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# Exploring the liaison between industrial CO2 emissions and economic growth in ASEAN countries: A dis-aggregated analysis

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## *ABSTRACT*

Global warming has become an emerging and serious issue in the world, with adverse effects on human life and a threat to survival. Besides being a key contributor to a country's economic growth (EG), the manufacturing and construction sector (M&C) is also one of the major sectors that cause environmental degradation. We investigate the link between M&C's $CO_2E$ and economic growth (both overall and sectoral growth) in the context of the Environmental Kuznets Curve (EKC) at aggregate and disaggregate levels in the Associations of Southeast Asia Nations (ASEAN), using data from 1995 to 2018. We employ the feasible generalized least squares (FGLS) and Panel-Corrected Standard Errors (PCSE) estimation techniques to examine the existence of the Environmental Kuznets Curve (EKC) at aggregate and disaggregate levels in ASEAN countries. We find evidence of an inverted U-shaped EKC at both the aggregate and disaggregate levels. After including other variables such as financial development, urbanization, foreign direct investment, and manufactured goods exports, our findings are robust and statistically significant. Our study suggests that policymakers should sanction such measures to reduce CO2 emissions from the M&C sector while maintaining economic growth.

**Contribution/ Originality:** This study contributes to the literature in the case of ASEAN by examining the liaison between industrial $CO_2E$ (i.e., CO2 emitted from the manufacturing and construction sectors) and the growth of the M&C sector in ASEAN countries. The validity of the EKC hypothesis at aggregate levels and at disaggregate levels is tested.

## 1. INTRODUCTION

As eloquently put by the UN Secretary-General, "The era characterized by global warming has ended, and a new era marked by global boiling has arrived."

The M&C sector has been recognized as a major contributor to both the economic growth of the economy and environmental degradation [1-4]. Substantial waste production in the M&C sector has a negative effect on human health, making it more risky and menacing [5]. The primary source of $CO_2$ emissions (henceforth $CO_2E$) is the combustion of fossil fuels, which accounts for about 80% of all anthropogenic emissions, with the remaining 20%

caused by deforestation [6]. An increase in $CO_2E$ is widely acknowledged as the main cause of global warming [7-9], and Southeast Asia is among the most vulnerable regions that are exposed to global warming risks [10].

Global warming has become one of the most urgent issues facing humanity [11]. According to Petteri Taalas[1] the World Meteorological Organization, there is an increasing urgency to mitigate greenhouse gas emission. The imperative for climate action transcends the realm of luxury and assumes the status of necessity. At the same time, the primary cause of climate change is human activity [12]. Climate change and global warming are two major global problems, and there is growing agreement that governments must find solutions to these problems [13-18]. Many researchers have focused on controlling $CO_2E$ and other causes of global warming linked to economic growth and industrialization [19, 20]. Between 1906 and 2005, the average global temperature increased by around $0.70^0$ C. It has been anticipated that the effects of global warming will cause the temperature to rise in the future. $CO_2E$, according to Piao, et al. [21] and Shiflett, et al. [22], is the primary contributor to the four main processes that cause global warming. Although the ASEAN area now emits less $CO_2$ than China or the United States [23], it is expected that in fifty years, the region will experience significant effects from the rising sea level. Due to the intermittent growth trend, the rise in $CO_2E$ in ASEAN may become substantial and might be comparable to China and the United States if nothing is done. In response to climate change, which is among its top concerns, ASEAN has set a target of net zero emissions achievement by 2050 [24]. ASEAN's population is projected to reach 770 million by 2040, and its economy will be the fourth largest in the world by 2030 [25]. The ASEAN Center for Energy (ACE) has predicted that ASEAN's GHG emissions will rise by between 34 and 147% from 2017 to 2040 [26]. As virtually every ASEAN nation has CO2E-producing industries, ASEAN is the region that subsidizes the most global CO2E. With 37% of all $CO_2E$ coming from the power-generating sector, this sector has become the primary source of $CO_2E$. The exponential growth of industrialization has resulted in considerable ecological damage, particularly in reaction to energy consumption and the release of carbon dioxide emissions [27]. The accelerated rates of urbanization and industrialization in the last 10 years have caused an increase in energy demand. According to reports, transportation, industry, and construction, as well as the production of heat and electricity, are the primary sources of $CO_2E$ in ASEAN nations [10].

Industrialization is necessary for any economy to achieve economic growth. As a result, many countries disregard environmental regulations in an effort to enhance their economic growth. Global warming is fundamentally characterized by carbon dioxide's contribution to GHGs (Greenhouse Gases). Whereas a significant increase in global warming was reported between 1990 and 2013 [28], a significant amount of it between 1970 and 2010 was attributed to the use of fossil fuels [29]. Due to a lack of technology, the manufacturing and construction industries consume enormous amounts of resources and generate a lot of emissions. For instance, the construction industry uses close to 40% of all primary energy [30]. Thus, it is essential to emphasize that economic growth is primarily responsible for the rise in CO2E [31-34]. Therefore, it is difficult for the global manufacturing and construction industries to maintain a healthy balance between GDP and CO2E. Industrialization is essential for the economic expansion of any nation, and industrial processes use energy from a variety of sources [35]. Different sources of energy, including petroleum and some other gases used in the industrial manufacturing process, create $CO_2E$. According to Stocker, et al. [36], $CO_2E$ is a primary and fundamental term of GHG on a global scale. The manufacturing and construction industries contribute to economic expansion, which has both positive effects on societal welfare and negative consequences for the environment due to the release of greenhouse gases. By using chemicals and fuels in industrial operations, the manufacturing industry emits greenhouse gases [28-32]. Manufactured exports are the main pillar of economic growth [33]. Many developing nations rely on exports of basic goods as their major source of foreign exchange. However, several studies argue that countries that prioritize the export of manufactured goods are likely to experience faster economic growth than those that prioritize the

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[1] For more details, read https://public.wmo.int/en/media/press-release/july-2023-set-be-hottest-month-record

export of raw materials [34, 35, 37, 38]. The stages of economic development have a connection with environmental degradation, and environmental specialists claim that focusing primarily on economic growth would threaten the environment [39, 40]. Early studies that explored the association between growth and environmental degradation revealed an inverted U-shaped curve called the EKC. Kuznets [41] predicted that as the economy progressed, economic inequality would initially climb, then peak, and then steadily fall. Based on the EKC hypothesis, it is pointed out that there is an initial phase of environmental degradation during the early stages of economic growth. However, it is worth noting that if country's economic growth surpasses a specific threshold, there is the tendency for environmental quality to exhibit signs of improvement. The idea is that there is a link between environmental decline and economic growth, which shows that economic growth, is the most effective way to combat environmental degradation. In order to fix the liaison between $CO_2E$ and economic growth, the EKC is the optimal analysis [42]. By examining historical evidence supporting the EKC theory, the liaison between $CO_2E$ and economic growth is studied [17, 43]. The EKC, which reveals the link between revenue growth and environmental destruction, is essential for addressing environmental and development issues confronted by countries. As a result, this link continues to be the subject of intense investigation [44]. The EKC, which appears recurrently in environmental economics literature, describes the environmental deterioration and economic growth (EG) nexus. According to the EKC, the rate of environmental degradation increases concurrently with per capita income. However, as the economy grows, the demand for environmental quality rises proportionally, resulting in a deceleration in environmental degradation [45]. Thus, if the EKC has an inverted U form, environmental improvement would ultimately take place as economies progress. As a result, without key changes, mankind may presume its normal course and achieve environmental sustainability [46]. The inconclusive evidence about the relationship between EG and CO2E, especially in the context of EKC, and the rising concerns about global warming require an investigation of the relationship at disaggregate levels.

This study adds to the existing literature on ASEAN economies in the following ways: it examines the relationship between EG (i.e., aggregated and disaggregated levels) and CO2E from the M&C sector in the context of the EKC, using ASEAN data from 1995 to 2018. Secondly, it utilizes CO2E from the M&C sector for the first time, at least in the case of ASEAN countries. The paper also investigates the relationship between CO2E and EG (aggregate levels). Thirdly, neither $CO_2E$ from fossil fuel combustion nor $CO_2E$ from biofuel combustion has been used for empirical study in the context of the EKC framework in existing literature regarding ASEAN countries. Fourthly, we use $CO_2E$ from both fossil fuel and biofuel combustions for this empirical study. We used two different models (i.e., overall case (aggregate level), and M&C sector case (disaggregated levels) for each $CO_2E$ (i.e., $CO_2E$ from fossil fuel combustion and $CO_2E$ from biofuel combustion). As existing literature on the environment-growth nexus is inconclusive, this study clarifies this relationship. A comprehensive analysis that examines several sectors individually can assist policymakers in acquiring a greater understanding of sectors within the economy that contribute more to the pollution. This, in turn, enables policymakers to formulate targeted plans aimed at reducing pollution within each specific factor. The rest of the study is in the following order: Section 2 presents a review of the literature, Section 3 presents the data and method, section 4 presents and discusses the results, and Section 5 concludes the study with policy implications for environmental management.

## 2. LITERATURE REVIEW

Many studies have concluded in favor of the EKC theory that there is an inverted U-shaped association between economic growth and environmental degradation on the one hand and between EG, energy use, and environmental degradation caused by$CO_2E$, on the other hand. Holtz-Eakin and Selden [47] developed the EKC estimation for CO2E using panel data. Employing panel regression to examine data from 130 nations between 1951 and 1986, the study confirmed the inverted U-shaped EKC with a turning point at USD 35,428. Nasir, et al. [48] examined the growth-$CO_2E$ relationship in ASEAN nations from 1982 to 2014, using the fully modified ordinaryleast-squares technique (FMOLS). Their results showed an inverted U-shaped connection in the long term. Using data from 1971 to 2014, Le [49] discovered that CO2E increases during the early stages of economic expansion but decreases as these countries advance economically.

Chandran and Tang [50] used the Johansen co-integration test to determine if the EKC hypothesis holds in four ASEAN nations. As opposed to Saboori and Sulaiman [51], who employed an auto-regressive distributed lag (ARDL) approach, three of the four ASEAN countries did not concur with the EKC hypothesis. Using panel smooth transition regression, Heidari, et al. [52] acknowledged an inverted U-shaped link between income and $CO_2E$ in ASEAN States. Liu, et al. [53] concluded that the EKC is invalid for $CO_2E$ and emphasized the significance of viable energy for the improvement of environmental quality by expanding many panel co-integration estimators for ASEAN nations. The Westerlund panel co-integration test was employed by Salman, et al. [54], and their findings supported the validity of the EKC for seven ASEAN nations. In four ASEAN nations, Kisswani, et al. [55] used ARDL but did not find any support for the EKC theory. Hong and Ho [56] determined that none of the four ASEAN nations have EKC for $CO_2E$ while Guzel and Okumus [57] confirmed the soundness of the pollution haven hypothesis (PHH) and EKC by examining five ASEAN nations using the MG method. Using the Driscoll-Kraay standard error estimation technique, Kongbuamai, et al. [58] confirmed an inverted U-shaped EKC for 10 ASEAN nations. Furthermore, they discovered that tourism had a smaller biodiversity impact. Munir, et al. [59] used panel completely-adapted, pooled, and dynamic OLS estimators and concluded that there is an inverted U-shaped link between $CO_2E$ and income for four ASEAN nations. Asghar, et al. [28] employed the method of Moments Quantile Regression and several panel data estimators for six ASEAN nations. The study confirmed the validity of the EKC. Adeel-Farooq, et al. [60], confirmed the effectiveness of the EKC for methane flow and revealed the polluting influence of trade openness using pooled mean-group (PMG) and mean-group (MG) estimators for six ASEAN nations. Three main research groups have looked into the connections between carbon emissions, energy consumption, and economic development [61]. The first group focused on determining if EKC, or the inverted U-shaped link between $CO_2E$ and economic expansion, existed. Kuznets [41], and the Kuznets Curves proponent explained how income inequality and economic growth are related. Eventually, the Kuznets curve became known as the EKC and represents the relationship between economic growth and environmental quality. Beginning with metropolitan area data from 42 different nations, Grossman and Krueger [39] looked into the inverted U-shaped relationship between economic development and ecological pollution. They concluded that environmental pollution initially increases, but after the economy reaches a certain threshold of real GDP per capita, it decreases gradually. The EKC theory was later confirmed by Stern, et al. [62], who investigated the association between income growth and energy pollution. However, Vincent [63] did not discover an inverted U-shaped relationship between wealth and energy pollution.

Ahmad, et al. [64] explored how carbon emissions and energy consumption impact economic growth. The findings indicated a long-run cointegration interaction and that the Environmental Kuznets Curve is true at both the aggregated and disaggregated levels. Investigating the effects of fossil fuel, industrial development, and inward foreign direct-investment (FDI) on $CO_2E$ in the context of the EKC theory, Ullah, et al. [65] uncovered the existence of a U-shaped relationship between industrial growth and $CO_2$. Zhang, et al. [9], examined the EKC of $CO_2E$ in 121 countries in the manufacturing and construction industries. The results supported the EKC theory for 95 countries out of 121. The results of energy consumption, economic improvement, and population growth on $CO_2E$-based environmental degradation examined by Mohsin, et al. [66], showed that the EKC is valid for Pakistan. Prastiyo, et al. [67] investigated how agriculture, manufacturing, and urbanization influence carbon emissions. The results revealed that the EKC hypothesis is effective, with a turning point at 2057.89 USD/capita and that the escalation of greenhouse gas emissions is affected by all economic variables. The classifications of sustainable manufacturing practices examined by Qureshi, et al. [68] indicated that most of the previous work on sustainable manufacturing concentrated on environmental valuation practices than providing holistic industrial engineering clarifications. As of now, various scholars have examined how the global manufacturing and construction industries relate to CO$_2$E. Ahmad, et al. [69] examined the relationship between energy consumption, economic growth, and CO2E in the Chinese construction industry. Using panel data from thirty provinces from 2000 to 2013, Xu and Lin [70] examined the CO$_2$E EKC in the Chinese iron and steel industry and established the occurrence of the EKC in the sector. According to Ma and Cai [17], analysis of the EKC theory of carbon emissions from Chinese commercial buildings at both the national and municipal levels exhibited an inverted U-shaped pattern. Additionally, utilizing provincial panel data from 2000 to 2013, Xu and Lin [71], used a nonparametric additive regression model to evaluate the EKC in China, and their findings supported the inverted U-shaped EKC theory. Numerous empirical studies on the CO2E and growth nexus in the context of EKC have been conducted on ASEAN economies, focusing on the national and regional levels [9, 16, 72-76]. A small number of studies have evaluated CO$_2$E in the context of EKC, with an emphasis on the industrial and construction sectors. Examples include Ahmad, et al. [69] on China's building and iron and steel industries; Ma and Cai [17] on Chinese commercial structures, and Xu and Lin [71] on China's provincial manufacturing industry. Hamit-Haggar [77] discovered the presence of the EKC relationship between industrial CO$_2$E and economic growth in Canada. Farooq, et al. [1] found an N-shaped relationship between M&C sector air pollution and sectoral growth using SAARC country data. No previous study has investigated the relationship between industrial CO$_2$E (emitted from the manufacturing and construction sector) and the growth of the M&C sector in ASEAN countries.

## 3. DATA AND MODEL

### 3.1. Data

This study examines the link between industrial (manufacturing and construction) CO$_2$E and EG (i.e., overall and sectoral) and assesses the validity of the EKC hypothesis in ASEAN (namely, Brunei Darussalam, Indonesia, Cambodia, Lao People's Democratic Republic (LPDR), Myanmar, Malaysia, the Philippines, Singapore, Thailand, and Vietnam). This study uses data for the period 1995 to 2018. GDP per capita (constant 2015 US$), industry (including construction), value-added (constant 2015 US$), urban population, foreign direct investment, and manufacturing exports (current US$) are obtained from the world development indicator (WDI). The data on emissions of CO$_2$ at aggregated and disaggregated levels have been obtained from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR). EDGAR measures data at sectoral as well as overall levels of the economy. EDGAR also reports emissions from both processes (i.e., CO$_2$E from fossil fuel combustion and CO$_2$E from biofuel combustion). The International Monetary Fund (IMF) provides data on the financial development index. LCO$_2$ refers to the log of CO$_2$E from the M&C sector. LEG stands for log of GDP per capita (constant 2015 US$), and LEG$^2$ stands for the square of LEG. LMECG is Log of industry (including construction), value added (constant 2015 US$), and LMCEG$^2$ stands for a square of LMCEG. FDI stands for foreign direct investment, net inflows (% of GDP). Urban stands for the share of the urban population. LMMX is referred to as the Log of Manufacture Exports (Current US$). FD represents the financial development Index. Table 1 shows the descriptive statistics.

**Table 1.** Descriptives

| Variable | N | Mean | SD | Min. | Max. |
|---|---|---|---|---|---|
| LCO2 | 240 | 8.495 | 2.243 | 3.364 | 11.647 |
| LEG | 240 | 8.136 | 1.447 | 5.420 | 11.019 |
| MCEG | 234 | 3.526 | 0.3475 | 2.323 | 4.305 |
| FDI | 193 | 2.203 | 4.220 | -3.437 | 22.594 |
| Urban | 240 | 47.657 | 24.497 | 17.311 | 100 |
| LMMX | 198 | 3.876 | 0.8500 | 0.6981 | 4.577 |
| FD | 240 | 0.3508 | 0.2082 | 0.0351 | 0.7867 |

### 3.2. Model

The goal of this paper is to examine the economic growth impact on environmental degradation in the context of EKC. Following Farooq, et al. [1] and Hye, et al. [78], we are using the following model for empirical examination (Equation 1 represents the overall model and Equation 2 for sectoral) of the liaison between said variables;

$$LCO_{2it} = \alpha_0 + \alpha_1 (LEG)_{it} + \alpha_2 (LEG2)_{it} + \alpha_3 X_{it} + \varepsilon_{it} \quad (1)$$

$$LCO_{2it} = \alpha_0 + \alpha_1 (LMCEG)_{it} + \alpha_2 (LMCEG2)_{it} + \alpha_3 X_{it} + \varepsilon_{it} (2)$$

Where $CO_2$ emission are displayed as a log of $CO_2E$, LEG and LEG2 stand for the log of economic growth and its square in model (1). In addition, LMCEG and LMCEG2 stand for the log of manufacturing and construction economic growth and its square in model (2). X is a vector that represents all other control variables used in both models. ε stands for the random error term. The signs of the parameters associated with growth will determine the shape of the EKC. There will be an inverted U-shaped relationship between $CO_2E$ and growth if the parameter of the linear term is positive and the quadratic term is negative. There will be a U-shaped link between $CO_2E$ and growth if the parameter of the linear term is negative and quadratic term is positive [79].

In the presence of CSD, Heteroskedasticity, and serial correlation, the Feasible Generalized Least Squares (FGLS) is a better choice among all competing models [79-85]. Therefore, the FGLS procedure is employed for examining the effects of EG on $CO_2E$. Because the number of years (T= 24) is greater than number of countries (N =10) (i.e., ASEAN countries), FGLS is better suited for decision-making in the present scenario. Additional, Panel Corrected standard errors (PCSE).

### 3.3. Cross-Sectional Dependence Tests CSD

According to Breusch and Pagan [86], the traditional approaches for the CSD analysis methodology (represented by Equations 3 and 4) are unreliable in this situation. The CSD test can be stated as H0: E (UitUjt) = 0, ∀t and $i \neq j$. And the test statistic (CSD statistic) can be estimated by:

$$\text{CSD} = \sqrt{\frac{2T}{N9n-1}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{n}\hat{\theta}\,\mathrm{ij}\right)(3)$$

$$\hat{\theta}_{\mathrm{ij}} = \boldsymbol{\theta}_{\mathrm{ji}} = \frac{\sum_{t=1}^{T}\hat{\mathrm{u}}_{\mathrm{it}}\ \ \hat{\mathrm{u}}_{\mathrm{jt}}}{\left(\sum_{\mathrm{t}=1}^{\mathrm{T}}\hat{\mathrm{u}}_{\mathrm{it}^2}\right)\left(\sum_{\mathrm{t}=1}^{\mathrm{T}}\hat{\mathrm{u}}_{\mathrm{jt}^2}\right)} \quad (4)$$

The projected residual is characterized here by using the null hypothesis, the CSD test statistic is assumed to be asymptotic [CSD N (0, 1)]. (H0). As a rule of thumb, when CSD is included in the model, the null hypothesis is forbidden.

### 3.4. Estimation Techniques

The panel FGLS model was used to estimate the coefficients in the variables of the models shown in Eqs. 1 and 2. These models incorporate variations in the estimations' standard errors to account for changes in the cross sections (unobserved Heteroskedasticity) [81]. FGLS performs better than other competing models, such as the panel fixed effect (FE) model and the panel random effect (RE), where cross-sectional differences are completely clarified by changes in intercept [84, 87]. Moreover, FGLS models may be robust for cross-sectional dependency, serial autocorrelation, and Heteroskedasticity by changing cross-sectional-specific standard errors [ 81, 83]. The result provides a mathematical formulation of the robust FGLS model.

$$\hat{\beta}\mathrm{GLS} = (\mathrm{X}'\hat{\Omega}\text{-}1\mathrm{X})\text{-}1\ \mathrm{X}'\hat{\Omega}\text{-}1\ \mathrm{y}\ (5)$$

$$\mathrm{Var}\ (\hat{\beta}\mathrm{GLS}) = (\mathrm{X}'\hat{\Omega}\text{-}1\mathrm{X})\text{-}1(6)$$

$$\Omega = \sum\nolimits_{\mathrm{m}*\mathrm{m}} \otimes{}' \mathrm{TixTi}\ (7)$$

$$\hat{\sum}_{ij} = \hat{\varepsilon}_i \hat{\varepsilon}_j / T \quad (8)$$

Heteroskedasticity and autocorrelation are taken into consideration when calculating the coefficients and standard errors using a modified identity matrix (Ω). According to Beck and Katz [80], the FGLS technique outperforms alternatives such as the PCSE and FE models for robustness. The reason is because it highlights issues with Heteroskedasticity, and first-order autocorrelation, the FGLS technique is more applicable than the PCSE and FE models [80, 81, 83, 84, 87, 88].

You can use Panel-Corrected Standard Errors (PCSE) as part of the PCSE strategy to get an estimate that is free from autocorrelation, accurate in terms of standard error, and less affected by estimates from outliers. Likewise, while working with dynamic heterogeneous panel data, the panel-corrected standard error (PCSE) approach is employed[89-91]. For further robustness of estimates, we also employed the generalized methods of moments (GMM) estimate, which tackles the endogeneity problem [92-94].

## 4. RESULTS AND FINDINGS

The first stage in the practical investigation is examining the dataset's Heteroskedasticity, serial correlation, and CD problems. The panel's diagnostic findings are displayed in Table 2. The dependent variable is $LCO_2$. For serial correlations, the Wooldridge test and modified Wald test for Heteroskedasticity. For cross-sectional dependency, use the BP-LM test (CSD). We used the Modified Wald test to detect the Heteroskedasticity problem. The data in the table shows the Heteroskedasticity issue in our sample. Furthermore, to scrutinize the issue of serial correlation, our study employed the Wooldridge test. The data showed that serial correlation existed. Additionally, the BP-LM test is used for the cross-sectional dependency and discovered the CSD problem.

**Table 2.** Panel diagnostic tests.

| **Test** | **Issues** | **(1)** | **(2)** |
|---|---|---|---|
| Modified Wald ($\chi$2) | Heteroskedasticity | 21343.61*** | 6637.05*** |
| Wooldridge test | Serial correlation | 61.02*** | 177.87*** |
| BP-LM test | CSD | 271.39*** | 315.94*** |

**Note:** ***show 0.001. Wald test for the group-wise Heteroskedasticity in FE (fixed effect) regression model. H0=sigma (i) ^2 = sigma^2 for all i: No Heteroskedasticity problem. Serial correlation = H0: No autocorrelation.

Table 3 demonstrates the outcomes of the nexus of overall EG and $LCO_2E$ using FGLS and PCSE. The findings indicate that $CO_2E$ is positively associated with EG, as 1% intensification in EG will increase $CO_2E$ by 10.38%. The $CO_2E$ is negatively related to LEG-2, as a 1% increase in LEG2 will decrease the $CO_2$ by 0.578% in FGLS estimator, while in the PCSE test, $CO_2E$ increases by 11.369 with the increase in the one percent increase in the LEG, and the square of LEG is decreased by 0.661%, which is improving the validation of the EKC in both model hypothesis in ASEAN countries. We also looked at how $CO_2$ emissions and total EG influence models, which show the same correlation as previously.

At the initial stage, $CO_2$ emissions increase due to an increase in LEG at a specific time. The economy will reach a developed stage, and any increase in LEG will decrease carbon emissions. The experiential effects have proven the presence of EKC. Our findings are in line with Tang and Tan [95] for Vietnam, Farooq, et al. [1] for SAARC nations, and in contrast to Al-Mulali, et al. [96] for ASEAN & Shahbaz, et al. [75] for the global sample. For the sake of the robustness of the estimates, we also used the GMM method using the same models presented in Table 3 and got similar results (available upon request). In this study, we are only presenting the results of $CO_2E$ from fossil fuel combustion. We also used $CO_2E$ from biofuel combustion for analysis (results are available upon request).

**Table 3.** $CO_2E$ and EG nexus: Aggregate levels analysis.

| Variable | FGLS | PCSE |
|---|---|---|
| LEG | 10.138***<br>(0.770) | 11.369***<br>(0.915) |
| $LEG^2$ | -0.578***<br>(0.046) | -0.661***<br>(0.054) |
| Constant | -34.244***<br>(3.209) | -38.872***<br>(3.833) |
| Wald stats (P-val) | 231.45 (0.000) | 156.63 (0.000) |

**Note:** $CO_2E$ is the dependent variable in all columns. *** represent 1 percent significance level. In all columns, 240 observations are used.

Table 4 illustrates the outcomes of the nexus of EG (manufacturing and construction sector) and $CO_2E$ using FGLS and PCSE. The outcomes indicate that $CO_2$ is positively linked with LMCEG, as a 1% rise in the EG will increase $CO_2$ by 45.964%. $CO_2E$ is negatively connected to LEG-2, as a 1% increase in LEG2 will decrease $CO_2$ by 6.218%. The outcomes are statistically significant in all models and show the presence of the EKC theory in ASEAN countries. Additionally, we looked at the moderating effects of CO2E and LMCEG in models, which show the same connection as previously. In the early phase of the CO2E increase due to an increase in LMCEG at a specific time, the economy will reach a developed stage, and any increase in LEG will decrease carbon emissions. The observed outcomes confirmed the existence of EKC. Our results are in line with Hamit-Haggar [77] for Canada, Farooq, et al. [1] for SAARC countries, and Ahmad, et al. [64] for India, and in contrast with the study of Ullah, et al. [65] for Vietnam.

**Table 4.** CO2 emissions and EG (Manufacturing & construction sector) EKC.

| Variable | FGLS | PCSE |
|---|---|---|
| LMCEG | 44.06***<br>(5.36) | 11.59***<br>(0.97) |
| LMCEG-2 | -5.88***<br>(0.76) | -4.98***<br>(0.88) |
| Constant | -72.72***<br>(9.42) | -58.80***<br>(10.83) |
| Wald stats | 111.98 | 50.30 |

**Note:** $CO_2$ is the dependent variable in all Columns. *** represent 1 percent significance level. In all columns, 204 observations are used.

## 5. ROBUSTNESS ANALYSIS

Table 5 displays the robustness of the interconnection of EG and $CO_2E$. The results show that $CO_2$ is definitely connected with EG, as an increase in EG will increase $CO_2$ by 15.04%. CO2E is negatively related to LEG-2, as a 1% increase in LEG2 will decrease $CO_2$ by 0.856%. The results are statistically significant in all models and prove the validation of the EKC hypothesis in ASEAN states. Additionally, LMMX and FD are positively connected to $CO_2$. Urban population and FDI are negatively related to CO2E. The outcomes expose the relationship as above in all models. The results we obtained are reliable and statistically significant.

Table 6 demonstrates the robustness of the interconnection of EG (M&C sector) and $CO_2E$. The answers show that $CO_2$is positively associated with LMCEG, as a 1% increase in LMCEG will increase $CO_2$ by 83.15%. $CO_2E$ is negatively related to LMCEG-2, as a 1% increase in the$LEG^2$ will decrease$CO_2E$ by 11.06%. The consequences are statistically significant in all models and prove the validity of the EKC premise in ASEAN republics. Additionally, LMMX and FD are positively connected to $CO_2E$. These findings are consistent with Farooq, et al. [1] for SAARC and Ul-Haq, et al. [79] for BRICS. The urban population has a mixed relationship and FDI is positively related to $CO_2E$. The empirical outcomes reveal an association in all models. Our outcomes are robust and statistically significant. The findings are consistent with the study of Shi, et al. [84] for China.

**Table 5.** CO2 emissions and EG (overall) EKC (robustness).

| **Variable** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| LEG | 8.38***<br>(1.06) | 6.97***<br>(1.09) | 6.09***<br>(1.18) | 7.65***<br>(1.15) | 6.44***<br>(1.24) | 5.53***<br>(1.30) |
| LEG-2 | -0.49***<br>(0.06) | -0.40***<br>(0.06) | -0.36***<br>(0.06) | -0.45***<br>(0.06) | -0.36***<br>(0.07) | -0.32***<br>(0.07) |
| LMMX | 0.51***<br>(0.02) | 0.55***<br>(0.02) | 0.43***<br>(0.05) | 0.52***<br>(0.03) | 0.54***<br>(0.03) | 0.44***<br>(0.05) |
| Urban |  | -0.01***<br>(0.005) | -0.01***<br>(0.006) |  | -0.01***<br>(0.005) | -0.01***<br>(0.006) |
| FD |  |  | 1.96**<br>(0.81) |  |  | 1.98**<br>(0.89) |
| FDI |  |  |  | -0.03*<br>(0.01) | -0.03*<br>(0.02) | -0.03*<br>(0.02) |
| Cons | -37.83***<br>(4.18) | -32.91***<br>(4.32) | -26.42***<br>(5.06) | -34.66***<br>(4.58) | -30.46***<br>(4.82) | -24.25***<br>(5.70) |
| Wald Stats | 1057.99 | 1062.4 | 660.49 | 916.22 | 685.19 | 669.80 |

**Note:** $CO_2$ is the dependent variable in columns in all FGLS models. ..* = P-value 10%, ** 5% and *** is 1 percent. In all columns, 168 observations are used.

**Table 6.** CO2 emissions and EG (overall) EKC (robustness).

| **Variable** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| LEG | 11.23***<br>(1.42) | 11.05***<br>(1.45) | 10.52***<br>(1.46) | 8.39***<br>(1.78) | 7.98***<br>(1.83) | 7.30***<br>(1.86) |
| LEG-2 | -0.65***<br>(0.08) | -0.63***<br>(0.08) | -0.62***<br>(0.08) | -0.48***<br>(0.10) | -0.45***<br>(0.10) | -0.42***<br>(0.02) |
| LMMX | 0.49***<br>(0.04) | 0.52***<br>(0.05) | 0.38***<br>(0.09) | 0.58***<br>(0.05) | 0.62***<br>(0.05) | 0.47***<br>(0.09) |
| Urban |  | -0.01<br>(0.009) | -0.006<br>(0.009) |  | -0.01<br>(0.009) | -0.01<br>(0.008) |
| FD |  |  | 2.34*<br>(1.33) |  |  | 2.55*<br>(1.30) |
| FDI |  |  |  | -0.06**<br>(0.02) | -0.07**<br>(0.02) | -0.07***<br>(0.02) |
| Cons | -49.70***<br>(5.67) | -49.74***<br>(5.69) | -44.14***<br>(6.52) | -39.67***<br>(6.84) | -39.19***<br>(6.93) | -32.70***<br>(7.94) |
| Wald stats | 450.57 | 473.15 | 497.46 | 511.49 | 532.94 | 561.13 |

**Note:** $CO_2$ is the dependent variable in columns in all PCSE models. ..* = P-value 10%, ** 5% and *** is 1 percent. In all columns, 168 observations are used.

To sum up, we find inverted U-shaped EKC at aggregated and disaggregated levels. The findings are robust and insensitive to the inclusion of other related controls as well as different econometric techniques (i.e., GMM). The disaggregated analysis gives a clearer picture of the said liaison and helps to identify key polluting sectors.

## 6. CONCLUSION AND POLICY RECOMMENDATIONS

This study examines how factors like economic growth and industrial expansion affect $CO_2E$ in ASEAN countries. The study examined the relationship between industrial (manufacturing and construction) $CO_2E$ and economic growth (i.e., overall as well as sectoral) and analyses the theory of the EKC Hypothesis in ASEAN nations for the 1995 to 2018 epoch using panel data analysis. Our empirical findings show that there is a positive and significant affiliation between economic growth and carbon emissions in all models and a negative connection between the square of economic growth and carbon emissions. These findings provide empirical evidence supporting the validity of the inverted U-shaped EKC hypothesis across all models examined. The outcomes are also robust and insensitive to the inclusion of additional controls.

The findings suggest that the government should focus on environmental issues, particularly the issue of environmental deterioration or harm brought on by human activity and economic activities like industrial expansion that increase carbon emissions. Government regulations are required for this, such as those that limit population growth, encourage the development of ecologically friendly companies, etc. The conclusions encourage policies to achieve development by enhancing environmental control and protection through the support of economic activities and low-carbon technologies, which will control harmful environmental externalities. Improving the industrial sector (manufacturing and construction) by using modern technologies will lead to a reduction in carbon emissions. The government can work on the industrial sector to increase economic growth. This paper suggests that policymakers should establish environmental protection policies that will confirm that international corporations use environmentally friendly equipment.

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