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Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment

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ABSTRACT

Green investment and technological advances are often regarded as efficient tools for carbon neutralization since they improve clean output and energy efficiency. To this end, this study aims to investigate the impact of renewable energy supply, green energy investment, environmental tax, and economic growth on green technology innovation in selected six Association of Southeast Asian Nations (ASEAN-6) countries over the period of 1995–2018. Thus, present study employed the advanced panel approach which provides robust results under cross-sectional dependency and slope heterogeneity. Specifically, the long-run relationship is investigated by using Westerlund and Edgerton (2008) cointegration test, and the long and short-run estimations are analyzed with a robust CS-ARDL method. The empirical findings for both the long-run and short-run show that the impacts of green energy and green investment on green technology innovation are positive, yet stronger in the long run. Moreover, the results also confirm the positive effects of economic growth and environmental taxes on green technology innovation. Furthermore, the Augmented mean group (AMG) results are in line with the estimates of CS-ARDL analysis. To accelerate green technology innovation in ASEAN-6 countries, incorporating the regulatory policies fostering a continuous increase in the share of renewable energy supply and investments into the agenda of environmental technological progress is crucial.

1. Introduction

The issue of environmental degradation and climate change are among the major challenges facing the world economy. This issue not only poses threats to human health but also to income and productivity levels (Mohanty and Mohanty, 2009; Wade and Jennings, 2016). As the economic activities continue to expand, the energy consumption also rises, resulting in greater greenhouse gas emissions that are harmful to the environment. As a means to tackle the climate change issue on a global scale, almost every nation has come together under the Paris Agreement and agreed to reduce greenhouse gas emissions. The nations' commitment to achieving the target set is important to ensure the mission will be successful and the sustainable development goals can be achieved. According to the Swiss Re Institute (2021), the climate change will cause the world economy to lose almost 18 percent of the GDP with the Asian economies projected to be affected the hardest. However, the effect can be minimized if prompt action in realizing the goals of the Paris Agreement (see Fig. 1).

Unfortunately, based on the UN Production Gap Report 2021, the current production plan is against the limit set in the Paris Agreement (United Nations Environment Program, 2021). Hence, all nations must take appropriate action to ensure carbon emissions can be reduced significantly and helps in realizing the sustainable development goals. Although many nations have started to move toward renewable energy and green energy as alternative energy sources, it is insufficient to meet the demand of global energy.

Alternatively, green technology innovation can be a remedy to the environmental problem since it helps in balancing and sustainable economic development with better environmental management (Yang et al., 2021; Xu et al., 2021; Yang et al., 2020). This is

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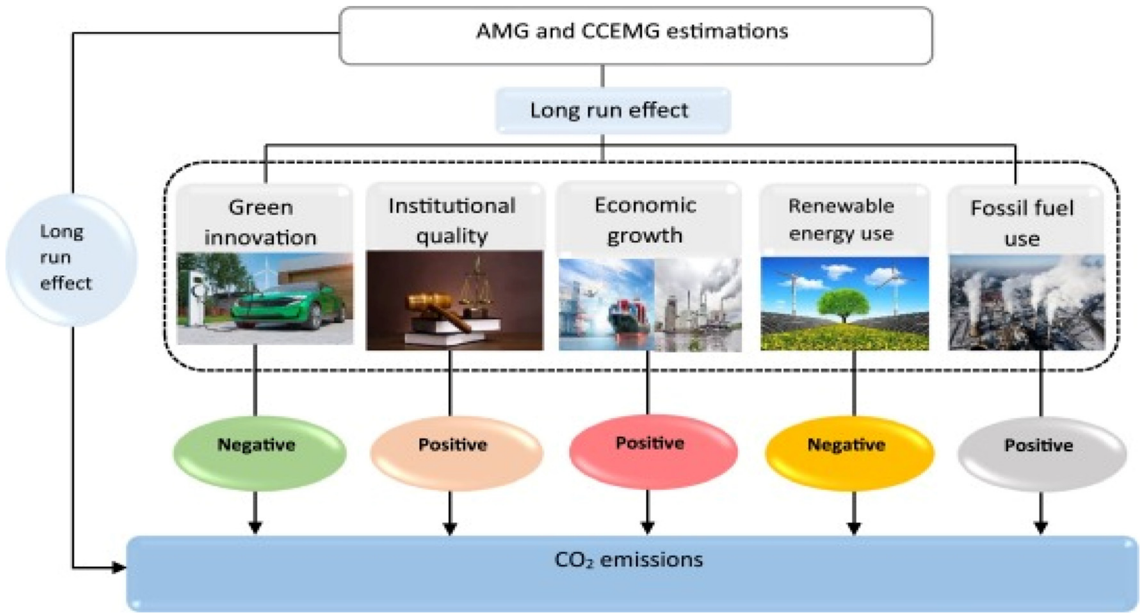

Fig. 1. Impact of Green Technology Innovation on Environment (). adopted from Moreno-Camacho et al., 2019

due to positive spillover from the innovation activities that result in the process of designing new products, processes and methods that can lessen the negative environmental impacts (Brunnermeier and Cohen, 2003; Rennings, 2000;). As supported by Popp (2012), developed countries managed to achieve greater environmental quality due to advanced technology that significantly reduced pollution and improved environmental conditions.

Despite the growing literature related to determinants of GTI (green technology innovation), however, most of these researches have concentrated on the countries which are developed since most innovation activities take place in the developed economies (Chen et al., 2006; Noailly and Ryfisch, 2015; Silva et al., 2013; Verdolini and Bosetti, 2017; Wang et al., 2019). However, since developing countries will be affected the most by climate change, understanding the factors contributing to green technology innovation in developing countries is crucial for policy responses (Arundel and Kemp, 2009; Wade and Jennings, 2016). Consistently as Popp (2012) argued, the technologies required to adjust to climate change will vary based on local conditions. Therefore, the study based on the developing countries is essential for policy formulation to promote green innovation.

The main contribution of the present research work is twofold. First, present study will provide an important and most significant contribution to the policymakers of Asian countries as these countries are most affected by the climate change and biodiversity. Whereas most of the past studies had been focused and worked on individual or advance countries. Second, despite the growing literature on green technology innovation, however, less attention has been given to green energy and green investment roles. Since green energy and green investment have started to gain popularity as alternative ways to reduce carbon emission, this is expected to increase the innovation activities and thereby becomes the motivation for this study.

Therefore, this study aims to enhance the available literature on GTI by assessing the roles of economic growth, environmental tax, green energy, and green investment on GTI in the ASEAN-6 countries. For this purpose, this study utilized the CS-ARDL method to estimate the long-run and short-run models. The main advantages of this method over other traditional methods are due to its efficiency in handling the issues related to CSD and SH that usually occur during the estimations of panel data (Mehmood et al., 2022; Mohammed et al., 2022).

Present study is structured and designed under following headings; firstly, we discussed about introduction of entire study followed by the review analysis pertaining to the factors contributing to green technology innovation, further followed by research design and methodology section and analysis and discussions. Last section of the study talks about conclusions and recommendations based on the empirical findings related to the proposed measures and studied variables i.e. renewable energy supply, green energy investment, environmental tax, and economic growth and GTI.

2. Literature review

GTI or eco innovations has emerged following the countries' effort to lessen the carbon emissions that contribute to the climate change problem. Green technology innovation refers to innovation activities that focus on lowering the environmental impact of the economic activities and have often been measured using green patents data (Earnhart, 2004; Kammerer, 2009; Chen et al., 2006; Çinar and Yilmazer, 2021; Yuan et al., 2020). Several studies also suggested the R&D expenditure as the measure of innovation (Albino et al., 2014). However, since the patent data is widely available and quantitatively represents the innovation that has occurred, and thereby is a suitable measure of the green technology innovation (Wydra, 2020; Urbaniec et al., 2021).

Green technology innovation can be seen as the key to solve the alarming environmental issue since it contributes to the evolution of new products and processes in which helps in energy conservation, reduce waste and pollution as well as provide better environmental management (Chen et al., 2020; Chen et al., 2006; Fogarassy and Finger, 2020; Ghisetti and Quatraro, 2017; Guo et al., 2018; Miao et al., 2017; Rennings, 2000; Zhang et al., 2020; Mahendru et al., 2022; Sharma et al., 2022). The importance of green innovation or eco-innovations can be traced back to the neoclassical approach that highlighted the importance of innovations as the key to achieving environmental sustainability (Urbaniec et al., 2021; Ghura, et al., 2022). Moreover, green technology innovation also serves as a tool to balance economic development with environmental protection, which is crucial for sustainable development (Cinar and Yilmazer, 2021). Some recent studies also argued that green innovation plays a crucial role in expanding business competitiveness and helps in achieving sustainable business performance and development (Shrivastava, 1995; Chen et al., 2006; Shahzad et al., 2020; Abbas and Sağsan, 2019). Hence, as part of initiatives by countries to reduce the environmental problem, the shift toward a green technology can be seen as an effective move since it is aligned with the sustainable development goals due to its benefit in saving energy and resources (Marin, 2014; Shen et al., 2021; Wang et al. 2021b).

The growing literature on the factors contributing toward green technology innovation has highlighted the importance of economic growth and government intervention as the important drivers of green innovation. Samad and Manzoor (2011) have highlighted the benefits and significance of economic growth in context to different determinants. In particular, they argued that the economic expansion would encourage green innovations since a bigger market can adopt greater technological changes and enable greater investment to be made to develop green technologies. Besides, the study carried out by Liu et al. (2020) on the effects of economic growth target suggests that the goals proposed and designed the government in its economic growth will affect the resource allocation and thereby influence the green innovation. Similarly, a study conducted by Meirun et al. (2021) in Singapore using the bootstrap autoregressive-distributed lag (BARDL) technique reveals the linkage between economic growth and green technology innovation exhibit a positive relationship in term of short and long-run both.

A recent study conducted by Shen et al. (2021) and Wang et al. (2021) claimed that the increase in economic growth target would negatively impact green technology innovations, thus supporting the idea that the economic growth will inhibit the green or eco innovations. This is due to the goals set are often on the quantity and not on the quality of the growth (Shen et al. (2021; Ramzan et al., 2022). In addition, the level of GTI will decline slowly in the area where the economic growth has passed the target, while the effect is insignificant in the area where the goals has not been attained. Besides the roles of economic growth in influencing green innovation, the link between GTI and environmental policy has also gained greater attention among researchers and policymakers. Although the shift towards green technology innovation is challenging for the business sector since it involved higher costs, the expansion of green technology innovation across countries becomes possible due to government intervention, mainly through environmental regulation.

A seminal work by Porter (1991) on the link between green innovations and environmental regulations has gained much interest among scholars. Based on the Porter hypothesis, a stringent environmental regulation that is well designed will stimulate innovation activities mainly among the high polluting firms and results in higher productivity level (Porter 1991; Porter and Van der Linde, 1995). This hypothesis also suggests that the innovation's benefit will offset the additional cost associated with complying with the regulation. Many researches have empirically tested the Porter hypothesis, but integrated results were found in the literature (Ambec et al., 2013). Several research highlighted that the regulations pertaining to environment have a high and positive influence on GTI since it becomes an incentive for the businesses to seek an alternative solution to offset the cost associated with the regulation (Arimura et al., 2007; Hamamoto, 2006; Popp, 2005; Ramanathan et al., 2017; Rennings and Rammer 2011; Rennings and Rexhäuser 2011; Ryszko, 2016; Shen et al., 2021). Besides, Van Leeuwen and Mohnen (2017) supports that implementing an environmental tax will promote green innovation, but Hattori (2017) claimed that it would encourage GTI only if for polluting goods elasticity demand is low. In contrast, although Acemoglu et al. (2012) argued that in view of planning and promotion of GTI carbon tax is essential and most important, and avoid any kind of disturbances and discouragement in using green using innovations practices and activities.

In contrast, some studies argued that the environmental regulation such as the environmental tax will discourage green technology innovation associated to the rising operating costs (Çinar and Yilmazer, 2021; Conrad and Wastl, 1995; Kemp and Pontoglio, 2011; Popp et al., 2009). Moreover, the crowding-out effects from the environmental regulation will be higher for the business sector facing financial constraints (Hottenrott and Rexhäuser, 2015). In contrast, some studies found the relationship to exhibit a nonlinear relationship (Ai et al.,2021; Perino and Requate, 2012; Wang and Yu, 2021). For example, Ai et al. (2021) found the u-shaped effect of regulations related to environment on the GTI whereby it will hinder the green innovation in the shorter run but becomes the driver of green innovation in the longer run. Thus, it can be concluded that all the effects are ambiguous created by of environmental regulation.

While most of the available literature has looked at economic growth and environmental regulation as the important drivers of GTI, the importance of green energy and green investment have less been given attention. As the world becomes more concerned over environmental conservation, green energy and green investment have started to gain popularity as alternative ways to reduce carbon emissions. The rise in green energy often requires support in terms of technologies, and thereby it is expected to promote green technology innovations. Similarly, as the green investment rises, this enables more innovation projects to be funded and is expected to boost green innovation. Therefore, examining the effect of green energy and green investment on green technology innovation could significantly contribute to the literature and become the motivation for this study.

3. Methodology and dataset

3.1. Cross-sectional dependence (CSD) test

In the panel data approach, it is crucial to use advanced econometric approaches to overcome the weaknesses of empirical analysis and to obtain more robust estimators. Performing basic initial tests such as CSD, homogeneity, and URT shed light on the selection of relevant approaches just before employing these advanced techniques. Cross-sectional dependence, which is the key stage for the remainder of the panel data analysis, is a typical issue observed in panel data due to various factors such as the interdependence of residuals, and a hidden observed and unobserved common shock. Neglecting spillover effects between the units can lead to the spurious inference, inconsistent estimators, and even biased results for stationarity and cointegration analysis (Chudik and Pesaran, 2013; Westerlund, 2007). Therefore, the presence of CSD in panel data analysis should be checked immediately at the first step of the analysis. The analysis of this study begins with the employing of Pesaran's (2015) test of cross-sectional dependence. CSD-statistics equation is given below:

$$\mathrm{CSDD}^{NT} = \sqrt{\frac{TN(N-1)}{2}} * \hat{\rho}_N \tag{1}$$

where $\hat{\rho}_N$ shows the pairwise correlation coefficient. The null hypothesis implies that between the units there is no CSD.

3.2. Unit root test

After testing the cross-sectional correlation of residuals, the next step is to investigate whether in the series of panel data has unit roots or not. The theoretical literature on panel URT began with the first generation of unit root methods (Levin et al. (2002), Choi (2001), Im et al. (2003), subsequently, it is classified under three different generations namely the one, two, and third- unit root tests (URT), over time. The generation one and two of URT have been the most widely availed in a variety of investigations on the empirical side in the panel data literature (Pesaran, 2007). The key difference between the tests here stems from whether the tests explicitly handle the concerns of correlation across panel units. However, the major shortcoming of these tests is that they do not focus on multiple structural changes, which have unknown numbers of breaks and dates, and on common dynamic factors. In case of the possible existence of unknown structural changes owing to country-specified or global factors, both generation one and two URT cannot handle these issues properly and have distortions of different powers. To minimum such issues, the most appropriate approach is using the third-generation PURT since it takes into account the heterogeneity and CSD, and also more importantly allows for possible breaks in multiple structural of the panel data. Following the CSD test, beyond the second-generation URT of Pesaran (2007), this study examines the unit root properties of panel data using a more powerful URT method of Carrion-i-Silvestre and Bai (2009) for panel data.

3.3. Cointegration testing

Following stage of the empirical analysis consists of employing updated version of Swamy's (1970) SHT designed by Pesaran and Yamagata (2008) to test the heterogeneity which exits in the slope. Given results show the presence of both CSD and heterogeneous slope parameters which indicates that the use of cointegration tests belong to first-generation, which is not robust in the existence of CDS and heterogeneity, would be misleading in determining the relationships among variables. By using more robust methods based on Carrion-i-Silvestre and Banerjee (2017) and Edgerton and Westerlund (2008) in this paper, we overcome the issue of CSD, SH along with unknown shift in heterogeneous in both the intercept and the slope of the cointegrated regression. The panel cointegration test of Westerlund and Edgerton (2008) is written as;

$$y_{it} = \alpha_i + \eta_i t + \delta_i D_{it} + x'_{it}\beta_i + (D_{it}x_{it})'\gamma_i + z_{it} \tag{2}$$

where D_{it} = 1 for t > T_i and 0 otherwise with T_i refers to SB for cross-section i, and k-dimensional vector of x_{it} which comprises the regressor pursues the following process: $x_{it} = x_{it-1} + w_{it}$. α_i and β_i refers to the slope and intercept before the break, while δ_i and γ_i refers to the change in the parameters at the time of the shift. Z_{it} Permits CSD by unobserved common factors. Z_{it} is presumed to have the following data-generating process:

$$z_{it} = \lambda'_i F_t + v_{it} \tag{3}$$

$$F_{jt} = \rho_j F_{jt-1} + u_{jt} \tag{4}$$

$$\varphi_i(L)\Delta v_{it} = \varphi_i v_{it-1} + e_{it} \tag{5}$$

In particular, the relationship of y_{it} with x_{it} in equation (2) is cointegrated if $\varphi_i < 0$, and the relationship between the variables is spurious if $\varphi_i = 0$. The null hypothesis of Westerlund and Edgerton (2008) states that there is no long-run relationship between green technology innovation and their determinants, while the alternative hypothesis indicates the cointegration among the variables exists. Using the LM bootstrap integration strategy, the panel LM-based statistics of H_0 vs. H_1 is defined as:

$$LM_{\text{test}} = N^{-1}\sum_{i=1}^{N} \frac{\widehat{\varphi}_i}{S.E(\widehat{\varphi}_i)} \tag{6}$$

$\widehat{z}_{it}$ denote the residuals of the model of y_{it} in Equation (2) is used for obtaining $\widehat{\varphi}_i$.

3.4. CS-ARDL (Cross-Sectionally Augmented Autoregressive Distributed Lags)

For short and long-run estimation, we benefit from the method of CS-ARDL to avoid misleading results that may arise from UCF which are associated in the model with the help of regressors. This robust approach using the dynamic correlated effects estimator overpowers the issues of SH, endogeneity, UCF and assures efficient results in CSD (Pesaran and Tosetti, 2011). The general equation form of (Chudik and Pesaran, 2015) CS-ARDL is given below as:

$$GTI_{i,t} = \alpha_i + \sum_{k=1}^{p}\gamma_{i,k}GTI_{i,t-k} + \sum_{k=0}^{q}\beta_{i,k}X_{i,t-k} + \sum_{k=0}^{Sz}\pi_{i,k}\bar{Z}_{i,t-k} + \varepsilon_{i,t} \tag{7}$$

By including means of cross-section ($\bar{Z}$) of both the dependent ($GTI_{i,t}$) and the set of independent variables ($X_{i,t=}$ $REN_{i,t,}$ $GINV_{i,t,}$ $ERT_{i,t,}GDP_{i,t}$),$\bar{Z}_{t=}(\bar{GTI}_{t,}\bar{X}_{t,})$ overcomes to CSD caused by SOE (Liddle, 2018a, 2018b; Chudik and Pesaran, 2015). Sz refers to the number of lagged cross-sectional averages for each variable.

The Error Correction Mechanism (ECM) representation of panel CS-ARDL is estimated as:

$$\Delta GTI_{i,t} = \alpha_i + \delta_i\left[GTI_{i,t-1} - \sigma_i X_{i,t-1}\right] + \sum_{k=1}^{p-1}\gamma^*_{i,k}\Delta GTI_{i,t-k} + \sum_{k=0}^{q-1}\beta^i_{i,k}\Delta X_{it-k} + \sum_{k=0}^{sz}\pi_{i,k}\bar{z}_{it-k} + \sum_{k=1}^{p-1}\delta_k \times \Delta\bar{GTI}_{t-k} + \sum_{k=0}^{q-1}\vartheta_k\Delta\bar{X}_{t-k} + \varepsilon_{i,t} \tag{8}$$

To check unbiased estimation results in the presence of non-stationary and UCF, robustness tests are performed in the analysis using two alternative approaches namely the AGM of Eberhardt and Teal (2010) and the CCEMG of Pesaran (2006).

3.5. Dataset

To explore the role of renewable energy supply as well as renewable energy investments in green technology innovation along with economic growth and environmental tax, this study allows the form of the GTI_{it} modeling function, which is written below:

$$GTI_{it} = f(REN_{it}, GNIV_{it}, ERT_{it}, GDP_{it}) \tag{9}$$

where GTI is the green technology innovation examined by the number of patent applications in technologies related to environment, REN is the renewable energy (% of primary energy supply) referred to as green energy, GINV is the investment in renewable or green energy (measured in million $), ERT is the environmental taxes (total % of GDP) and finally, GDP refers to real gross domestic product. Patent applications are the most commonly used indicator for green technology innovation since they are both based on objective standards that change slowly, and are easily accessible (EEA, 2011). For this reason, this study utilizes the number of patent applications as the measure of technological innovation in the green area. Also, we use the environmental tax and economic growth data as control variables. All data, except renewable energy investment, are retrieved from the OECD statistics database. The data on renewable energy investment is derived from International Renewable Energy Agency website. We use all variables in their natural logarithmic forms to minimize variability and smooth the data. To empirically examine the nexus between GTI and its determinants, we utilize the annual dataset of Singapore, Malaysia, Thailand, Indonesia, the Philippines, and Vietnam, which are represented through "i" in Eq. (8), while "t" shows the time-period of 1995–2018.

4. Empirical results

The test statistics reported in Table 1 show the empirical results of Pesaran's (2015) CSD method as the first step of the investigation. The findings support the existence of dependency among countries for all the variables including GTI_{it}, REN_{it}, $GINV_{it}$, ERT_{it}, GDP_{it} in the panel data. All CSD hypothesis are accepted at the 0.01. (1%) level of significance according to all CSD test results. The estimation of the CSD test reflect the CSD among the countries, so the shock arising from one of the six countries also spreads to the other five countries because of the growing degree of economic and environmental integration. Based on these results, it can be said that different countries have similar structural parameters such as environmental, financial, and economic.

Following the proposition by the empirical literature in the case of CSD between the countries, we aim to determine the stationary properties of the variables using Carrion-i-Silvestre and Bai (2009) and Pesaran (2007) PURT by considering the CSD, heterogeneity, and SB in the data set. Table 2 reports the estimations of URT. The result of the URT based on Pesaran (2007) reveals that all variables are stationary at the level. On the other hand, Carrion-i-Silvestre and bai (2009) test fail to reject the proposed null hypothesis of unit root at the level. However, the test statistics of Carrion-i-Silvestre and bai (2009) URT obtained at the first significant difference which accept the alternative hypothesis non-stationarity in all variables. Therefore, it can be concluded that all variables of the study are I (1).

After analyzing CSD and the URT, the following step is to query for the presence of homogeneous or heterogeneous slope coefficients. As seen in Table 3 where the evidence of the adjusted and significant delta statistics of SH tests by Pesaran and Yamagata (2008) are provided, the null hypotheses of homogeneous slope coefficients are rejected at 1% significance level. The delta test results affirm that slope coefficients are heterogeneous in the CSD, and the model of the analysis has the heterogeneity problem.

Table 4 gives us the results based on the Westerlund and Edgerton (2008) analysis for the estimation of panel cointegration with SB. The null hypothesis implies that in the presence of problems related to panel data such as SB, SH, CSD, serial correlation, there is no cointegration exists for a long run. Given that all statistics of Edgerton and Westerlund are significant at 1%, we reject the null hypothesis of no long run cointegration with no regime shift, mean shift, and breaks, and endorse the long run cointegration for GTI with REN, GINV, ERT, and GDP. Whereas according to the empirical results of the Banerjee and Carrion-i-Silvestre (2017) cointegration analysis shown in Table 5, the null hypothesis that argues no cointegration exists among the variables is rejected at 1% level for the full sample and each country individually including Vietnam, Malaysia, Singapore, Philippines, Indonesia and Thailand. The significant statistics for the test demonstrate the cointegration relationship which is exist among the variables for ASEAN-6 countries. Since the cointegration relationship is confirmed by both Westerlund and Edgerton (2008) and the Banerjee and Carrion-i-Silvestre (2017) cointegration analysis, we decided to proceed to investigate the long and short-run relationship between GTI and its determinants.

Table 1
Results of CSD analysis.

Variable	Test Statistics (p-values)
GTI	18.129*** (0.000)
REN	22.053*** (0.000)
GINV	17.146*** (0.000)
ERT	24.031*** (0.000)
GDP	19.115*** (0.000)

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *, while the values in parentheses are the P-values.

To estimate the coefficients of both runs (short and long) we utilize a superior cointegration approach of CS-ARDL method. Tables 6 and 7 provide the empirical findings based on CS-ARDL approach in the both runs (short and long). In the runs (short and long), RENE supply, RENE investment, environmental taxes, and economic growth are determined as the key drivers in explaining green technology innovation for Vietnam, Malaysia, Singapore, Philippines, Indonesia and Thailand. In particular, the empirical results point out that all variables exert a statistically significant positive effect on green technology innovation both runs (short and long). In addition, all variables have a simulative effect on green technology innovation, but the effects are stronger in the long run. The impact of short run coefficients is fairly lower than the long run for all studied variables. This is mainly because the adoption of green technologies is laborious, costly, and time-consuming due to their special nature. These economies have enormous growth potential, and the process for the development of GTI by incorporating green technology into industrial development is in progress as well in these economies. The long-run equilibrium re-convergence for CS-ARDL is affirms by lagged error correction term which is negatively significant with 0.301 coefficient.

The main focus of this study is to investigate the impacts of renewable energy supply and renewable energy investment on GTI. Thus, we shed light on a detailed analysis of the role of renewable energy supply and investments in all environmental-related technological innovations. The empirical findings reveal that renewable energy supply positively influence GTI in ASEAN-6 countries. In the long run, GTI will increase by 0.273% following a 1% increase in RENE supply. In the shorter run, GTI increased by 0.082% because of a 1% increase in RENE supply. These results indicate that enhancing RENE supply in total energy supply can give these countries an advantage in reducing polluting activities by boosting green GTI. Any attempts and regulations like shifting sources from non-RENE supply to RENE supply to increase the share of RENE in the total primary energy supply can stimulate green patent activity in the field of environment-related technologies in the regions. Similarly, renewable energy investment is also positively associated with green technology innovation with a coefficient of 0.348 implies that a 1% increase in RENE investment will increase GTI by 0.348% in the longer duration. In the shorter run, a 1% rise in RENE investment will results in a 0.075% increase in GTI. Just as with RENE supply, investment in RENE is of critical importance for ASEAN-6 countries to increase the number of patent applications in environmental technologies. Targeting the expansion of investments in RENE aimed at raising green technology innovations should be the precedence of these countries. This creates a potential for the shift to a green economy. When looking at long and short-run associations for environmental tax, the findings suggest a positive relationship between GTI and ET. A 1% rise in the ET increases GTI by 0.176% in the long run and 0.074% in the short run. Environmental taxes can give explicit assistance to technological innovation. Thus, environmental taxes are also useful policy tools for innovation and can encourage technological innovation via firms patenting new products to reduce environmental

Table 2
Results of URT with & without SB Pesaran (2007).

Variables	Level I (0) CIPS	M-CIPS		First Difference I(1)	CIPS	M-CIPS
GTI	−3.182***	−5.041**			–	–
REN	−4.135***	−3.173**			–	–
GINV	−3.169***	−4.142**			–	–
ERT	−5.027***	−3.185**			–	–
GDP	−4.144***	−4.120**			–	–
Carrion-i-Silvestre and Bai (2009)						
	Z	**P_m**	**P**	**Z**	**P_m**	**P**
GTI	0.351	0.194	16.154	−6.009***	4.126***	53.162***
REN	0.179	0.316	20.071	−3.153***	3.157***	76.053***
GINV	0.264	0.253	17.140	−5.041***	5.041***	61.137***
ERT	0.182	0.172	22.015	−4.138***	4.135***	55.189***
GDP	0.238	0.261	18.163	−3.125***	6.010***	69.140***

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *. Critical values for P are 56.06, 48.60 and 44.90 and Z and Pm statistics are 2.326, 1.645 and 1.282, all are based on Bai & Carrion-i-Silvestre (2009) and significance at 1%, 5% and 10% levels.

Table 3
Results of Slope heterogeneity (SH) analysis.

Statistics	Test value (P-value)
Delta tilde	84.162*** (0.000)
Delta tilde Adjusted	65.210*** (0.000)

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *, while the values in parentheses are the P-values.

Table 4
Results of Westerlund and Edgerton (2008) panel cointegration analysis.

Test	No break	Mean shift	Regime shift
$Z_{\varphi}(N)$	−8.691***	−8.061***	−8.410***
P_{value}	0.000	0.000	0.000
$Z_{\tau}(N)$	−7.026***	−8.085***	−6.554***
P_{value}	0.000	0.000	0.000

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *, while the values in parentheses are the P-values.

Table 5
Results of Banerjee and Carrion-i-Silvestre (2017) cointegration analysis.

Countries	No deterministic specification	With constant	With trend
Dependent Variable: Green Technology Innovation			
Full Sample	−5.014***	−3.146***	−6.005***
Singapore	−5.167***	−5.035***	−5.174***
Malaysia	−4.123***	−4.167***	−5.071***
Thailand	−3.180***	−4.130***	−4.136***
Indonesia	−6.005***	−6.182***	−6.023***
Philippines	−3.194***	−5.054***	−3.155***
Vietnam	−5.071***	−4.129***	−4.119***

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *. The critical value for result with constant at 5% and 10% is −2.32 and −2.18 while with trend is −2.92 and −2.82.

Table 6
Results of CS-ARDL analysis (Long run CS-ARDL Results).

Variables	Coefficients	t-statistics	p-values
REN	0.273***	3.672	0.000
GINV	0.348***	5.661	0.000
ERT	0.176***	4.043	0.000
GDP	0.485***	6.968	0.000

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *.

Table 7
Results of CS-ARDL analysis (Short run CS-ARDL Results).

Variables	Coefficients	t-statistics	p-values
REN	0.082***	4.142	0.000
GINV	0.075***	6.993	0.000
ERT	0.074**	2.080	0.044
GDP	0.138***	3.711	0.000
ECT(-1)	0.301***	−3.853	0.000

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *.

degradation. However, environmental tax reform can urge firms to invest more in technology innovation to abstain from taxes. These results are supporting the estimations of Karmaker et al. (2021), OECD (2010). According to the analysis of the OECD (2010), environmental taxes can serve as a catalyst for the creativity that is the foundation of a thriving economy. Economic growth is also determined to have the greatest impact on green technology innovation, with a long run coefficient of 0.485% and a value of 0.138% for the short run. This implies that green technology innovation raised by 0.485% because of a 1% rise in growth. In the shorter run, GTI raised by 0.138% because of a 1% increase in growth. The estimations depict that economic growth is one of the significant contributors to green innovation. Environmental-related patents application increase as economy grows.

For verifying the strength of the model and econometric approach, we conduct a robustness check using AMG test and CCEMG test and the results are presented in Table 8. The estimations of AMG and CCEMG tests are consistent with that of CS-ARDL. The outcomes of the robustness check confirm the positive relationship of GTI with RENE supply, renewable energy investment, environmental taxes, and economic growth.

5. Conclusion

Due to global concerns arising from climate change, countries are focusing heavily on preventing environmental degradation and achieving the target of net-zero carbon dioxide emissions. This process inevitably forces countries to discover fresh and viable solutions based on greener technologies, such as renewable energy, in operational ways. In parallel, governments inevitably incorporate environmentally related taxes as a policy tool into their green agendas. On the one hand, a continuous rise in global gross domestic product caused by a high-growing population and resulting in increasing energy demand is one of the key actors' actively driving environmental degradation. However, environmental technologies and innovations aimed to decrease

Table 8
Results of AMG & CCEMG for Robustness Check.

Dependent Variables GTI	Augmented Mean Group (AMG)			Common Correlated Effect Mean Group (CCEMC)		
	Coefficients	t-statistics	p-values	Coefficients	t-statistics	p-values
REN	0.175***	3.154	0.000	0.188***	4.970	0.000
GINV	0.241***	4.680	0.000	0.236***	4.543	0.000
ERT	0.190***	3.962	0.000	0.175***	5.309	0.000
GDP	0.300***	3.105	0.000	0.325***	3.675	0.000
Wald test	–	12.071	0.000	–	–	0.000

Note: Significance levels 1%, 5%, 10% are denoted by ***, ** and *.

environmental degradation impacts on the economy which is vital engine for sustainable growth. Renewable energy plays an active role in green technology innovation by mitigating environmental degradation. The growing concerns over the climate change issue have raised economists' interest in green technology innovations to solve the environmental problem and achieve sustainable and responsible development (Dangelico et al., 2017; Kiefer et al., 2019). Although some of the past studies have extensively discussed the underlying factors that contribute to green technology innovation, most of the studies have focused on developed countries and highlighted the roles of economic growth and environmental regulation. Thus, examining the contribution of RENE supply and RENE investments along with environmental taxes and economic growth to green technology innovation provides a guide to easily tackling mentioned environmental challenges global.

Against to this backdrop, the current study primarily aims to specify the dynamic effects of renewable energy supply and renewable energy investment on GTI, by controlling the effect of ET and economic growth for 6 ASEAN countries including Vietnam, Malaysia, Singapore, Philippines, Indonesia and Thailand using balanced panel data from 1995 to 2018. For this purpose, various advanced panel data approaches, such as the CSD test of Pesaran (2015), the third-generation URT of Carrion-i-Silvestre and Bai (2009), and the cointegration test of Westerlund and Edgerton (2008) are used in the analysis. The estimations of the both runs (short and long) are examined by employing a robust CS-ARDL method. Using the CS-ARDL method, the findings of this study reveal that economic growth, environmental tax, green energy, and green investment play a crucial role in promoting GTI in the ASEAN-6 countries. In particular, economic growth plays a prominent role in promoting green innovations, followed by green investment and green energy. In addition, although the result of the environmental tax supports that the Porter hypothesis applies in the context of the ASEAN-6 economies, its role in promoting green innovation is relatively weak compared to other factors.

This study offers several implications for the policy to encourage green innovations. First, since economic growth is the leading factor contributing to green innovation, ensuring high and stable economic growth is essential for developing green innovations. However, it is important to ensure that the economic growth does not come from a source that is harmful to the environment since it will be against the objective of the green innovations. For this reason, encouraging green growth should be the main priority of the country. Second, this study reveals that the expansion in green energy will trigger innovation activities. Hence, the policy that supports and encourages green energy use should be strengthened to transform the economy towards a green economy. Third, more efforts should be taken to promote green investment behavior among firms, contributing toward a greater level of green innovation. For instance, the government can provide a tax incentive to firms engaged in green investment to enable more innovative projects to be funded. Finally, a well-structured environmental tax can be implemented to encourage firms to innovate and avoid the tax burden. Since this study only focused on the ASEAN-6 economies, future research may extend the analysis by including other developing countries. Besides, other indicators to measure green technology innovation should also be developed to better explain the innovation activities that take place across countries. This study provides a conceptual and theoretical groundings for the future research in relation to link the green technology innovations, economic growth and environmental tax in any countries across the World. In addition, green energy and green investment are also some crucial elements for establishing the above said relationship that could be separately investigated by the upcoming research. As suggested by the empirical findings of the present work, eco-innovations are the game changer for the reduction of CO_2 emissions and environmental degradation without diminishing the economic growth. Hence, upcoming studies need to focus on eco-innovations, sustainable energy and people friendly environmental tax.

CRediT authorship contribution statement

Arshian Sharif: Conceptualization, Data curation, Supervision. **Sinem Kocak:** Supervision, Software. **Hafizah Hammad Ahmad Khan:** Software. **Gizem Uzuner:** Investigation, Methodology. **Sunil Tiwari:** Writing original - draft, Writing review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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