic component symbolizing individual transition factors and measures the idiosyncratic distance between the common factor u_t and the systematic part of the panel data. It is supposed that r_{it}converges to some limiting value $r_i$for each country.

Considering the hypothesis of convergence, the mean difference between $r_{it}$and$r_i$reduces over time, at a rate proportional to

$$\frac{1}{t^{\alpha} \log(t+1)} \tag{2}$$

for $\alpha \geq 0$ and $r_i = r$ for each investigated country. This process helps in finding the convergence, by analyzing whether factor loadings r_{it}converge.Subsequently, the transition path, h_{it}, is calculated as follows:

$$h_{it} = \frac{\log y_{it}}{\log g_t} \tag{3}$$

Here, $\overline{\log g_t}$ presents the log values for CO_2 emissions intensity for each country. By employing equation (3), the ratio of the cross-sectional variation (H_1/H_t) can be calculated using:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 \tag{4}$$

The variations for each investigated country can be calculated through equation (4), which represents the distance of the panel from the common limit. Therefore, we establish the null and alternative hypothesis for convergence or divergence for each country as follows:

Null hypothesis: $r_i = r$ with $\alpha \geq 0$

Alternative hypothesis: $r_i \neq r$ for any i and $\alpha < 0$

The following equation tests the hypothesis in a statistical framework:

$$\log(H_1/H_t) - 2\log L(t) = c + b\log t + u_t \tag{5}$$

For $[\tau T], [\tau T] + 1, \dots, T$ with $\tau > 0$. Here, $L(t) = \log(t)$ and τ indicates a discarded fraction from the investigated panel, which is default by PS to be 0.3. We calculate standard errors using a consistent estimator of heteroskedasticity and autocorrelation for the long-term variance of the residual. On the other hand, as the one-sided *t*-test result is less than -1.65, we concluded that the null hypothesis is rejected at the 5% significance level for the full sample. Thus, if the full sample does not converge at the 5% significance level, we test the convergence of subgroups of clubs. Here, we employ a clustering procedure to determine the number of clubs and their members. This procedure contains the following steps.

Step 1: Ordering. The members in the panel will be ordered depending upon the last observations in descending order.

Step 2: Forming All Possible Core Groups: To form the optimal core cluster size, k^*, PS tries to maximize the $\log(t)$ statistics $t_k = t(G_k)$, where $N > k \geq 2$. Hereby, we denote $G_g$for the sub-group, which comprises the k highest countries. Moreover, $k^* = \text{argmax}(t_k)$set as criterion, on conditional basis $\min(t_k)$ greater than -1.65. If this condition does not hold, the last member country will be eliminated from the clusters and a new group will be formed. This process will continue until it identifies the core cluster.

Step 3: Sieve Individuals for club membership: Once the core cluster is identified, the rest of the countries will be eliminated to join the core cluster by repeating the $\log(t)$ statistics. Adding a new country at a time to the cluster and employing the $\log(t)$ test to obtain $t_s$for membership, $t_s > c^*$, where c^* is the critical value. PS suggested setting the c^* to 0, when the size of the sample is not greater or equal to 50. Subsequently, the first cluster is defined; the $\log(t)$ statistics will be enforced to the cluster to ensure that conditiont_b is greater than -1.65. Otherwise, it will necessary to increase the critical value of c, that is, c^*.

Step 4: Stopping Procedure: Once the null hypothesis is rejected, stop forming the additional subgroups. Once $t_k > -1.65$, we assume that the remaining countries, states, regions, or industries diverge.

3.4 Empirical Results

We perform a graphical analysis of the convergence issue for the CO_2 emissions intensity of EU-28 countries. First, we examined the relative transition path of CO_2 emissions intensity of EU-28 countries to visually decide whether the investigated group of countries converges at one steady state level. However, as is obvious in Figure 2, the countries have many ascents and descents relative to the transition of CO_2 emissions intensity, and show decoupling from each other. Moreover, during the period under investigation, we observed average annual growth of CO_2 emissions intensity in Belgium, Croatia, Cyprus, Ireland, Netherlands, Poland, Portugal, Romania, and Spain. In the remaining EU-28 member countries, the CO_2 emissions intensity shows a decreasing pattern. However, in recent years, the smallest average annual decrease in CO_2 emissions intensities were in Germany, Luxembourg, Malta, the Slovak Republic, and the United Kingdom. Instances of highest decrease were observed in Estonia, Finland, Greece, and Slovenia. These differences were mostly related to economic activities or structures, economic transition enforcements, technological advancement, and the differences in the growth rates of the economies. On the other hand, the fluctuations were mostly observed after the fifth enlargement process of the EU, possibly due to enforcement for membership or pursuit of standards. Thus, we employed the PS method to further investigate the different steady states for the members who share a common trend for different time periods. In addition, we also wanted to check if the enlargement process has significant effects on the dynamics of convergence for countries during their transition terms.

Moreover, we employed this test for EU-15 and EU-new member countries for the periods under investigation to observe their inter-temporal dynamics and the behavior related to CO_2 emissions intensity.

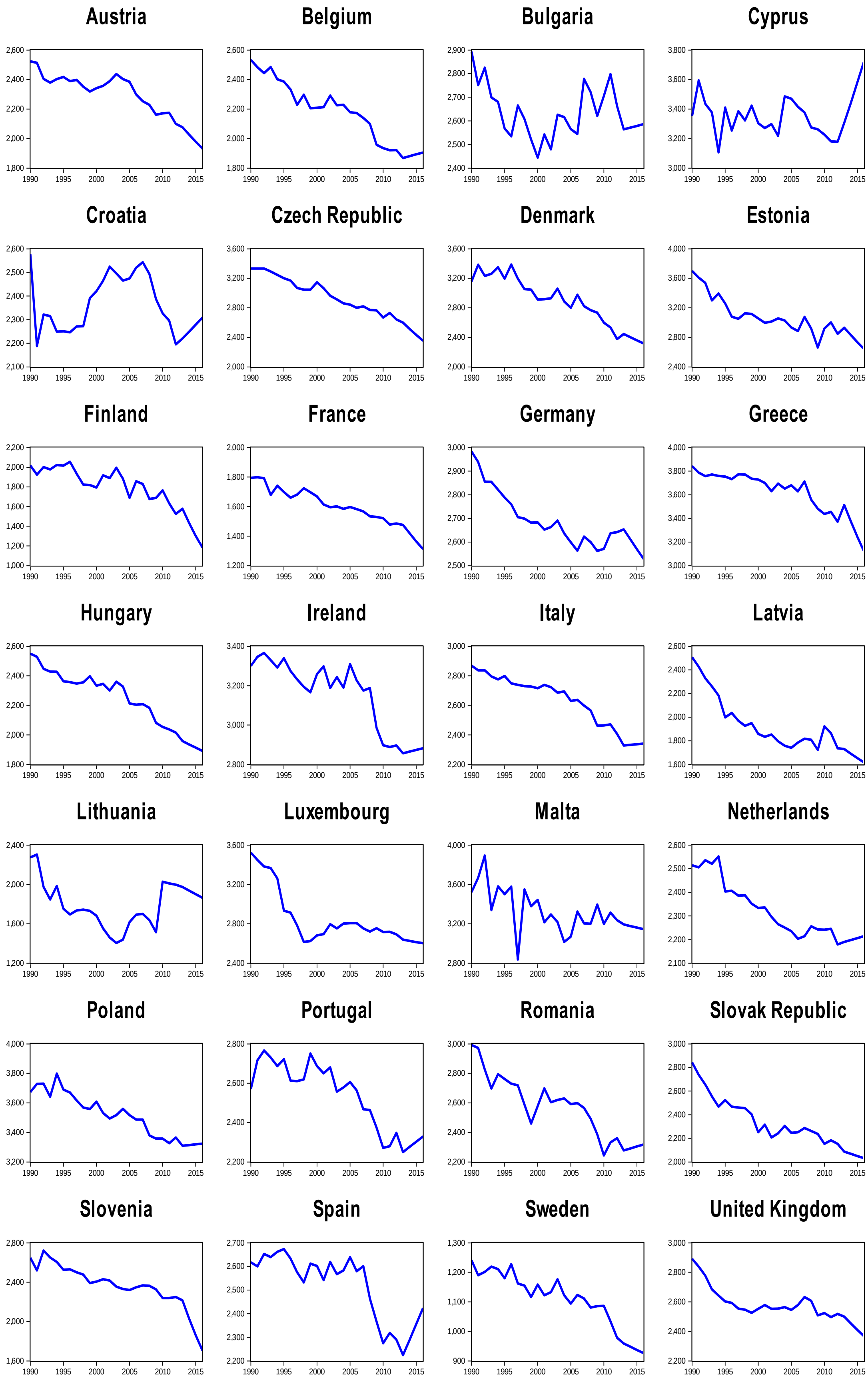

Figure 2: CO2 Emissions Intensity of EU-28 countries

3.4.1 Full Sample Club Convergence

As we observed decoupled trends in Figure 2, we employed the Phillips and Sul (2007) methodology to find several steady state levels and classify the homogenous group of countries. Table 6 illustrates the findings of log *t*-tests of club convergence methodology for CO_2 emissions intensity of EU-28 countries. For all identified periods (1990-2016, 1990-2004, and 2005-2016), we found one-sided t-statistics at less than the critical level. Thus, the null hypothesis of convergence of full sample at unity is rejected at the 5% significance level. Therefore, we employed the clustering procedure. To this end, for 1990-2016, we identified five different groups of countries that consist of 5,8,8,4, and 2 members, respectively. Furthermore, one country, namely Sweden, was categorized as the non-convergent country among others. The first club has the highest convergence speed of CO_2 emissions intensity and consists of Cyprus, Greece, Lithuania, Malta, and Poland. Moreover, the second club, which has lower speed than the first club but a higher speed than the third, fourth, and fifth convergence clubs, consists of Bulgaria, Croatia, Czech Republic, Estonia, Germany, Ireland, Luxembourg, and the United Kingdom, followed by other countries with different convergence speeds. Finland and France were classified as the last group members and have the lowest convergence speed for environmental remediation. On the other hand, when the analysis was repeated, considering the fifth enlargement process, before 2005, the diversification in transition patterns and the dynamics of CO_2 intensity was higher than after the enlargement process. For 1990-2004, decoupling among countries was high and we obtained seven groups of countries. However, this reduces to six after the enlargement process, perhaps due to EU enforcement of environmental issues, common policies, and the economic integration/advancement of countries. We analyzed the possibility of transition of member countries from one club to another or merging of clubs for the time period under investigation. This allows us to observe the countries that share common long-run trends and transition dynamics.

No clubs merge in the 1990-2016 period; however, the second and third club merged for the 1990-2004 period, and the number of clubs decrease to six, while we observe the same situation after the enlargement period (see from Table 6). This implies the presence of a larger subgroup of the combined clubs related to CO_2 emissions intensity. Moreover, the results from the club convergence methodology clarify the differences in the environmental quality of the countries, as well as the environmental awareness in each club. Lastly, we observe that club 1 has older and less efficient industrial infrastructure in terms of environment than other clubs. In other words, club 1 members emit higher CO_2 per unit of energy consumed.

Table 6: Convergence Clubs of CO2 Intensity for EU-28

Periods	**log*t* test**		**Convergence Clubs Before Merging**									
	Coeff.	**t-stat**	**No of Clubs**	**Club 1**	**Club 2**	**Club 3**	**Club 4**	**Club 5**	**Club 6**	**Club 7**	**Not Convergent Group**
1990-2016	-0.961	-51.635	5	**Coeff: 0.036** **t-stat: 0.347** Cyprus, Greece, Lithuania Malta, Poland	**Coeff: 0.174** **t-stat: 5.919** Bulgaria, Croatia, Czech Republic, Estonia, Germany, Ireland, Luxembourg, United Kingdom	**Coeff: 0.225** **t-stat: 2.447** Austria, Denmark, Italy, Netherlands Portugal, Romania, Slovak Republic, Spain	**Coeff: 0.155** **t-stat: 1.027** Belgium, Hungary, Latvia, Slovenia	**Coeff: 4.146** **t-stat: 2.618** Finland, France			Sweden
1990-2004	-1.071	-155.496	7	**Coeff: 0.035** **t-stat: 0.333** Cyprus, Poland	**Coeff: 0.001** **t-stat: 0.016** Croatia, Ireland, Malta	**Coeff: 0.258** **t-stat: 2.765** Czech Republic, Denmark, Estonia, Italy, Portugal,	**Coeff: 0.325** **t-stat: 4.824** Austria, Bulgaria, Germany, Hungary, Luxembourg Romania, United Kingdom	**Coeff: 0.687** **t-stat: 8.047** Belgium, Netherlands, Slovak Republic	**Coeff: -0.490** **t-stat: -0.311** Finland, Latvia	**Coeff: -2.325** **t-stat: -1.366** France, Lithuania	**Coeff: -0.944** **t-stat: -48.155** Greece, Slovenia, Sweden

						Spain					
2005-2016	-1.239	-261.878	6	**Coeff: 1.623** **t-stat: 8.525** Greece, Malta, Poland	**Coeff: 0.056** **t-stat: 0.568** Bulgaria, Estonia, Germany, Ireland, Lithuania	**Coeff: 0.460** **t-stat: 2.794** Czech Republic, Netherlands United Kingdom	**Coeff: 1.409** **t-stat: 4.984** Croatia, Denmark, Italy, Portugal, Romania, Spain	**Coeff: 0.060** **t-stat: 0.604** Austria, Belgium, Hungary, Latvia, Slovenia	**Coeff: 3.968** **t-stat: 1.549** Finland, France		**Coeff: -1.298** **t-stat: -155.252** Cyprus, Luxembourg, Slovak Republic, Sweden
Convergence Clubs After Merging											
1990-2016	No Clubs can be merged										
1990-2004			6	**Coeff: 0.035** **t-stat: 0.333** Cyprus, Poland	**Coeff: -0.008** **t-stat: -0.109** Croatia, Czech Republic, Denmark, Estonia, Ireland, Italy, Malta, Portugal, Spain	**Coeff: 0.325** **t-stat: 4.824** Austria, Bulgaria, Germany, Hungary, Luxembourg, Romania, United Kingdom	**Coeff: 0.687** **t-stat: 8.047** Belgium, Netherlands, Slovak Republic	**Coeff: -0.490** **t-stat: -0.311** Finland, Latvia	**Coeff: -2.325** **t-stat: -1.366** France, Lithuania		**Coeff: -0.944** **t-stat: -48.155** Greece, Slovenia, Sweden

2005-2016			5	**Coeff: 1.623** **t-stat: 8.525** Greece, Malta, Poland	**Coeff: -0.042** **t-stat: -0.525** Bulgaria, Czech Republic, Estonia, Germany, Ireland, Lithuania, Netherlands, United Kingdom	**Coeff: 1.409** **t-stat: 4.984** Croatia, Denmark, Italy, Portugal, Romania, Spain	**Coeff: 0.060** **t-stat: 0.604** Austria, Belgium, Hungary, Latvia, Slovenia	**Coeff: 3.968** **t-stat: 1.549** Finland, France			**Coeff: -1.298** **t-stat: -155.252** Cyprus, Luxembourg, Slovak Republic, Sweden

3.4.2 EU-15 and EU-new Sub-Group Club Convergence Relative to CO_2 Intensity

We employ the initial classifications for the EU-15 and EU-new member countries based upon the log t algorithm. Table 7 lists the members of each corresponding club. Depending on the test results for each club, the coefficients on the log t term are negative and statistically insignificant. Thus, we conclude that for the identified time periods, each club converges at different steady state points and has diverging CO_2 emissions intensity. On the other hand, the results indicate that the heterogeneity of behavior of CO_2 emissions intensity among EU-15 countries is consistent in the long run and none of the clubs merge. On the contrary, the heterogonous behavior of CO_2 emissions intensity among EU-new member countries disappears slightly in the long term, and many countries move from one club to another or the clubs merge. This may be due to technological improvements, development in economic structure or performance, imposing strict regulations to achieve EU standards, role of internalization, and compliance with international agreement obligations for environment and economic issues during their transition term. However, the degree of intra-distribution mobility among the clubs is quite low and limited. It seems that most countries tended to stay in their original club before and after the fifth enlargement term. Consequently, we can say that heterogeneity within EU-15 and EU-new members as well as between both groups continues after the fifth enlargement period (see Table 7).

Table 7: Convergence clubs of EU-15 and EU-new Member Countries

Periods	**Log t test**		**Convergence Clubs Before Merging**						
	Coeff.	**t-stat**	**No of Clubs**	**Club 1**	**Club 2**	**Club 3**	**Club 4**	**Club 5**	**Not Convergent Group**
EU-15 Countries before merge									
1990-2016	-1.007	-68.059	3	**Coeff: 0.243** **t-stat: 2.207** Germany, Ireland, Luxembourg, United Kingdom	**Coeff: 0.384** **t-stat: 4.327** Austria, Denmark, Italy, Netherlands, Portugal, Spain	**Coeff: 4.146** **t-stat: 2.618** Finland, France			**Coeff: -0.893** **t-stat: -307.818** Belgium, Greece, Sweden
1990-2004	-0.923	-53.451	1	**Coeff: 0.026** **t-stat: 0.452** Austria, Denmark, Germany, Italy, Luxembourg, Portugal, Spain, United Kingdom					**Coeff: -0.971** **t-stat: -54.818** Belgium, Finland, France, Greece, Ireland, Netherlands, Sweden
2005-2016	-1.233	-150.967	3	**Coeff: 0.543** **t-stat: 4.054** Germany, Ireland, Luxembourg	**Coeff: 0.680** **t-stat: 6.129** Denmark, Italy, Netherlands,	**Coeff: 3.968** **t-stat: 1.549** Finland, France			**Coeff: -1.105** **t-stat: -53.507** Austria, Belgium, Greece, Sweden

					Portugal, Spain, United Kingdom				
EU-New member Countries before merge									
1990-2016	-0.744	-33.438	5	**Coeff: 2.639** **t-stat: 2.649** Cyprus, Poland	**Coeff: 0.625** **t-stat: 4.504** Bulgaria, Czech Republic, Estonia, Lithuania	**Coeff: 6.856** **t-stat: 10.205** Croatia, Romania	**Coeff: 1.013** **t-stat: 1.109** Slovak Republic, Slovenia	**Coeff: 0.165** **t-stat: 0.957** Hungary, Latvia	Malta
1990-2004	-1.40	-198.129	4	**Coeff: 0.035** **t-stat: 0.333** Cyprus, Poland	**Coeff: 0.59** **t-stat: 4.001** Croatia, Czech Republic, Estonia	**Coeff: 0.349** **t-stat: 2.652** Bulgaria, Romania	**Coeff: 1.733** **t-stat: 4.674** Hungary, Slovenia		**Coeff: -1.495** **t-stat: -615.845** Latvia, Lithuania, Malta, Slovak Republic
2005-2016	-1.165	-145.772	4	**Coeff: 0.308** **t-stat: 3.716** Malta, Poland	**Coeff: 0.076** **t-stat: 0.648** Bulgaria, Estonia	**Coeff: 0.860** **t-stat: 4.198** Czech Republic, Lithuania, Romania	**Coeff: 0.302** **t-stat: 2.200** Hungary, Latvia, Slovenia		**Coeff: -1.626** **t-stat: -202.527** Croatia, Cyprus, Czech Slovak Republic

<table>
<tr><th colspan="10">EU-15 Convergence Clubs After Merging</th></tr>
<tr><td>1990-2016</td><td colspan="9">No Clubs can be merged</td></tr>
<tr><td>1990-2004</td><td colspan="9">No Clubs can be merged</td></tr>
<tr><td>2005-2016</td><td colspan="9">No Clubs can be merged</td></tr>
<tr><th colspan="10">EU-new members Convergence Clubs After Merging</th></tr>
<tr><td>1990-2016</td><td></td><td></td><td>4</td><td>Coeff:-0.048
t-stat: -0.484
Bulgaria, Cyprus, Czech Republic, Estonia, Lithuania</td><td>Coeff: 6.856
t-stat: 10.205
Croatia, Romania</td><td>Coeff: 1.013
t-stat: 1.109
Slovak Republic, Slovenia</td><td>Coeff: 0.165
t-stat: 0.957
Hungary, Latvia</td><td></td><td>Malta</td></tr>
<tr><td>1990-2004</td><td></td><td></td><td>3</td><td>Coeff: 0.035
t-stat: 0.333
Cyprus, Poland</td><td>Coeff: 0.264
t-stat: 2.542
Bulgaria, Croatia, Czech Republic, Estonia, Romania</td><td>Coeff: 1.733
t-stat: 4.674
Hungary, Slovenia</td><td></td><td></td><td>Coeff: -1.495
t-stat: -615.845
Latvia, Lithuania, Malta, Slovak Republic</td></tr>
<tr><td>2005-2016</td><td></td><td></td><td>3</td><td>Coeff: 0.308
t-stat: 3.716
Malta, Poland</td><td>Coeff: 0.007
t-stat: 0.090
Bulgaria, Czech</td><td>Coeff: 0.302
t-stat: 2.200
Hungary, Latvia,</td><td></td><td></td><td>Coeff: -1.626
t-stat: -202.527
Croatia, Cyprus, Slovak Republic</td></tr>
</table>

					Republic, Estonia, Lithuania, Romania	Slovenia			

3.5 Conclusion

The literature has still not paid full attention to the consequences of anthropogenic GHGs emissions on the environment. The few studies primarily focus on the intensity level of CO_2 emissions by considering a single steady state point. Thus, these papers obtain ambiguous and mixed results. Therefore, this study put forth and employed the club clustering methodological approach in the case of EU-28 member states.

This study contributes to the existing literature in terms of convergence evaluation aspects on the existence of different steady state points or convergence clubs of EU-28 member states, rather than the presence of an overall or regional single convergence level during time spans investigated (1990-2016, 1990-2004, and 2005-2016). With this, the rejection of the null hypothesis (overall convergence) leads us to identify some clubs that tend to different equilibrium levels within the EU-28, EU-15, and EU new member countries. We identified a relative convergence within the identified clubs as five to seven convergence clubs, depending on the investigated time periods at the country level. However, three to five convergence clubs were identified in terms of categorical level (EU-15, EU-new members).

For the case of the EU, carbon emissions continue to be quite high due to the massive dependence on fossil fuels for energy generation to support sustained economic growth. Due to the large emissions, the environment continues to degrade with no reduction in sight. It is almost impossible to implement a direct solution that would effectively reduce the amount of energy intensity because of how much the apparently homogenous region depends on the current level of energy usage. In the

EU, there is an ongoing process of energy transitions through common agreements that are Kyoto Protocol and Paris Agreement, in order to reduce energy consumption, CO_2 emission, and environmental degradation by 20% as well as reducing global temperature by 1.5°C. To this end, the carbon reduction roadmap was designed while focusing on increasing energy efficiency through rapid reduction in energy demand, comprehensive electrification of energy supply, replacing fossil fuel consumption with renewable energy sources *etc.* However, social and political roadblocks, such as political paralysis and denials; financial, governance and implementation constraints; inequitable wealth distributions and social dependences prevent rapid de-carbonization within the EU. Therefore, our findings carry significant policy implications for environmental degradation. Accordingly, the EU must first accelerate the enforcements through agreements as well as implement some strict regulations in order to achieve a low carbon economy. Secondly, depending on the economic and energy dependency, the EU should strengthen economic capacity by producing goods and services with lower energy requirement and CO_2 emissions. Moreover, the member states should change the structure of the electricity sector and diversify energy sources in order to generate more efficient electricity for the industry and households. This will cause to gain institutional thickness and capacity to have less energy intensity in electricity generation. Thus, political leaders, investors, and environmentalist should promote and subsidize the cost of installing renewable energy sources along with providing accommodation and subsidies for entities that are investing into research and development of eco-friendly technologies. Furthermore, the governments and legislators should introduce stricter regulations on fossil fuel dependent technologies through common agreements that also contribute to mitigating carbon emissions and environmental degradation. In other words, both consumers and producers should be encouraged to adapt environmental friendly technologies and energy conserving procedures that contribute to sustainable economic growth and maintain high qualitative environmental standards. Additionally, the EU should continue to protect vulnerable communities from the ravages of degradation. Thus, it should increase CO_2 emission permit prices and expanding such policies into covering all greenhouse gasses that are methane and nitrous oxide, including shipping and air transport. Moreover, since energy related CO_2 emission is measured as 80% of total emission and transportation sector has the highest share depending on continuous increase in road transportation that is triggered by growing trade volumes, the EU should develop policy on fuel switching to biofuels or other renewable energy sources and introduce more energy efficient technologies to the citizens.

In contrast, depending on heterogeneous characteristics of the EU-member countries, there is a need to adopt new strategies that consider the homogenous clubs' properties and contribute to sustainable economic growth processes, which also sustain the environmental standards. Thus, the club convergence assessment helps us recommend further consideration of environmental degradation and club specific policies to reduce heterogeneity among countries and gather them into one club to develop more effective common policies to reach the target.

Chapter 4

ENERGY INTENSITY, CARBON EMISSIONS, RENEWABLE ENERGY, AND ECONOMIC GROWTH NEXUS: NEW INSIGHTS FROM ROMANIA

4.1 Introduction

The topics of energy consumption, energy intensity, and economic growth are well discussed in energy economics literature for both developed and developing nations. The theme has gained the attention of energy practitioners as well as policy- and decision-makers given the growth trend in countries with high-energy production and increased per capita income. Thus, it is crucial for policy- and decision-makers to understand the dynamic relationship between energy consumption, carbon emissions, and economic growth for effective, robust energy and environmental policies.

However, economic prosperity and energy intensity may be mutually determined, while the direction of causality between other variables of interest is indecisive. Biesiot and Noorman (1999) posited that economic growth and energy intensity is correlated before the birth of industrial revolution. That is, growth and intensity increased along with the industrial revolution. This seen relationship has posed a challenge with the rise of environmental pollution via increased carbon emissions as results of increased industrial production using fossil fuels to sustain economic output. According to Halicioglu (2009), the path to economic prosperity entails more than intensifying energy consumption or production to increase real output levels. It is expected that as economic output increases, environmental quality will decrease.

The dynamic relationship between energy consumption and economic growth offers that energy use and economic growth is mutually determined. However, the direction of causality is unclear. The seminal study of Kraft and Kraft (1978) on economic growth and energy consumption was an invitation to several other studies (see Masih and Masih 1996; Cheng and Lai 1997; Glasure and Lee 1998; Asafu-Adjaye 2000; Stern 2000; Soytas and Sari 2003; Paul and Bhattacharya 2004; Wolde-Rufael 2005; Mehrara 2007; Narayan and Smyth 2008) These studies all analyze the long-run equilibrium relationship between energy consumption and economic growth. Several other studies also apply other nonlinear estimation techniques (see Seifritz and Hodgkin 1991; Yoo and Kim 2006; Lee and Chang 2007). However, much has been documented in the energy economic literature for decades, mostly in developed and developing economies. Little is known about this very interesting dynamic interaction in developing economies. Thus, this current study focuses on Romanian which has very interesting energy dynamics, given her new entry into the EU-membership. Details on the energy-growth literature nexus see Table 8.

This study contributes the existing literature in two-folds. First, focuses on the investigation of the long-short run relationship between energy intensity, carbon emissions, renewable energy consumption, and economic growth in Romania for the first time in a multivariate framework against previous studies built on bi-variate framework, which arguable to be flawed with the omitted variable bias (model misspecification) axioms of classical linear regression (Lütkephol and Kratzig,2004).

Thus, a multivariate framework is used to avoid spurious regression analysis and subsequent inferences and policy implications. The choice of Romania becomes crucial given her strategic position and dynamic energy statistics among the European Union and as a signatory to the Kyoto Protocol energy agreement. Second, this study also contributes to the strand of the literature for the case of Romania in terms of scope by the incorporation of renewable energy into the econometric modelling and also given her position as a new entrant into the EU membership. Our study seeks to investigate the theme to ascertain if Romanian has prospect to attain her energy target being a new entrant into the EU membership having suffered revolution and economic decline in the late 1980 and early 1990's. Thus, it is worthy to investigate the causal long run and short run interactions for the variables under review for Romania.

Table 8: Summary of energy consumption, carbon emissions and GDP growth in nexus literature

Author	**Period**	**Region**	**Methodology**	**Causality**
Ozturk & Acaravi (2010)	1968-2005	Turkey	ARDL bounds testing	N/A
Al-Mulali *et al.* (2016)	1980–2012	Kenya	ARDL bounds testing	N/A
Baek (2015)	1960–2010	Arctic countries	ARDL bounds testing	N/A
Al-Mulali *et al.* (2015)	1981–2011	Vietnam	ARDL bounds testing	N/A
Halicioglu (2009)	1960-2005	Turkey	ARDL bounds testing, Granger causality	Y↔C
Apergis & Ozturk (2015)	1990–2011	Asian countries	GMM	N/A
Shahbaz *et al.* (2015)	1980–2012	African countries	FMOLS, Pedronicointegration, VECM.	Y↔C EC→C
Osabuohien *et al.* (2014)	1995–2010	Africa	DOLS, Pedronicointegration.	N/A
Cho *et al.* (2014)	1971–2000	OECD countries	DOLS, FMOLS, and Pedronicointegration.	N/A
Soytas *et al.* (2001)	1960-1995	Turkey	ARDL technique	EC→C

Shafiei & Salim (2014)	1980–2011	OECD countries	Westerlund Panel Cointegration, VECM Granger causality	Y→C EC→C
Tiwari *et al.* (2013)	1966–2011	India	ARDL bounds testing, VECM, Johansen cointegration.	Y↔C EC↔C
Kleemann & Abdulai (2013)	1990–2003	90 developed and developing countries	Fixed effect model	N/A
Ozcan (2013)	1990–2008	Middle East	Westerlund Panel cointegration, VECM Granger causality	Y↔C EC→C
Govindaraju & Tang (2013)	1965–2009	China and India	Cointegration, VECM	Y↔C EC→C

Note: →represents direction of causality while ↔ indicates bidirectional causality. N/A denotes no causality test. C is carbon emission, Y is GDP, and EC is energy consumption.

The remainder of this study proceeds as follows: Section 2 provides a synopsis of Romania's energy sector. Section 3 details the methods adopted for this empirical analysis. Section 4 presents results and discussion. Section 5 provides conclusions and policy implications.

4.2 Romania Energy Sector: A Synopsis

Romanian has very rich geographical features with an area of 238,400 square kilometers; Romanian is reputed to be the twelfth-largest country in Europe. The country is suited in the southeastern Europe bordering on the black sea. Romanian is bordered around other counties like Republic of Moldova and Ukraine lie to the east, Bulgaria around to the south, while on the west is Serbia and Hungary.

Since 2007, Romania has been a member of the European Union (EU) alongside Bulgaria as new entrant into the membership of the blocs of countries in the region. In December 1989, Romania experienced a revolution which left the country in the dark. The revolution period is characterized by low economic growth, high unemployment rate. However, since 2000's the economy has picked up rapidly with strong evidence of growth trends in her economic indicators like (GDP level, unemployment rate e.t.c) and is now rated as an upper-middle income EU country with dynamic economic development. Its nominal gross domestic product places Romania as the eleventh largest economy in the EU, and Romania ranks 8th based on purchasing power parity (PPP), making it the 49th largest economy in the world.

Romania is well-endowed with natural resources, including oil, petroleum, natural gas, and agricultural produce. Available data from the US Energy Information Administration reveals that, in 2008, Romania ranked 39th in the world in terms of energy consumption. Romania has numerous energy sources, primarily natural gas, oil, coal, and uranium as well as also renewable energy sources namely; hydro power, wind power energy sources scattered across the country. These energy sources offer huge prospects for the country's economic development and economic growth by extension. However, the country's diverse energy sources are insufficient to satisfy the nation's total energy consumption. Recently, Romania has aligned with the EU strategy, as part of the Kyoto Protocol, to ameliorate carbon emissions by using more renewable energy resources.

Romania's total energy consumption between 2000 and 2008 grew 9% from 36,374 to 39,658 thousand tons of oil, as well as a sharp decline in 2009 and 2010 to 34,328 thousand tons of oil (European Commission, 2012). The key sources of energy consumption are natural gas, accounting for more than 30% of the country's total energy consumption (Negut *et al*. 2008). Figure 3 and 4 provides the energy mix dynamic available in Romanian. Conspicuously seen are the trend and progress observed in the energy sector for the study area under consideration after the 1989 and early 1990's Romanian revolution. For example the trend analysis in Figure 3 shows strong evidences of economic progress as real GDP trend upward. Similarly, there is also an upward trend in the production of renewable energy consumption as seen in Figure 3 which also collaborates with the chart in Figure 4. There been significant jump in the share of renewable production from 1990 to 2014 from 4% to laudable 23%. This is commendable and needs to be sustained.

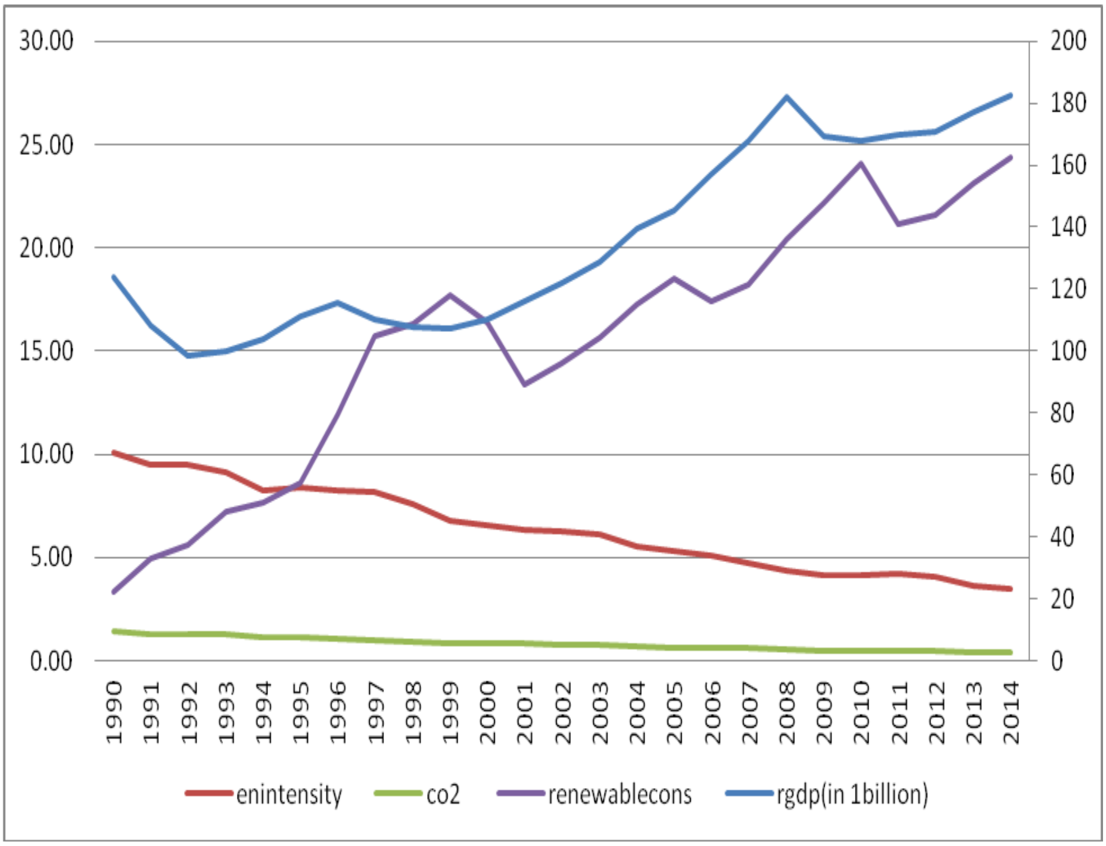

Figure 3: Trend analysis of energy intensity, CO2, renewable energy and economic growth (1990-2014)
Source: Authors' computation on WorldBank World Development Indicators (WDI) data (2018)

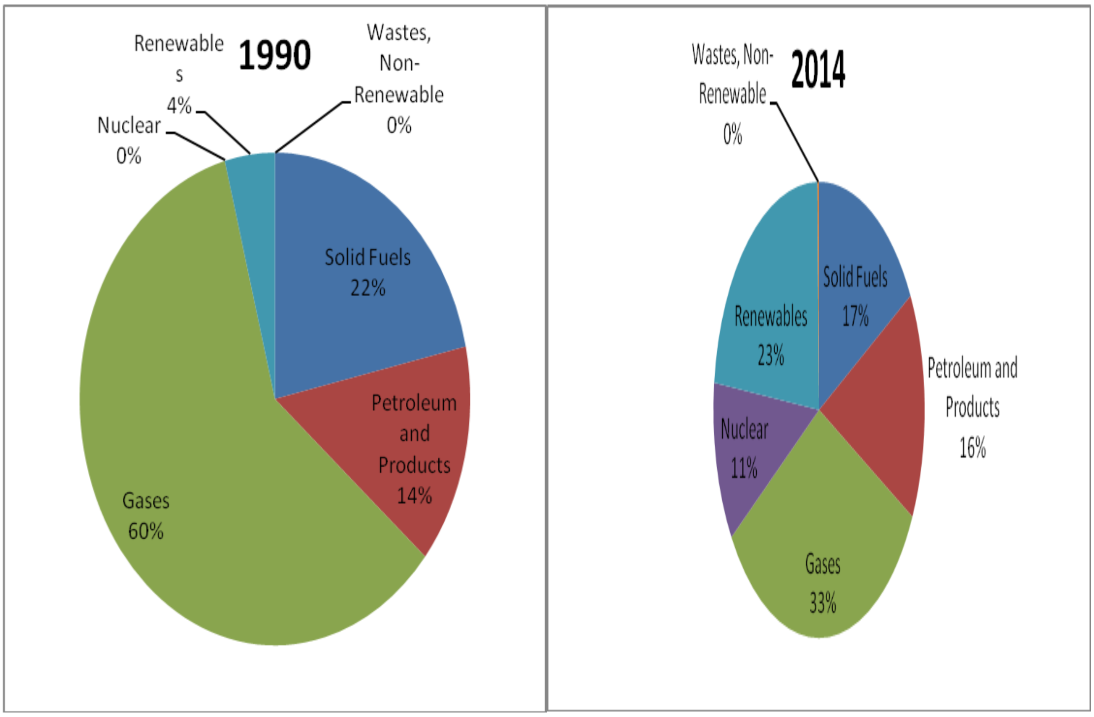

Figure 4: Romanian Energy production mix
Source: European Commission Energy Statistics, 2018

4.2 Methodology

This section concerns with the data and econometric procedure applied in the current study.

4.2.1 Data

In a single-country study, using per capita data instead of total data only scales the variable down (Soytas *et al.* 2007). Accordingly, while the Kyoto Protocol emphasizes a deduction of carbon dioxide (CO2) emissions, it proposes the use of total amount of emissions instead of using per capita amounts (Friedl and Getzner, 2003). Therefore, the data here is emissions total, not per capita.

In order to investigate the dynamic interaction between energy intensity, CO2 emission, renewable energy and economic growth for the case of Romania, our study empirically follows on (El-aasar and Hanafy, 2018; Shabaz *et al.*, 2015). To this end, the observed variables are CO2 emissions in kilogram per 2010 USD of GDP, GDP in constant 2010 USD (RGDP), energy intensity (ENINT) in MJ per 2011 PPP GDP, and renewable energy consumption (RECONS) as a percentage of total final energy consumption. Real GDP and CO2 emissions are used proxies for economic growth and environmental degradation respectively. All the variables for the study were retrieved from World Development Indicators (WDI-CD-ROM, 2017). The study period spans from 1990Q1 to 2014Q4[1]. The choice of the time frame reflects economic episodes and political events in the study area, the data is restricted based on the availability and trimmed for uniformity of estimations.[2]

The empirical procedure for this study is of three-fold. First, the stationarity test is applied to ascertain the maximum order of integration of the investigated variables and also asymptotic traits of the selected time series data through Augmented Dickey-Fuller and Phillips and Perron unit root tests in order to avoid spurious regression. Second, proceeds to perform cointegration test to establish if there exist long run equilibrium relationships among the variables. Finally, dynamic causality test to examine causal relationships between variables. The following sections discuss model specification, stationarity tests (unit root tests), cointegration, and causality test.

4.2.2 Model Specification

The empirical estimation model contains four variables: RGDP, energy intensity, CO2, and renewable energy consumption. The econometric model is given as

$$RGDP = f(ENINT, CO2, RECONS) \qquad (1)$$

---

[1] Our study leverages on (McDermott & McMenamin, 2008; Shahbaz and Lean, 2012; Shahbaz *et al.*, 2016) to apply the quadratic match sum interpolation method to convert the annual dataset into quarterly frequency.

[2] The study spans from 1990Q1 to 2014Q4 given the availability of CO2 till 2014 available at (https://databank.worldbank.org/). Also, our study data source and span was informed by the post Romanian revolution that is after 1989.

$$RGDP_t = \alpha + \beta_1 ENINT_t + \beta_2 CO_{2t} + \beta_3 \mathrm{RECONS}_t + \varepsilon_t \quad (2)$$

Here, ∝ represents the model intercept, β1, β2, and β3 are the elasticity coefficients for energy intensity (ENINT), CO2 emissions (CO2), and renewable energy consumption (RECONS) respectively.

4.2.3 Unit Root Tests

In time series econometrics, the need to investigate stationarity properties of the variables is crucial. This is in order to avoid the spurious regression trap and by extension misleading policy implications. To achieve this, two unit root tests were conducted namely Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). (Dickey and Fuller, 1998; Phillips and Perron, 1988).

The general form of the unit root equation is given as

$$\Delta Y_t = \beta_1 + \beta_2 t + \partial Y_{t-1} + \sum_{i=1}^{m} \theta_i \Delta Y_{t-i} + \in_t \quad (3)$$

where∈t performs for Gaussian white noise (considered with a mean value of zero, and possible autocorrelation performs series to be regressed on time t). The null hypothesis of a unit root is conducted for a critical value against the alternative of stationarity for both ADF and PP.

4.2.4 Cointegration Test

To examine the long-run equilibrium relationship between real GDP, energy intensity, CO2 emissions, and renewable energy consumption, a bounds testing approach to cointegration is used as developed by Pesaran *et al*., (1999) which wasfurther extended by Pesaran *et al*., (2001). Due to the outcome of the unit root test results with mixed order of integration, the bound testing autoregressive distributive lag (ARDL) approach is used as the most efficient approach, and it gives robust estimates. ARDL is also applicable for small samples compared to large sample techniques. Both long-run and short-run error correction are generated by bound tests, simultaneously. For the mixed order of integration (that is when variables are integrated whether I (0) or I (1)) a bound test makes the estimation of a cointegration relationship is most suitable.

ARDL has two steps. The first is to estimate the long-run equilibrium relationship between the selected variables through the bound test proposed by Pesaran *et al.* (2001). The second is to account for causal directions between variables.

$$\Delta Y = \mu_0 + \mu_1 t + \theta_1 y_{t-1} + \sum_{i=1}^{N} \partial_1 \upsilon_{it-1} + \sum_{j=1}^{p} \phi_j \Delta Y_{t-j} + \sum_{i=1}^{N} \sum_{j=1}^{P} \gamma_{ij} \Delta \upsilon_{it-j} + \varphi D_t + \varepsilon_t \tag{4}$$

where υ_t accounts for vector and D_t represents structural break as an exogenous variable. The null hypothesis of the bound test set by using F-statistics of no cointegration is contrary to the alternative of cointegration. The hypotheses for the bound test are

Ha: ϕ1 = ϕ2 =…. = ϕk+2 = 0   Null hypothesis

Hb: ϕ1 ≠ ϕ2 ≠…. ≠ ϕk+2 ≠ 0   Alternative hypothesis

Correspondingly, rejection of Ha implies existence of a long-run equilibrium relationship between variables.

4.2.5 Causality Tests

The traditional regression does not show causation; thus, a causality test is needed given the policy implication that can be gleaned from such estimations. In this study, the Toda and Yamamoto (1995) causality approach was used. The Toda and Yamamoto (TY) (1995) test is the upgraded version of the Wald test, with superior merits over conventional Granger causality. The TY approach gives efficient and consistent estimates even in the presence of a mixed order of integration. The TY model is conducted in vector autoregressive framework VAR (K+dmax), where K indicates optimal order of the VAR and dmax is the maximum integration order.

VAR framework Var(K+dmax) can be expressed as

$$RGDP_t = \varphi_{2j} + \omega_{2j}\Sigma_{t-1} + \sum_k \psi_{22tk} RGDP_{t-k} + \sum_k \psi_{21tk} CO2_{t-k} + \sum_k \psi_{23tk} ENINT_{t-k} + \sum_k \psi_{23tk} RECONS_{t-k} + \mu_{1t} \quad (5)$$

$$ENINT_t = \varphi_{2j} + \omega_{2j}\Sigma_{t-1} + \sum_k \psi_{22tk} ENINT_{t-k} + \sum_k \psi_{21tk} CO2_{t-k} + \sum_k \psi_{23tk} RGDP_{t-k} + \sum_k \psi_{23tk} RECONS_{t-k} + \mu_{1t} \quad (6)$$

$$C02_t = \varphi_{2j} + \omega_{2j}\Sigma_{t-1} + \sum_k \psi_{22tk} C02_{t-k} + \sum_k \psi_{21tk} RGDP_{t-k} + \sum_k \psi_{23tk} ENINT_{t-k} + \sum_k \psi_{23tk} RECONS_{t-k} + \mu_{1t} \quad (7)$$

$$RECONS_t = \varphi_{2j} + \omega_{2j}\Sigma_{t-1} + \sum_k \psi_{22tk} RECONS_{t-k} + \sum_k \psi_{21tk} CO2_{t-k} + \sum_k \psi_{23tk} RGDP_{t-k} + \sum_k \psi_{23tk} ENINT_{t-k} + \mu_{1t} \quad (8)$$

4.3 Results and Discussions

This section deals with the empirical results and discussions. The investigated variables are reported in their logarithm forms in order to achieve homoscedasticity. For the visual inspections of the variables see Figure A1 in the Appendix section. Graphical analysis shows trends, which reflects significant economic and political episodes in Romania. Subsequently, Table A2 and Table A3 report the descriptive statistics and the Pearson correlation coefficient estimates for the variables respectively. In Table A2, all variables are negatively skewed with exception of real GDP, which exhibits positive trend. Table A3 provides the correlation estimate with positive and significant relationship seen between renewable energy and economic growth. However, negative significant relationship was observed between CO2, energy intensity and energy consumption for this study.

The stationarity properties of our study are achieved by ADF and PP tests reported in Table 9 which indicate that the null hypothesis of unit root existence cannot be rejected at 5% significance at level. This implies that the variables are nonstationary at this level except renewable energy and CO2. However, when the first variable differences are evaluated, the null hypothesis is rejected in both tests at the 1% significance level. Therefore, the series is of mixed order of integration. Unit root test results are reported in Tables 9 and 10.

Table 10 outlines the stationarity tests of the variables under review. The tests account for structural break dates. The simulation reveals also mixed order of integration in harmony with ADF and PP unit root tests. The break dates reflect the new government's austerity reforms in terms of privatization, monetary and fiscal policies and reduction in governmental role in economy. This austerity plans aimed to open the Romanian's economy to the foreign investments. Also seen is the well-known global financial crisis period of 2008-2009.

Table 9: Unit root results

	Level				First Difference			
Variables	ADF		PP		ADF		PP	
	τ_μ	τ_T	τ_μ	τ_T	τ_μ	τ_T	τ_μ	τ_T
LNRGDP	-0.96	-2.59	0.05	-3.86	-3.36**	-3.11**	-3.63**	-3.58**
LNCO2	-0.44	-5.24**	0.28	-2.94	-4.31**	-4.29***	-4.49***	-4.47***
LNEINT	-0.07	-4.41***	-0.25	-2.75	-5.34***	-5.31***	-4.79***	-4.76***
LNRECONS	-2.00	-2.38	-4.59***	-3.84**	-5.21***	-5.26*	-5.20***	-5.25***

Note: τ_μ *represents model with intercept while* τ_T *denotes model with intercept and trend. ***,** Significant at 1% and 5% level, respectively.*

Table 10: Break-point unit root tests

Level						
Variable	ADF	P-value	Lag	Break date	Critical value (1%)	(5%)
LNRGDP	-2.6776	0.8389	5	2003Q1	-4.9491	-4.4436
LNEINT	-1.5951	>0.99	9	1997Q4	-4.9491	-4.4436
LNRECONS	-3.5666	0.3493	5	1995Q1	-4.9491	-4.4436
LNCO2	-1.9789	0.9834	8	2005Q3	-4.9491	-4.4436
First Difference	ADF	P-value	Lag	Break date	Critical value (1%)	(5%)
LNRGDP	-4.7126	0.0236	0	2009Q1	-4.9491	-4.4436
LNEINT	-6.0073	<0.01	3	1999Q1	-4.9491	-4.4436
LNRECONS	-5.8488	<0.01	0	1997Q3	-4.9491	-4.4436
LNCO2	-6.5300	<0.01	7	2010Q4	-4.9491	-4.4436

Augmented Dickey-Fully (ADF) test statistics are reported in the table above. F-test is automatically chosen to select lag length. The trend and intercept specification is selected for the simulation. Specification for break date applies only to intercept model. However, break type selects an innovation outlier. The simulation follows Vogelsang's (1997) asymptotic, one-sided P-value for the critical values

Furthermore, our study proceeds to investigate long run equilibrium relationship (cointegration) as reported in Table 11. Table 11 reports the bound test results for cointegration with the variables under review. This study uses Akaike information criteria (AIC) with a lag length of one for the ARDL model. Models were subjected to both the cumulative sum of recursive residuals CUSUM and CUSUM squared stability test.[3] The F-statistics critical value for both models is greater than the critical value of the significance level for 1%. Thus, based on the empirical results, there exists long run equilibrium relationship between the selected variables.

Table 11: Bound F-statistics test for non-existence of cointegration.

	Bound Test Estimation	S.L	I(0)	I(1)
	Without deterministic trend	10%	2.72	3.77
		5%	3.23	4.35
K	3	2.5%	3.69	4.89
F	5.6292	1%	4.29	5.61
	With deterministic trend			
K	3	10%	3.47	4.45
F	7.2953	5%	4.01	5.07
		2.5%	4.52	5.62
		1%	5.17	6.36

Note: The F-statistics fall within the acceptance region of the null hypothesis for the lower and the upper bounds' critical values.

Table 12: ARDL estimate of the level RGDP equation

ARDL estimate of the level RGDP equation (short-run)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNRGDP(-1))	0.5639***	0.0647	8.7062	0.0000
D(LNRECONS)	-0.0046	0.0039	1.1534	0.2517
D(LNEINT)	-0.1780***	0.0404	-4.4092	0.0000
D(LNCO2)	0.1216***	0.0313	3.8810	0.0002
COINTEQ(-1)	-0.0576***	0.0176	-3.2743	0.0015

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[3] CUSUM and CUSUMSQ tests are available in section 4.1

ARDL estimate of the level RGDP equation (long-run)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNRECONS	0.0797^{**}	0.0812	0.9810	0.0329
LNEINT	-3.0899^{***}	0.8408	-3.6749	0.0004
LNCO2	2.1116^{***}	0.7391	2.8569	0.0053
C	31.5644^{***}	1.5755	20.0342	0.0000

Note: Variables are significant *** *at 0.01 and* ** *0.05 levels, respectively*

The ARDL regression equation for both the long run and short-run is provided in Tables 12, with optimum lag length as suggested by AIC. The cointegration equation for the current study reveals over 5% convergence speed to equilibrium path by the contribution of renewable energy, energy intensity and carbon emission on a quarterly basis. Interestingly, we observed positive significant relationship between economic growth and CO2. This implies that economic growth enhance higher carbon emission in Romania. This is indicative for energy practitioners and stakeholders. Our empirical results also show negative insignificant relationship between economic growth and renewable energy consumption in the short run while positive significant relationship in the long run. This is laudable for the study area been a signatory to Kyoto Protocol and EU energy regulations. Thus, our study affirms the success story of Romania attending the vision 2020 renewable energy target. However, energy practitioners and stakeholders are employed to sustain the momentum and intensify concerted effort to diversify the energy portfolio in the country. This is in consonant with the argument put forth by (Shahbaz *et al.*, 2013; Aceleanu *et al.* 2017). Energy intensity exhibits negative significant relationship in the short run which is expected while positive significant relationship in the long run given that as economy grows there is bound to be more energy consumption as revealed in our study. Energy intensity is statistically significant both in the long run and short-run at one-percent significance level. This implies that there is a trade-off between energy intensity and economic growth[4].

Table 13: DOLS estimate of the level RGDP equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNRECONS	0.0379^{**}	0.0360	-1.0518	0.0295
LNEINT	-1.7183^{***}	0.3924	-4.3788	0.0000
LNCO2	0.8164^{**}	0.3398	2.4025	0.0185
C	29.0022^{***}	0.7688	37.7224	0.0000

Note: Variables are significant *** *at 0.01 and* ** *0.05 levels, respectively.*

Table 13 presents the dynamic ordinary least squares (DOLS) coefficients estimate that affirms the ARDL cointegration regression results. The DOLS coefficient estimate for CO2 aligns with the ARDL sign as well as the significance level. This affirms the trade-off that exists between economic output and environmental degradation. Interestingly, this study shows that renewable energy impact positively on economic growth. Thus, confirming the compliance of Romania with the Kyoto Protocol. Energy intensity shows a negative and significant relationship, which is expected for emissions with high-energy demand and use in EU countries.

Table 14: Granger block exogeneity results

Dependent variable: LNRGDP

Excluded	Chi-sq	df	Prob.
LNRECONS	4.5908	1	0.0321^{**}
LNEINT	2.7533	1	0.0971^{*}
LNCO2	2.1977	1	0.1382
All	6.8244	3	0.0777

Dependent variable: LNRECONS

Excluded	Chi-sq	df	Prob.
LNRGDP	2.1724	1	0.1405
LNEINT	0.1011	1	0.7506
LNCO2	0.0135	1	0.9073
All	2.9382	3	0.4013

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[4] Energy intensity is computed by energy consumption to GDP ratio which implies the energy consumed per unit of production.

Dependent variable: LNEINT Excluded	Chi-sq	df	Prob.
LNRGDP	3.0280	1	0.0818*
LNRECONS	0.1152	1	0.7343
LNCO2	0.1227	1	0.7261
All	3.2640	3	0.3527
Dependent variable: LNCO2 Excluded	Chi-sq	df	Prob.
LNRGDP	1.2726	1	0.2593
LNRECONS	0.0548	1	0.8149
LNEINT	0.4365	1	0.5088
All	1.8339	3	0.6076

Note: Significant at * *0.10,* ** *0.05, and* *** *0.01 levels, respectively.*

The study proceeded with the TY Granger causality test reported in Table 14. The results reveal bidirectional (feedback) causality between energy intensity and economic growth and unidirectional causality running from renewable energy consumption to economic growth (RGDP). This implies that an increase in energy consumption spur economic growth, validating the energy-induced growth hypothesis for Romania. However, there is a trade-off for environmental quality. These findings resonate with other similar studies (see Kleemann and Abdulai 2013; Shahbaz *et al.* 2015; Shafiei and Salim 2014).

Table 15: Residual Diagnostic Test

Ramsey RESET Test			
F-stat	2.5334	F(1,95)	Prob. (0.1148)
Breusch-Godfrey Serial Correlation LM Test			
F-stat	3.5269	F(2, 94)	Prob. (0.2532)
Breusch-Pagan-Godfrey Heteroskedasticity Test: White			
F-stat	6.0557	F(3, 96)	Prob. (0.3642)

Source: Authors computation

Table 15 reports the diagnostic tests of the model selected for this study that proves the specified model is free from model misspecification, autocorrelation and heteroscedasticity problems. Thus, we infer that our model is suitable for policy directions and implications in Romania.

4.3.1 Model Stability Test

CUSUM and CUSUMSQ tests advanced by Brown, Dublin and Evans (1975) were used to examine the stability of chosen model. The tests, which were applied to the residuals, indicate stability in the coefficients over the investigated period. Okunola (2016) asserts that if the plot of the blue line goes outside the area of 5% critical lines (red lines), the coefficients are not stable. However, the current study model selection indicates stable and robust model. The graphs plots are provided as;

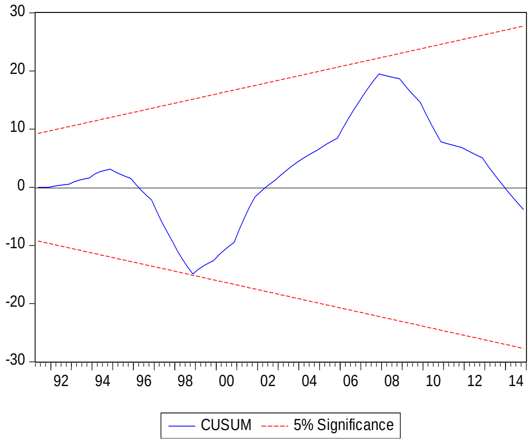

Figure 5: CUSUM

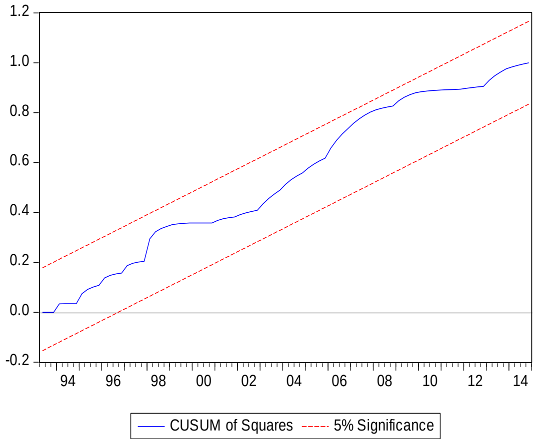

Figure 6: CUSUMSQ

4.4 Conclusion

This study examines the dynamic relationship between economic growth, environmental degradation proxy by carbon emissions, energy intensity and renewable energy consumption for Romania between 1990Q1 and 2014Q4. Economic growth was measured by real GDP. This study employed the use of the

ARDL bound test for cointegration between the selected variables and DOLS for long-run regression, while for causality analysis we adopted the modified version of Wald test Toda- Yamamoto causality test.

Empirical findings provide support for a long-run equilibrium relationship between economic growth, energy intensity, CO2, and renewable energy consumption as given by the ARDL bounds test. This implies that there is convergence among these variables, affirming the energy-induced growth hypothesis for Romania. This study shows bi-directional causality running between energy intensity and economic growth. Also, uni-directional causality is seen running from renewable energy consumption to economic growth. This finding is in line with the studies of (Shahbaz *et al.*, 2013; Aceleanu *et al.*, 2017), were both studies affirms the positive impact of renewable energy consumption to economic growth as corroborated by our study. These findings resonate with the success story of Romania attending her energy targets within two decades. This is laudable and as such, more concerted efforts need to be employed by government and environmental specialists to sustain this milestone. However, more concerted efforts are required to curb environmental pollution. Thus, our study brings attention of all energy stakeholders to further diversify Romania energy portfolio into alternative energy sources like wind energy, solar energy (photovoltaic energy) and biomass energy sources in order to achieve clean environmental energy goals and as well as adopt environmental friendly technologies to boost economic growth given the rise in demand for cleaner energy as the consciousness of citizenry and all stakeholders are awakened. This is necessary given Romanian is a signatory to the Kyoto Protocol and her current success story of Romanian in the achievement of her renewable energy goals and general clean energy targets. Further researchers can query the literature by conducting same study for other new entrants country to the EU region like Bulgaria, Hungary to see if there exist progress or not ?. Also panel analysis for the bloc of EU countries is also a gap in the energy literature and finally direction for other scholars is in the area of asymmetry by modelling non-linearity in the econometrics framework.

Chapter 5

CONCLUSION

Energy and environment are the vital source for the life sustainability. However, energy use is in turn responsible for environmental degradation and climate change. Therefore, legislators, governmental and non-governmental organizations, environmentalists, energy economists and other policy makers have long debated the quality of environment, energy consumption and economic growth. Particularly, legislators and ecologists argue that working on reducing CO2 pollution for better environment hampers the economic growth of countries. However, their opposites argue that policies to reduce the level of irremediable global damage due to anthropogenic emissions of greenhouse gasses are strictly necessary. Therefore, it is of utmost importance to develop effective policies that focus on environmental, social, and economic differences to mitigate economic asymmetries and anthropogenic GHG, while simultaneously, increasing energy efficiency. Accordingly, environmental scientists, policymakers, and scientific bodies, attempt to design common international policies to mitigate the pace of global climate change and global warming as well as increasing energy efficiency and providing energy security assuming the countries that has unity in the long run. Thus, the causal and long run relationship between energy, environment and economic growth were analyzed to determine whether policies—applied or applicable—might slow down the life and economic sustainability.

To this end, the second chapter demonstrated the evidences of heterogeneity and no unity among investigated countries in terms of energy efficiency by using Phillips and Sul (2009) method. Indeed, after the expansion of the EU, the north-south division within member countries, and depending on the decoupling of energy intensity levels amongst EU countries, convergence became more common and diverse. Thus, convergence of countries around different steady states is due to heterogeneity in their economic structures, environmental awareness and economic advances. Furthermore, the existence of merging was investigated within two or more groups to assess if convergence was achieved as a result of the various countries' transitional energy intensity patterns, revealing that certain groups merged within the three selected periods of time.

On the other hand, third chapter investigates the CO2 intensity convergence among EU-28 member states during the periods 1990-2016, 1990-2004, and 2005-2016. With this, the rejection of the null hypothesis (overall convergence) leads us to identify some clubs that tend to different equilibrium levels within the EU-28, EU-15, and EU new member countries. We identified a relative convergence within the identified clubs as five to seven convergence clubs, depending on the investigated time periods at the country level. However, three to five convergence clubs were identified in terms of categorical level (EU-15, EU-new members).

Additionally, in Chapter 4, the dynamic relationship between economic growth, environmental degradation proxy by carbon emissions, energy intensity and renewable energy consumption were examined for Romania between 1990Q1 and 2014Q4. Empirical findings provide support for a long-run equilibrium relationship between economic growth, energy intensity, CO2, and renewable energy consumption as given by the ARDL bounds test. This implies that there is convergence among these variables, affirming the energy-induced growth hypothesis for Romania. This study also shows bidirectional causality running between energy intensity and economic growth. Similarly, unidirectional causality is seen running from renewable energy consumption to economic growth.

In contrast, depending on heterogeneous characteristics of the EU-member countries, there is a need to adopt new strategies that consider the homogenous clubs' properties and contribute to sustainable economic growth processes, which also sustain the environmental standards. Thus, the club convergence assessment helps us recommend further consideration of environmental degradation and club specific policies to reduce heterogeneity among countries and gather them into one club to develop more effective common policies to reach the target.

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APPENDIX

Table A. 1 Brief Summary of Recent Researches

Part A: Causality analysis

Authors	Countries	Period	Methodology	Results
Chang (2010)	China	1981–2006	VECM	Economic growth causes CO2, oil consumption and coal consumption. Electricity consumption causes economic growth and CO2.
Ozcan (2013)	12 selected Middle East Countries	1990–2008	FMOLS and Panel VECM	Environmental Kuznets curve hypothesis is supported in five countries out of twelve. Unidirectional causality of economic growth on energy consumption and of energy consumption on CO2.
Salahuddin and Gow (2014)	GCC	1980–2012	Panel Granger causality	Bidirectional causality found between energy consumption and CO2. Unidirectional causality of economic growth on energy consumption. Bidirectional non-causality found between economic growth and CO2.
Jammazi and Aloui (2015)	GCC	1980–2013	Wavelet Window Cross Correlation	Bidirectional causality between energy consumption and economic growth. Unidirectional causality of energy consumption on CO2.
Part B: Convergence Analysis				
Apergis and Christou (2016)	Selected 31 countries	1972-2012	Club Convergence	The results documented the absence of full sample convergence. However there is 6 subgroups convergence at different steady state levels.
Payne *et al*. (2017)	Fifty US states	1970-2013	LM and RALS-LM unit root tests	All US states and the District of Columbia exhibit long run equilibrium in relative per capita fossil fuel consumption, except Nevada.
Mohammadi and Ram(2017)	US states	1970-2013	Selected parametric and non-parametric methods	The overall result shows that there is a lack of stochastic convergence across US states in relative energy consumption per capita
Kounetas(2018)	23 European Countries	1970-2010	Quah's methodology	Hypothesis of convergence patterns in terms of energy use, CO2 emissions and their intensity levels are not valid.
Berk *et al.* (2018)	14 EU members	1990-2014	The System Generalized Method of Moments (GMM)	All selected countries show strong evidence of convergence in relative renewables' share in primary energy consumption. CO2 emission, Foreign Direct Investment and electricity prices contribute to the speed of convergence among 14 EU members.

Solarin *et al*. (2018)	27 OECD countries	1965-2014	A Fractional Integration Approach	Parametric method documented that Mexico, Switzerland and Sweden along with the USA, Spain, Czech republic, Portugal and South Korea have cointegration relationship in relative renewable energy consumption. The nonparametric method gives the result as these 8 countries along with Australia, Japan, Greece, Poland, Italy and France will converge. However, remaining 13 countries cannot support the hypothesis of long run equilibrium.
Bhattacharya *et al*. (2018)	Contiguous states and territories in India	1988-2016	Club Convergence	Convergence clubs for energy productivity exist in India’s contiguous states and territories.

BRICS: Brazil, Russia, India, China and South Africa **US:** United States, **OECD:** The Organization for Economic Co-operation and Development **GCC:** Gulf Cooperation Council member states **FMOLS:** Fully Modified Ordinary Least Square

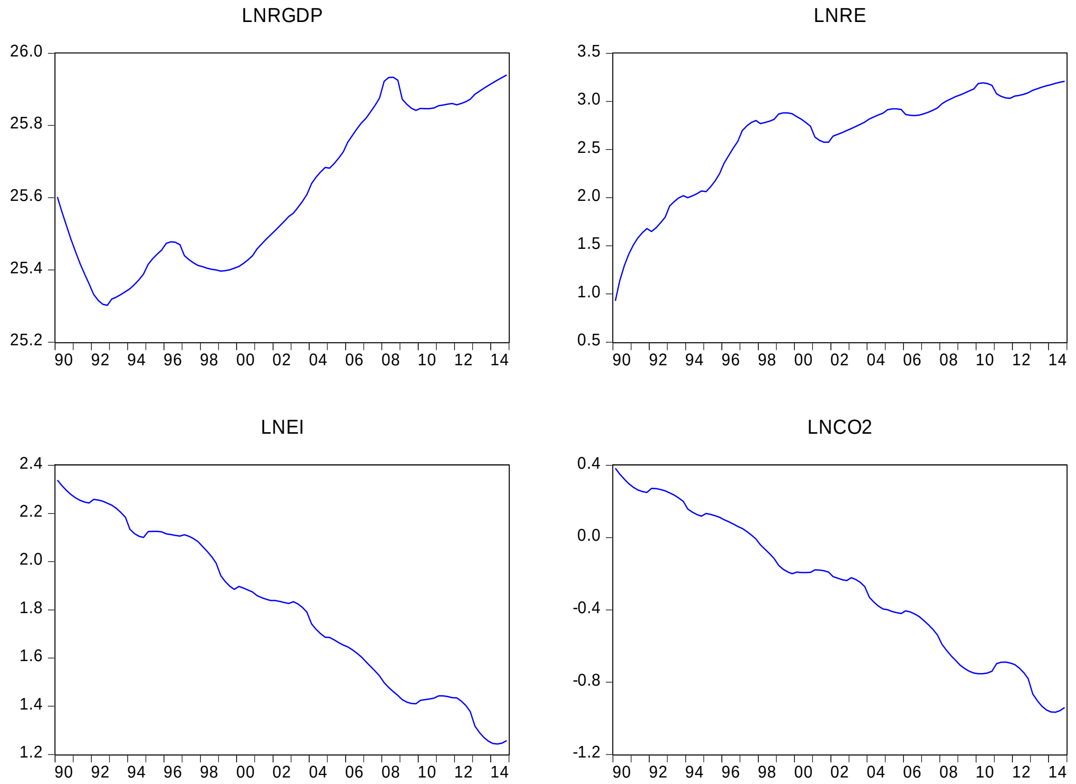

Figure A. 1. Visual Plot of Series Under Concentration (Romania)

Source: Authors' computation on Worldbank World Development Indicators (WDI) data

Table A.2. Summary Statistics (Romania)

	RGDP	CO2	ENINT	RECONS
Mean	25.6113	-0.2707	1.8021	2.6258
Median	25.5528	-0.2237	1.8341	2.8144
Maximum	25.9395	0.3833	2.3382	3.2087
Minimum	25.3020	-0.9665	1.2427	0.9289
Std. Dev.	0.2140	0.3892	0.3284	0.5346
Skewness	0.2052	-0.1275	-0.0858	-1.2251
Kurtosis	1.4422	1.8481	1.7028	3.6201
Jarque-Bera	10.8128	5.7992	7.1343	26.6167
Probability	0.0045	0.0550	0.0282	0.0000
Sum	2561.134	-27.0068	180.2098	262.5812
Sum Sq. Dev.	4.5339	14.9962	10.6775	28.2993
Observations	100	100	100	100

Note: Variables are in their level forms.

Table A.3. Pearson correlation estimates (Romania)

	LNRGDP	LNCO2	LNEINT	LNRECONS
LNRGDP	1.0000			

LNCO2	-0.9099	1.0000		
t-Statistic	(-21.7232)	-----		
p-value	0.0000	-----		
LNEINT	-0.9250	0.9963	1.0000	
t-Statistic	(-24.1024)	(115.2916)	----	
p-value	0.0000	0.0000	-----	
LNRECONS	0.6762	-0.8754	-0.8583	1.0000
t-Statistic	9.0859	-17.9259	-16.5608	----
p-value	0.0000	0.0000	0.0000	-----

Note: Table reports the estimates of the Pearson correlation coefficient between the pairs of variables. t-stat is the t-statistics for the significance of the correlation coefficient, and p-value is its marginal probability.