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Original Research

Impact of Economic Openness and Innovations on the Environment: a New Look into ASEAN Countries

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Abstract

This study aims to investigate the effects of economic openness and innovations on the environment of ASEAN countries for 1990-2014. We have employed several techniques for empirical analysis. To examine cross-sectional dependence and unit root test, we have used the Pesaran CD test and Pesaran CIPS unit root test. Pedroni and Kao and Westurland cointegration tests have been employed to confirm the cointegration among the variables. For estimations of long-run relationship, we have utilized DOLS and FMOLS techniques. Moreover, to determine the causality directions, we have employed Dumitrescu-Hurlin causality test. The results of the study show that energy use and trade openness significantly increase CO_2 emissions in ASEAN countries. On the other hand, FDI, GDP and patents markedly depress CO_2 emissions. The findings depict that energy use and trade openness harm the environment by escalating CO_2 emissions while FDI, GDP and patents improve the environment by depressing CO_2 emissions. Therefore, policy-makers should encourage investment in renewable energy sources and boost green trade openness in ASEAN countries.

Keywords: economic openness, innovations, CO_2 emissions, environment, ASEAN countries

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Introduction

In the last couple of years, FDI, trade openness and economic growth have received an enormous concentration of researchers and policy-makers due to their substantial environmental effects. FDI and trade openness boosts global manufacturing and energy utilization. This expansion of international manufacturing and energy use have drastically affected the environment all over the world. The statistics of the International Energy Agency (IEA) show that the global CO_2 emissions and energy consumption increased annually by 2% between 1997 and 2015 [1]. The developing economies have received more severe results of environmental degradation due to their weak ecosystems [2]. The rise in economic growth results in deteriorating environmental sustainability. Therefore, sustainable economic growth policy has drawn the attention of many researchers and policy-makers. For sustainable economic development, reduction of CO_2 emissions is very crucial because it is a hurdle in the way of environmental sustainability [3]. Innovation has become a key focus in the policy discussions of environmental sustainability due to its capability to deal with the effects of FDI, trade openness and economic growth on the environment [4]. Therefore, innovation appeared as an essential tool to achieve energy-efficient production, and it ensures sustainable development in both the developing and developed world. FDI, trade openness, economic growth, energy consumption and urbanization rise CO_2 emissions because these variables mainly rely on fossil fuel energy sources [5, 6]. Transforming to sustainable energy sources from fossil fuel energy production requires modern technologies and sustainable energy policies [7, 8]. It will promote economic growth and development without deteriorating the environment.

Many studies have analyzed the association between FDI, trade openness, economic growth and environment for instance [2, 4, 9-14]. A famous Environmental Kuznets Curve (EKC) hypothesis specifies that the association between economic growth and environment have a U-shaped curve. EKC is defined as an increase in economic growth and development results in the rise of environmental pollution [15]. According to EKC theory, income and emissions are directly proportional to each other as the higher level of economic activity would lead to a higher level of energy consumption and could result in a higher level of emissions [16]. However, innovation can mitigate the effects of CO_2 emissions [17]. Technological innovation can play an essential role in reducing emissions. The existing studies reveal that FDI, trade openness and economic growth have a tendency to increase pollution, but technological innovation reduces the adverse environmental effects by mitigating CO_2 emissions. In the endogenous growth theory, technological innovation has a positive impact on the environment, as it enhances environmental friendly production sources by substituting pollutant sources. It implies that technological innovation can reduce pollution without affecting economic growth [18]. The transformation to sustainable economies having low-carbon production sources require provisions of affordable and secure energy for social development and economic growth [19]. The Paris Agreement has already proposed a target to transform the global economic structure in the upcoming decades by reducing the global temperature for conducive environmental habitation [20]. Therefore, it is essential to prioritize technological innovation into the policy-making of emissions mitigation.

The Association of Southeast Asian Nations (ASEAN) comprises of ten South Asian economies that aim to promote social, cultural and economic cooperation among the member countries. ASEAN came into existence in 1967, with the membership of ten countries including Malaysia, Indonesia, Brunei, Cambodia, Myanmar, Singapore, Philippines, Vietnam, Laos and Thailand. ASEAN region also faces a similar global issue of secure, affordable and sustainable energy [21]. According to an estimation, 8% of the total fossil fuel reserves are present in ASEAN countries. Due to excess utilization of fossil fuel production sources, the share of global greenhouse gas emissions will become double by 2040 [20].

In the above context, our study aimed to investigate the impact of economic openness and innovation on the environment of ASEAN member countries for 1990-2014. This study will answer the following main research questions: (1) Does economic openness such as FDI, trade openness, and economic growth harm the environment of the ASEAN region? (2) Does technology innovation improve the environmental quality of ASEAN countries? The novel aspect of this study is twofold; first, we investigate the impact of economic openness on the environment of ASEAN countries, and secondly, we have examined the role of technology innovation in mitigating the CO_2 emissions. Previous studies have only considered the import-CO_2 emissions, exports-CO_2 emissions, Economic growth-CO_2 emissions, innovations-CO_2 emissions etc. But we have analyzed the association among the overall economic openness, CO_2 emissions and technology innovation in our study. Moreover, we have utilized different econometric models to have a new look into ASEAN countries. This study will assist governments and policy-makers in decision making regarding environmental sustainability.

We have organized the remaining part of the study as follows: Review of Literature section will thoroughly elaborate the association among economic openness, innovation and environment. Methodology and Model specification section will discuss the data and empirical techniques of the study. Discussion and Results section will thoroughly explain the findings of the study and elaborate the obtained results. Finally, Conclusion and policy recommendations section will conclude the study and provide useful policy recommendations for the governments and policy-makers.

Literature Review

The study explored the association among FDI, trade openness, economic growth, technological innovations, and carbon emissions. Numerous studies have already examined the inter-relationship among economic openness, innovations and CO_2 emissions. We will review all aspects with the help of existing relevant evidence. The theoretical and empirical literature on the impact of economic openness on the emissions consists of mixed opinions, and it continued to be a debatable topic. For instance, the study about China, evaluates the impact of FDI and international trade on the CO_2 emissions of Chinese provinces for 1997-2014. By employing the quantile regression approach, the study found negative and significant impacts of FDI and trade on CO_2 emissions [22]. Similarly, another study examined the effects of FDI and economic growth on CO_2 emissions in the case of Kuwait for 1980-2013. By employing the ARDL model, the study concluded that FDI and economic growth increase CO_2 emissions [14]. Likewise, another study investigated the impact of trade openness, income and energy use on the CO_2 emissions of selected emerging economies for 1971-2011. By employing the unit root test of Zivot-Andrews, the bound co-integration techniques and the VECM Granger causality tests, the study found co-integration among the underlying variables. Additionally, the study found that trade openness, energy use and real income enhances CO_2 emissions [23]. On the other hand, a study examined FDI-carbon emissions nexus in the case of Turkey for 1974-2013. The study found that FDI reduces CO_2 emissions [24]. Similarly, another study about selected Asian countries, investigated the effects of FDI on CO_2 emissions for 1982-2016 for five countries. The study found that FDI reduces CO_2 emissions by enhancing environmental friendly technology and environmentally friendly management practices in China, India, Iran, Indonesia and South Africa [25]. On the contrary to that, a study analyzed the link among CO_2 emissions, energy use, FDI and economic growth in the case of Vietnam for 1976-2009. The study employed the Granger causality test and cointegration test and found that there was a long-run equilibrium among the underlying variables. Moreover, two-way causalities were also observed between foreign direct investment-CO_2 emissions and CO_2 emissions-income. The study recommended FDI as an essential instrument for mitigating the effects of CO_2 emissions through clean technology transfers [26]. An empirical study examined the relationship among trade openness, economic growth financial development, coal consumption and CO_2 emissions in South Africa. By employing the ARDL bounds testing method, the results of the study reveal that trade significantly contributes to the improvement of the environment in South Africa [27]. Likewise, another study investigated the association among trade openness, CO_2 emissions, GDP and energy consumption in 25 OECD countries. The results obtained from panel FMOLS and DOLS confirmed the effectiveness of trade for mitigating CO_2 emissions in OECD countries [28]. Moreover, another study analyzed the association among trade, real income, population, energy consumption and CO_2 emissions in 82 emerging economies for 1880-2012. By employing several empirical approaches, such as mean group (MG) using various mean group (MG) and cross-correlated and augmented method, the results reveal that increase in trade results in decline in CO_2 emissions. Also, openness enhances environmental quality [29]. The study about Common Wealth of Independent States (CIPS) investigated the causal link and long-run association among CO_2 emissions, trade openness, economic growth and energy consumption in a panel of Common Wealth of Independent States (CIPS). The results found a unidirectional short-run causality from trade openness to CO_2 emissions [30]. Another study found that trade openness, economic growth, financial development and energy consumption determine CO_2 emissions. Moreover, there was unidirectional causality from trade openness to CO_2 emissions. The study confirmed the validity of the KKC hypothesis for Turkey in short-run as well as long-run [31].

A study about Pakistan examined the nexus among economic growth, energy consumption and CO_2 emissions by using ARDL method. The time-series data of 1965-2015 shows a positive relationship between economic growth and CO_2 emissions in Pakistan both in the short and long-run [32]. Similarly, another study examined the association between economic growth and CO_2 emissions in the presence of other variables such as financial development, international trade and tourism expenditure. The results of ARDL estimations show that economic growth enhances CO_2 emissions in Greece for 1970-2014 [33]. Likewise, a study examined the relationship between economic growth and CO_2 emissions for a panel of 31 emerging economies. The threshold framework model shows that there is a positive impact of economic growth on CO_2 emissions in a regime with high growth while a negative impact has been detected in case of low growth regimes. Moreover, the study doesn't support the Environmental Kuznets Curve hypothesis [34]. Another study investigates the connection between per capita growth and the environment by using panel data in non-OECD economies for 1971-1997. The results of this study also do not provide support for the environmental Kuznets curve. Moreover, the findings came up with two-income regimes, namely low-income regime and middle to high-income regime. The emissions rise with the increase of economic growth in low-income regime while a decrease in the middle to the high-income regime [35]. The study about BRICS investigates the relationship among economic growth, energy use and carbon dioxide in five BRICS countries for 1992 to 2016. The results of the STIRPAT model indicate that economic growth and energy use increase CO_2 emissions in five BRICS countries [36]. Similarly, an ARDL study investigated the connection among economic growth, energy consumption and CO_2 emissions in Malaysia for 1975-2014. The findings from ARDL estimations show that CO_2 emissions do not affect economic growth and energy consumption, but economic growth and energy consumption have a positive impact on CO_2 emissions in the case of Malaysia [37]. Moreover, another study analyzed the effects of economic growth on the environment along with other variables of the study in 34 countries of Sub-Saharan Africa for 1995-2015. By using GMM techniques, the results of the study indicate that there is an inverted U-shaped connection between economic growth and CO_2 emissions. Furthermore, the findings confirm the presence of Environmental Kuznet Curve in case of low and middle income countries of Sub-Saharan Africa [38].

Foreign firms have emerged as environmentally friendly due to their efficient production sources in the countries where environmental regulations are usually weak. The foreign firms often depend on advanced technology, and they have a spillover effect on the domestic firms in the host economy [39]. An empirical study on G-6 countries analyzed the relationship between innovation and environment for 2004-2016. By utilizing firm-level data, the authors found that innovation and CO_2 emissions are inversely proportional to each other [40]. Another study analyzed the impact of innovation on CO_2 emissions in Malaysia from 1971 to 2013. The study found that technological innovation reduces CO_2 emissions in the short run. The study suggests that innovation boosts economic growth as well as environmental sustainability [41]. An empirical study analyzed the impact of technological innovation on CO_2 emissions of China by utilizing the STIRPAT model. The study found that innovations reduce CO_2 emissions in China [42]. Another study investigated the nexus between innovations and CO_2 emissions of 18 developed and developing countries for 1990 to 2016. The study employed Dickey-Fuller (CADF) and Westerlund cointegration techniques to observe co-integration among variables. The findings of FMOLS and DOLS estimations show that technological innovations mitigate CO_2 emissions in G6 countries but increase emissions in BRICS and MENA economies [43]. A study about China depicted that innovations positively affect the environment in China by reducing CO_2 emissions [44]. Hence, a vast number of studies show that innovations mitigate the deteriorating effects of the environment [45, 46].

Considering the lack of significant studies in the existing literature, this study aims to analyze the impact of economic openness and innovations on ASEAN countries. Therefore, the main objective of this study to investigate the environmental effects of FDI, trade openness, economic growth and innovations on the ASEAN region to overcome the gaps in the previous studies.

Methodology and Model Specification

In this section, we will discuss our estimation techniques and data of the study. The basic model of our research study is as follows.

$$CO_2 = f(FDI_{it}, TO_{it}, GDP_{it}, EU_{it}, PAT_{it}, TM_{it}) \quad (1)$$

Where FDI indicates foreign direct investment; TO represents trade openness; GDP shows economic growth; EU illustrates energy use; PAT specifies patents and TM is for trademark. In our model, i shows countries and t means time. We have taken data of FDI, GDP, EU, PAT and TM from the World Bank database. The data for trade openness has been taken from UNTCAD database. The detailed description and definitions of variables are presented in Table 1. For convenience, we transform the variables into log form. Hence, we can write the above equation as follows:

$$lnCO_{it} = \alpha_0 + \beta_1 FDI_{it} + \beta_2 TO_{it} + \beta_3 GDP_{it} + \beta_4 EU_{it} + \beta_5 PAT_{it} + \beta_6 TM_{it} + \mu_{it} \quad (2)$$

...where α_0 and μ_{it} represent constant term and the error term, respectively; β_1, β_2, β_3 and β_4 stand for undermined coefficients.

$$lnFDI_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 TO_{it} + \beta_3 GDP_{it} + \beta_4 EU_{it} + \beta_5 PAT_{it} + \beta_6 TM_{it} + \mu_{it} \quad (3)$$

$$lnTO_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 FDI_{it} + \beta_3 GDP_{it} + \beta_4 EU_{it} + \beta_5 PAT_{it} + \beta_6 TM_{it} + \mu_{it} \quad (4)$$

$$lnGDP_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 FDI_{it} + \beta_3 TO_{it} + \beta_4 EU_{it} + \beta_5 PAT_{it} + \beta_6 TM_{it} + \mu_{it} \quad (5)$$

$$lnEU_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 FDI_{it} + \beta_3 TO_{it} + \beta_4 GDP_{it} + \beta_5 PAT_{it} + \beta_6 TM_{it} + \mu_{it} \quad (6)$$

$$lnPAT_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 FDI_{it} + \beta_3 TO_{it} + \beta_4 GDP_{it} + \beta_5 EU_{it} + \beta_6 TM_{it} + \mu_{it} \quad (7)$$

$$lnTM_{it} = \alpha_0 + \beta_1 CO_{2it} + \beta_2 FDI_{it} + \beta_3 TO_{it} + \beta_4 GDP_{it} + \beta_5 EU_{it} + \beta_6 PAT_{it} + \mu_{it} \quad (8)$$

Descriptive Statistics

In our study, we have collected data from six ASEAN member countries such as Indonesia, Malaysia, Philippine, Singapore, Thailand and Vietnam for 1990-2014. The data has been taken from the

World Bank and UNTCAD databases. Additionally, we have provided a description of the variables in Table 1 and the data description in Table 2. According to the availability of the data, we have chosen our study period. The maximum value of patents in ASEAN countries is 12581, with a mean value of 4453.307 across our panel. Likewise, the maximum value of FDI was calculated at 26.3266 % with 5.212923 mean value. The trade openness varied between 596753.1 maximum and 119724.8 minimum with the average value 119724.8. The maximum value of per capita GDP accounted for 52994.04 with an average of 8892.384. The maximum values of trademark and energy use accounted for 2.14512 and 7370.653 with average mean values of 0.9579905 and 1717.105. Finally, the values of CO_2 varied between 18.04087 maximum value and .3029989 minimum value with an average value of 0.958. Moreover, Fig. 1 presents the scattered plotting

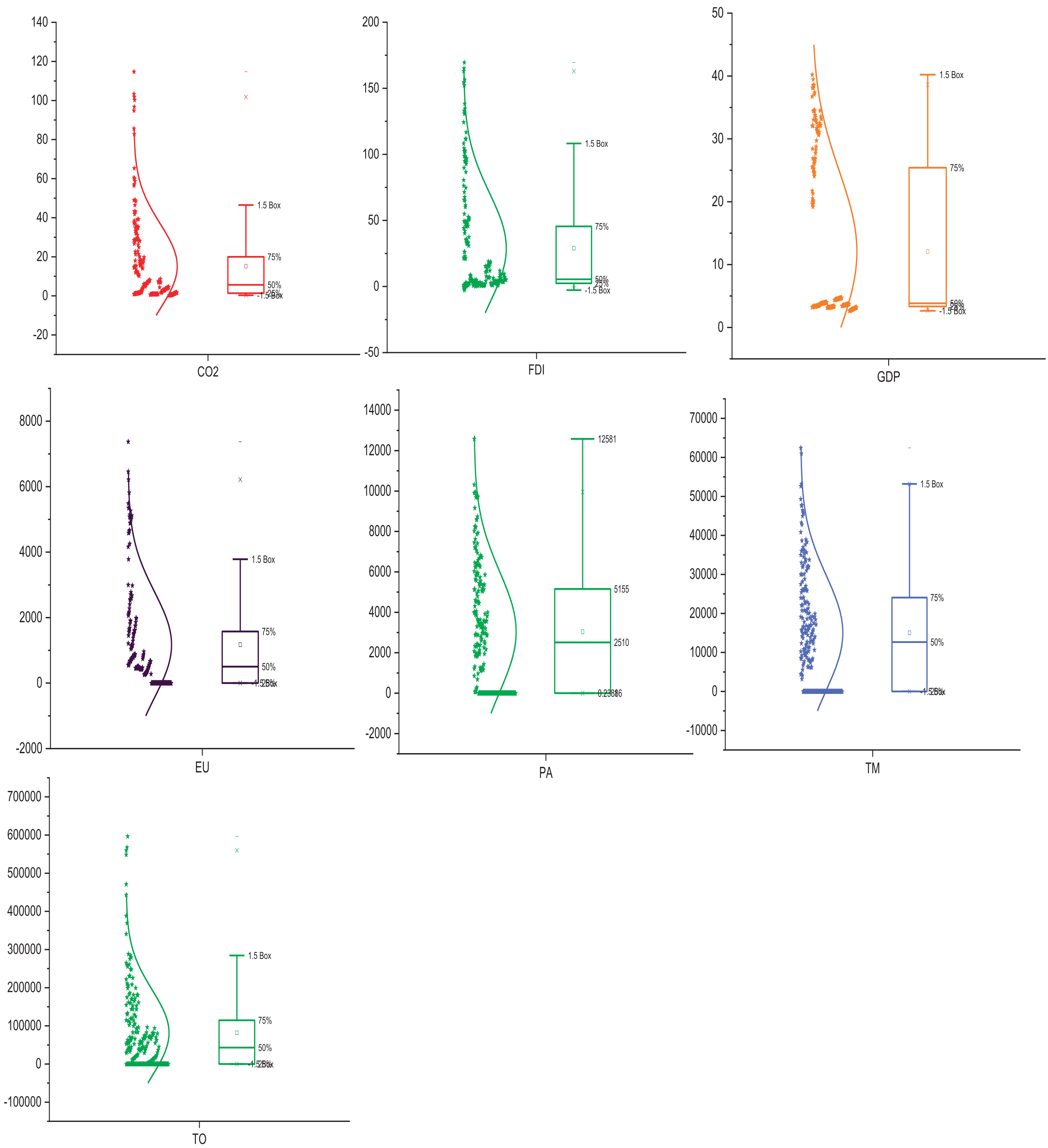

Fig. 1. Box chart of the seven variables. Note: The square represents the average value, the horizontal bar in the box represents the median, the dots represent the minimum/maximum value, and the upper and lower edges of the box represent the 75th and 25th percentage points, respectively.

Table 1. Variables, definitions, and measures for the period 1990-2014.

Variable	Unit of measurement	Definition	Source
CO_2 emissions	Tons	„Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement."	WDI
Foreign direct investment	Percentage	Foreign direct investment, net inflows (% of GDP)	WDI
Patent applications (PA)	Numbers	"Sum of total residents patent applications and non-residents patent applications."	WDI
Trade openness (TO)	Constant US dollars	"Total trade of goods and services measured in millions of constant US dollars."	UNTCAD
GDP per capita (GDP)	Constant 2010 US dollars	"Gross domestic product divided by midyear population."	WDI
Trademarks	Numbers	"Total number of trademark applications."	WDI
Energy Use	kg of oil equivalent per capita (kgoe)	"Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport."	WDI

Table 2. Descriptive statistics.

Variable		Mean	Std.Dev.	Min	Max	Observations
PA	Overall	4453.307	2592.951	62	12581	N = 150
	Between		2198.484	1786.56	8132.28	n = 6
	Within		1633.581	-1421.973	8902.027	T = 25
FDI	Overall	5.212923	5.727271	-2.75744	26.3266	N = 150
	Between		5.368549	1.126316	15.55837	n = 6
	Within		2.93644	-6.116918	15.98116	T = 25
TO	Overall	119724.8	118540.8	1913	596753.1	N = 150
	Between		85247.62	38835.28	271128.8	n = 6
	Within		89192.59	-83914.54	445349.1	T = 25
GDP	Overall	8892.384	13202.34	433.2839	52994.04	N = 150
	Between		13803.47	916.2912	36677.83	n = 6
	Within		3802.147	-5213.539	25208.6	T = 25
TM	Overall	0.9579905	0.4943999	0.00006	2.14512	N = 150
	Between		0.3735512	0.5622042	1.481597	n = 6
	Within		0.3627828	-0.5235468	1.621513	T = 25
EU	Overall	1717.105	1700.085	260.791	7370.653	N = 150
	Between		1804.554	425.5069	5137.688	n = 6
	Within		397.9891	362.1373	3950.07	T = 25
CO_2	Overall	3.947879	3.995822	.3029989	18.04087	N = 150
	Between		4.019567	.8634235	11.10329	n = 6
	Within		1.553102	-2.8128	10.88547	T = 25

Note: Std. Dev. indicates standard deviation; Max and Min show maximum and minimum values, respectively.

of FDI, trade openness and GDP, energy use, patents and trademarks of ASEAN countries.

Estimation Techniques

We present a systematic procedure for the empirical estimation of equation (2). (i) We employed the Pesaran CD test for examining the cross-sectional dependence among the underlying variables in our model. (ii) For the unit root test, we have utilized the Pesaran CIPS test. (iii) For observing co-integration among the variables, Pedroni-cointegration and Kao-cointegration tests have employed. (iv) We have used FMOLS and DOLS estimation techniques to analyze the determinants of CO_2 emissions. (v) We have employed Dumitrescu and Hurlin panel causality test to examine the directions of causalities.

Cross-Sectional Dependence

To avoid any erroneous results, there should be cross-sectional dependence in the model [47, 48]. Therefore, in this study, we have used the Breusch-Pagan Lagrange multiplier (LM) test to check for cross-sectional dependence in our panel.

Panel Unit Root Test

After confirming cross-sectional dependence in the panel, the unit root tests of the first generation such as Im, Pesaran, and Shin (IPS) Augmented Dickey-Fuller (ADF), Phillips- Perron (PP) seem to be invalid. Hence, we choose second-generation unit root tests, i.e. Pesaran Augmented Dickey-Fuller (CADF), and the Pesaran cross-sectionally Augmented Im Pesaran and Shin (IPS) tests. Pesaran and Shin developed these tests [49].

Panel Co-Integration Test

We have used Pedroni co-integration test for detecting cointegration in our panel. Pedroni developed this cointegration test [50]. The Kao panel co-integration test has also been employed to avoid any prejudiced results [51]. The panel-specific autoregressive (AR) test statistic and the same- specific autoregressive (AR) tests statistic have been used for cross-sectional dependencies of panel co-integration test.

Panel Causality Test

We have employed the D-H panel causality test in our study, which was introduced by Dumitrescu and Hurlin [52].

Results and Discussion

Outcomes of Cross-Sectional Dependence

We have presented the results of cross-sectional dependence test in Table 3. The results show that there is a strong cross-sectional dependence among the underlying variables of the study. The study rejected the null hypothesis at 1% significance level and accepted the alternate hypothesis.

Outcomes of Panel Unit Root Test

We have used the Pesaran (CIPS) unit root test to confirm the stationarity level of the variables. We have presented the outcomes of the Pesaran (CIPS) unit root test in Table 4. The results show that the null hypothesis is rejected at level, with intercept, intercept and trend. At first difference, stationarity was observed at 1% level for intercept and intercept and trend. It depicts that the underlying variables are integrated at the order I (1). Therefore, it is justified that we can investigate the long-run relationship.

We have double checked the stationarity properties of the underlying variables by using Harris-Tzavalis unit-root test, Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (2003) unit root test. The outcomes of the unit root tests are presented in Table 5. According

Table 3. Estimation of cross-sectional dependence.

Variable	$CD_{Pesaran}$	$LM_{Breusch\text{-}Pagan}$	$LM_{Pesaran\ scaled}$	$LM_{Bias\text{-}corrected\ scaled}$
PA	11.5083***	138.8005***	22.6027***	22.4777***
FDI	14.377***	21.8714*	1.2546**	1.1296**
TO	18.5352***	343.9598***	60.0597***	59.9347***
GDP	18.8778***	356.4323***	62.3368***	62.2118***
TM	18.737***	279.9518***	48.3734***	48.2483***
EU	4.8123***	145.4204***	23.8114***	23.6862***
CO_2	6.2522***	209.5754***	35.5245***	35.3995***

Note: *, ** and *** indicate significance at the 10%, 5% and 1% level respectively, Null hypothesis = no cross-sectional dependence.

Table 4. Pesaran CIPS Panel unit root test.

Variable	Level		First difference		Integration order
	Constant	Constant & trend	Constant	Constant & trend	
PA	-2.718	-2.944	-5.128	-5.190	I (1)
FDI	-2.433	-2.931	-5.261	-5.224	I (1)
TO	-0.606	-2.731	-3.717	-3.319	I (1)
GDP	-2.337	-2.595	-3.123	-3.355	I (1)
TM	-2.086	-2.224	-4.407	-4.504	I (1)
EU	-1.652	-2.567	-4.216	-4.031	I (1)
CO_2	-0.567	-3.417	-4.418	-4.360	I (1)

Note: critical values at 10%, 5% and 1% including constant; -2.21, -2.33, -2.57; and including constant & trend are; -2.73, -2.86, and -3.1 respectively.

Table 5. Panel unit root tests.

Harris-Tzavalis unit-root test	Level		First difference	
	Constant	Constant & trend	Constant	Constant & trend
PA	0.5775 ^{x}	0.1749 ^{x}	-0.3056 ^{x}	-0.3026 ^{x}
FDI	0.3187 ^{x}	0.0897 ^{x}	-0.3555 ^{x}	-0.3536 ^{x}
TO	1.0258	0.8045	-0.0447 ^{x}	0.0573 ^{x}
GDP	1.0043	0.5704 ^{y}	-0.0234 ^{x}	0.3061 ^{x}
TM	0.9357	0.4005 ^{x}	-0.3171 ^{x}	-0.2977 ^{x}
EU	0.6160 ^{x}	0.3945 ^{x}	-0.2028 ^{x}	-0.1952 ^{x}
CO_2	0.7877 ^{y}	0.5247 ^{x}	-0.1734 ^{x}	-0.1564 ^{x}
Levin-Lin-Chu (LLC) unit-root test				
PA	0.1358	-2.8362 ^{x}	-8.3620 ^{x}	-6.9950 ^{x}
FDI	-2.6579 ^{y}	-2.1673 ^{x}	-7.2582 ^{x}	-5.7144 ^{x}
TO	4.1025	0.9051	-4.4561 ^{x}	-4.4973 ^{x}
GDP	4.1357	-0.0078	-3.4799 ^{x}	-4.6798 ^{x}
TM	1.3706	-0.5413	-4.7439 ^{x}	-3.9114 ^{x}
EU	-0.9283	-0.3821	-2.6454 ^{x}	-0.9228
CO_2	-0.2671	-1.9109 ^{x}	-6.3065 ^{x}	-4.8530 ^{x}
Im-Pesaran-Shin (IPS) unit-root test				
PA	-0.0741	-3.2432 ^{x}	-6.4837 ^{x}	-6.5434 ^{x}
FDI	-3.1180 ^{x}	-3.9248 ^{x}	-6.9535 ^{x}	-6.9746 ^{x}
TO	6.7815	-0.1072	-5.5602 ^{x}	-6.3038 ^{x}
GDP	8.7310	0.7089	-5.3207 ^{x}	-5.3207 ^{x}
TM	3.8071	-1.6088 ^{z}	-5.7485 ^{x}	-5.9231 ^{x}
EU	0.2265	-1.9810 ^{y}	-4.4858 ^{x}	-4.2223 ^{x}
CO_2	1.0898	-2.6784 ^{x}	-5.9900 ^{x}	-6.0717 ^{x}

Note: x, y, and z Show the level of significance at 1%, 5%, and 10%.

Table 6. Panel co-integration results.

Ho: No cointegration Ha: All panels are cointegrated	Statistic	p-value(s)
Pedroni-cointegration		
Modified Phillips-Perron t-statistics	2.9149	0.0018
Phillips-Perron t-statistics	-4.1486	0.0000
Augmented Dickey-Fuller t-statistics	-2.6625	0.0039
Kao-cointegration		
Modified Dickey-Fuller (MDF) t-statistics	-1.8024	0.0357
Dickey-Fuller (DF) t-statistics	-2.2264	0.0130
Augmented Dickey-Fuller (ADF) t-statistics	-1.8650	0.0311
Unadjusted modified Dickey-Fuller (UMDF) t-statistics	-7.4667	0.0000
Unadjusted Dickey-Fuller (UDF) t-statistics	-4.4128	0.0000

Note: Ho is the null hypothesis, Ha is an alternative hypothesis and significance level at 5% and 1%.

to the obtained results, the null hypothesis has been rejected at 1% level for intercept and intercept and trend, as shown in Table 5. The underlying variables in ASEAN panel are integrated at the order I (1); hence it justifies the investigation of long-run relationship.

Outcomes of Panel Co-Integration Test

We have utilized Pedroni 2004 and Kao 1999 to find the co-integration among the variables, as shown in Table 6. According to Pedroni test, the variables of the study seemed to be significant. It implies that there is co-integration among the variables. Furthermore, the outcomes of Kao test also show co-integration among the underlying variables of our model. Hence, the results of Pedroni and Kao tests justified investigating the long-run relationship. Consequently, FMOLS and DOLS techniques are used to determine the long-run relationship.

Westerlund Panel Cointegration Tests

Due to the presence of cross-sectional dependence among the variables, we have utilized Westerlund, 2007 for the cointegration test. The outcomes of Westerlund panel cointegration test shows that there is cointegration among the variables in the panel of ASEAN countries. The obtained results imply that a long-run relationship exists among the underlying variables. The Westerlund, 2007 cointegration account for cross-sectional dependence because it contains bootstrap properties that eliminate such problems as the correlation among the units. The Gt, Ga (between- and among-group cross-sectional units) and Pt, Pa

Table 7. Westerlund ECM panel cointegration tests.

Ho: No cointegration Statistic	Value	Robust p-value
Gt	-2.274	0.089
Ga	-3.194	0.065
Pt	-3.536	0.046
Pa	-3.780	0.075

(between and among the whole panel) statistics with p values and robust p values show a rejection of the null hypothesis of no cointegration. This means that there is cointegration, evidence of a long-run relationship among the series.

Panel FMOLS and DOLS Results

We have presented the results of FMOLS and DOLS estimations in Table 8. The estimated results of FMOLS and DOLS techniques are almost similar to each other. The estimations of long-run coefficients depict that energy use significantly increases CO_2 emissions at 1% significance level. A unit increase in energy use results in an increase of 63% to 54% CO_2 emissions. Numerous studies have identified energy consumption as a significant source of CO_2 emissions [53]. Therefore, the findings are parallel with the results of mainstream literature. Trade openness has a positive and significant impact on CO_2 emissions at 10% significance level. It implies that a unit increase in trade openness rises 27% to 33% CO_2 emissions. Rasoulinezhad and Saboori [30] and Sun et al. [2] also found similar results. FDI negatively and significantly affects the CO_2 emissions at 1% significance level. A unit increase of FDI depresses 3% to 4% CO_2 emissions in the ASEAN region. Our results established that FDI has a positive impact on environmental quality. Sarkodie and Strezov [25] and many other mainstream studies have also got the same results. Likewise, there was a negative and significant association between GDP and CO_2 emissions at a 5% level of significance. We found that a unit increase in GDP decreased by 74% to 90% emissions. The findings

Table 8. Results of FMOLS and DOLS estimation.

	FMOLS		DOLS	
	Coefficient	P value	Coefficient	P value
LnEU	0.630213	0	0.543102	0
LnFDI	-0.033333	0	-0.046662	0
LnGDP	-0.903357	0.032	-0.745907	0.048
LnPA	-0.235603	0	-0.330612	0
LnTM	-0.138218	0.214	-0.420812	0.431
LnTO	0.272336	0.066	0.334011	0.076

Table 9. Results of Dumitrescu Hurlin panel causality test.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LnEU ≠LnCO$_2$	2.43153	0.17429	0.0616
LnCO$_2$≠LnEU	1.43355	-0.78389	0.0331
LnFDI ≠ LnCO$_2$	1.08968	-1.11025	0.0569
LnCO$_2$ ≠LnFDI	2.51784	0.23434	0.0147
LnGDP ≠ LnCO$_2$	3.97237	1.65366	0.0982
LnCO$_2$ ≠LnGDP	2.21630	-0.03236	0.0742
LnPA ≠LnCO$_2$	2.01911	-0.22168	0.0246
LnCO$_2$≠LnPA	5.77506	3.38444	0.0007
LnTM ≠LnCO$_2$	1.91559	-0.32107	0.7482
LnCO$_2$ ≠LnTM	4.13194	1.80687	0.0708
LnTO ≠ LnCO$_2$	5.26483	2.89457	0.0038
LnCO$_2$ ≠LnTO	1.56641	-0.65632	0.5116
LnFDI ≠LnEU	2.40759	0.13054	0.8961
LnEU ≠LnFDI	3.47040	1.13115	0.2580
LnGDP ≠LnEU	2.25481	0.00462	0.9963
LnEU ≠LnGDP	2.86684	0.59224	0.5537
LnPA ≠LnEU	1.22816	-0.98108	0.3266
LnEU ≠LnPA	5.72278	3.33425	0.0009
LnTM ≠LnEU	1.16306	-1.04358	0.2967
LnEU ≠LnTM	4.79436	2.44287	0.0146
LnTO ≠LnEU	2.01603	-0.22464	0.8223
LnEU ≠LnTO	2.92920	0.65211	0.5143
LnGDP ≠LnFDI	5.12115	2.68530	0.0072
LnFDI ≠LnGDP	4.17546	1.79495	0.0727
LnPA ≠LnFDI	5.45761	3.00207	0.0027
LnFDI ≠LnPA	1.63924	-0.59285	0.5533
LnTM ≠LnFDI	3.93833	1.57170	0.1160
LnFDI ≠LnTM	4.94245	2.51706	0.0118
LnTO ≠LnFDI	3.64472	1.29527	0.1952
LnFDI ≠LnTO	3.62505	1.27675	0.2017
LnPA ≠LnGDP	1.60491	-0.61935	0.5357
LnGDP ≠LnPA	8.02273	5.54245	3.E-08
LnTM ≠LnGDP	7.79529	5.32408	1.E-07
LnGDP ≠LnTM	10.5833	8.00089	1.E-15
LnTO ≠LnGDP	2.81900	0.54630	0.5849
LnGDP ≠LnTO	3.62010	1.31544	0.1884
LnTM ≠LnPA	7.35290	4.89934	1.E-06
LnPA ≠LnTM	3.40743	1.11126	0.2665
LnTO ≠LnPA	11.1174	8.51368	0.0000
LnPA ≠LnTO	1.97322	-0.26574	0.7904
LnTO ≠LnTM	5.45765	3.07970	0.0021
LnTM ≠LnTO	4.50192	2.16209	0.0306

Note: The Dumitrescu Hurlin test is estimated with 3 lag and Zbar-statistics, LnX ≠LnY suggests that Ln X does not homogeneously cause LnY

are opposite to the majority of the studies but similar to the results of Fang et al. [7]. Moreover, patents negatively and significantly affects the CO_2 emissions at 1% significance level, implies that a unit increase in patents decreases by 23% to 33% CO_2 emissions in ASEAN countries. Our results are similar to Choi and Han [54] and Dinda [46].

Results of Dumitrescu-Hurlin Causality Test

To check the causality among the underlying variables of the study, we have used Dumitrescu-Hurlin causality test. Table 9 depicts the causal relationship among the variables for the panel of BRICS countries. The results show that there was a bidirectional causality from energy use, FDI, GDP and patents to CO_2 emissions. There was also a bidirectional causality from GDP to FDI. A unidirectional causality was detected from CO_2 emissions, energy use and FDI to trademark. Moreover, one-way causalities were detected from trade openness to CO_2, energy use to patents and patents to FDI. Various other studies such as Intisar et al. [55] and Le and Van [56] have also used Dumitrescu-Hurlin causality test to find causalities among the variables.

Conclusion and Recommendations

Conclusion

We have investigated the impact of economic openness and innovations on the environment of ASEAN for 1990-2014. We have used the Pesaran CD test to examine cross-sectional dependence and Pesaran CIPS unit root test to check the stationarity. Pedroni and Kao tests and Westurland cointegration tests have been employed to confirm the cointegration among the variables. To estimate the long-run relationship, we have utilized DOLS and FMOLS techniques. Moreover, to determine the causality directions, we have employed Dumitrescu-Hurlin causality test. The results show that there was a bidirectional causality from energy use, FDI, GDP and patents to CO_2 emissions. There was also a bidirectional causality from GDP to FDI. A unidirectional causality was detected from CO_2 emissions, energy use and FDI to trademark. Moreover, one-way causalities were detected from trade openness to CO_2 emissions, energy use to patents and patents to FDI. The results of the study indicate that there is a strong cross-sectional dependence among the underlying variables of the study in the panel of ASEAN countries due to rising economic interdependence among the countries. Secondly, the study found that energy use and trade openness significantly increases CO_2 emissions in ASEAN countries. On the other hand, FDI, GDP and patents markedly depress CO_2 emissions. The findings depict that energy use and trade openness harms the environment by escalating CO_2 emissions while FDI, GDP and patents improve the environment by depressing CO_2 emissions.

Policy Recommendations

This study proposes some policy recommendations for the government and policy-makers. As energy use results in rising CO_2 emissions in the region, therefore policy-makers should encourage renewable energy investment for a sustainable environment. Renewable energy sources such as wind energy and solar energy are environmentally friendly and efficient to mitigate CO_2 emissions in the whole world, including developed and developing countries. Moreover, the governments and policy-makers should utilize technology innovation for mitigating the effects of CO_2 emissions; for instance, the process of waste recycling during the production process can reduce pollution. For this purpose, research and development funds should be raised for a sustainable, energy-efficient and technology-intensive production process. All this could be done by incorporating public and private sectors for cleaner production processes which lead to environmental sustainability. There is a need for efficient collaboration between developing and developed nations for mitigating the effects of CO_2 effects because environmental sustainability is a common issue all over the world. Policy-makers should encourage foreign investors to invest in low-carbon and energy-efficient technologies by offering tax incentives. Regarding the matters of trade openness, governments should stimulate green trade liberalization for environmental sustainability. These policies will not be only useful for the sustainability of the environment but also result in rising FDI in the region.

Future Research

Considering the importance of the topic, the same study can be done in other regions as well. Future researchers can also do a comparative analysis of different regions such as SAARC, BRICS, ASEAN, BRI countries, G8 countries, etc.

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Conflict of Interest

The authors declare no conflict of interest.

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