ANALYZING THE IMPACT OF ECO-INNOVATION ON CARBON EMISSIONS ABATEMENT: EVIDENCE FROM OECD COUNTRIES

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ABSTRACT

This present study aimed to assess the impact of eco-innovation on carbon emission abatement in OECD countries. However, 34 OECD countries were sampled in a panel to carefully understand the phenomenon. The data for the study were sourced from OECD database and World Bank's World Development Indicators from 2005 to 2018. Numerous econometric approaches were followed to arrive the conclusion of this study. Econometric approaches such as unit root rests, correlation matrix, cointegration test, Granger causality test, ordinary least square regression method, and fully modified ordinary least square regression method. The findings of the study suggest that eco-innovation could positively and negatively impact carbon emission abatement regarding the kind of proxy used. From the findings, it was realised that energy intensity, and patents positively impact carbon emission abatement, hence a percentage point increase in energy intensity could lead to an increase in carbon emission by 0.677% and 0.705% while a percentage increase in patent could also lead to 0.073% and 0.087% of carbon emission, respectively. On the other hand, research and development expenditure seemingly contribute to carbon emission abatement, where a percentage point increase in research and development expenditure could lead to 0.032% carbon emission abatement. This implies that increase in real income could encourage research and development and reduce energy intensity. Moreover, to ensure low carbon economy, conservation policies that support reduction in energy intensity, strengthening of environmental regulations, and improving research and development should be encouraged.

Contribution/Originality: This study contributes to the existing literature, and assessed the impact of eco-innovation on carbon emission abatement in OECD countries. The findings of the study suggest that eco-innovation could positively and negatively impact carbon emission abatement regarding the kind of proxy used.

1. INTRODUCTION

A number of studies have recently focused on the relationship between energy use, economic growth and pollution of the atmosphere (Smulders & Bretschger, 2000) but far less attention has been paid to the correlation between eco-innovation (i.e. research and development) and the reduction of CO2 emissions. A literature review shows that the majority of these studies are observational and represent the policies declared by the countries rather than the actual individual success of these countries (Schultze & Trommer, 2012) while the academic debate continues. The sustainability of economic development has become a crucial priority for most economies in recent decades. The top refined oil exporting countries are committed to reducing greenhouse gases (GHG) down to the

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target level, in line with the goals set by the Kyoto Protocol in 1997 and the Paris Agreement in 2015 associated with environmental pollution and global warming. Countries such as the United States, Russia, Canada, Japan, and developing countries, however, have not signed the Doha Amendment-the second commitment duration of the Kyoto Protocol. It is important to remember that a global agreement is required to be in place to tackle climate change and minimize environmental emissions by the world's largest emitters. Researchers and practitioners who are vigorously looking for effective ways of reducing global carbon emissions have long been of great interest in and empirically studied this issue.

To achieve this goal, greenhouse gas emissions must be stabilized or reduced, which requires transitioning to a low or zero carbon production system. Innovation has emerged within this context as a key factor in achieving an efficient energy market and at the same time, in ensuring the sustainable growth of every economy (Fernández, López, & Blanco, 2017). Innovation 1 is one of the most critical methods for achieving this systemic change. Schumpeter (1934) claimed that it is creativity that drives economic growth. Nevertheless, it was after Solow's (1957) work that innovation and technological progress took a growing role as a catalyst for economic growth in advanced economies. There is ample literature in the theory of economic growth that ties economic growth to the accumulation of knowledge either through learning or R&D investment (R&D) (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1986; Romer, 1990; Young, 1991). According to the endogenous economic growth model, through the use of human resources and the stock of established expertise, the R&D sectors establish technical innovation (Romer, 1986). In fact, economic theory considers it necessary for economic growth to accumulate R&D.

The purpose of this study is to analyze the role of eco-innovation in reducing carbon dioxide (CO_2) emissions in the expanded view of the Kuznets Environmental Curve (EKC) for the 34 OECD countries. Based on the above-mentioned observations, the findings of the present empirical analysis are manifold. The study breaks new ground by exploring, in the STIRPAT model, the effect of real GDP, energy intensity, renewable energy, foreign direct investment, patent rights and R&D on CO_2 emissions for the 34 OECD countries.

The study encompasses five sections, thus section one outlines the introduction of the study; section two entails the literature review; section three explains the methodology of the study; section four presents the findings, and section five emphasizes on the conclusion and findings discussion.

2. LITERATURE REVIEW

Since the first ground-breaking research by Kraft and Kraft (1978) the different ways in which the relationships between energy use and real income growth (i.e. economic growth) affect environmental pollution have already been subject to substantial empirical inspection in the energy literature. The positive effects of energy usage and economic development on CO_2 emissions were found in several studies that followed (Ang, 2008; Katircioğlu, 2014; Ozturk & Acaravci, 2010; Soytas, Sari, & Ewing, 2007; Zhang & Cheng, 2009). This is called the destruction of the climate. Some research, however, looked at the validity of the environmental Kuznets curve (EKC) and presented mixed evidence as to whether the EKC hypothesis posits an inverted U-shaped relationship between environmental deterioration and per capita income (Coondoo & Dinda, 2002; Dinda, 2004; Jaunky, 2011; Luzzati & Orsini, 2009).

Other studies evaluate energy intensity evolution and whether or not it converges between countries or regions, suggesting that energy efficiency gains can be related to reducing energy intensity differences (Duro, Alcántara, & Padilla, 2010; Duro & Padilla, 2011; Liddle, 2009; Mulder & De Groot, 2012). The key factors influencing the emergence of energy intensity are defined by Mendiluce, Pérez-Arriaga, and Ocaña (2010): the changes in the economic system and the changes in the economic sectors' energy intensity. Fisher-, Jefferson, Liu, and Tao (2004) claim that creative initiative is an aspect that greatly results in the decrease in the business context of energy intensity; Porter and Van der Linde (1995) had already considered this concept in particular. In Yuxiang and Chen (2010) the decomposition of the energy consumption system and its connection to the level of public expenditure is discussed.

Balsalobre, Alvarez-Herránz, and Baños (2016) examined the effect on GHG emissions of 24 OECD countries from 1992 to 2010 of economic development, energy innovation policies and promotion of renewable sources. They demonstrate that governments' attempts to innovate and substitute oil are related to a reduction in GHG emissions. The relationship between research and development (R&D) and carbon dioxide (CO2) emissions is one of the latest research focused on by Churchill, Inekwe, Smyth, and Zhang (2019). This study examines the effect of research and development (R&D) on emissions of carbon dioxide (CO2) in G7 countries and indicates that the association between R&D and CO2 differs over time. The G7 countries or the oil refining sector make a substantial contribution to the world's real income (i.e. economic growth) and can accommodate R&D investment; therefore, technological advances can regulate the use of energy or energy consumption.

From the review of literature, this presents intend to analyse the impact of eco-innovation on carbon emission abatement, and the novelty it presents is the introduction three (3) important measures of eco-innovation as proxies to critically understand the relationship.

3. EMPIRICAL METHODOLOGY

3.1. Data

The study sourced data from the OECD data repository from 2005 to 2018 to assess the impact of eco-innovation on carbon emissions. However, the 34 OECD countries are considered in a panel study. The dependent variable of the study is carbon emission, the independent variable is eco-innovation as proxy of patent, research and development, and energy intensity. Other variables such as economic growth, foreign direct investment, renewable energy consumption, and urbanization were used as control variables following the STIRPAT model (Stochastic Impact by Regression on Population, Affluence, and Technology) model propounded by Dietz and Rosa (1994). This model is commonly used in the field of carbon emission issues, however, it is used to describe the major environmental determinants (Bi & Liu, 2016). Table 1 outlines the details of the variables used for the study.

Table-1. Variables description.

Variables	Measurement	Source
Carbon emission	Carbon dioxide per metric ton and Nitroxide emission per metric tons	OECD database
Eco- innovation	Patent, research, and development (R&D) and Energy Intensity	OECD database
	Energy intensity = primary energy use/GDP per capita	
Economic growth	GDP per capita	OECD database
Urbanization	Urban population growth rate %	World Development Indicators- World Bank
Foreign direct investment	Net inflows % of GDP	OECD database
Renewable Energy Consumption	% of total final energy consumption	OECD database

3.2. Methodology

The study utilised an econometric technique to achieve its objective; hence, proposed an econometric model in that regard. The econometric model for the study can be found below:

$$CO2_{it} = \beta_0 + \beta_1 \, Eco - innovation_{it} \begin{bmatrix} PNT \\ R - D \\ EINT \end{bmatrix} + \beta_2 \, GDP - CAP_{it} + \beta_3 \, FDI_{it} + \beta_4 \, RE_{it} + \beta_5 \, URP_{it}$$
$$+ \, \varepsilon_{it}$$

In the model, CO2 represents carbon emissions, PNT represent patents, R-D represents research and development expenditure, and EINT represents energy intensity; as proxies of eco-innovation. Also, GDP-CAP represents economic growth as gross domestic product per capita. FDI represents foreign direct investment inflows, RE represents renewable energy consumption, and URP represents urban population growth. The parameters β_0 to β_5 are the coefficients to be estimated for the variables selected for the study. On the other hand, i represents the cross-section of 34 countries, t represents the time period from 2005 to 2018, and ε represents the error term in the model.

To analyze the data, some econometric approaches were followed:

Step 1: unit root test was performed to check for the stationarity status of the variables. Checking for unit root in the variables assume that at 5% significance level, the null hypothesis of unit root must be rejected. Therefore, evidence of no unit root suggests that, the variables are stationary; hence, further analysis to estimate the long-run relationship would not amount to spurious coefficients and analysis. Moreover, the following unit root test were performed; ADF-Fisher and PP-Fisher Maddala and Wu (1999); Im, Pesaran, and Shin (2003) and Levin, Lin, and Chu (2002) tests.

Step 2: cointegration test requires a cointegration relationship between dependent and independent variables at 5% significance level. Therefore, evidence of cointegration relationship suggests that there is a long-run relationship between the dependent and the independent variables. However, the performance of regression analysis could further reveal the long-run coefficients and relationship. In spite of this, Pedroni (2000) and Kao (1999) cointegration tests were performed.

Step 3: the next approach was to compute for correlation matrix. Correlation matrix reveals two important statistical information. The first information is, correlation connection between the dependent and the independent variables, and the second information is collinearity information. To ensure the variables are free from collinearity or multicollinearity, Sun, Tong, and Yu (2002) suggest that no two independent variables should have correlation coefficients of -/+0.70 with the dependent variable. However, correlation matrix was computed in that regard.

Step 4: The study performed Granger causality test as the fourth step to reveal the direction of causality of the variables. Identifying the direction of causality provides keenly information for policy direction and also throws more light into the long-run estimation. Two directions are expected from the Granger causality test, thus unidirectional and bidirectional. The unidirectional causality suggests that one variable causes another, but the bidirectional causality suggests that both variables cause each other at any variation vice versa.

Step 5: at this stage, the regression analysis is performed to ascertain the long-run relationship between the dependent and the independent variables. For that reason, the ordinary least square regression method was employed for the long-run estimation. But for the limitation of the ordinary least square regression method to check for cross-sectional heterogeneity, and serial correlation (Kao & Chiang, 2000). Pedroni (2000); Pedroni (2001) proposed the fully modified ordinary least square regression method as the best estimator over the ordinary least square with the strength of overcoming the problem of cross-sectional heterogeneity, simultaneity, and serial correlation.

4. FINDINGS AND DISCUSSIONS

Table 2 presents the descriptive statistics of the selected variables for the study. From the table, it reports that the average rate of carbon emissions in the OECD countries from 2005 to 2018 was 2.041%, research and development expenditure increased annually at an average of 0.478%, patent registration increased by an average of 5.143% annually, energy intensity fell by 12.698 averagely per annum. Also, economic growth for the OECD

countries grew at an average of 10.486% per annum, and foreign direct investment inflows increased annually at an average of 8.443% while urbanization or urban population fell by an average of 0.138% per annum.

Table-2. Descriptive statistics.

	CO2	R_D	PNT	EINT	RE	GDP_CAP	FDI	URP
Mean	2.042	0.478	5.143	-12.698	2.362	10.486	8.443	-0.138
Median	2.028	0.523	5.565	-12.669	2.319	10.525	9.258	0.000
Maximum	3.207	1.598	9.868	-11.410	4.497	11.667	13.090	1.170
Minimum	1.131	-1.311	-0.087	-14.564	-0.673	9.385	0.000	-6.098
Std. Dev.	0.434	0.616	2.275	0.565	0.933	0.387	3.118	0.782
Skewness	0.290	-0.728	0.102	-0.332	-0.234	-0.115	-1.719	-2.177
Kurtosis	2.687	3.129	2.228	3.246	3.432	3.475	5.366	12.687
Jarque-Bera	8.611	42.421	12.654	9.965	8.054	5.525	345.406	2237.091
Probability	0.013	0.000	0.002	0.007	0.018	0.063	0.000	0.000
Observations	476	476	476	476	476	476	476	476

Table 3 displays the unit root tests for the variables revealing their stationarity status. From the table, it reports that at level form, not all the variables could pass the unit root tests. However, CO2, EINT, GDP_CAP, and RE showed evidence of unit root as they could not pass all the four tests. Furthermore, the tests were performed at first difference, and at that form, all variables passed the unit root tests at a 1% significance level. Therefore, the null hypothesis that the variables have unit root is rejected for all the tests at a 1% significance level.

Table-3. Unit root tests

Level Form	CO2	EINT	R_D	PNT	RE	GDP_CAP	FDI	URP
LLC	-1.950**	-1.343	-5.224***	-6.537***	0.575	-3.542***	-39.741***	-4.681***
IPS	2.593	4.949	-3.215***	-4.243***	-4.863***	3.615	-14.967***	-6.165***
ADF-Fischer	38.555	32.889	130.645***	135.399***	137.175***	43.856	220.338***	159.568***
PP-Fischer	37.952	63.919	117.906***	179.126***	238.504***	60.503	227.014***	83.092**
First Difference								
LLC	-10.181***	-16.473***	-26.933***	-20.240***	-135.340***	-15.895***	-34.001***	-11.004***
IPS	-7.779***	-12.413***	-14.051***	-15.835***	-42.878***	-11.729***	-22.885***	-10.600***
ADF-Fischer	185.378***	261.847***	249.957***	325.776***	313.887***	250.508***	399.403***	227.376***
PP-Fischer	379.470***	297.283***	281.811***	409.064***	285.496***	350.987***	601.994***	257.470***

Note: ** denotes 5% significance level, *** denotes 1% significance level. LLC=Levin, Lin & Chu test, IPS= Im, Pesaran, & Shim test, ADF-Fischer and PP-Fischer = Maddala & Wu tests.

The test for cointegration suggests that there is a lon-run relationship between the dependent and the independent variables hence the further estimation with a regression method would reveal the long-run coefficients of the variables. However, Pedroni (2004) and Kao (1999) cointegration were performed to unravel the long run relationship among the variables. Table 4 presents the results of the tests. According to the table, the variables are cointegrated confirming from four (4) out of seven (7) tests from Pedroni showing significance at a 1% significance level. Also, Kao test showed a 1% significance level confirming that the variables have cointegration relationship. At this junction, the null hypothesis that states that there is no cointegration between the dependent and the independent variables is rejected.

Table 5 exhibits the outcome of the correlation matrix. According to the table, R_D, PNT, and GDP_CAP, are positively correlated to carbon emissions at a 1% significance level, respectively. Apparently, FDI showed positive correlation with carbon emission, but it insignificant. On the other hand, EINT and RE showed negative correlation with carbon emission at 5% and 1% significance level, respectively. To account for collinearity or multicollinearity, table 5 depicts that the variable with the highest coefficient is GDP_CAP, thus 0.453, and the second highest is RE, thus -0.357. In spite of these revelation, the study can confidently infer that there is problem of collinearity or multicollinearity.

Table-4. Pedroni and Kao cointegration tests.

Pedroni Residual Cointegration Test							
Null Hypothesis: No cointegration							
Trend assumption: No deterministic trend							
Alternative hypothesis: common AR coefs. (within-dimension)							
					Weighted		
		Statistic	Prob.	Sig.	Statistic	Prob.	Sig.
Panel v-Statistic		–1.930	0.973		–3.174	0.999	
Panel rho-Statistic		5.882	1.000		6.472	1.000	
Panel PP-Statistic		–9.922	0.000	***	–7.703	0.000	***
Panel ADF-Statistic		–6.281	0.000	***	–4.996	0.000	***
Alternative hypothesis: individual AR coefs. (between-dimension)							
		Statistic	Prob.	Sig.			
Group rho-Statistic		8.761	1.000				
Group PP-Statistic		–15.721	0.000	***			
Group ADF-Statistic		–6.555	0.000	***			
Kao Residual Cointegration Test							
Null Hypothesis: No cointegration							
Trend assumption: No deterministic trend							
		t-Statistic	Prob.	Sig.			
ADF		–4.833	0.000	***			

Note: *** denotes 1% significance level.

Table-5. Correlation matrix.

Correlation Probability	CO_2	R_D	PNT	RE	GDP_CAP	FDI	EINT
CO_2	1						
R_D	0.352***	1					
PNT	0.250***	0.613***	1				
RE	–0.357***	–0.054	–0.299***	1			
GDP_CAP	0.453***	0.551***	0.398***	0.034	1		
FDI	0.044	–0.048	0.253***	–0.182***	–0.032	1	
EINT	–0.102**	–0.302***	–0.409***	0.075	–0.774***	–0.067	1

Note: ** denotes 5% significance level, *** denotes 1% significance level. CO_2 = Carbon emission, R_D= Research and Development, PNT= Patents, RE= Renewable energy, GDP_CAP = gross domestic product per capita, FDI = Foreign direct investment, EINT = Energy intensity.

Evidence from Table 6 suggest that there is a unidirectional causal relationship between EINT and CO_2, also, CO_2 and RE. Meanwhile, the study found a bidirectional causal relationship between CO_2 and GDP_CAP. The unidirectional causal relationship between EINT and CO_2 suggests that EINT granger causes CO_2, hence any variable in EINT would cause a change in CO_2 but a variation in CO_2 cannot explain any changes in EINT. Besides, CO_2 granger causes RE, hence any variation in carbon emission simply relates to a change in RE. On the other hand, GDP_CAP and CO_2 granger causes each other, hence a variation in one of them explains the variation of the other.

In estimating the long-run relationship between carbon emission, and eco-innovation, the ordinary least square regression method was employed. Table 7 displays the results, and according to the table, evidence suggests that eco-innovation and carbon emission are positively related. Evidence from the table suggests that two proxy variables that measure eco-innovation (EINT and R_D) showed positive and significant relationship with carbon emission three (3) out of four (4) models developed to critically understand their relationship. However, one of the proxy variables, thus PNT showed an insignificant relationship with carbon emission. Specifically, a percentage increase in EINT could lead to a positive contribution of 0.568% and 0.579% carbon emission.

Table-6. Granger causality test.

Pairwise Granger Causality Tests				
Null Hypothesis:	Obs	F-Statistic	Prob.	
R_D does not Granger Cause CO_2	408	1.290	0.277	
CO_2 does not Granger Cause R_D		0.430	0.651	
PNT does not Granger Cause CO_2	408	0.493	0.611	
CO_2 does not Granger Cause PNT		0.721	0.487	
EINT does not Granger Cause CO_2	408	6.404	0.002	**
CO_2 does not Granger Cause EINT		2.293	0.102	
RE does not Granger Cause CO_2	408	1.708	0.183	
CO_2 does not Granger Cause RE		4.742	0.009	**
GDP_CAP does not Granger Cause CO_2	408	29.351	0.000	***
CO_2 does not Granger Cause GDP_CAP		2.850	0.059	*
FDI does not Granger Cause CO_2	408	0.142	0.868	
CO_2 does not Granger Cause FDI		1.040	0.355	
URP does not Granger Cause CO_2	408	0.484	0.617	
CO_2 does not Granger Cause URP		1.236	0.292	

Note: * denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level. CO_2 = Carbon emission, R_D= Research and Development, PNT= Patents, RE= Renewable energy, GDP_CAP = gross domestic product per capita, FDI = Foreign direct investment, EINT = Energy intensity.

Also, R_D could lead to 0.079% carbon emission with a percentage point increase. Nonetheless, RE showed negative and significant relationship with carbon emission signalling its effectiveness to abate carbon emission. At a 1% significance level across all the four (4) models developed, RE showed significant and negative relationship with carbon emission consistently. Moreover, a percentage point increase in RE implies that carbon emission could be abated by 0.021%, 0.183%, 0.170%, and 0.204%, simultaneously. More importantly, GDP_CAP showed positive and significant relationship with carbon emission. This implies that economic growth leads to carbon emission in the long-run. Moreover, most pollutions are caused by industries in pursuit to achieve growth in production. Specifically, at a 1% significance level, a percentage point increase in GDP_CAP translates into 1.166%, 0.555%, 0.451%, and 1.194% of carbon emission, respectively.

Due to the limitation of the ordinary least square regression method to check for cross-sectional heterogeneity and serial correlation among the panel, the study further employed fully modified ordinary least square regression method to robust check the latter. The fully modified ordinary least square method has the ability to resolve the problem of heterogeneity and cross-sectional serial correlation in the panel. For this reason, the next step was to estimate the long-run relationship between carbon emissions and eco-innovation. Table 8 presents the estimation results.

The results from the fully modified ordinary least square method suggests that eco-innovation could positively and negatively contribute to carbon emission abatement. With respect to the proxy measures of eco-innovation, EINT positively relates to carbon emission abatement. This finding substantiate the result from the ordinary least square method. But for PNT and R_D, the results produced by the fully modified ordinary least square method is different from the ordinary least square. This implies that the FMOLS has resolved the problem of heterogeneity and cross-sectional serial correlation in the panel to effect the unbiased coefficients. However, the results now suggest that PNT positively and significantly relates to carbon emission abatement, and R_D negatively and positively relates to carbon emission abatement. Also, FDI and URP which showed insignificant relationship with carbon emission abatement now depict positive and significant relationship with carbon emission abatement concurrently. The R^2 of the four (4) models showed values of 0.961, 0.962, 0.967, and 0.969. This implies that the independent variables explained variations of 96.1%, 96.2%, 96.7%, and 96.9% on the dependent variations.

Table-7. Estimation with OLS.

OLS	1	2	3	4
EINT	0.568			0.579
	(14.917)***			(14.061)***
PNT		-0.013		0.003
		(-1.511)		(0.334)
R_D			0.079	-0.026
			(2.444)**	(-0.765)
RE	-0.201	-0.183	-0.170	-0.204
	(-13.878)***	(-9.843)***	(-9.617)***	(-13.216)***
GDP_CAP	1.166	0.555	0.451	1.194
	(21.056)***	(11.737)***	(8.825)***	(17.894)***
FDI	0.006	0.0001	-0.001	0.006
	(1.434)	(0.171)	(-0.134)	(1.252)
URP	0.008	-0.012	0.005	0.005
	(0.445)	(-0.571)	(0.217)	(0.304)
C	-2.536	-3.286	-2.312	-2.695
	(-6.856)***	(-6.819)***	(-4.373)***	(-6.122)***
R^2	0.554	0.347	0.352	0.555
Adjusted R^2	0.550	0.340	0.345	0.548
F-Statistics	116.971***	49.878***	51.002***	83.389***
Heteroskedasticity test	13.891	6.446	6.446	14.759
Prob.	0.999	1.000	1.000	0.998

Note: ** denotes 5% significance level, *** denotes 1% significance level. CO_2 = Carbon emission, R_D= Research and Development, PNT= Patents, RE= Renewable energy, GDP_CAP = gross domestic product per capita, FDI = Foreign direct investment, EINT = Energy intensity.

Table-8. Estimation with FMOLS.

FMOLS	1	2	3	4
EINT	0.677			0.705
	(23.876)***			(31.753)***
PNT		0.073		0.087
		(11.722)***		(17.500)***
R_D			-0.006	-0.032
			(-0.751)	(-4.956)***
RE	-0.094	-0.108	-0.110	-0.089
	(-19.471)***	(-23.026)***	(-22.134)***	(-23.638)***
GDP_CAP	0.752	-0.313	-0.276	0.757
	(16.847)***	(-25.599)***	(-21.967)***	(21.676)***
FDI	0.002	0.001	0.001	0.001
	(3.631)***	(1.191)	(1.740)*	(3.111)**
URP	0.032	0.028	0.030	0.028
	(11.730)***	(10.555)***	(10.809)***	(12.997)***
R^2	0.967	0.962	0.961	0.969
Adjusted R^2	0.964	0.958	0.957	0.966

Note: * denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level. CO_2 = Carbon emission, R_D= Research and Development, PNT= Patents, RE= Renewable energy, GDP_CAP = gross domestic product per capita, FDI = Foreign direct investment, EINT = Energy intensity.

5. CONCLUSION AND DISCUSSION

This present study aimed to assess the impact of eco-innovation on carbon emission abatement in OECD countries. However, 34 OECD countries were sampled in a panel to carefully understand the phenomenon. The data for the study were sourced from OECD database and World Bank's World Development Indicators from 2005 to 2018. Numerous econometric approaches were followed to arrive the conclusion of this study. Econometric approaches such as unit root rests, correlation matrix, cointegration test, Granger causality test, ordinary least square regression method, and fully modified ordinary least square regression method. The ordinary least square regression method was used as the main regression method, and the fully modified regression method was used a robust check method to help resolve the limitations of the latter.

The findings of the study suggest that eco-innovation could positively and negatively impact carbon emission abatement regarding the kind of proxy used. From the findings, it was realised that energy intensity, and patents positively impact carbon emission abatement, hence a percentage point increase in energy intensity could lead to an increase in carbon emission by 0.677% and 0.705% while a percentage increase in patent could also lead to 0.073% and 0.087% of carbon emission, respectively. Scores of studies have found that the relationship between energy consumption, in other words, energy intensity, and carbon emission is positive. These studies findings support this study's finding that energy intensity positively relates to carbon emission (Apergis & Payne, 2009; Farhani, Chaibi, & Rault, 2014; Pao, Yu, & Yang, 2011). On the other hand, research and development expenditure seemingly contribute to carbon emission abatement, where a percentage point increase in research and development expenditure could lead to 0.032% carbon emission abatement. Research and development proxies have been substantiated to have a negative impact on carbon emission abatement. Numerous studies have understood the relationship between research and development, and they contend that it spurs innovation which in the long-run contributes to the effort to reduce carbon emission. However, these studies are in consistent with this present study's finding (Fernández et al., 2017; Shahbaz, Nasreen, Abbas, & Anis, 2015; Tang & Tan, 2015).

On the backdrop of the EKC hypothesis, the study's findings suggest the existence of the long-run relationship between carbon emission and economic growth. The findings suggest that a percentage increase in economic growth implies that there would be an increase in carbon emission, but interestingly, the findings also suggest that investment in innovations could support economic growth to negatively impact carbon emission, in support of findings from Vitenu-Sackey (2020); Shahbaz, Khraief, Uddin, and Ozturk (2014); Pao and Tsai (2011) and Lean and Smyth (2010). Moreover, foreign direct investment positively impact carbon emission implying that there is a direct influence of FDI on carbon emission, hence any increase in FDI could translate into an increase in carbon emission. Most industries transitioning into other countries tend to swerve environmental regulations to indulge in pollution. Moreover, these industries envisage the attracted countries as pollution havens. Specifically, foreign direct investment could lead to an increase in carbon emission when the investments are not green (Hongli & Vitenu-Sackey, 2019; Vitenu-Sackey, 2020; Vitenu-Sackey, Barfi, & Oppong, 2019; Xinying, Oppong, & Vitenu-Sackey, 2019; Yushang, Baku, & Vitenu-Sackey, 2019). Urbanization tends to burden governments to strategise to provide infrastructures, and other public goods. Due to urban-rural migration for greener pastures, most urban cities encounter over-population which results in environmental problems like noise pollution, industrial pollution, and people pollution through transportation etc. From the study's findings, it was realised that urbanisation positively impact carbon emission. Anderson (2001) and Lee and Min (2015) support this findings as they contended that urbanization has a dire consequence on carbon emission abatement. More importantly, renewable energy seems to actively reduce carbon emission. Evidence from the study's findings suggest increase renewable energy usage could lead to carbon emission abatement. This findings is consistent with the study from Hongli and Vitenu-Sackey (2019).

5.1. Policy Implication

According to the findings of the study, investment in research and development translates into carbon emission abatement in OECD countries. This implies that increase in real income could encourage research and development and reduce energy intensity. Moreover, to ensure low carbon economy, conservation policies that support reduction in energy intensity, strengthening of environmental regulations, and improving research and development should be encouraged. That notwithstanding, more investment should be channelled into renewable energy, research and development, and also regulations for environmental protection should strengthened for patent registrations. Likewise, urban development should be improved to support sustainable development.

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