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Zeqiraj, Veton; Sohag, Kazi; Soytas, Ugur

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Stock Market Development and Low-Carbon Economy: The Role of Innovation and Renewable Energy

Veton Zeqiraj

Faculty of Economics, University of Prishtine, pn. 10000, St. Agim Ramadani, Kosovo.
Central Bank of the Republic of Kosovo, Garibaldi Street No. 33 Prishtine, Kosovo
veton.zeqiraj@uni-pr.edu

Kazi Sohag[1]
Graduate School of Economics and Management
Ural Federal University, Russia;
&
Center of Research Excellence in Renewable Energy and Power Systems, King Abdulaziz University, Jeddah, Saudi Arabia

Email: sohagkaziewu@gmail.com

Ugur Soytas

Department of Business Administration, Middle East Technical University,

Cankaya, 06800 Ankara, Turkey

soytas@metu.edu.tr

&

Department of Technology, Management and Economics, Denmark Technical University, Copenhagen, Denmark

uguso@dtu.dk

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[1] Corresponding Author

Stock Market Development and Low-Carbon Economy: The Role of Innovation and Renewable Energy

Abstract

We examine the effect of stock market development (SMD) on the low-carbon economy (LCE). We consider two channels, renewable energy and technological innovation, by which this affect occurs. We use the cross-sectional autoregressive distributed lags (CS-ARDL) approach to analyse panel time-series data over the period 1980-2016 for European Union member countries. We demonstrate that SMD impedes LCE in the long run. In contrast, technological innovation (TI) is found to be a driving factor in achieving LCE in the long run. Our results also support the argument that renewable energy consumption and production enhance LCE. Stock market development fosters LCE through the channels of renewable energy and technological innovation. Overall results are robust to the conditions of short- and long-run homogeneity and the cross-sectional dependence in the sample. Our results pose important policy implications.

Keywords: CS-ARDL; innovation; low-carbon economy; market capitalisation; European Union

1. Introduction

The smooth transition towards a more sustainable economic and social system requires development of sound and sustainable financial systems. The financial system is basically composed of the banking sector and the capital markets. In developed countries the main driver of the financial system is the stock market, whereas in developing countries the financial systems rely more heavily on the banking sector. This paper focuses on how the stock market is related to the carbon emission burden of the economy in EU member countries. To assess the true impact of the stock market changes on the emissions, it is important to understand the channels through which the two are related.

The goal of scrutinising the role of stock market development (SMD) in achieving a low-carbon economy (LCE) in EU countries via the channels of renewable energy (RE) and technological innovation (TI) is motived by several important factors. First, financial development (FD) can influence energy demand, carbon emissions, and carbon intensity. For instance, FD, including stock market development, increases economic activity by mobilising capital, a higher inflow of foreign investment, and local investment, and consequently, promotes energy demand and carbon emissions. Some studies in the literature argue that financial development augments foreign direct investment to enhance economic growth, hence financial development indirectly elevates carbon emissions through the channel of higher energy use (Javed and Sharif, 2016; Frankel and Romer, 1999; Zhang, 2011). A well-run financial system in an economy reduces market friction and enhances allocative efficiency. Sadorsky (2010) points out that FD helps the economy in a number of ways, including reducing financial risk and transactional costs, enhancing transparency between economic agents, promoting access to investment, technological innovation, increases in energy demand, and improving energy efficiency. Further, Sadorsky (2010) documents that FD fosters energy demand as it makes it easier for consumers to take out a loan to purchase a car, a house, and household appliances. SMD in particular makes it easier for companies to obtain capital and equity financing for their investments, which eventually promotes activities in several different industries, including energy, renewable energy, research and development (R&D), and manufacturing. A developed stock market increases the wealth effect, which in turn influences consumer and business confidence (Mankiw and Scarth, 2008). The stock market is often regarded as a key economic indicator and increased stock market activity is perceived as a sign of economic growth and prosperity, which reinforces consumer and business confidence. Many studies stress the importance of measuring the effect of financial development on carbon emissions (Tamazian et al., 2009; Tamazian & Bhaskara Rao 2010; Zhang, 2011; Dogan & Seker 2016; Salahuddin et al., 2018; Khan et al., 2019; Acheampong, 2019, Acheampong et al. 2020) and energy consumption (Sadorsky, 2010, & 2011; Jalil and Feridun, 2011; Acheampong, 2018). However, little is known about the direct impact of market capitalisation on carbon intensity or an LCE in member countries of the European Union (EU).

Second, many empirical studies document that renewable energy (RE) and technological innovation (TI) improve energy efficiency and reduce carbon intensity. To produce RE and efficient technologies requires capital investment, while many investors may hesitate to participate in RE and TI industries because of high risk and low return expectations. Hsu, Tian, and Xu (2014) argue that the production process of RE and TI are not only long, distinctive, and fickle but it also involves uncertainty. Moreover, RE and TI require a large initial investment and private funding sources are often unable to finance such large projects. Interestingly, a recent study by Al-Mamun et al., (2018) provides evidence that financial market development, including stock market development increases the share of renewable energy in member countries of the Organisation for Economic Co-operation and Development (OECD). In addition, Hsu, Tian, and Xu (2014) provide a cross country evidence that financial development spurs innovation in the context of developed and emerging countries. Given the findings of Al Mamun et al. (2018) and Hsu, Tian, and Xu (2014), we conjecture that a well-developed and efficient stock market plays a role in influencing carbon intensity through the channel of renewable energy and technological innovation. This is consistent with the opinion expressed by Stiglitz (2002) that sustainable development is compatible with renewable energy. In addition, the International Energy Agency (IEA, 2015) predicted that renewable electricity generation will increase by more than one-third by 2022 and the share of electricity production from renewable energy sources will increase by 40% globally by 2050. Renewable energy is one of the most effective tools in mitigating global climate change. Thus, a financial system that generates efficient funding opportunities for renewable energy investments is crucial if we want to limit the rise in global temperature to within 2.0° C (IEA, 2017).

Another stream of the literature argues that technology innovation is crucial for improving energy efficiency (Fisher-Vanden et al., 2006; Hang and Tu, 2007; Li and Lin 2014; Samargandi, 2017). Fisher-Vanden et al., (2006) document that technological advancement coupled with higher relative price of energy, R&D expenditure and reform of property law are driving factors in augmenting energy productivity and reducing carbon emission in Chinese economy. A recent study by Malinauskaite et al., (2019) argues that technological progress and various renewable energy sources including the technology for industrial waste heat improve energy efficiency in EU member countries. *RE* is generally regarded as an environmentally friendly source of energy and a potential candidate for replacing fossil fuels (Ari and Koksal, 2011). Lopez-Menendez et al. (2014) argue that the generation of *RE* significantly ramped up for several reasons, e.g., compatibility with a healthy environment, reduction of air pollution, and renewability. Kumar (2016) confirms that RE helps to reduce CO_2 emissions. Energy efficiency in return may also help reduce the environmental impact, provided that there are no significant rebound effects that offset the emission reductions. Depending on the overall impact of energy efficiency on emissions, the role of SMD in promoting a LCE via this channel is expected to change. Based on the discussions above, we assume that stock market development can influence carbon intensity through the channel of renewable energy and technological progress[2]. By synthesising this notion, we can conclude that stock market development can influence carbon intensity through the channel of RE and TI directly as well as indirectly.

Third, total contribution of EU countries to global climate change is high, but the EU aims to progressively cut back emissions till 2050. The EU emphasises the importance of both renewable energy and green technology for reducing carbon intensity (CI). According to the updated Energy Efficiency Directive, the target for 2030 energy efficiency is 30% and the EU pledged to reach 20% renewable energy (RE) in the total energy mix and 10% RE in the transport sector to decrease carbon intensity. In addition, the European Strategic Energy Technology Plan (SET-Plan) was set up to develop low-carbon technologies and make them economically viable to ensure smooth transition towards a LCE. It aims to accelerate the uptake of new technologies such as next-generation wind turbines and bioenergy by reducing their costs and increasing efficiency. As parallel activities, many EU countries adopted action plans including the improvement of the capital market to encourage investments in low-carbon technologies and renewable energy sectors (Al Mamun et al., 2018). To assess whether the renewable energy and energy intensity targets can be met or not and to design a financial system to facilitate necessary investments, one has to understand how SMD works through these channels in the EU. For example, many EU member countries have taken several initiatives to transform their economy into an LCE including use of renewable energy (Bölük & Mert, 2014). There are many public and private limited companies with Initial Public Offering (IPO) in EU accumulating capital through stock market operation e.g., Abengoa S.A.; Acciona ; Anemos Energy Corporation; Centrosolar Group AG; Centrotherm Photovoltaics AG;

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[2] Campiglio, E. (2016); Sadorsky, 2013; Ma & Stern, 2008; Adom & Amuakwa-Mensah, 2016; Li & Lin, 2014;Adom, 2015; Adom & Kwakwa, 2014; Elliott, Sun, & Chen, 2013; Zheng, Qi, & Chen, 2011; Bhattacharya et al., 2017.

Conergy AG; Dongfang Electric; Enel Green Power S.p.A.; Energiekontor AG; EDP Renováveis, S.A.; Finavera Renewables, Inc; Gamesa Corporación Tecnológica; Good Energy Group plc; Green Plains Renewable Energy, Inc; Iberdrola Renovables SA; Kedco plc; Neoen; Nordex AG; Ormat Technologies Inc; Phoenix Solar AG; PV Crystalox Solar plc; Run of River Power Inc; SMA Solar Technology, AG; SolarWorld AG; Terna Energy; Vestas Wind Systems; Ørsted (company). Figure 1 shows that many EU member countries are using more than 20% of renewable energy in the total energy mix, e.g., Austria, Denmark, Finland, Croatia, Portugal and Sweden.

[Insert Figure 1 Here]

This study contributes to the literature in 3 ways. First, to the best of our knowledge, no major studies to date have focused on measuring the role of stock market development on carbon intensity (LCE), corroborating the roles of RE and TI in the context of EU member countries. Second, we incorporate renewable energy consumption and production hence attempt to measure the impact from both the supply and demand points of view. Third, because EU member countries are closely connected by geographic location, trade, and financial integration, we account for the potential cross-sectional dependency issue. We applied the CS-ARDL approach, which is robust in the presence of misspecification bias, serial correlation of error terms, cross-sectional dependency, non-stationarity, and the endogeneity bias problem, unlike other panel ARDL approaches. The CS-ARDL also addresses the arbitrary integration order problem. Our analysis provides short- and long-run coefficients along with error-correction mechanisms. This study demonstrates that stock market development seem to augment carbon intensity if the appropriate channels are not explicitly considered. We provide empirical support that stock market development helps in achieving an LCE by advancing renewable energy and technological innovation.

The remainder of the paper is organised as follows. Section 2 outlines our model specifiation, data, and methodology. Section 3 provides the sample descriptive statistics, the panel unit-root test and the main results. Section 4 concludes and provide policy implications.

2. Model Specification, Data, and Estimation Framework

2.1 Specification

We develop the following framework based on the review of the literature. The framework shows that stock market development is directly and indirectly associated with carbon intensity (Figure 2). Stock market development indirectly influences CI by increasing RE and TI. However, we also consider the gross domestic product (GDP) as a scale effect on carbon intensity. In addition, this study accounts for the role of trade openness as it enhances international competitiveness, which may reduce carbon intensity by spurring efficiency. Moreover, trade openness enhances the diffusion of technological innovation.

[Insert Figure 2]

Our framework can be tested by estimating the following models.

$$CI_{i,t} = \beta_0 + GDP_{i,t} + TO_{i,t} + SMD_{i,t} + REC_{i,t} + SMD_{i,t} * REC_{i,t} + E_{i,t}. \quad (1)$$

Model 1 shows that carbon intensity (CI) is a function of GDP, trade openness (TO), stock market development (SMD), renewable energy consumption (REC), technological innovation, and the interaction of SMD and REC. The joint effect specifically measures the joint elasticity of stock market development along with renewable energy consumption. Since we consider the consumption of renewable energy hence, model 1 portrays the demand side of the market.

$$CI_{i,t} = \beta_0 + GDP_{i,t} + TO_{i,t} + SMD_{i,t} + REP_{i,t} + SMD_{i,t} * REP_{i,t} + E_{i,t} \quad (2)$$

We develop model 2, where CI is the function of GDP, trade openness (TO), stock market development (SMD), renewable energy production (REP), and the interaction of SMD and

REP. Model 2 incorporates the role of renewable energy production (REP) highlighting the impact of supply side of the renewable energy market on carbon intensity. The interaction effect of SMD and REP measures the joint elasticity of stock market development along with renewable energy production on carbon intensity. Our disaggregate analysis of demand and supply sides provide distinct set of policy implications by stressing on demand-induced supply of renewable energy. In addition, our empeircal investigation would be able to demonestrate the magnitude of impacts from reneable energy consumption as well as production seperately.

$$CI_{i,t} = \beta_0 + GDP_{i,t} + TO_{i,t} + SMD_{i,t} + TI_{i,t} + SMD_{i,t} * TI_{i,t} + E_{i,t} \qquad (3)$$

Model 3 shows that GDP, TO, SMD, TI, SMD and TI jointly explain CI.

2.2. Data and Sources

Using a sample of 23 EU member countries[3], we examine the role of market capitalisation (as a proxy of stock market development) on carbon intensity (CI) as a proxy for a low-carbon economy (LCE) for the period 1980-2016. In this study, we specifically focus on stock market development, instead of other measures of financial market development, because the EU's market capitalisation is about 77.9% of its nominal GDP by December 2017, including companies focused on renewable energy and technological innovation. Moreover, most of the sample countries use a common currency. However, renewable energy requires a long-term financing commitment. Hence, we consider the stock market capitalisation of the listed companies as the sole measure of the stock market development[4].

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[3] Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

[4] We use a natural logarithmic transformation of market capitalization as our measure of equity market development; however, our results hold by using market capitalisation as a percentage of GDP as well.

We also consider the role of renewable energy (RE) and technological innovation (TI) in linking MC and LCE. Concerning the demand and supply sides of the economy, we use both renewable energy production and renewable energy consumption as a robustness check. As for the control variables, we incorporate GDP per capita (GDPC) to determine whether it is conducive to achieving an LCE. We account for the role of trade openness, as it enhances international competitiveness, which may reduce carbon intensity by spurring efficiency. We transform all our variables by taking the natural log to reduce any abnormal size effect in our estimation. Table 1 provides the variable definitions and their sources.

[Insert Table 1]

2.3. Cross-Section Dependence, Panel Unit-Root Tests, and CS-ARDL

We have applied the cross-sectional dependency (CD) test developed by Pesaran et al., (2008) because our sample countries are related through several economic, social, and cultural networks, and hence generate spill-over effects. The null hypothesis is the existence of cross-sectional independence among the sample countries, while the alternative hypothesis is the presence of cross-sectional dependence among the sample countries.

The equation of the test statistic is as follows:

$$CD = \left(\frac{TN(N-1)}{2}\right)^{1/2} \bar{\bar{P}} \tag{4}$$

where $\bar{\bar{P}} = \left(\frac{2}{N(N-1)}\right)\sum_{i-1}^{N-1}\sum_{j=i+1}^{N}\hat{P}_{ij}$ and $\hat{P}_{ij}$ indicate the pair-wise correlation coefficient of the cross-sectional residuals obtained from the augmented Dickey-Fuller (ADF) regression. T and N indicate the time and cross-section dimensions, respectively. After obtaining the results from the CD test, the cross-sectional augmented Dickey-Fuller test known as CIPS (cross-sectionally augmented panel unit root) has been applied to examine the order of integration. The CIPS approach is referred to as the second-generation panel unit-root tests, which are developed to account for the presence of cross-sectional dependency (Pesaran, 2007;

Moon & Perron, 2004; Bai & Ng, 2004). The CIPS method can be applied using the following procedure.

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{it-1} + \gamma_i \bar{Y}_{t-1} + \phi_i \Delta \bar{Y}_t + \varepsilon_{it} \qquad (5)$$

Here, $t=1, \ldots, T$, $i = 1, \ldots N$, and $\bar{Y}_t$ indicates the mean of the cross sections and is derived from $\bar{Y}_t = N^{-1} \sum_{i=1}^{N} Y_{it}$. The insertion of the mean value mitigates the contemporary correlation among Y_{it}. The null hypothesis of Eq. (5) is $\mathrm{H}_0: \beta_i = 0$ for all i, and the alternative hypothesis is $\mathrm{H}_1: \beta_i < 0$ for some i. The CIPS test is given by Pesaran (2007) as follows:

$$CIPS\,(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T), \qquad (6)$$

where $t_i(N,T)$ indicates the t-statistics for β_i.

The variables in the study are likely to be cross-sectionally dependent because the EU countries have so much in common. Moreover, they are connected through trade relations, financial integration, and information and communication technologies. Therefore, we apply the CS-ARDL estimation technique developed by Chudik and Pesaran (2015) to estimate the models under consideration. The CS-ARDL is an updated version of the pooled mean group by Pesaran et al. (1999), and its framework includes a long-run parameter, a short-run parameter coupled with the error correction coefficient, and a cross-sectional mean for each respective variable both in the short and the long run. The CS-ARDL can address the potential endogeneity, serial correlation, and common correlation-bias problems.

To compute the effects of the unobserved common factors, this approach applies unit-specific ARDL specifications, which helps in estimating the long-run effects indirectly. In the presence of unobserved common factors, the CS-ARDL is recommended for its efficiency (Chudik et al., 2016). This approach is well known for addressing the cross-sectional dependency in both the short and long run. The estimators of the mean group are based on the standard CS-ARDL assumption; therefore, they are asymptotically unbiased as $N \to \infty$ for both fixed T and $T\rightarrow\infty$. We estimate the three different versions of CS-ARDL to capture the probable cross-sectional bias independently in the short run, in the long run, and together in the short and long run.

Hence, the baseline regression equations for the CS-ARDL are given as following:

$$\Delta CI_{it} = \mu_i + \varphi_i(CI_{it-1} - \beta_i X_{it-1} - \phi_{1i}\overline{CI}_{t-1} - \phi_{2i}\bar{X}_{t-1}) + \sum_{j=1}^{p-1} \lambda_{ij}\Delta CI_{it-j} + \sum_{j=0}^{q-1} \zeta_{ij}\Delta X_{it-j} + \eta_{1i}\Delta\overline{CI}_t + \eta_{2i}\Delta\bar{X}_t + \varepsilon_{it}, \qquad (7)$$

where ΔCI_{it} is the dependent variable, X_{it} represents all independent variables in the long run, $\overline{CI}_{t-1}$ is the mean of the dependent variable in the long run, $\bar{X}_{t-1}$ is the mean of independent variables in the long run, ΔCI_{it-j} is the dependent variable in the short run, ΔX_{it-j} is the independent variables in the short run, $\Delta\overline{CI}_t$ is the mean of dependent variable in the short run, $\Delta\bar{X}_t$ is the mean of the independent variables in the short run, and ε_{it} is the error term. Note that j stands for the cross-sectional dimension, where $j = 1,..., J$, time $t = 1, ……, T$ and β_j represent the coefficients of the independent variables, λ_{ij} is the short-run coefficient of the dependent variable, ζ_{ij} are the short-run coefficients of the independent variables, and $\eta_{1i}\ and\ \eta_{2i}$ represent the means of the dependent and the independent variables in the short run.

3. Results and Discussion

3.1. Descriptive Analysis

Table 2 reports the descriptive statistics. The logarithmic mean value and standard deviation (std. dev.) of carbon intensity (CI) are 0.864 and 0.263 respectively, indicating the observations vary from the mean within a small range. The mean value of GDPC is 10.019 while the standard deviation is 0.776, which implies that GDPC varies within a narrow range over time and across EU member countries. However, the standard deviation of SMD (share of GDP) is high as

44.055, indicating that market capitalization follows a skewed distribution across the EU. Thus, the mean values of REC and REP and the standard deviations are very high, indicating high heterogeneity in renewable energy consumption and production output among the sample countries. Results in Table 2 also suggest little variation in technological innovation among the sample countries.

[Insert Table 2]

Table 3 highlights the coefficients of correlation along with statistical significance (p-values) of all variables. Interestingly, CI is negatively and significantly correlated with MC, which is in line with our expectation. In addition, CI is also negatively and significantly correlated with GDPC, which is contrary to our assumption. As expected, TI and CI are negatively and significantly related, but the coefficient is smaller. Importantly, REC and REP are both inversely correlated with CI, which is consistent with our assumption. Overall, our results from the correlation matrix in Table 3 provide the first sign of a possible negative effect of MC on carbon intensity.

[Insert Table 3]

At this stage, we investigate the cross-section dependency on our variables. Table 4 reports the results. It is important to detect the presence of CD for selecting appropriate framework to analyse our models. Pesaran (2004) argues that standard econometric techniques for analysing panels often cannot overcome the bias that occurs because of the presence of CD. The results of the CD test are presented in column 2 in Table 4. The CD statistics in Table 4 are highly significant for all the variable in the sample countries, indicating that all variables are cross-sectionally dependent. Notably, the CD statistics are high for *GDPC* but low for *SMD*. Because we detect the strong presence of CD in our variable, we apply a second panel unit-root approach (CIPS) by Pesaran (2007) to investigate the order of integration of each variable. The primary feature of CIPS test is that it is cross-sectionally unbiased. Note that the investigation on the order of integration is another important determinant in selecting the estimation technique. We found that variables follow a mixed order of integration. The presence of CD and mixed-order integration supports the use of a CS-ARDL framework to analyse our models.

[Insert Table 4]

3.2. Empirical Findings

To measure the dynamic impact of stock market development on carbon intensity incorporating the role of renewable production, we apply the CS-ARDL approach. The second, third, and last columns in Table 5 report the results obtained from model 1 after addressing CD in the short run, long run, and both short and long run respectively. However, we focus on the results in the last column in Table 5 as economic spill-over occurs in the short and long run among EU member countries. We find the coefficient of ECM is negative and significant, which conforms to the long-run equilibrium by adjusting 19% per year after any economic shocks. Perhaps the speed of adjustment to equilibrium is faster in our model due to higher resilience of our sample economies from any shock coupled with a high degree of integration and high level of development.

The positive and significant coefficient of GDPC indicates that it increases carbon emissions. Our finding implies that the scale effect is positive towards carbon intensity in the long and short run. The positive relation between GDPC and CI coincides with findings in numerous studies (e.g., Omri, 2013; Alkhathlan & Javid, 2013; Lotfalipour et al., 2010; Pao &

Tsai, 2011; Ang, 2008). A higher volume of economic activities increases energy consumption; thus, carbon emissions increase at a similar magnitude. The impact of trade openness is found to be insignificant with respect to carbon intensity. The inconclusive impact of TO can be explained by the fact that it has multiple impacts on CI. TO increases local energy demand but at the same time it increases competitiveness. Therefore, the negative impact of TO is offset by the positive impact, translating into an insignificant coefficient. Another explanation could be that pollution haven hypothesis does not hold for EU countries. EU member countries do not seem to shift their carbon intense production abroad and rely on imports for those products.

The coefficient of stock market development is positive and significant, indicating that an increment of market capitalisation promotes carbon intensity in the long and short run. This finding is consistent with our argument that FD increases carbon intensity by increasing the demand for and consumption of fossil fuel. For instance, Sadorsky (2010) highlights that FD enables consumers to borrow money for buying cars, gasoline, and household appliances, hence a higher consumption of energy leads to higher carbon emissions. Specifically, SMD promotes business activities through higher investment. This finding confirms several other studies as well. For instance, Javed and Sharif (2016), Frankel and Romer (1999) and Zhang (2011) argue that financial development augments foreign direct investment to enhance economic growth, hence financial development indirectly elevates carbon emission through the channel of higher energy use. Particularly, financial development expands the use of consumer loans, which enable consumers to purchase energy intensive devices like automobile, air-conditioners and other electronic appliances. Therefore, FD augments carbon emissions through increasing use of household energy consumption. The positive role of SMD on carbon intensity is also consistent with the findings by Tamazian et al. (2009); Tamazian and Bhaskara Rao (2010); Zhang (2011); Dogan and Seker (2016), and Salahuddin et al. (2018).

As expected, Table 5 shows that the long-run coefficient of REP is negative and significant, implying that it reduces carbon intensity. Our finding is consistent with many empirical studies that establish an inverse relationship between renewable energy and carbon emissions. For instance, Kumar (2016) documents that RE reduces carbon emissions. Stiglitz (2002) also argues that RE is the driving factor in accomplishing the sustainable development agenda. Because renewable energy sources, such as solar, wind, and hydropower are non-carbon forms of energy, which can increase economic growth without harming the environment. The interaction of stock market development and renewable energy production is negatively related with carbon intensity in the long run, implying that SMD reduces carbon intensity through the REP channel. Our investigation partially coincides with the findings by Al Mamun et al. (2018), who demonstrate the positive and significant impact of financial development on renewable energy. The joint negative effect of SMD and REP clearly demonstrates our framework, that the impact of SMD on CI is conditional. The finding implies that when SMD is conducive in promoting REP, it can reduce carbon intensity.

[Insert Table 5]

At this stage, we estimate model 2 by considering renewable energy consumption to observe the impact of demand-induced renewable energy on CI. Our findings in Table 6 are consistent with model 1. The coefficient of EC is negative and significant, confirming the stability of model 2. Interestingly, the EC is greater in model 2 than in model 1. The finding implies that the speed of adjustment in the demand side of the economy of RE is higher in converging to the equilibrium. The estimated coefficient of SMD appears to be positive and significant at the 5% level, demonstrating that stock market development accelerates carbon intensity. Nevertheless, the negative and significant coefficient of REC implies that it reduces carbon intensity and promotes an LCE in the long run. Given expectations, Table 6 reports a negative and significant coefficient (joint) of the interaction between SMD and REC. This shows that the SMD has a synergistic impact on the role of REC in reducing carbon intensity. Our findings imply that renewable energy functions consistently from the demand and supply perspective in EU economies. Estimated results obtained from models 1 and 2 are in perfect harmony, confirming the robustness of our findings.

[Insert Table 6]

At this stage, we estimate model 3, focusing on the impact of SMD by incorporating the role of technological innovation in carbon intensity. Table 7 reports the results. Consistently, the estimated coefficient of GDPC is positive and significant in explaining long-run carbon intensity. However, trade openness becomes positive and significant with respect to carbon intensity. The positive and significant coefficient of SMD implies that it fosters carbon intensity directly. Prior literature found that SMD helps listed enterprises to reduce financing costs, expands financing channels, reduces operating risks, and improves the asset-liability ratio, so as to benefit new shares and invest in new projects and then intensify energy use and CI (Dasgupta et al., 2001).

[Insert Table 7]

Nevertheless, technological innovation is negative and significant, indicating that it is conducive to reducing carbon intensity in the long run. TI reduces CI by creating energy efficiency in advanced and efficient technologies and advanced equipment, entailing substantive capital investment, and alterations in the structural composition of the economic growth paradigm. Technological innovation is critical to improving energy efficiency and reducing carbon intensity (Fisher-Vanden et al., 2004; Brock & Taylor, 2005; Hang & Tu, 2007; Zhou, Levine, & Price, 2010; Sohag et al., 2015). The interaction effect of SMD and TI is negative and significant with respect to carbon intensity. This shows that SMD improves the role of TI in reducing CI. Our finding is partially consistent with findings by Hsu, Tian, and Xu (2014), who demonstrate that financial development spurs innovation. Tamazian et al. (2009) document that financial development helps listed companies to encourage technology innovation, so as to intensify energy efficiency and promote an LCE. In addition, Claessens and Feijen (2007) reveal that FD may increase company performance and then reduce energy use and carbon emissions. Thus, our findings clearly demonstrate that SMD can reduce carbon intensity through the channel of technological innovation.

4. Robustness Check

[Insert Table 8]

CS-ARDL method would be criticized in terms of imposition of long run homogeneity restriction on the long run parameters when the panel countries are diverse in terms of the size and structure of the economies. We account the fact that European union member countries are subject to certain level heterogeneities in terms of economic size, financial markets, trade openness, technological innovation, energy structure despite many similarities. Thus, we apply Common Correlation Effect- Mean Group (CCEMG) developed by Pesaran (2006) which allows the parameters can be heterogenous in the long run. Table 8 confirms validity of our findings from CS-ARDL as the interactions of SMD and REC, SMD and REP and SMD and TI are negative and significant respectively.

5. Conclusions

The development of a sound stock market is important in realising an LCE by underpinning the production and consumption of renewable energy, technological innovation, and efficiency. We investigate the role of stock market development in promoting an LCE (reducing carbon intensity) in EU member countries using a robust methodology.

Our analysis has several interesting findings. First, SMD has three impacts on carbon intensity: SMD significantly increases carbon intensity in both the short and long runs; SMD reduces carbon intensity through the channel of renewable energy (both production and consumption); and SMD reduces carbon intensity through market capitalisation–induced technological innovation. The overall impact depends on the size of the three affects.

Second, GDP growth also increases carbon intensity in both the short and long run. Third, trade openness promotes carbon intensity by increasing international demand in the short and long run. Fourth, both renewable energy production and consumption are negatively related to carbon intensity in both the short and long run. Fifth, technological innovation is conducive to achieving an LCE by reducing carbon intensity.

Our findings provide a few crucial policy implications. The development of a stock market, accompanied by energy and environmental policies, is an important step in reducing carbon intensity and achieving a low-carbon economy. A developed stock market facilitates capital acquisition of firms, making it easier for them to acquire capital necessary for investments. A lower cost of capital is also essential for renewable energy investments as they involve high initial costs. Therefore, emphasising development of the stock market to fund renewable energy industry should be a key priority for policy makers in order for firms to increase the production of renewable energy to reduce greenhouse gases and achieve a low-carbon economy. For example, socially responsible funds or renewable energy funds may facilitate and improve the role of SMD on RE investments by making it easier for RE firms to acquire capital. Promoting responsible financial investments may also benefit RE firms. Our finding highlighting the conducive role of technological innovation implies that stock market development should be coupled with government policy to promote the innovation to ensure the energy efficiency. RE technologies are improving rapidly. These improvements led solar and wind energy to become competitive without subsidies. Which in turn made RE stocks attractive from an investor's point of view. Hence, promoting TI may further boost interest in RE stocks, shorten the capital acquisition period and cost of capital of RE firms. In sum, designing policies that focus on RE and TI channels of SMD can improve sustainability.

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