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**Multivariate Granger Causality between CO<sub>2</sub> Emissions, Energy Intensity and Economic Growth in Portugal: Evidence from Cointegration and Causality Analysis**

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# MULTIVARIATE GRANGER CAUSALITY BETWEEN CO<sub>2</sub> EMISSIONS, ENERGY INTENSITY AND ECONOMIC GROWTH IN PORTUGAL: EVIDENCE FROM COINTEGRATION AND CAUSALITY ANALYSIS

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**Abstract.** The present study aims to investigate the relationship between economic growth, energy intensity and CO<sub>2</sub> emissions by incorporating financial development in CO<sub>2</sub> emissions function using Portuguese annual data over the period of 1971–2011. The unit root problem of variables is examined by applying Zivot-Andrews unit root test and the ARDL bounds testing approach is for long run relationship. The direction of causal relationship between the series is examined by the VECM Granger causality approach and robustness of causality analysis is tested by innovative accounting approach (IAA).

Our empirical evidence confirmed that the variables are cointegrated for long run relationship. The results exposed that economic growth and energy intensity increase CO<sub>2</sub> emissions, while financial development condenses it. The VECM Granger causality analysis showed the feedback effect between energy intensity and CO<sub>2</sub> emissions, while economic growth and financial development Granger causes CO<sub>2</sub> emissions. The study suggests that environment degradation can be controlled by using energy efficient technologies. Financial development can also play its role in improving the environmental quality by encouraging investment in energy efficient technology to enhance domestic production and save the environment from degradation.

**Keywords:** growth, energy, financial development, CO<sub>2</sub> emissions.

**JEL Classification:** O1, Q4, F65, Q5.

## Introduction

The analysis of the Portuguese energy system would enable us to suggest an appropriate energy and environmental policy to sustain economic growth as well as to improve the environmental

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quality for better living standards in the country. In these days, the Portugal's economy is under debate on the basis of two hot issues; its economy's growth for the last two decades and reduction in emissions of greenhouse gases following political agenda of Kyoto Protocol. So, adoption of energy and environmental policy in the Portuguese economy may affect the policy targets imposed by European Union. This entails that there is a tradeoff between efficient use of energy including environmental quality and sustained economic growth in long run. Since 1986, more concern has been paid on energy security, environmental protection and economic growth, after the inclusion of Portugal as a member in European Union. The surface area of the Portuguese economy is 92,000 square kilometers with a population of around 10.7 million. After access to European Union, Portugal has been diversifying itself by developing service-based economy, for instance; telecommunications, finance, transportation, and energy sectors. These services have enhanced international competitiveness which stimulates economic growth. Portugal was recognized as a rapid growing economy among the member countries of European Union after 1990s, although energy market in the country is relatively small and has a limited access to the domestic energy resources.

Due to limited availability of energy resources, per capita energy consumption is low in the Portugal as compared to other EU member countries, although energy consumption is growing higher than the growth of GDP per capita. But rising trend of primary and final energy intensities results in absolute energy intensity. Absolute energy intensity is upsetting the environmental situation, which seems to be unfavorable for Portugal compared to other EU member countries. The pattern of energy is based on oil products, although Portugal has not much of her own fossil

energy resources but due to sustained economic growth, domestic energy resources such as, hydroelectric and biomasses are utilized to meet the rising demand of the country.

Following the terms of the EU allocation agreement, it is required to analyze whether Portugal can fulfill the targets set by the European Union by preventing the hike in greenhouse gases emissions up to 40 percent, for the period of 2008–2012 or not. The principal cause of rise in CO<sub>2</sub> emissions is the rapid use of fossil fuel. Portugal contributed 74.6 percent to total greenhouse gases emissions in 2000. Due to fossil fuel consumption in 1990–2000, only 43.6 percent of CO<sub>2</sub> emissions were increased. This shows that target to reduce CO<sub>2</sub> emissions up to 40 per cent in 2008–2012 would not be fulfilled. During 1990s, fossil fuel consumption raised CO<sub>2</sub> emissions to 90–91 percent and carbon emissions were increased to 44.5 percent. This implies that it is difficult for the Portuguese economy to reduce present CO<sub>2</sub> emissions up to 40 percent. That is why; rising trend of carbon emissions is the most important issue in the current political debate. The most important challenge for energy policy making authorities is to introduce new measures that can help in reducing energy emissions.

In case of Portugal, Narayan and Prasad (2008) and Chontanawat *et al.* (2008) reported the unidirectional causality running from energy consumption to economic growth. Shahbaz *et al.* (2011) exposed that energy consumption and economic growth are interdependent and same is confirmed by Fuinhas and Marques (2012) and later on Behemiria and Mansob (2012). Acaravci and Ozturk (2010) investigated the relationship between energy consumption, economic growth and CO<sub>2</sub> emissions for the EU including Portugal. They found that economic growth and CO<sub>2</sub> emissions Granger cause energy consumption. The unidirectional causality exists running from

energy consumption and economic growth to CO<sub>2</sub> emissions. We find that results of above studies are vague and could not be helpful for policy makers in designing comprehensive economic, energy and environmental policy to sustain long run economic growth for the Portuguese economy. Moreover, the above studies ignored the role of structural break stemming in series also affect energy consumption and economic growth as well as CO<sub>2</sub> emissions in an economy. We find the importance of financial development because it is also a determinant of economic growth and CO<sub>2</sub> emissions as well as energy consumption (Islam *et al.* 2013). We use energy intensity (capturing technological advancement) rather than energy consumption. Further, we augment the CO<sub>2</sub> emissions function by incorporating financial development and this is the main motivation for us to investigate the relationship between, energy intensity, economic growth, financial development and CO<sub>2</sub> emissions in case of Portugal.

This study contributes in existing literature by five ways applying: (i) Zivot and Andrews (1992) structural break unit root test; (ii), the ARDL bounds testing approach to cointegration for long run relationship between the variables; (iii), OLS and ECM for long run and short run impacts (iv) the VECM Granger causality approach for causal relationship and (v) Innovative Accounting Approach (IAA) to test the robustness of causality analysis. Our empirical findings show that cointegration is found for long run relationship among the variables such as; economic growth, energy intensity, financial development and CO<sub>2</sub> emissions in case of Portugal. A rise in economic growth and energy intensity (financial development) increases (condenses) CO<sub>2</sub> emissions. The causality analysis reveals that bidirectional causal relationship is found between CO<sub>2</sub> emissions and energy intensity while economic growth and financial development Granger

cause CO<sub>2</sub> emissions. These results may provide new avenues for policy makers to design a comprehensive energy, economic, financial and environmental plan to sustain economic growth as well as, to help Portuguese economy in attaining Kyoto Protocol targets.

## **1. Literature review**

First strand of energy literature deals with wide range of mixed result studies about energy consumption and economic growth nexus. Now a days, energy-growth relation has been empirically investigated extensively since the pioneering study conducted by Kraft and Kraft (1978). The empirical findings of the existing energy literature are unambiguous due to the use of various econometrical approaches such as; correlation analysis, simple regressions, bivariate causality, unit root testing, multivariate cointegration, panel cointegration, vector error correction modeling (VECM) and innovative accounting approach to detect the direction of causality between economic growth and energy consumption (Chontanawat *et al.* 2008). These inconclusive empirical evidences could not help economic policy architects in articulating a comprehensive energy plan to sustain long run economic growth (Payne 2010; Ozturk 2010). The appropriate knowledge about direction of causality between energy consumption and economic growth is very important regarding theoretical and policy point of view (Ghali, El-Sakka 2004).

In recent studies Payne (2010) and Ozturk (2010) reviewed the existing literature between energy consumption and economic growth nexus and provided four empirical competing hypotheses for said issue: (i) growth hypothesis i.e. energy consumption Granger causes economic growth implies that energy reduction policies should be discouraged and new sources

of energy must be explored, (ii) if causality is found running from economic growth to energy consumption, then energy reduction policies would not have adverse effect on economic growth because economic growth of the country does not seem to be dependent on energy, (iii) feedback hypothesis implies the interdependence of energy consumption and economic growth. A rise in economic growth leads to increase in energy demand, which in return stimulates economic growth. In such a situation, energy conservation policies are detrimental for economic growth and (iv) no causality between energy consumption and economic growth infers neutrality hypothesis indicating that energy and growth are not interdependent. The adoption of conservation and exploration of energy policies will not have favorable effect on economic growth.

In case of Portugal, few studies investigated the relationship between energy consumption and economic growth. For instance; Narayan and Prasad (2008) investigated the direction of causality between both variables by applying bootstrapping causality approach<sup>1</sup>. Chontanawat *et al.* (2008) examined the causal relationship between energy consumption and economic growth by applying bivariate system using cross section data of 100 developed and developing countries including the Portugal. Their empirical exercise indicated that energy consumption Granger causes economic growth in case of Portugal. On same line, Shahbaz *et al.* (2011) re-examined the relationship between energy consumption, economic growth and employment and reported the feedback hypothesis between energy consumption and economic growth. This

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<sup>1</sup> Narayan and Prasad (2008) and Shahbaz *et al.* (2011) used electricity consumption as an indicator of energy consumption to examine the energy-growth nexus.

implies that new sources of energy should be explored to spur economic growth in Portuguese economy. Fuinhas and Marques (2012) examined relationship between energy use and economic growth in Portugal, Italy, Greece, Spain, and Turkey applying ARDL bounds testing and VECM Granger causality approach for long run and causal relationship between the variables. Their empirical findings confirmed that variables are cointegrated for long run relationship while feedback hypothesis is validated between energy consumption and economic growth. Later on; Behemiria and Mansob (2012) applied VECM and, Toda and Yamamoto (1995) Granger causality approaches to test the relationship between crude oil consumption and economic growth. They reported the bidirectional causality between both variables, which implies that energy conservation policies should be discouraged.

Second strand of existing literature on this topic provides empirical evidence on the relationship between economic growth and CO<sub>2</sub> emissions i.e. so called environmental Kuznets curve (EKC). The EKC hypothesis postulates that relationship between economic growth and CO<sub>2</sub> emissions is non-linear and inverted-U shaped. This implies that economic growth is linked with an increase in CO<sub>2</sub> emissions initially and declines it, once economy matures<sup>2</sup>. Existing studies including Hettige *et al.* (1992); Cropper and Griffiths (1994); Selden and Song (1995); Grossman and

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<sup>2</sup> At initial level of economic growth, a rise in income is linked with an increase in energy consumption that raises CO<sub>2</sub> emissions and hence environmental degradation. It implies that there is positive relationship between economic growth and CO<sub>2</sub> emissions at low level of income. After achieving certain of level of income, awareness about clean environment increases. This leads the government and people to increase their spending on environment protection and regulation. In such situation, environmental degradation and CO<sub>2</sub> emissions tend to decrease. This shows that how EKC is an inverted U-shaped i.e. an increase in income shifts the positive link between economic growth and CO<sub>2</sub> emissions to zero and then goes to negative relation between the both variables (Wang 2013).



Kueger (1995) & Martinez-Zarzoso and Bengochea-Morancho (2004) among others investigated the relationship between income and emissions and validated the existence of EKC. On contrary; Dinda and, Coonndoo (2006) used panel data and provided ambiguous results about economic growth and CO<sub>2</sub> emissions relationship. Recently, various studies validated the environmental Kuznets curve (EKC) using cross-sectional data. For instance; Lean and Smyth (2010) for ASEAN; Apergis and Payne (2009, 2010) for Central America and commonwealth of independent states; Pao and Tsai (2011a) for BRIC countries; Acaravci and Ozturk (2010) for Denmark and Italy; Pao and Tsai (2011b) for Russia; Iwata *et al.* (2011) for 28 countries & Wang (2013) for 138 developing and developed countries etc. But using time series data; Machado (2000); Mongelli *et al.* (2006); Ang (2007, 2008); Song *et al.* (2008); Jalil and Mahmud (2009); Shiyi (2009); Dhakal (2009); Halicioglu (2009); Ozturk and Acaravci (2010)<sup>3</sup>; Alam *et al.* (2011); Tiwari *et al.* (2013); Fodha and Zaghdoud (2010); Nasir and Rehman (2011); Shahbaz *et al.* (2012) and Shahbaz *et al.* (2013) also supported the empirical presence of environmental Kuznets curve (EKC) for Brazil, Italy, France, Malaysia, China, Turkey, India, Tunisia, Pakistan and Romania.

Third strand deals with country case studies, for example in case of United States, Soytas *et al.* (2007) investigated the dynamic relationship between CO<sub>2</sub> emissions, income and energy consumption. Their results showed that CO<sub>2</sub> emissions Granger cause income and energy consumption contributes to CO<sub>2</sub> emissions. A similar exercise was conducted by Ang (2007, 2008) for France and Malaysia. The results indicated that economic growth Granger causes

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<sup>3</sup> Akbostanci *et al.* (2009) did not support their findings.

energy consumption and carbon emissions in France and in Malaysia, the unidirectional causality is found running from economic growth to energy consumption. Chebbi (2010) collected the Tunisian data to investigate the causal relationship between energy consumption, income and CO<sub>2</sub> emissions. The empirical evidence indicated that energy consumption stimulates economic growth which Granger causes CO<sub>2</sub> emissions. In case of India; Gosh (2009) investigated the causal relationship between income and CO<sub>2</sub> emissions by incorporating investment and employment as additional determinants of CO<sub>2</sub> emissions but reported no causality between income and CO<sub>2</sub> emissions. Chang (2010) applied multivariate causality test to examine the causal relation between economic growth, energy consumption and CO<sub>2</sub> emissions using Chinese time series data. The findings of the study revealed that economic growth Granger causes energy consumption that leads to CO<sub>2</sub> emissions. Using Turkish data, Halicioglu (2009) also reported feedback hypothesis between economic growth and CO<sub>2</sub> emissions. In case of South Africa; Menyah and Wolde-Rufael (2010) concluded that energy consumption Granger causes CO<sub>2</sub> emissions and in resulting economic growth is being Granger caused by CO<sub>2</sub> emissions. On contrary, Odhiambo (2011) reinvestigated the causality between energy consumption, economic growth and CO<sub>2</sub> emissions and unidirectional causality is found running from economic growth to CO<sub>2</sub> emissions. Similarly, Alam *et al.* (2011) examined the link between energy consumption, economic growth and energy pollutants in case of India. Their empirical evidence revealed the bidirectional causal relationship between energy consumption and CO<sub>2</sub> emissions while neutral hypothesis exists between CO<sub>2</sub> emissions and economic growth. In case of Bangladesh, Alam *et al.* (2012) detected the causal relationship between these variables and opined that variables are cointegrated for long run. These long run results are robust, confirmed by ARDL bounds testing. Their VECM causality analysis reported the presence of the feedback hypothesis

between energy consumption and CO<sub>2</sub> emissions, while the unidirectional causality is found running from CO<sub>2</sub> emissions to economic growth. In case of Greece, Hatzigeorgiou *et al.* (2011) applied the VECM Granger causality test to investigate the causality between energy intensity, income and CO<sub>2</sub> emissions by applying Johansen multivariate cointegration approach. Their results concluded the existence of long run relationship between the series. The VECM Granger causality analysis reported that unidirectional causality is found running from economic growth to energy intensity and CO<sub>2</sub> emissions, while the feedback hypothesis exists between energy intensity and CO<sub>2</sub> emissions.

In fourth strand of economic literature, Tamazian *et al.* (2009) paid their attention to test the affect of other potential determinants of CO<sub>2</sub> emissions such as economic, institutional, financial variables. In their pioneering effort, Tamazian *et al.* (2009) investigated the impact of economic development as well as financial development on CO<sub>2</sub> emissions in case of Brazil, Russia, India, China, Untied States and Japan and later on Tamazian and Rao (2010) examined the role of institutions on CO<sub>2</sub> emissions. Their empirical evidence reported that economic development, trade openness, financial development and institutions play their role to control environment from degradation while supporting the presence of EKC hypothesis. Additionally, Claessens and Feijen (2007) explored the role of governance in reducing CO<sub>2</sub> emissions and reported that with the help of more advanced governance; enterprises can lower growth of CO<sub>2</sub> emissions. So, financial development may stimulate the performance of firms due to the adoption of energy efficient technologies which reduce carbon emissions. In case of China; Yuxiang and Chen (2010) argued that financial sector polices enables the firms to utilize advanced technology which emits less CO<sub>2</sub> emissions and enhances domestic production. They also claimed that

financial development promotes capitalization and financial regulations that favor environmental quality. Later on; Jalil and Feridun (2010) tested the impact of economic growth, energy consumption and financial development on carbon emissions in case of China. They disclosed that energy consumption, economic growth and trade openness are harmful for environmental quality. On contrary, financial development and foreign direct investment save environment from degradation. Recently; Zhang (2011) reinvestigated the finance-environment nexus and concluded that financial development increases CO<sub>2</sub> emissions due to inefficient allocation of financial resources to enterprises. In case of Sub Saharan African countries, Al-mulali and Sab (2012) examined the dynamic relationship between energy consumption, income, financial development, and CO<sub>2</sub> emissions by incorporating investment and employment as potential determinants of domestic production. Their empirical exercise reported that energy consumption spurs economic growth. A rise in economic growth and energy consumption adds to the demand of financial services and hence financial development that increases the improvements in environmental quality by controlling CO<sub>2</sub> emissions through the implementation of well-organized and transparent financial policies.

The existing review of literature failed to provide any study in case of Portugal which discusses the causality between energy intensity, economic growth, financial development, and CO<sub>2</sub> emissions. Hatzigeorgiou *et al.* (2011) empirically investigated the said issue for Greek economy but did not pay their attention to include financial development as a potential determinant of CO<sub>2</sub> emissions. Financial development may affect CO<sub>2</sub> emissions by stimulating economic activity and encouraging the enterprises to use advanced technology for the enhancement of domestic production that saves the environment from degradation. The exact direction of causality

between economic growth and CO<sub>2</sub> emissions has major policy implications to expedite economic growth by controlling carbon emissions in case of Portugal. The causality running from carbon emissions to economic growth implies that we have to sacrifice economic growth to lower energy pollutants. An efficient energy policy must be implemented which may not have detrimental impact on economic growth if economic growth Granger causes carbon emissions. So, CO<sub>2</sub> emissions can be reduced without fall in economic growth. The policy regarding environment may be adopted to improve the environmental quality if there is no causal relationship between income and CO<sub>2</sub> emissions then environmental policy does not have adverse impact on economic growth. But reductions in CO<sub>2</sub> emissions may have negative effect on economic growth if the feedback hypothesis exists between both the variables. The present study is an effort to fill the gap in energy literature regarding the case study of Portugal.

## **2. Modelling framework and data collection**

Existing energy economics literature provides various empirical studies investigating the dynamic relationship between economic growth, energy consumption and CO<sub>2</sub> emissions. For instance, Ang (2007, 2008) for France and Malaysia; Soytas *et al.* (2007) for United States; Zhang and Cheng (2009); Chang (2010) and Wang *et al.* (2011) for China; Halicioglu (2009) and Ozturk and Acaravci (2010) for Turkey; Pao and Tsai (2011a) for Brazil and Alam *et al.* (2011, 2012) for India and Bangladesh examined causal relationship between the series. Some studies included other potential determinants of CO<sub>2</sub> emissions such as capital by Xepapadeas (2005) and latter on by Menyah and Wolde-Rufael (2010); fossil fuels consumption by Lotfalipour *et al.* (2010); coal consumption by Baloch *et al.* (2012); electricity consumption by Lean and Smyth (2010); openness and urbanisation by Hossain (2011); foreign direct investment by Pao and Tsai

(2011a); energy intensity by Roca and AlcaHntara (2001) and latter on by Hatzigeorgiou *et al.* (2011).

Tamazian *et al.* (2009) and Tamazian and Rao (2010) added financial development as potential determinant of CO<sub>2</sub> emissions. Latter on; Yuxiang and Chen (2010); Jalil and Feridun (2010) and Zhang (2011) investigated the empirical relationship between financial development and energy pollutants. Sound and developed financial markets stimulate capitalization by attracting local and foreign investors to accelerate economic growth (Frankel, Romer 1999). Financial development allocates financial resources to firms to utilize environment-friendly technology (Frankel, Rose 2002) which uses energy efficiently (Sadorsky 2010, 2011) and emits less carbon emissions (Tamazian *et al.* 2009; Tamazian, Rao 2010; Leitão 2013). However, financial development harms environment by increasing CO<sub>2</sub> emissions via the growth of industrial sector for dirty products. Following above discussion, we investigate the relationship between economic growth, energy intensity, financial development and CO<sub>2</sub> emissions. The general form of our empirical model can be written in the following way:

$$C_t = f(E_t, Y_t, F_t) \quad (1)$$

Now we transform all the series into logarithms to attain direct elasticities. The empirical equation is modelled as follows:

$$\ln C_t = \alpha_0 + \alpha_E \ln E_t + \alpha_Y \ln Y_t + \alpha_F \ln F_t + \mu_i \quad (2)$$

Where  $C_t$  is CO<sub>2</sub> emissions (measured in kt) per capita,  $E_t$  is energy intensity per capita,  $F_t$  is financial development proxied by real domestic credit to private sector per capita and  $Y_t$  is real GDP per capita used as a proxy of economic growth. Finally,  $\mu_t$  is error term assumed to be normally distributed with zero mean and constant variance. We presume that a rise in energy intensity will increase carbon emissions and  $\alpha_E > 0$ .  $\alpha_Y > 0$ , an increase in economic growth is linked with high CO<sub>2</sub> emissions otherwise  $\alpha_Y < 0$ . Sound financial sector may act as conduits by enabling firms in adopting advanced cleaner and environment friendly techniques (Talukdar, Meisner 2001) to save environment from degradation and  $\alpha_F < 0$  otherwise  $\alpha_F > 0$  if the focus of financial sector is to boost industrial sector.

The data on real GDP per capita, energy intensity per capita, domestic credit to private sector as share of GDP and CO<sub>2</sub> emissions (measured in kt) per capita has been collected from world development indicators (World Development Indicators 2012). We use CPI (consumer price index) and population series to convert domestic credit to private sector into real terms and then into per capita. The data sample of the present study is 1971–2011.

### **3. Estimation strategy**

Numerous unit root tests are available in applied economics to test the stationarity properties of the variables. These unit tests are ADF by Dickey and Fuller (1979); P-P by Phillips and Perron (1988); KPSS by Kwiatkowski *et al.* (1992); DF-GLS by Elliott *et al.* (1996) and Ng-Perron by Ng and Perron (2001). These tests provide biased and spurious results due to not having information about structural break points occurred in series. In doing so; Zivot and Andrews

(1992) developed three models to test the stationarity properties of the variables in the presence of structural break point in the series: (i) this model allows a one-time change in variables at level form, (ii) this model permits a one-time change in the slope of the trend component i.e. function and (iii) model has one-time change both in intercept and trend function of the variables to be used for empirical purpose. Zivot and Andrews (1992) followed three models to check the hypothesis of one-time structural break in the series as follows:

$$\Delta x_t = a + ax_{t-1} + bt + cDU_t + \sum_{j=1}^k d_j \Delta x_{t-j} + \mu_t \quad (3)$$

$$\Delta x_t = b + bx_{t-1} + ct + bDT_t + \sum_{j=1}^k b_j \Delta x_{t-j} + \mu_t \quad (4)$$

$$\Delta x_t = c + cx_{t-1} + ct + dDU_t + dDT_t + \sum_{j=1}^k d_j \Delta x_{t-j} + \mu_t \quad (5)$$

Where dummy variable is indicated by  $DU_t$  showing mean shift occurred at each point with time break while trend shift variables are shown by  $DT_t$ <sup>4</sup>. So,

$$DU_t = \begin{cases} 1 & \dots \text{if } t > TB \\ 0 & \dots \text{if } t < TB \end{cases} \quad \text{and} \quad DT_t = \begin{cases} t - TB & \dots \text{if } t > TB \\ 0 & \dots \text{if } t < TB \end{cases}$$

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<sup>4</sup> We used model-5 for empirical estimations following Sen (2003).



The null hypothesis of unit root break date is  $c = 0$  which indicates that series is not stationary with a drift not having information about structural break point while  $c < 0$  hypothesis implies that the variable is found to be trend-stationary with one unknown time break. Zivot and Andrews unit root test fixes all points as potential for possible time break and provides estimation through regression analysis for all possible break points successively. Then, this unit root test selects that time break which decreases one-sided t-statistic to test  $\hat{c}(= c - 1) = 1$ . Zivot and Andrews intimates that in the presence of end points, asymptotic distribution of the statistics is diverged to infinity point. It is necessary to choose a region where end points of sample period are excluded. Further, we followed the Zivot and Andrews suggested “trimming regions” i.e. (0.15T, 0.85T).

After testing the stationarity properties of the series, we apply the ARDL bounds testing approach developed by Pesaran *et al.* (2001) to investigate cointegration for long run relationship between economic growth, energy intensity, financial development and carbon emissions for the case of Portuguese economy. Various cointegration approaches have been applied to test the presence of cointegration between the variables in numerous studies. These approaches are Engle and Granger (1987); Johansen and Juselius (1990) and Phillips and Hansen (1990) require that all the series should be integrated at unique order of integration. The ARDL bounds testing approach is more appropriate as compared to other traditional cointegration approaches. For example, it seems flexible regarding the stationarity properties of the variables. This approach is more suitable once variables are found to be stationary at I(1) or I(0) or I(1)/I(0). The ARDL bounds testing approach provides efficient and consistent empirical evidence for small sample data (Narayan, Smyth 2005) as in case of Portugal. This approach investigates short run as well

as long run parameter instantaneously. The unrestricted error correction model (UECM) version of ARDL model is expressed as follows:

$$\begin{aligned} \Delta \ln C_t = & \beta_1 + \beta_T T + \beta_C \ln C_{t-1} + \beta_E \ln E_{t-1} + \beta_Y \ln Y_{t-1} + \beta_F \ln F_{t-1} + \sum_{i=1}^p \beta_i \Delta \ln C_{t-i} \\ & + \sum_{j=0}^q B_j \Delta \ln E_{t-j} + \sum_{k=0}^r \beta_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \beta_l \Delta \ln Y_{t-l} + \mu_t \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta \ln E_t = & \phi_1 + \phi_T T + \phi_C \ln C_{t-1} + \phi_E \ln E_{t-1} + \phi_Y \ln Y_{t-1} + \phi_F \ln F_{t-1} + \sum_{i=1}^p \phi_i \Delta \ln E_{t-i} \\ & + \sum_{j=0}^q \phi_j \Delta \ln C_{t-j} + \sum_{k=0}^r \phi_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \phi_l \Delta \ln F_{t-l} + \mu_t \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta \ln Y_t = & \varphi_1 + \varphi_T T + \varphi_C \ln C_{t-1} + \varphi_E \ln E_{t-1} + \varphi_Y \ln Y_{t-1} + \varphi_F \ln F_{t-1} + \sum_{i=1}^p \varphi_i \Delta \ln Y_{t-i} \\ & + \sum_{j=0}^q \varphi_j \Delta \ln C_{t-j} + \sum_{k=0}^r \varphi_k \Delta \ln E_{t-k} + \sum_{l=0}^s \varphi_l \Delta \ln F_{t-l} + \mu_t \end{aligned} \quad (8)$$

$$\begin{aligned} \Delta \ln F_t = & \theta_1 + \theta_T T + \theta_C \ln C_{t-1} + \theta_E \ln E_{t-1} + \theta_Y \ln Y_{t-1} + \theta_F \ln F_{t-1} + \sum_{i=1}^p \theta_i \Delta \ln F_{t-i} \\ & + \sum_{j=0}^q \theta_j \Delta \ln C_{t-j} + \sum_{k=0}^r \theta_k \Delta \ln E_{t-k} + \sum_{l=0}^s \theta_l \Delta \ln Y_{t-l} + \mu_t \end{aligned} \quad (9)$$

The difference operator is shown by  $\Delta$  and  $\mu_t$  is for residual terms. The appropriate lag length of the first differenced regression is chosen on the basis of minimum value of akaike information criteria (AIC). The F-statistic is much sensitive with lag order selection. The inappropriate lag

length selection may provide misleading results. Pesaran *et al.* (2001) developed an F-test to determine the joint significance of the coefficients of lagged level of the variables. For example, the hypothesis of no cointegration between the variables in equation-2 is  $H_0: \beta_C = \beta_E = \beta_Y = \beta_F = 0, H_0: \phi_C = \phi_E = \phi_Y = \phi_F = 0, H_0: \varphi_C = \varphi_E = \varphi_Y = \varphi_F = 0, H_0: \theta_C = \theta_E = \theta_Y = \theta_F = 0$  while hypothesis of cointegration is  $H_a: \beta_C \neq \beta_E \neq \beta_Y \neq \beta_F \neq 0, H_a: \phi_C \neq \phi_E \neq \phi_Y \neq \phi_F \neq 0, H_a: \varphi_C \neq \varphi_E \neq \varphi_Y \neq \varphi_F \neq 0, H_a: \theta_C \neq \theta_E \neq \theta_Y \neq \theta_F \neq 0$ . Pesaran *et al.* (2001) generated two asymptotic critical values i.e. upper critical bound (UCB) and lower critical bound (LCB), are used to take decisions whether cointegration exists or not between the series. The lower critical bound is used to test cointegration if all the series are integrated at I(0) otherwise we use upper critical bound (UCB). Our computed F-statistics are  $F_C(C/E, Y, F), F_E(E/C, Y, F), F_Y(Y/C, E, F)$  and  $F_F(F/C, E, Y)$  for equations (6) to (9) respectively. The long run relationship between the variables exists if our calculated F-statistic is greater than upper critical bound (UCB). There is no cointegration between the series, if our calculated F-statistic does not exceed lower critical bound (LCB). Our decision regarding cointegration is inconclusive if calculated F-statistic falls between LCB and UCB. In such an environment, error correction method is an easy and suitable way to investigate cointegration between the variables. We have used critical bounds generated by Narayan (2005) to test cointegration rather than Pesaran *et al.* (2001) and Turner (2006).

The direction of causality between economic growth, energy intensity, financial development, and CO<sub>2</sub> emissions is investigated by applying the VECM Granger causality approach after confirming the presence of cointegration between the variables. On the same lines; Granger (1969) argued that vector error correction method (VECM) is more appropriate to examine the

causality between the series if the variables are integrated at I(1). The VECM is restricted form of unrestricted VAR (vector autoregressive) and restriction is levied on the presence of long run relationship between the series. The system of error correction model (ECM) uses all the series endogenously. This system allows the predicted variable to explain itself both by its own lags and lags of forcing variables as-well-as error correction term and by residual term. The VECM equations are modeled as follows:

$$\Delta \ln C_t = \alpha_{01} + \sum_{i=1}^l \alpha_{11} \Delta \ln C_{t-i} + \sum_{j=0}^m \alpha_{22} \Delta \ln Y_{t-j} + \sum_{k=0}^n \alpha_{33} \Delta \ln E_{t-k} + \sum_{r=0}^o \alpha_{44} \Delta \ln F_{t-r} + \eta_1 ECT_{t-1} + \mu_{1i} \quad (10)$$

$$\Delta \ln E = \beta_{11} + \sum_{i=1}^l \beta_{11} \Delta \ln E_{t-i} + \sum_{j=0}^m \beta_{22} \Delta \ln C_{t-j} + \sum_{k=0}^n \beta_{33} \Delta \ln Y_{t-k} + \sum_{r=0}^o \beta_{44} \Delta \ln F_{t-r} + \eta_2 ECT_{t-1} + \mu_{2i} \quad (11)$$

$$\Delta \ln Y_t = \varphi_{01} + \sum_{i=1}^l \varphi_{11} \Delta \ln Y_{t-i} + \sum_{j=0}^m \varphi_{22} \Delta \ln C_{t-j} + \sum_{k=0}^n \varphi_{33} \Delta \ln E_{t-k} + \sum_{r=0}^o \varphi_{44} \Delta \ln F_{t-r} + \eta_3 ECT_{t-1} + \mu_{3i} \quad (12)$$

$$\Delta \ln F_t = \rho_{11} + \sum_{i=1}^l \rho_{11} \Delta \ln F_{t-i} + \sum_{j=0}^m \rho_{22} \Delta \ln C_{t-j} + \sum_{k=0}^n \rho_{33} \Delta \ln Y_{t-k} + \sum_{r=0}^o \rho_{44} \Delta \ln F_{t-r} + \eta_4 ECT_{t-1} + \mu_{4i} \quad (13)$$

Where  $u_{it}$ , are random terms and supposed to be normally distributed with zero means and constant variances. The established long run relation between the series is further confirmed by the statistical significance of lagged error term i.e.  $ECT_{t-1}$ . The estimates of  $ECT_{t-1}$  also shows the speeds of convergence from short run towards long run equilibrium path. The vector error correction method (VECM) is appropriate to examine causality between the variables once series

are found to be cointegrated and then causality must be found at least from one direction. The VECM also distinguishes causality relationships between short-and-long runs. The VECM is also used to detect the causality in long run, short run and joint i.e. short-and-long runs respectively.

The t-statistic of estimate of lagged error term i.e.  $ECT_{t-1}$  with negative sign is used to test long run casual relation and the joint  $\chi^2$  statistical significance of the estimates of first difference lagged independent variables is used to investigate short run causality. Economic growth Granger causes carbon emissions if  $\alpha_{22,i} \neq 0 \forall_i$  is found statistically significant. On contrary, if  $\beta_{22,i} \neq 0 \forall_i$  is statistically significant then causality runs from CO<sub>2</sub> emissions to economic growth. The rest of causality hypotheses can be inferred similarly. The joint causality i.e. long-and-short runs is investigated by using Wald or F-test on the joint significance of estimates of lagged terms of independent variables and error correction term. The presence of short-and-long run causality relation between the variables is known as measure of strong Granger causality (Shahbaz *et al.* 2011).

#### **4. Results and their discussions**

Table 1 shows the results of descriptive statistics and pair-wise correlations between the series. The results exposed that all the variables have normal distributions while error term is having zero mean as well as finite variance confirmed by the statistic of Jarque-Bera. The pair-wise correlation analysis reveals that energy intensity, economic growth and financial development are positively correlated with CO<sub>2</sub> emissions. A negative correlation exists between economic

growth and energy intensity and same is true for financial development and energy intensity. A positive correlation is found between financial development and economic growth. This correlation analysis provides no evidence of multi-collinearity between the variables.

Table 1. Descriptive Statistics and Correlation Matrix

| Variables   | $\ln C_t$ | $\ln E_t$ | $\ln Y_t$ | $\ln F_t$ |
|-------------|-----------|-----------|-----------|-----------|
| Mean        | 1.3681    | -1.7968   | 9.1084    | 8.9002    |
| Median      | 1.5284    | -1.7540   | 9.1813    | 8.5677    |
| Maximum     | 1.8624    | -1.6064   | 9.4684    | 10.100    |
| Minimum     | 0.6399    | -2.0866   | 8.5851    | 8.0686    |
| Std. Dev.   | 0.3803    | 0.1449    | 0.2876    | 0.6550    |
| Skewness    | -0.2968   | -0.3967   | -0.1689   | 0.6647    |
| Kurtosis    | 1.5765    | 1.8798    | 1.5363    | 1.8012    |
| Jarque-Bera | 3.9646    | 3.1407    | 3.7606    | 5.3411    |
| Probability | 0.1377    | 0.2079    | 0.1525    | 0.0692    |
| $\ln C_t$   | 1.0000    |           |           |           |
| $\ln E_t$   | 0.4486    | 1.0000    |           |           |
| $\ln Y_t$   | 0.5060    | -0.2639   | 1.0000    |           |
| $\ln F_t$   | 0.1068    | -0.0346   | 0.1820    | 1.0000    |

We apply the ARDL bound testing approach to examine the long run relationship between economic growth, energy intensity, financial development and CO<sub>2</sub> emissions in case of

Portugal. The advantage of bounds testing is that it is flexible regarding the order of integration of the series. This requires the variables to be integrated at  $I(0)$  or  $I(1)$  or  $I(0)/I(1)$ . The computation of the ARDL F-statistic becomes useless if none of the variables is stationary at  $I(2)$  or beyond that order of integration. In doing so, we have applied Zivot, Andrews structural break trended unit root test to ensure that all the variables are integrated at  $I(0)$  or  $I(1)$  or  $I(0)/I(1)$ <sup>5</sup>. This test accommodates the information about single unknown structural break stemming in the series. The results of Zivot and Andrews (1992) structural break trended unit root test are reported in Table 2. Our empirical evidence discloses that all the series show unit root problem at their level but found to be integrated at  $I(1)$ . This entails that the series are stationary at their first differenced form. So, unique level of the variables leads us to examine the existence of long run relationship between economic growth, energy intensity, financial development and CO<sub>2</sub> emissions by applying the ARDL bounds testing approach to cointegration over the period of 1971–2011.

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<sup>5</sup> Various unit root tests are available in economics literature to examine the stationarity properties of the series. These unit root tests are ADF (Dickey, Fuller 1979); DF-GLS (Elliot *et al.* 1996); Ng-Perron (Ng, Perron 2001) etc. These tests may provide biased and inconsistent empirical evidence regarding stationarity properties of the variables. The main reason is that ADF, DF-GLS and Ng-Perron do not seem to have information about structural breaks occurring in the time series data (Baum 2004).

Table 2. Zivot-Andrews structural break trended unit root test

| Variable  | At Level    |            | At 1 <sup>st</sup> Difference |            |
|-----------|-------------|------------|-------------------------------|------------|
|           | T-statistic | Time Break | T-statistic                   | Time Break |
| $\ln C_t$ | -3.522 (2)  | 2001       | -8.107 (0)*                   | 1991       |
| $\ln E_t$ | -3.462 (2)  | 2002       | -8.824 (1)*                   | 1996       |
| $\ln F_t$ | -3.551 (3)  | 1990       | -3.871(1)***                  | 2000       |
| $\ln Y_t$ | -3.729 (3)  | 2002       | -6.817 (1)*                   | 1990       |

Note: \* and \*\*\* represent significant at 1%, and 10% level of significance. Lag order is shown in parenthesis.

Before applying the ARDL bounds testing, there is a pre-requisite to choose appropriate lag order of the variables to compute suitable the ARDL F-statistic and to test whether cointegration exists between the variables or not. The computation of F-test is very much sensitive with the selection of lag length (Ouattara 2004). We chose lag length 2 following minimum value of akaike information criterion (AIC) as shown in Table 3. The AIC criterion has superior power properties as compared to SBC and provides effective and reliable results which help in capturing the dynamic relationship between the series (Lütkepohl 2006)<sup>6</sup>.

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<sup>6</sup> The results of lag order of the variables are available from authors upon request.



Table 3. The results of ARDL cointegration test

| Bounds testing to cointegration                        |                         |                     | Diagnostic tests  |                 |                  |                          |
|--|-------------------------|---------------------|-------------------|-----------------|------------------|--------------------------|
| Estimated models                                       | Optimal lag length      | F-statistics        | $\chi^2_{NORMAL}$ | $\chi^2_{ARCH}$ | $\chi^2_{RESET}$ | $\chi^2_{SERIAL}$        |
| $F_C(C/E, F, Y)$                                       | 2, 2, 2, 2              | 10.667*             | 0.3285            | [1]: 0.7889     | [1]: 0.9365      | [1]: 0.2083; [2]: 0.7884 |
| $F_E(E/C, F, Y)$                                       | 2, 2, 2, 1              | 14.158*             | 0.6448            | [1]: 3.9821     | [1]: 0.3746      | [1]: 1.7145; [2]: 1.3143 |
| $F_F(F/C, E, Y)$                                       | 2, 2, 2, 1              | 0.217               | 0.4757            | [1]: 0.1547     | [1]: 1.5110      | [1]: 4.5934; [2]: 4.1174 |
| $F_Y(Y/C, E, Y)$                                       | 2, 2, 2, 2              | 2.705               | 0.2622            | [1]: 0.9978     | [1]: 2.9656      | [1]: 0.0173; [2]: 0.0086 |
| Significant level                                      | Critical values (T= 40) |                     |                   |                 |                  |                          |
|  | Lower bounds $I(0)$     | Upper bounds $I(1)$ |                   |                 |                  |                          |
| 1 per cent level                                       | 7.527                   | 8.803               |                   |                 |                  |                          |
| 5 per cent level                                       | 5.387                   | 6.437               |                   |                 |                  |                          |
| 10 per cent level                                      | 4.447                   | 5.420               |                   |                 |                  |                          |
| Note: * represents significant at 1 per cent at level. |                         |                     |                   |                 |                  |                          |

The next step is to apply F-test investigating cointegration for long run between the variables. Table 3 reports the results of the ARDL bounds testing approach to cointegration. The results showed that our calculated F-statistics are greater than upper critical bound at 1 percent level, once we used CO<sub>2</sub> emissions and energy intensity are treated as predicted variables. It leads us to reject the null hypothesis of no cointegration. This indicates that there are two cointegrating vectors. This confirms that the variables are cointegrated for long run relationship between economic growth, energy intensity, financial development and CO<sub>2</sub> emissions in case of Portugal.

Table 4. Long-and-short runs analysis

| Dependent variable = $\ln C_t$ |             |             |             |              |
|--------------------------------|-------------|-------------|-------------|--------------|
| Long run analysis              |             |             |             |              |
| Variables                      | Coefficient | T-Statistic | Coefficient | T-Statistic  |
| Constant                       | -5.3958*    | -5.0277     | -13.8480*   | -4.4327      |
| $\ln E_t$                      | 0.9559*     | 6.1073      | 0.7555*     | 6.1057       |
| $\ln F_t$                      | -0.0784*    | -2.7983     | 1.6100**    | 2.6310       |
| $\ln F_t^2$                    | ....        | ....        | -0.0917*    | -2.7576      |
| $\ln Y_t$                      | 1.0078*     | 9.4075      | 1.0483*     | 13.2041      |
| Short run analysis             |             |             |             |              |
| Variables                      | Coefficient | Std. Error  | T-Statistic | Prob. values |
| Constant                       | -0.0023     | 0.0090      | -0.2601     | 0.7966       |
| $\ln E_t$                      | 0.8823*     | 0.1391      | 6.3404      | 0.0000       |

|   |             |             |         |        |
|---|-------------|-------------|---------|--------|
| $\ln F_t$   | -0.0399     | 0.0621      | -0.6423 | 0.5257 |
| $\ln F_{t-1}$   | 0.1389***   | 0.0783      | 1.7735  | 0.0866 |
| $\ln Y_t$   | 0.8774*     | 0.2034      | 4.3138  | 0.0002 |
| $ECM_{t-1}$   | -0.9916*    | 0.2183      | -4.5412 | 0.0001 |
| $R^2$   | 0.7890      |             |         |        |
| F-statistic   | 21.6962*    |             |         |        |
| D. Watson   | 1.8870      |             |         |        |
| Short Run Diagnostic Tests  |             |             |         |        |
| Test  | F-statistic | Prob. value |         |        |
| $\chi^2_{NORMAL}$   | 0.3332      | 0.8464      |         |        |
| $\chi^2_{SERIAL}$   | 0.1976      | 0.8218      |         |        |
| $\chi^2_{ARCH}$   | 2.3768      | 0.1101      |         |        |
| $\chi^2_{WHITE}$  | 0.5167      | 0.8614      |         |        |
| $\chi^2_{REMSAY}$   | 0.8386      | 0.3676      |         |        |
| Note: *, ** and *** show significant at 1, 5 and 10 per cent levels of significance respectively. |             |             |         |        |

After investigating long run relationship between the variables, next step is to examine marginal impacts of economic growth, energy intensity and financial development on CO<sub>2</sub> emissions. The results are reported in Table 4 indicate that energy intensity has positive and statistically significant impact on CO<sub>2</sub> emissions. This shows that an increase in energy intensity contributes to energy pollutants significantly. The results inferred that a 1 percent rise in energy intensity is

linked with a 0.9559 percent increase in CO<sub>2</sub> emissions, all else same. The impact of financial development is negative and it is statistically significant at 1 percent level of significance. It implies that a 0.0784 percent decline in CO<sub>2</sub> emissions is linked with a 1 percent increase in financial development. This exposes that financial sector development contributes in condensing CO<sub>2</sub> emissions by directing banks to provide loans to firms for those investment projects which are environment friendly. The relationship between economic growth and CO<sub>2</sub> emissions is positive and it is significant at 1 percent level. Keeping other things same, a 1 percent increase in economic growth raises CO<sub>2</sub> emissions by 1.007 percent. Our empirical exercise indicates that economic growth is a major contributor to CO<sub>2</sub> emissions after energy intensity in case of Portugal. Furthermore, our results confirmed the presence of inverted U-shaped relationship between financial development and CO<sub>2</sub> emissions. The impact of linear and nonlinear terms of financial development is positive and negative on CO<sub>2</sub> emissions and it is statistically significant at 5 percent and 1 percent levels respectively. This entails that initially CO<sub>2</sub> emissions are positively linked with financial development and financial development starts to decline it once financial sector matures. It is suggested that financial sector should provide loans (subsidies) for energy efficient technologies and allocate funds to energy system for exploring new sources of energy such as renewables.

The short run results illustrated that energy intensity and economic growth have positive impact on carbon emissions and it is statistically significant at 1 percent level of significance. It is found that energy intensity is major contributor to carbon emissions in short run. Financial sector development is negatively related with CO<sub>2</sub> emissions but insignificant. Surprisingly, financial sector development with lagged period also increases carbon emissions. The statistically

significant estimate of lagged error term i.e.  $ECM_{t-1}$  with negative sign corroborates our established long run relationship between economic growth, energy intensity, financial development and carbon emissions. The empirical evidence reported in Table 4 pointed out that coefficient of  $ECM_{t-1}$  is  $-0.9916$  which is statistically significant at 1 percent level of significance. This concludes that changes in CO<sub>2</sub> emissions are corrected by 99.16 percent every year in long run<sup>7</sup>. It suggests that full convergence process will take more than a year to reach the stable path of equilibrium. This implies that adjustment process is very fast and significant for Portuguese economy in any shock to CO<sub>2</sub> emissions equation in the case of Portugal.

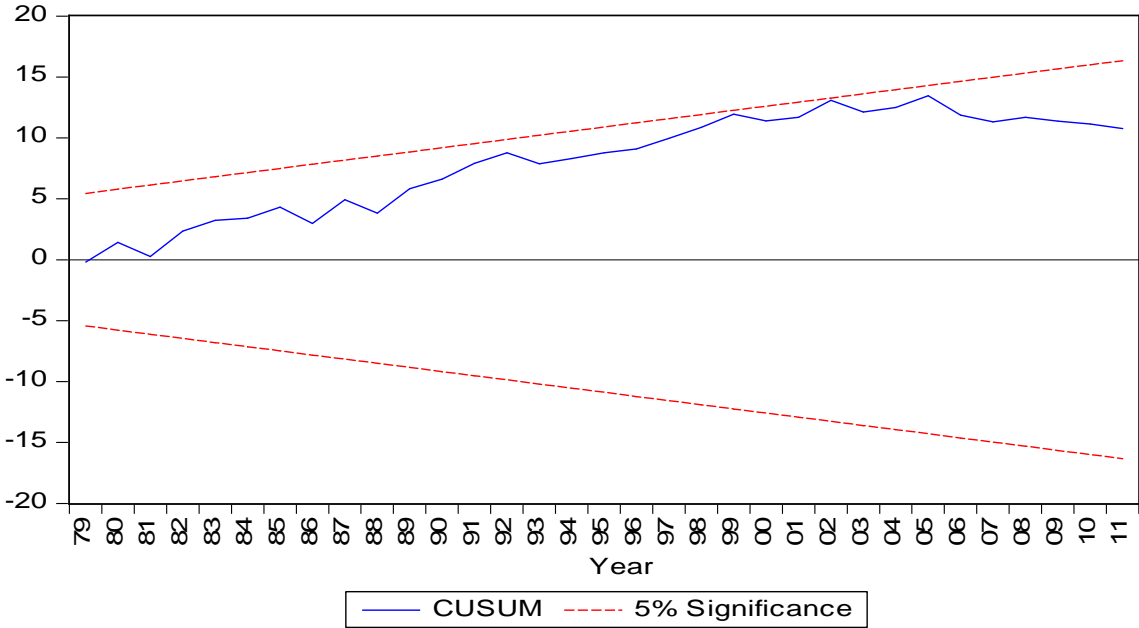
The plots of both CUSUM and CUSUMsq are shown by Figures 1 and 2 at 5 percent level of significance. Results indicated that plots of both tests are within critical bounds at 5 percent level of significance. The empirical evidence for diagnostic tests is detailed in Table 4. The results suggest that short run model seems to pass all tests successfully such as test of normality, serial correlation, autoregressive conditional heteroskedasticity, white heteroskedasticity and specification of short run model. This indicated that there is no problem of non-normality of error term, no serial correlation between the variables as well as no evidence is found for autoregressive conditional heteroskedasticity. The variables are homoscedastic and functional form of short run model is well organized. The stability and sensitivity analysis favors that the

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<sup>7</sup> The statistically significance of lagged error term i.e.  $ECM_{t-1}$  is a further proof of the existence of stable long run relationship between the series (Banerjee *et al.* 1998).

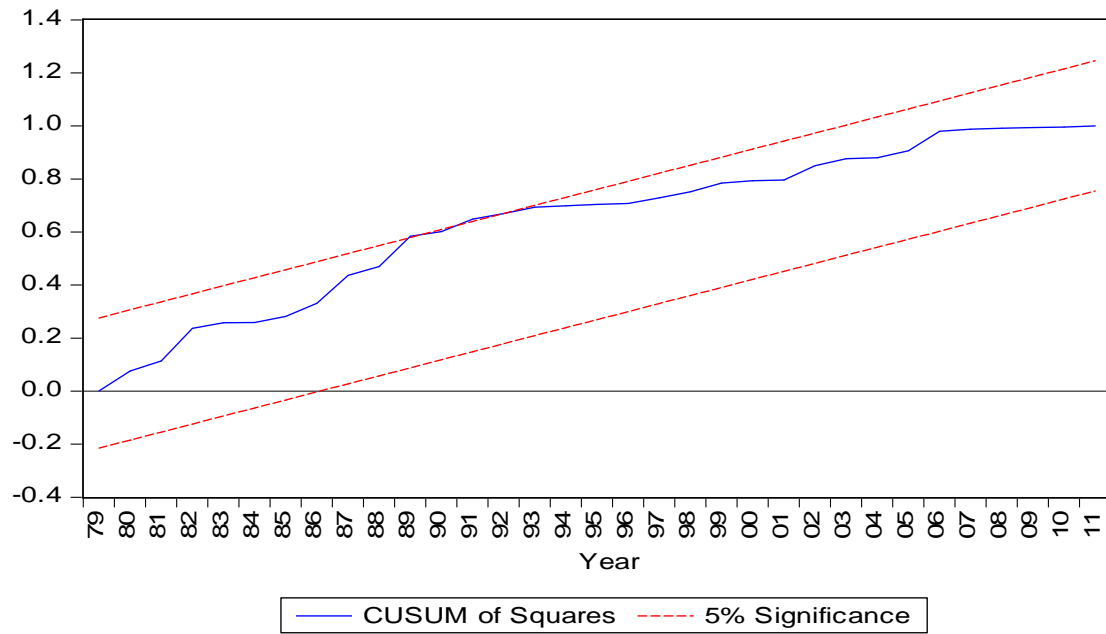
parameters of long run and short run empirical evidence is consistent and stable for policy purpose regarding carbon emissions in case of Portugal.

Fig. 1. Plot of cumulative sum of recursive residuals



The straight lines represent critical bounds at 5% significance level

Fig. 2. Plot of cumulative sum of squares of recursive residuals



The straight lines represent critical bounds at 5% significance level

The presence of cointegration for long run economic growth, energy intensity, financial development, and carbon emissions leads us to implement the VECM Granger causality approach to analyze the direction of causal relationship between the series. The appropriate knowledge about the direction of causality between the variables helps policy making authorities in articulating inclusive energy, economic, financial and environmental policy to sustain economic growth and improve the environmental quality in long run. Granger (1969) suggested that in the presence of cointegration, once variables are found to be stationary at unique order then the VECM Granger causality framework is an appropriate approach to detect the long-and-short runs causal relationship between economic growth, energy intensity, financial development and carbon emissions. Table 5 reports the results of Granger causality test.

In long span of time, empirical evidence indicated that the bidirectional causal relationship is found between energy intensity and CO<sub>2</sub> emissions. This implies that efficient use of modern technology declines energy intensity that results in lowering CO<sub>2</sub> emissions during production process and vice versa. This finding is with the line of existing energy literature such as Papadopoulos and Haralambopoulos (2006) and later on with Hatzigeorgiou *et al.* (2011) in case of Greece. This empirical evidence implies that in current setup it is difficult for Portuguese economy to find decoupling carbon emissions. There is a need of overhauling energy structure to encourage energy efficient technologies by considering a number of policy reforms. The unidirectional causality is found running from economic growth to energy intensity also suggests adopting energy efficient technology which helps in enhancing domestic production but with less CO<sub>2</sub> emissions. Economic growth Granger causes CO<sub>2</sub> emissions. This shows that Portugal is growing at cost of environment. It implies the exploration of environment friendly sources of energy for example wind, solar and other renewable energy sources as well as implementation of energy efficient technology to boost domestic production and hence economic growth.



Table 5. The VECM Granger Causality Analysis

| Dependent Variable | Direction of Causality |                      |                      |                      |                        |                                    |                                 |                                 |                                 |
|--------------------|------------------------|----------------------|----------------------|----------------------|------------------------|------------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                    | Short Run              |                      |                      |                      | Long Run               | Joint Long-and-Short Run Causality |                                 |                                 |                                 |
|                    | $\Delta \ln C_{t-1}$   | $\Delta \ln E_{t-1}$ | $\Delta \ln F_{t-1}$ | $\Delta \ln Y_{t-1}$ | $ECT_{t-1}$            | $\Delta \ln C_{t-1}, ECT_{t-1}$    | $\Delta \ln E_{t-1}, ECT_{t-1}$ | $\Delta \ln F_{t-1}, ECT_{t-1}$ | $\Delta \ln Y_{t-1}, ECT_{t-1}$ |
| $\Delta \ln C_t$   | ....                   | 24.5188*<br>[0.0000] | 0.6861<br>[0.5811]   | 27.8183*<br>[0.0000] | -0.5729**<br>[-2.4283] | ....                               | 20.2686*<br>[0.0000]            | 2.8869***<br>[0.0532]           | 46.8625*<br>[0.0000]            |
| $\Delta \ln E_t$   | 28.6458*<br>[0.0000]   | ....                 | 0.9136<br>[0.4123]   | 4.7349**<br>[0.0166] | -0.7317*<br>[-2.8783]  | 20.6499*<br>[0.0000]               | ....                            | 2.9131***<br>[0.0512]           | 14.6628*<br>[0.0000]            |
| $\Delta \ln F_t$   | 0.0467<br>[0.9544]     | 0.0175<br>[0.9825]   | ....                 | 0.5131<br>[0.6038]   | ....                   | ....                               | ....                            | ....                            | ....                            |
| $\Delta \ln Y_t$   | 15.4471*<br>[0.0000]   | 12.4398*<br>[0.0001] | 0.3213<br>[0.7277]   | ....                 | ....                   | ....                               | ....                            | ....                            | ....                            |

Note: \*, \*\* and \*\*\* show significance at 1, 5 and 10 per cent levels respectively.

This exposes that a rise in economic activity raises more demand for energy and in result increases CO<sub>2</sub> emissions. Our empirical evidence is contradictory with findings of Hatzigeorgiou *et al.* (2011) who reported bidirectional causal relationship between economic growth and energy intensity. Finally, the unidirectional causality is also found from financial development to energy intensity. This supports the view argued by Shahbaz and Lean (2012) that sound financial sector enables the firms to adopt advance and energy efficient technology during production process. Although, they reported that bidirectional causality exists between financial development and energy consumption in case of Tunisia. Finally, unidirectional causality is found running from financial development to carbon emissions. This supports the argument that financial sector development lowers CO<sub>2</sub> emissions by encouraging the firms to adopt advanced technology which emits less carbon emissions during production. These results are consistent with energy literature such as Talukdar and Meisner (2001).

In short span of time, causality analysis exposed that economic growth and energy intensity are interdependent. The bidirectional causality is found between energy intensity and CO<sub>2</sub> emissions. The feedback hypothesis also exists between economic growth and CO<sub>2</sub> emissions. The joint long-and-short runs causality analysis also supports the empirical findings for long run as well as short run. The neutral effect exists between financial development and energy intensity and same is true for financial development and carbon emissions. Economic growth and financial development are independent.

It is argued in economic literature that the Granger causality approaches such as the VECM Granger causality test has some limitations. The causality test cannot capture the relative strength

of causal relation between the variables beyond the selected time period. This weakens the reliability of causality results by the VECM Granger causality approach. To solve this issue, we applied innovative accounting approach (IAA) i.e. variance decomposition method and impulse response function. We have implemented the generalized forecast error variance decomposition method using vector autoregressive (VAR) system to test the strength of causal relationship between economic growth, energy intensity, financial development and CO<sub>2</sub> emissions in case of Portugal. The variance decomposition approach indicates the magnitude of the predicted error variance for a series accounted for by innovations from each of the independent variable over different time-horizons beyond the selected time period. It is pointed by Pesaran and Shin (1999) that the generalized forecast error variance decomposition method shows proportional contribution in one variable due to innovative shocks stemming in other variables. The main advantage of this approach is that like orthogonalized forecast error variance decomposition approach; it is insensitive with ordering of the variables because ordering of the variables is uniquely determined by VAR system. Further, the generalized forecast error variance decomposition approach estimates the simultaneous shock affects. Engle and Granger (1987) and Ibrahim (2005) argued that with VAR framework, variance decomposition approach produces better results as compared to other traditional approaches.

The results of variance decomposition approach are described in Table 6. The empirical evidence indicates that a 10.65 percent portion of CO<sub>2</sub> emissions is contributed by its own innovative shocks and one standard deviation shock in financial development explains energy pollutants by 59.96 percent. This implies that financial development plays vital role to improve the

environmental quality by directing financial resources to projects where firms utilize advanced technology to enhance domestic production with less CO<sub>2</sub> emissions.

Table 6. Variance decomposition approach

| Variance decomposition of $\ln C_t$ |        |           |           |           |           |
|-------------------------------------|--------|-----------|-----------|-----------|-----------|
| Period                              | S.E.   | $\ln C_t$ | $\ln E_t$ | $\ln F_t$ | $\ln Y_t$ |
| 1                                   | 0.0522 | 100.0000  | 0.0000    | 0.0000    | 0.0000    |
| 2                                   | 0.0638 | 76.6092   | 2.1222    | 0.6995    | 20.5690   |
| 3                                   | 0.0748 | 63.4918   | 2.8381    | 2.5768    | 31.0931   |
| 4                                   | 0.0886 | 47.0122   | 6.6878    | 7.13683   | 39.1630   |
| 5                                   | 0.1021 | 36.3854   | 8.7809    | 15.3446   | 39.4889   |
| 6                                   | 0.1152 | 28.9803   | 9.6342    | 23.5514   | 37.8339   |
| 7                                   | 0.1274 | 24.0528   | 9.4032    | 30.9497   | 35.5941   |
| 8                                   | 0.1386 | 20.5698   | 8.9114    | 36.8973   | 33.6213   |
| 9                                   | 0.1490 | 18.0081   | 8.4077    | 41.7433   | 31.8407   |
| 10                                  | 0.1587 | 16.0382   | 7.9792    | 45.7951   | 30.1874   |
| 11                                  | 0.1678 | 14.4817   | 7.6004    | 49.3234   | 28.5943   |
| 12                                  | 0.1763 | 13.2282   | 7.2468    | 52.4534   | 27.0715   |
| 13                                  | 0.1842 | 12.2058   | 6.9068    | 55.2478   | 25.6393   |
| 14                                  | 0.1916 | 11.3622   | 6.5834    | 57.7409   | 24.3133   |
| 15                                  | 0.1984 | 10.6582   | 6.2809    | 59.9652   | 23.0955   |
| Variance decomposition of $\ln E_t$ |        |           |           |           |           |

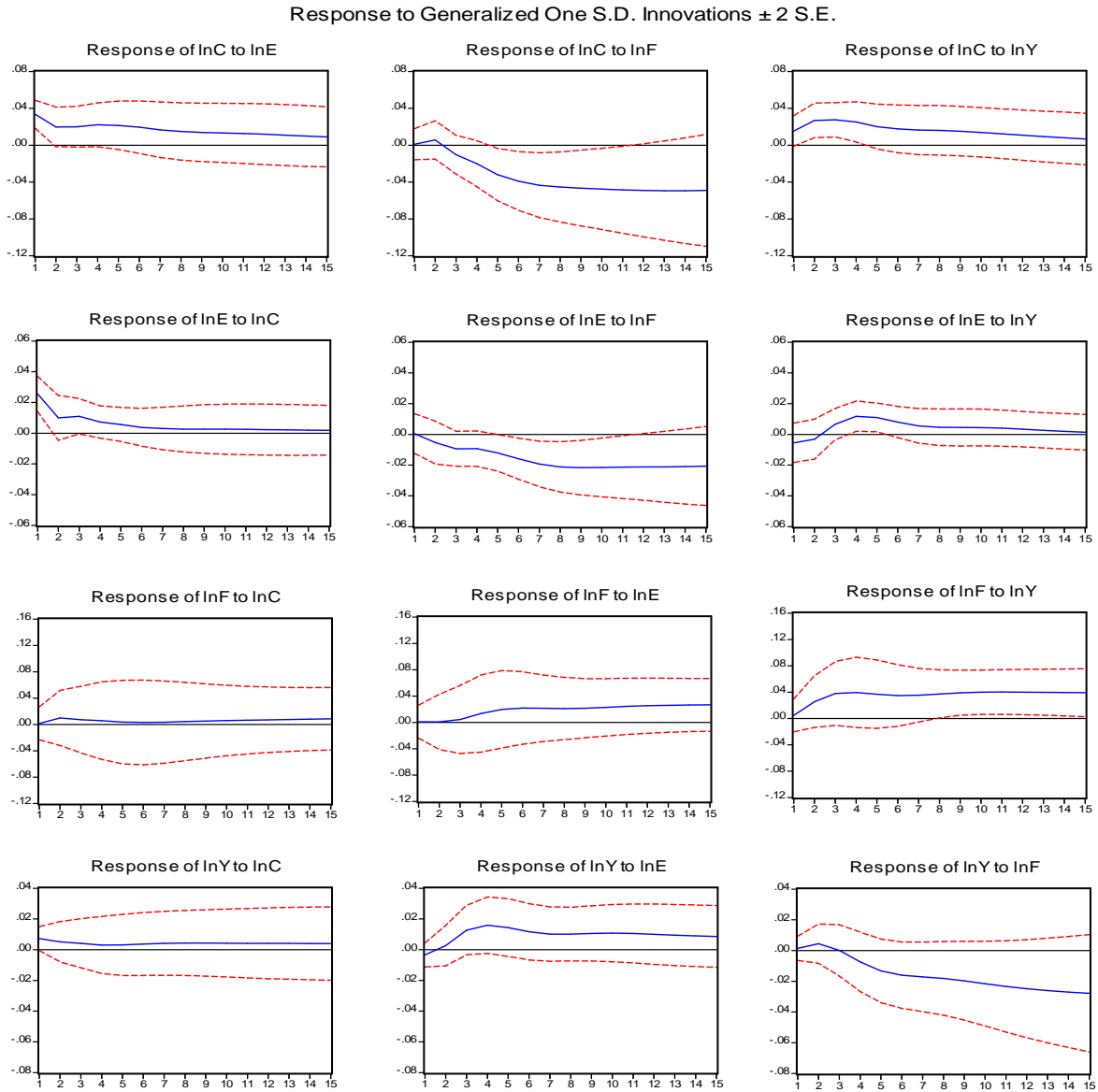
| Period                              | S.E.   | $\ln C_t$ | $\ln E_t$ | $\ln F_t$ | $\ln Y_t$ |
|-------------------------------------|--------|-----------|-----------|-----------|-----------|
| 1                                   | 0.0397 | 41.3522   | 58.6477   | 0.0000    | 0.0000    |
| 2                                   | 0.0427 | 40.9854   | 57.2635   | 1.6685    | 0.0825    |
| 3                                   | 0.0453 | 42.2503   | 51.0118   | 5.9790    | 0.7586    |
| 4                                   | 0.0483 | 39.5151   | 45.0318   | 9.1273    | 6.3256    |
| 5                                   | 0.0521 | 35.1489   | 39.2479   | 13.3500   | 12.2530   |
| 6                                   | 0.0567 | 30.1423   | 35.0699   | 19.1538   | 15.6338   |
| 7                                   | 0.0614 | 25.8761   | 31.5370   | 26.2586   | 16.3281   |
| 8                                   | 0.0660 | 22.5906   | 28.2826   | 33.1124   | 16.0142   |
| 9                                   | 0.0702 | 20.1345   | 25.4707   | 38.9132   | 15.4814   |
| 10                                  | 0.0739 | 18.2557   | 23.1955   | 43.5723   | 14.9764   |
| 11                                  | 0.0774 | 16.7622   | 21.3710   | 47.3929   | 14.4737   |
| 12                                  | 0.0806 | 15.5348   | 19.8806   | 50.6536   | 13.9309   |
| 13                                  | 0.0836 | 14.5082   | 18.6277   | 53.5168   | 13.3471   |
| 14                                  | 0.0864 | 13.6447   | 17.5533   | 56.0483   | 12.7535   |
| 15                                  | 0.0889 | 12.9165   | 16.6260   | 58.2762   | 12.1811   |
| Variance decomposition of $\ln F_t$ |        |           |           |           |           |
| Period                              | S.E.   | $\ln C_t$ | $\ln E_t$ | $\ln F_t$ | $\ln Y_t$ |
| 1                                   | 0.0770 | 0.0408    | 0.0000    | 99.9591   | 0.0000    |
| 2                                   | 0.1255 | 0.6199    | 0.3527    | 97.2746   | 1.7527    |
| 3                                   | 0.1649 | 0.5499    | 0.2049    | 93.6071   | 5.6380    |
| 4                                   | 0.1946 | 0.4757    | 0.5709    | 89.5279   | 9.4252    |

| 5                                   | 0.2166 | 0.4086    | 1.5751    | 85.3679   | 12.6483   |
|-------------------------------------|--------|-----------|-----------|-----------|-----------|
| 6                                   | 0.2327 | 0.3697    | 2.6028    | 81.6620   | 15.3653   |
| 7                                   | 0.2450 | 0.3514    | 3.3926    | 78.3072   | 17.9486   |
| 8                                   | 0.2553 | 0.3510    | 3.9892    | 75.0770   | 20.5826   |
| 9                                   | 0.2645 | 0.3642    | 4.5265    | 71.8050   | 23.3040   |
| 10                                  | 0.2729 | 0.3876    | 5.0845    | 68.4894   | 26.0383   |
| 11                                  | 0.2808 | 0.4184    | 5.6766    | 65.2112   | 28.6936   |
| 12                                  | 0.2882 | 0.4553    | 6.2742    | 62.0685   | 31.2018   |
| 13                                  | 0.2953 | 0.4978    | 6.8441    | 59.1347   | 33.5232   |
| 14                                  | 0.3023 | 0.5449    | 7.3671    | 56.4568   | 35.6310   |
| 15                                  | 0.3092 | 0.5954    | 7.8368    | 54.0673   | 37.5004   |
| Variance decomposition of $\ln Y_t$ |        |           |           |           |           |
| Period                              | S.E.   | $\ln C_t$ | $\ln E_t$ | $\ln F_t$ | $\ln Y_t$ |
| 1                                   | 0.0244 | 8.7243    | 18.4880   | 0.2776    | 72.5100   |
| 2                                   | 0.0394 | 5.0323    | 7.1570    | 1.3121    | 86.4983   |
| 3                                   | 0.0521 | 3.5118    | 10.4445   | 0.7509    | 85.2926   |
| 4                                   | 0.0620 | 2.7139    | 16.0544   | 1.9805    | 79.2510   |
| 5                                   | 0.0694 | 2.3590    | 18.1751   | 5.2498    | 74.2160   |
| 6                                   | 0.0755 | 2.2222    | 17.9333   | 9.0049    | 70.8394   |
| 7                                   | 0.0811 | 2.1861    | 17.0002   | 12.3479   | 68.4656   |
| 8                                   | 0.0866 | 2.1698    | 16.1278   | 15.2859   | 66.4163   |
| 9                                   | 0.0921 | 2.1412    | 15.4834   | 18.1446   | 64.2307   |

|    |        |        |         |         |         |
|----|--------|--------|---------|---------|---------|
| 10 | 0.0974 | 2.0993 | 14.9746 | 21.1300 | 61.7959 |
| 11 | 0.1027 | 2.0539 | 14.4755 | 24.2461 | 59.2243 |
| 12 | 0.1078 | 2.0108 | 13.9415 | 27.3862 | 56.6613 |
| 13 | 0.1127 | 1.9712 | 13.3897 | 30.4480 | 54.1909 |
| 14 | 0.1174 | 1.9336 | 12.8481 | 33.3804 | 51.8377 |
| 15 | 0.1219 | 1.8966 | 12.3319 | 36.1716 | 49.5997 |

The contribution of economic growth to CO<sub>2</sub> emissions is 23.09 percent. This contribution in CO<sub>2</sub> emissions due to economic growth first rises, goes to peak point, and then starts to fall. This confirms the existence of inverted-U relationship between economic growth and CO<sub>2</sub> emissions in case of Portugal. A very little portion of CO<sub>2</sub> emissions is explained by innovative shocks stemming in energy intensity i.e. 6.28 percent. A 12.91 percent portion of energy intensity is explained by one standard deviation shock in CO<sub>2</sub> emissions and 16.62 percent portion is contributed to energy intensity by its own innovative shocks. A standard deviation shock stemming in financial development and economic growth attribute to energy intensity by 58.27 percent and 12.18 per cent respectively. A 37.50 percent contribution exists in financial development by shocks stemming in economic growth. CO<sub>2</sub> emissions and energy intensity explain financial development minimally and one standard innovative shock stems in financial development explains itself by 54.06 percent. The contribution of CO<sub>2</sub> emissions, energy intensity and financial development to economic growth 1.89 percent, 12.33 percent and 36.17 percent respectively and rest is explained by its own standard innovative shocks. The existing empirical evidence confirms the feedback hypothesis between financial development and economic growth.

Fig. 3. Impulse response function



The impulse response function is alternate of variance decomposition approach and shows the reaction in one variable due to shocks stemming in other variables. Figure 3 indicated the positive response in carbon emissions due to standard shocks stemming in economic growth and energy intensity while CO<sub>2</sub> emissions is negatively responded by financial development. This



means that financial sector development contributes in condensing carbon emissions. The contribution of carbon emissions and economic growth is positive to energy intensity while financial development declines energy intensity due to adoption of energy-efficient technologies. The response of financial development is positive due to innovative shocks stemming in energy intensity and economic growth. A standard shock occurs in energy intensity stimulates economic growth while financial sector development declines it. This shows that financial development does not contribute to economic growth. This confirms that current financial crisis in the Europe has decayed economic activity in case of Portugal.

## **5. Conclusions and future directions**

This study investigated the dynamic relationship between economic growth, energy intensity, financial development, and CO<sub>2</sub> emissions in case of Portuguese economy over the period of 1971–2011. For this purpose, we applied the ARDL bounds testing approach to cointegration to examine the cointegration among the variables for long run, the VECM Granger causality to test the direction of causal relationship between the variables and robustness of causality analysis was tested by applying innovative accounting approach (IAA).

Our results indicated that the variables are cointegrated for long run relationship. The empirical evidence showed that energy intensity increases carbon emissions and economic growth is a major contributor to CO<sub>2</sub> emissions. Financial sector development condenses carbon emissions and inverted-U shape relationship is confirmed between financial sector development and carbon emissions. This validates the contribution of financial sector to improve the quality of environment. The causality analysis exposed the bidirectional causality between energy intensity

and carbon emissions. The unidirectional causal relation is found running from economic growth and financial development to CO<sub>2</sub> emissions. This suggests that carbon emissions can be reduced at the cost of economic growth or energy efficient technologies should be encouraged to enhance domestic production with the help of financial sector. Economic growth and financial development Granger causes energy intensity which suggests that adoption of energy conservation would not adversely affect economic growth. Again, financial sector must fix its focus on the allocation of funds to those firms which adopt environment friendly technologies and encourage the firms to use more energy efficient technology for production purpose and hence to save environment from degradation.

The rising trend of carbon emissions in current momentum is a debatable issue in case of Portugal. To overcome this controversial issue, there is a need of comprehensive economic, financial and energy policy reforms to sustain economic growth by developing domestic financial sector. This present study has some limitations about other potential determinants of CO<sub>2</sub> emissions. Future research may be conducted by investigating the relationship between renewable energy consumption, nonrenewable energy consumption, economic growth and carbon emissions following (Tiwari 2011a, b). Other variables may also be included in model as potential determinants of carbon emissions such as urbanisation, (Hossain 2011); trade openness, (Hossain 2011); intra-industry trade (Leitão 2011); foreign direct investment, (Pao, Tsai 2011a); exchange rate / terms of trade (Jalil, Feridun 2010); interest rate (Karanfil 2009); population or population density (Himayatullah *et al.* 2009) and industrialization (Zhang 2011) to examine relationship between economic growth, energy intensity and CO<sub>2</sub> emissions in case of Portugal.

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