Journal of International Economics and Management
Journal homepage: http://jiem.ftu.edu.vn

Extended environmental Kuznets curve in Asia Pacific countries: an empirical analysis

Nguyen Binh Duong[1]
Foreign Trade University, Hanoi, Vietnam
Everett E. Mayers
New York University, New York City, United States of America
Nguyen Duc Nhan
Foreign Trade University, Hanoi, Vietnam
Dau Thu Huong
Foreign Trade University, Hanoi, Vietnam
Hoang Thi Thuy Duong
Foreign Trade University, Hanoi, Vietnam

Received: 25 May 2022; **Revised:** 30 August 2022; **Accepted:** 10 September 2022
https://doi.org/jiem.022.3.0053

Abstract

This paper aims to study the impacts of economic growth, energy use, and trade liberalization on CO_2 emissions in Asia Pacific countries. By using panel data to build an environmental Kuznets curve (EKC), the empirical result shows that the EKC of Asia Pacific countries has N shaped. Besides, energy use is one of the factors that worsen the environment. Finally, trade liberalization is an important factor that improves environmental quality in the region.

Keywords: Asia Pacific, EKC, Environment, Growth, Trade liberalization

1. Introduction

The relationship between economic growth, trade liberalization, and environmental pollution has become a topic of debate among economists and environmentalists. From the viewpoint of many economists, trade reduces environmental pollution because high-income countries can access and apply advanced technologies, which are more environmentally friendly (Dinda, 2004). Meanwhile, environmentalists argue that the pursuit of economic growth will promote environmental degradation, and trade liberalization will contribute to speeding up this process (Stern, 2004).

[1] Corresponding author: duongnb@ftu.edu.vn

Asia Pacific is a dynamic economic region, accounting for more than 60% of world economic growth (IMF, 2018). However, economic growth in this region can cause environmental pressure. The increase in production activities, energy use, and trade liberalization affects production and consumption, thereby changing the level of CO_2 emission. According to the study by Nosheen *et al.* (2021), in Asian countries, a rise of 1% in trade openness increases carbon emission by 0.358%, and a 1% rise in energy use increases carbon emission by 0.645%. Many developing countries have a comparative advantage in producing goods that generate many pollutants. With trade liberalization, the production of these goods can be transferred from developed countries to developing countries. Through export activities, trade liberalization provides higher income for developing countries. The increase in income stimulates people to raise their environmental protection spirit and to have a habit of using cleaner and more environmentally friendly products.

The trade-off between economic growth and environmental pollution has become one of the challenges for the Asia Pacific countries' governments. Meeting the requirements of an increasing population, reducing poverty, and protecting the environment, all at the same time, has long been a dilemma for governments.

One of the most important environmental challenges today is climate change which seriously threatens the natural, economic, and social systems in Asia Pacific countries. The consequences of climate change have become an actual threat to the region's prosperity and livelihoods. Climate-related disasters can quickly erase decades-long accumulated economic development achievements. Climate change affects food security, water security, and living environment, and force people to relocate. Numerous small islands, especially in the Pacific region, will be directly threatened by sea-level rise. As the sea level continues to rise, some coastal areas will be permanently submerged.

In that context, this paper aims to study the impacts of economic growth, energy use, and trade liberalization on CO_2 emissions in Asia Pacific countries. Section 2 of this study gives an overview of environmental pollution and the evolution of CO_2 emissions in the Asia Pacific region. Section 3 presents the theory of the environmental Kuznets curve as well as the relationship between energy use and trade liberalization on CO_2 emission. Section 4 builds a model using panel data to analyze the impacts of economic growth, energy use, and trade liberalization on environmental pollution in Asia Pacific countries. Section 5 analyzes the empirical results of the said model.

2. Environment pollution and evolution of CO_2 emission in the Asia Pacific region

One of the most important causes of climate change is the increase in CO_2 emission. This leads to an increase in the greenhouse effect and global warming. Although the majority of emitted greenhouse gases are generated by developed countries, developing countries in Asia Pacific have now become new sources of emission. Burning coal to generate electricity, inefficient transport systems run on fossil fuels, rapid urbanization, and uncontrolled industrial development are the causes of air pollution.

To measure the CO_2 emission of a country, the national CO_2 emission level is one common indicator. The disadvantage of this indicator is that it does not take into account the country's population size. For example, China has the highest CO_2 emission in comparison with other countries. This is logical because China is also the most populated country in the world. To fairly compare among nations, the country's population size should be considered. Consequently, in most cases, use of CO_2 per capita is an indicator to compare the CO_2 emission between countries and regions.

Figure 1 shows the amount of CO_2 per capita in the Asia Pacific region in comparison with North America, European Union, Sub-Saharan Africa, and the world. We see that the amount of CO_2 per capita in the Asia Pacific region and in the world gradually increases over time. The Asia Pacific region's CO_2 growth rate is higher than the world average. In 2018, CO_2 emissions in Asia Pacific countries were 74% higher than the world's average.

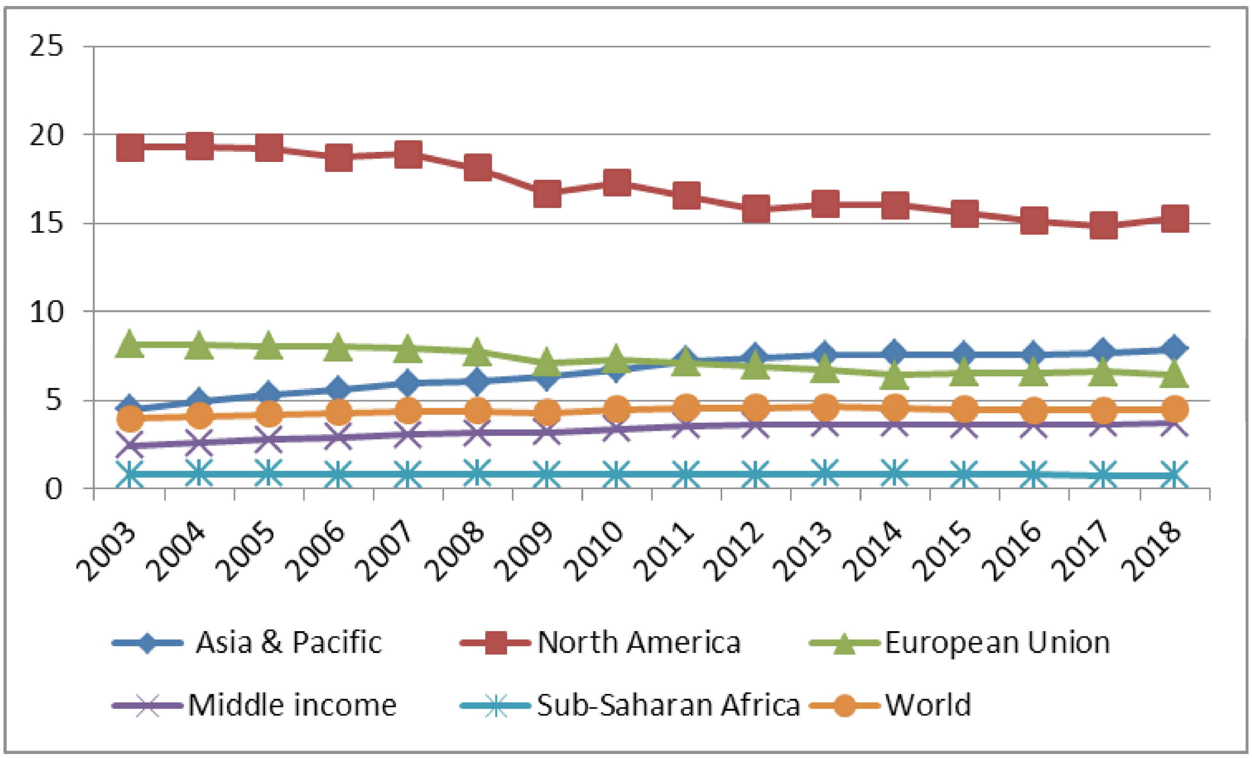

Figure 1. Evolution of CO_2 emission in the Asia Pacific region

Source: World Development Indicators (2020)

According to Ritchie and Roser (2020), CO_2 emissions tend to divide between the North and the South region. The CO_2 emissions per capita in high-income countries are greater than in low-income countries. Southern regions such as Sub-Saharan Africa and South America have CO_2 emissions per capita below five tons per year. However, the Northern region has a high CO_2 emission per capita, which is more than five tons. Especially in North America, this level exceeds 15 tons per year.

3. Literature review

In environmental economics theories, the relationship between environmental pollution and economic growth is represented by the environment Kuznets curve (EKC). Grossman and Krueger (1991) are the first scholars who describe the EKC line as a function of environmental pollution and GDP per capita. In the early stages of economic growth, human activities lead to an increase in environmental pollution. When income per capita exceeds a certain level, this trend reverses. Therefore, at high-income levels, economic growth leads to environmental improvement. This implies that the relationship between environmental pollution and GDP per capita is an inverted-U function.

Hussen (2005) argues that the EKC suggests that environmental degradation initially rises with per capita income. However, when income reaches a certain level, the demand of consumers for clean products increases, in other words, the demand for environmental quality increases. That change contributes to reducing environmental pollution. Stern (2004) argues that in the case of EKC having an inverted U shape, when income per capita increases to a certain level, the environment finally will be improved. Therefore, if economies continue to grow stably, they will achieve environmental sustainability. The inverted U shaped EKC is also analyzed in the studies of Munasinghe (1999) and Markandya *et al.* (2002). If there is an inverted U shapedd EKC, environmental improvements would eventually occur as economies grow. Consequently, humanity could, without any significant deviation, go back to business as usual and still achieve environmental sustainability.

However, many debates about EKC shape continue. Suri and Chapman (1998), and Torras and Boyce (1998) argue that the EKC may have an N shaped. According to Torras and Boyce (1998), environmental pollution, after a decrease, will re-increase if per capita income exceeds a certain level. One of the reasons is that the scale effect can become greater than both the composition effect and technology effect. In addition, manufacturers have to face diminishing returns due to technology obsolescence. This in turn makes environmental pollution increase. The EKC in this case has the N shaped.

Lorente and Alvarez-Herranz (2016) suggest that EKC could have different shapes such as: monotonic, U shaped, and N shaped. They build a function where the dependent variable is environmental pollution. The independent variable is the first, second, and third-order income, and the shape of EKC depends on the coefficient of income variables. Hasanov *et al.* (2021) present a model where environmental pollution and income variables are in logarithmic form, and EKC could have different shapes, as shown by Lorente and Alvarez-Herranz (2016).

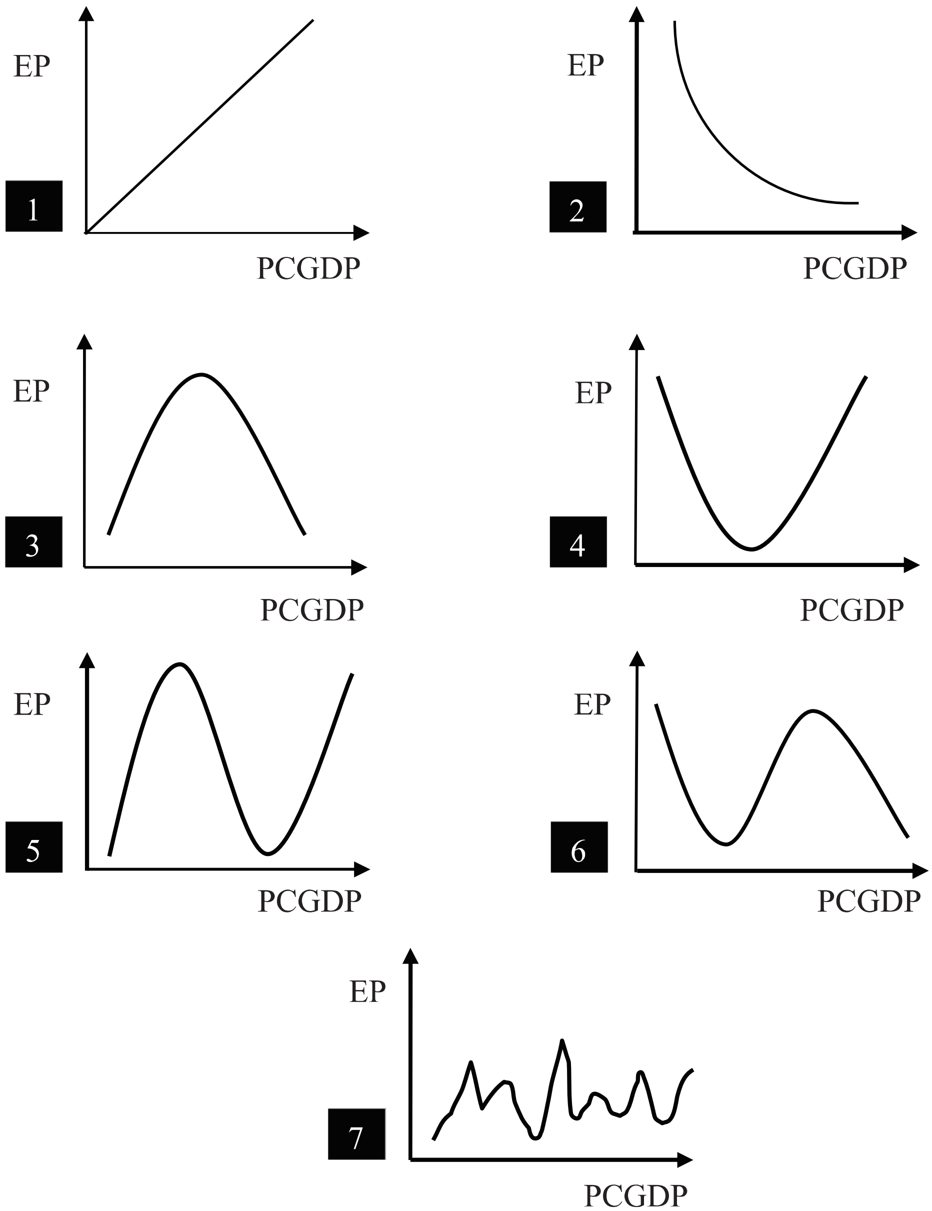

Figure 2. Different shapes of the EKC

Source: Lorente and Alvarez-Herranz (2016)

Environmental pollution is also closely related to globalization. Cole *et al.* (1997) argue that differences in environmental regulations between countries can provide a comparative advantage for developing countries in pollution intensive goods.

Regarding the debates on characteristics of different ECKs, Copeland and Taylor (1994) show that the shape of EKC depends also on the trade liberalization of countries. Free trade has three types of effects on countries. The first is the technology effect in which rising income increases the consumption of clean goods. Free trade induces people's interest in environmental problems and environmental policies. Thus, the technological effect of free trade is likely to improve the environment. The second is the scale effect. Free trade can lead to an increase in world trade volume, and each country's production increase, which can negatively impact the environment. The third is the composition effect. Developing countries tend to attract polluting industries through foreign direct investment. Developed countries are likely to avoid such industries. A decrease in pollution depends on the relative size of the technology and composition effects. Therefore, three effects of trade liberalization determine the shape of the EKC (Alvarez-Herranz *et al.* 2017).

Scale effect

In the early stages of economic growth, to increase in output quantity it is necessary to increase inputs. To meet production requirements, the demand for energy may increase. In the early stages of development, fossil energy use increases. That leads to environmental degradation. The characteristic of these stages is that the economic structure shifts from agriculture activities to capital intensive manufacturing. That leads to an increase in environmental degradation. According to Torras and Boyce (1998), scale effects during these stages reduce environmental quality.

Composition effects

According to the production approach, the composition effect refers to the transformation of the economic structure from pollution intensive activities to less polluted activities. During this period, technical and technological advances contributed to improving the production process, increasing the share of the services and labor industries in the economic structure, and shifting the production process to a less polluted one. Technical advances contribute to improving labor productivity and promoting clean technology, which improves environmental quality.

Technical obsolescence effect

In the post-industrial era, existing technology becomes obsolete, polluting, and inefficient. It is necessary to apply new technologies to increase productivity and improve environmental quality. High-income countries often focus on research and development (R&D) activities to own newer, cleaner, more efficient technologies to move towards a new stage of production.

Among EKC studies focusing on the Asia Pacific, Cemal (2012) examines the relationship between globalization and CO_2 emissions. The study is then appliedto data collected from Japan and ASEAN countries. Taguchi (2012) analyzes the EKC in Asia and shows that carbon emissions has inclination to increase along with income per capita in the observed range. Jose (2016) analyzes the validity of EKC's hypothesis for the Asia Pacific Economic Cooperation Forum (APEC) countries. Two econometric models are performed, which use different environmental quality indicators as dependent variables. The first model uses CO_2 total emission in APEC. The second model uses CO_2 emission generated from petroleum consumption. The analysis finds that these models show an inverted U shaped behavior.

In general, a great number of studies refer to the relationship between economic growth and environmental pollution. However, the number of studies conducted in Asia Pacific countries, especially, which focus on the impact of trade liberalization, and tariff barriers on environmental degradation are still limited.

This paper aims to fill that research gap by providing a model to analyze the impact of trade liberalization, tariff barriers, and openness on environmental pollution in Asia Pacific countries.

4. Model specification, data, and estimation method

4.1 Model specification

According to many points of view, not only income but also environmental policies, trade liberalization, and energy consumption have an impact on environmental pollution. Among the empirical studies on EKC, Lorente and Alvarez-Herranz (2016) build a model where the dependent variable is pollution measured by the Greenhouse gas per capita index - GHG_pc. Independent variables are income per capita (PCGDP), and Z_{it}, which represents other impacts on environmental pollution. The index *i* represents the country or region. The index t is the time.

Hasanov *et al.* (2021) represent the model of Alvarez-Herranz's (2016) equation. However, all variables are in logarithmic form.

The equation of the extended EKC is as follows:

$$lnEP_{it} = \alpha_{0it} + \alpha_1 lnPCGDP_{it} + \alpha_2 lnPCGDP^2_{it} + \alpha_3 lnPCGDP^3_{it} + \alpha_4 lnZ_{it} + e_{it}. \quad (1)$$

Based on the value allocated to coefficient α, the EKC can have different shapes:

Inspired by the EKC model of Hasanov *et al.* (2021), we built our model to examine the impact of economic growth, energy use, and trade liberalization on CO_2 emissions in Asia Pacific countries.

The model of the extended EKC then defined as follows:

$$LnCO_2PC_{c,t} = a_0 + a_1 lnGNIPC_{c,t} + a_2 ln(GNIPC)^2_{c,t} + a_3 ln(GNIPC)^3_{c,t} + a_4 lnENUPC_{c,t} + a_5 ln\,TR_{c,t} + a_6 lnOPEN_{c,t} + e_{c,t}$$

where $CO_2PC_{c,t}$ is CO_2 per capita emission of country c at time t; $GNIPC_{c,t}$ is gross national income per capita of country c at time t; $(GNIPC)^2_{c,t}$ is squared gross national income per capita of country c at time t; $(GNIPC)^3_{c,t}$ is cubic gross national income per capita of country *c* at time t; $ENUPC_{c,t}$ is energy use per capita of country c at time t; $TR_{c,t}$ is imports tarrif of country c at time t; $OPEN_{c,t}$ is trade openness of country c at time t; $e_{c,t}$ is error ($e_{c,d,t} = u_c + w_t + \eta_{c,t}$) ; u captures all individual (country-specific) effects omitted from our model specification; w is time effects; η is random effects.

All data used in this study are latest data obtained from the World Development Indicators database of the World Bank. We built panel data including 12 Asia Pacific countries, which are Australia, Brunei Darussalam, China, India, Indonesia, Japan, Malaysia, New Zealand, Thailand, Vietnam, Singapore, and the Republic of Korea. Data were collected from 2003 to 2014. These 12 countries are chosen since they account for 75% GDP of the Asia Pacific region and 40.9% of the global GDP (World Development Indicators, 2020). The data of CO_2PC was carbon dioxide emissions metric tons per capita. The gross national income per capita (GNIPC) of Asia Pacific countries is collected from the World Bank database. Its values were obtained at current USD. Energy use (ENUPC) refers to the use of primary energy, which equals the weight in kilogram of oil equivalent per capita. The import tariff (TR) data are the Most Favored Nation (MFN) rates of Asia Pacific countries. Trade openness (OPEN) equals the ratio of total export value and import value of goods and services at the current USD to total GDP.

4.2. Data description

Appendix 1 shows that there is heterogeneity among these Asia Pacific countries. This is caused by the differences among Asian Pacific countries in terms of income, population, level of energy use, and trade openness. The highest CO_2 emission per capita was from Brunei with 24.6 metric tons, while the lowest emission country in the region was India with 0.99 metric tons (World Development Indicators, 2020).

In terms of the independent variables, the highest GNI per capita in this region belongs to Singapore 56.370 USD, which is approximately 112 times higher than Vietnam 500 USD. China had the largest labor force of 787 million, while Brunei's labor force was only 0.16 million. Brunei, however, was the country that had the highest level of energy use per capita, which was about 9829 kg of oil. This indicator in Vietnam's was only 424 kg. In terms of trade, some countries liberalize remarkably. For example, Singapore had an average tariff of only 0.02%. Others India maintained a high tariff barrier of 29.51%. Brunei had the highest trade openness in the region 2.65. This value was much higher than that of India, which was only 0.75 (World Development Indicators, 2020).

Appendix 2 represents the matrix of correlation between variables. The result shows that there is not any coefficient with the value higher than 0.67. There fore, there is no perfect multicollinearity among independent variables.

4.3. Estimation method

To estimate the coefficients of the model with panel data, we have to choose among the ordinary least square (OLS), fixed effects model (FEM), and random effects model (REM). The Breusch and Pagan Lagrangian multiplier test (Appendix 4) shows that the REM model is better than pooled OLS. Next, the Hausman test (Appendix 5) shows that the FEM model is better than REM.

Therefore, FEM is selected to test the presence of heteroscedasticity, correlation, and autocorrelation on error terms, and cross-section dependence of the model. The empirical results show that the correlation between errors is absent, but there are heteroscedasticity and autocorrelation on error terms. We have corrected these problems and the result is presented in the CRFEM model, which is the FEM model with correction of heteroscedasticity and autocorrelation on error terms.

5. Empirical results

In the FEM model with corrections for heteroscedasticity and autocorrelation (Table 1). The coefficients associated with the gross national income per capita (GNIPC, GNIPC2, cubic GNIPC) are statistically significant in the model at the 99% confidence level.

Table 1. Corrected fixed effect model (CRFEM)

$\ln CO_2PC$	CRFEM
lnGNIPC	0.294 (0.892)***
ln(GNIPC)²	-0.311 (0.114)***
ln(GNIPC)³	0.012 (0.004)***
lnENUPC	0.709 (0.182)***
lnTR	0.168 (0. 046)***
lnOPEN	-0.245 (0.080)***
_cons	-13.614 (2.65)***
N	144

Note: *, ** and *** denote statistical significance at 10%, 5%, and 1% levels, respectively. The numbers in brackets are standard errors.

Source: Authors' calculation

The coefficient associated with the gross national income per capita indicates that in the first period, an increase of 1% in national income per capita leads to an increase of 0.29% in CO_2 emission in Asia Pacific countries. In the second period, economic growth has a positive effect on the environment. An increase of 1% in national income per capita squared leads to a decrease of 0.31% in CO_2 emission. In the following period, when incomes increase by 1%, CO_2 emission increases by 0.011%.

The coefficients of income show that the EKC of Asia Pacific countries has an N shaped. This result is different from Taguchi (2012) and Jose's (2016) studies, indicating that EKCs in Asia follow the expected inverted U shaped.

The turning points of the EKC* are determined when the first-order derivative of the EKC's function is equal to 0.

In the region, economic development varies widely, with national GDP ranging from hundreds of USD to more than 80,000 USD. For high-income countries in the region, the air pollution levels are below 30 µg/m3 of PM2.5. That level was stable or decreased from

2003 to 2014. Meanwhile, some middle-income countries in East Asia have a high level of PM2.5 pollution and the pollution increased during the period of 2003-2014 (UNEP, 2019).

The results of the empirical model show that the EKC of Asia Pacific countries has a N shaped. This means that, unlike the case where the EKC curve has an inverted U shaped, environmental degradation will increase again when income per capita exceeds a certain level. One explanation could be that when income per capita is higher than a given level, the scale effect is greater than the composition effect, and the technology effect. In addition, manufacturers have to face diminishing returns problems due to technology outmodedness. That makes environmental pollution increase again. The EKC of Asia Pacific countries in this case has the N shaped.

In terms of energy use, in the model, the coefficients associated with the ENUPC variable are statistically significant at the 99% confidence level. This finding shows that an increase in energy use leads to an increase in CO_2 emissions in Asia Pacific countries. In the model, this coefficient is equal to 0.7, explaining that an increase of 1% in energy use leads to an increase of 0.7% in CO_2 emission.

Asia Pacific material consumption has increased sharply over the past four decades, accounting for more than 50% of world consumption. The materials used in the region increased from 26.3 billion tons in 2005 to 46.4 billion tons in 2015. This annual growth rate of 6.1% was higher than the economic and population growth rates (UNEP, 2015). The average energy use level increased by 5.7% per year, while the energy supply continued to rely on fossil fuels (UNEP, 2015). The region's renewable energy has seen rapid growth due to significant investment in developing infrastructure. However, renewable energy supply has not satisfied the energy demand. In 1970, one-third of the energy in the region came from burning biomass. In 2015, the proportion of all renewable energy fell to only 14% (UNEP, 2015).

In another research, Wetselaar (2013) shows that in ASEAN countries fossil energy use is causing heavy damage to the environment. Most electricity produced from coal is from the projects implemented in Vietnam and Indonesia, which are the two countries with the largest coal reserves in the region. The electricity capacity produced from coal in ASEAN countries was expected to double, reaching 80GW, by 2020, and continue to increase to 160GW by 2035. The abuse of coal use can seriously damage the environment. The amount of CO_2 emission from coal burning will cause fog, acid rain, and even premature death (Wetselaar, 2013). According to World Bank (2013), India annually spends about 80 billion USD on solving pollution and environmental problems. India's experience has become a lesson for Southeast Asian countries in reforming their energy plans. According to Shell's recent survey of 3,400 people in six countries in the Asia Pacific region, including Indonesia, Philippines, Thailand, Vietnam, Singapore, and Australia, seven out of ten people think that CO_2 should be

[*] The first turning point (the maximum) of the EKC is attained at the point: exp[(-a2+ √Δ)/3a3] and the second turning point (the minimum) of the EKC is attained at the point: exp[(-a2-√Δ)/3a3] where Δ equal to a^2_2-3a_3*a_1

reduced. CO_2 reduction is believed to be very important and most of the respondents state that the government plays a key role in the the plan of cleaning energy of their country (Wetselaar, 2013).

Finally, trade liberalization is an important factor that can explain environmental degradation in Asia Pacific countries. In the regression model, the tariff and trade openness are variables that represent trade liberalization. The result shows that trade liberalization improves environmental quality in Asia Pacific countries. The coefficient associated with tariff rates is positive and statistically significant at a 99% confidence level, explaining that the tariff cuts lead to a decrease in CO_2 emission in Asia Pacific countries. The model's coefficient equals to 0.16 showing that a decrease of 1% in tariff leads to a decrease of 0.16% in CO_2 emission. This result is completely logical with the coefficient of trade openness. The coefficient associated with trade openness is negative, and statistically significant at a 99% confidence level, explaining that an increase in trade openness leads to a decrease in CO_2 emission in Asia Pacific countries. In the regression model, this coefficient is equal to -0.24 showing that an increase of 1% in trade openness leads to a decrease of 0.24% in CO_2 emission.

Trade liberalization can improve the environment through composition and technique effects. According to traditional international trade theories, a larger trade amount leads to a larger income. Environmental regulations can be strengthened to encourage new technologies that reduce pollution. Through international trade, environmental pollution decreases in one country while increasing in another. Dinda (2004) explains this phenomenon through two hypotheses, which are "Displacement Hypothesis" and "Pollution Hypothesis". A less developed country may reduce pollution through technological transfer from foreign direct investment (FDI).

According to the "Displacement Hypothesis", the changes in the structure of production in developed economies are not accompanied by equivalent changes in the structure of consumption. Therefore, EKC will record the displacement of dirty industries to less developed economies. Under certain circumstances, pollution-intensive industries migrate from countries with stronger environmental regulations to those with weaker ones.

According to Agras and Chapman (1999), the trade structure represents the level of energy consumption in a country. The production of goods in a country is directly proportional to its energy consumption. Dirty stages of the production process will move from developed countries to less developed countries. Besides, polluting industries are also moved from developed countries to less developed countries without changing the consumption structure. With an increase in intra-industry trade in recent years, the inverted U shape of the EKC curve reflects a change in the structure of production. The dirty and natural resource-intensive industries will be concentrated in poor countries. Meanwhile, clean and low-polluting industries will be concentrated in rich countries (Cole *et al.*, 1997). In other words, environmental pollution is not reduced but only moved from one country to another. According to Harrison (1996), trade liberalization will lead to an increase in "dirty" industries in less developed countries, especially in the context that developed countries adopt stricter environmental standards. According to the "Pollution Haven Hypothesis", trade contributes to ameliorating environmental pollution. An increase in trade in developing countries is directly proportional to an increase in per capita income, which creates a higher demand for clean products. However, trade liberalization could facilitate the transfer of polluting industries from developed countries to less developed countries. "Pollution Haven Hypothesis" considers that the low environmental standards are a comparative advantage of less developed countries. This hypothesis refers to the phenomenon of "the race to the bottom". In particular, in developed countries, high-polluting production activities lead to high costs. This encourages some highly polluting industries to be relocated abroad. To ensure economic growth and reduce unemployment, developed countries prefer to limit capital outflows by relaxing environmental standards. It explains why in a post-industrial economy, environmental degradation increases when the income level increases.

The evidence of Asia Pacific's EKC, especially at the developed stage where economic growth lessens CO_2 emissions suggests that we can improve the environmental quality by the adoption of new technologies, the use of renewable energy, and environment-friendly trade relations. This is the trend of development, which is observed not only in the Asia Pacific but also in the whole world toward a prosperous and sustainable future.

6. Conclusion

In the Asia Pacific region, economic progress has lifted millions of people out of poverty. However, besides economic achievements, environmental degradation in the region is increasing and has negative impacts on human life. This paper aims to study the impact of income growth, energy use as well as trade liberalization on environmental degradation in Asia Pacific countries. By using panel data to build the EKC, we see that the EKC of this region has the N shaped. In addition, an increase in energy use causes environmental damage in Asia Pacific countries. Besides, trade liberalization is an important factor in improving the environmental quality of this region. To overcome regional environmental challenges, Asia Pacific countries have made great efforts to mitigate the impacts of climate change as well as integrate sustainable development goals into national policies. However, for Asia Pacific countries, a carbon-free economy remains a big challenge. Renovating energy plans, and promoting R&D activities are solutions for Asia Pacific countries to overcome economic as well as environmental challenges.

Acknowledgment: This research is funded by Foreign Trade University under research program number FTURP01-2020-05.

References

Agras, J. and Chapman, D. (1999), "A dynamic approach to the Environmental Kuznets Curve hypothesis", *Ecological Economics,* Vol. 28 No. 2, pp. 267 - 277.

Alvarez-Herranz, A., Balsalobre-Lorente, D., Shahbaz, M. and Cantos, J.M. (2017), "Energy innovation and renewable energy consumption in the correction of air pollution levels", *Energy Policy,* Vol. 105, pp. 386 - 397.

Cemal, A. (2012), "Carbon emissions, trade liberalization, and the Japan-ASEAN interaction: a group-wise examination", *Journal of the Japanese and International Economies,* Vol. 26 No. 1, pp. 167 - 178.

Cole, M.A., Rayner, A.J. and Bates, J.M. (1997), “The environmental Kuznets curve: an empirical analysis”, *Environment and Development Economics,* Vol. 2 No. 4, pp. 401 - 416.

Copeland, B.R. and Taylor, M.S. (1994), “North-South trade and the environment”, *Quarterly Journal of Economics,* Vol. 109 No. 3, pp. 755 - 787.

Dinda, S. (2004), “Environmental Kuznets curve hypothesis: a survey”, *Ecological Economics,* Vol. 49 No. 4, pp. 431 - 455.

Grossman, G.M. and Krueger, A.B. (1991), “Environmental impacts of a North American free trade agreement”, Working Paper 3914, National Bureau of Economic Research.

Harrison, A. (1996), “Openness and growth: a time-series, cross-country analysis for developing countries”, *Journal of Development Economics,* Vol. 48 No. 2, pp. 419 - 447.

Hasanov, F.J., Hunt, L.C. and Mikayilov, J.I. (2021), “Estimating different order polynomial logarithmic environmental Kuznets curves”, *Environmental Science and Pollution Research,* Vol. 28, pp. 41965 - 41987.

Taguchi, H. (2012), “The environmental Kuznets curve in Asia: the case of sulphur and carbon emissions”, *Asia Pacific Development Journal,* Vol. 19 No. 2, pp. 77 - 92.

Hussen, A. (2005), *Principles of environmental economics and sustainability: an integrated and ecological approach*, Routledge.

IMF. (2018), *Regional economic outlook: Asia Pacific*, International Monetary Fund.

Jose, D. (2016), “Sustainable economic growth: an empirical study for the Asia Pacific Economic Cooperation Forum”, *International Journal of Energy Economics and Policy,* Vol. 6 No. 3, pp. 594 - 601.

Lorente, D.B. and Alvarez-Herranz, A. (2016), “An approach to the effect of energy innovation on environmental Kuznets curve: an introduction to inflection point”, *Bulletin of Energy Economics,* Vol. 4 No. 3, pp. 224 - 233.

Markandya, A., Harou, P., Bellu, L.G. and Cistulli, V. (2002), *Environmental economics for sustainable growth: a handbook for practitioners,* Edward Elgar Publishing Ltd.

Nosheen, M., Iqbal, J. and Khan, H.U. (2021), “Analyzing the linkage among CO2 emissions, economic growth, tourism, and energy consumption in the Asian economies”, *Environmental Science and Pollution Research,* Vol. 28, pp. 16707 - 16719.

Munasinghe, M. (1999), “Is environmental degradation an inevitable consequence of economic growth: tunneling through the environmental Kuznets curve”, *Ecological Economics,* Vol. 29 No. 1, pp. 89 - 109.

Ritchie, H. and Roser, M. (2020), “CO_2 and greenhouse gas emissions”, *Our World in Data,* Available at https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions (Accessed 25 June, 2020).

Stern, D.I. (2004), “The rise and fall of the environmental Kuznets curve”, *World Development,* Vol. 32 No. 8, pp. 1419 - 1439.

Suri, V. and Chapman, D. (1998), “Economic growth, trade and energy: implications for the environmental Kuznets curve”, *Ecological Economics,* Vol. 25 No. 2, pp. 195 - 208.

Torras, M. and Boyce, J.K. (1998), “Income, inequality, and pollution: a reassessment of the environmental Kuznets curve”, *Ecological Economics,* Vol. 25 No. 2, pp. 147 - 160.

UNEP. (2015), *Environment programme: annual report*, UN Environment Programme.

UNEP. (2019), *Air pollution in Asia and the Pacific: science-based solutions*, UN Environment Programme.

Wetselaar, M. (2013), "Southeast Asia can lead the way in clean energy future", *Shell,* Available at https://www.shell.com.sg/media/2013-media-releases/clean-energy-future-opinion-editorial-maarten-wetselaar.html (Accessed 25 June, 2020).

World Development Indicators. (2020), "World Development Indicators", Available at http://wdi.worldbank.org/ table/3.10 (Accessed 25 June, 2020).

Appendices

Appendix 1. Description of data

	Variable	Obs	Mean	Std.Dev.	Min	Max
1	Ln CO2PC	144	1.733	0.894	-0.008	3.203
2	Ln GNIPC	144	9.084	1.463	6.215	11.095
3	Ln $(GNIPC)^2$	144	84.636	25.845	38.621	123.109
4	Ln $(GNIPC)^3$	144	806.274	348.603	240.017	1365.946
5	Ln ENUPC	144	7.774	0.906	6.050	9.193
6	Ln TR	144	1.526	1.530	-3.912	3.385
7	Ln OPEN	144	0.1079	0.251	-0.276	1.077

Source: Authors' calculation

Appendix 2. Matrix of correlation

Variable	ln GNIPC	ln ENUPC	ln TR	ln OPEN
ln GNIPC	1.000			
ln ENUPC	0.657	1.000		
ln TR	-0.557	-0.515	1.000	
ln OPEN	0.262	0.438	-0.190	1.000

Source: Authors' calculation

Appendix 3. Coefficients of independent variables estimated in the model

lnEP	REM	FEM
ln GNIPC	0.315 (1.317)***	0.293678 (1.313)***
ln $(GNIPC)^2$	-0.347 (0.156)***	-0.310 (0. 154) ***
ln $(GNIPC)^3$	0.013 (0. 006)***	0.011 (0. 005) ***
ln ENUPC	0.869 (0.080)***	0.7093 (0. 118) ***

Appendix 3. Coefficients of independent variables estimated in the model *(continued)*

lnEP	REM	FEM
ln TR	0.143 (0. 022)***	0.168 (0. 031) ***
ln OPEN	-0.163 (0. 097)***	-0.245 (0. 105) ***
_cons	-15.027 (3.865) ***	-13.614 (3.863)***
N	144	144

Note: *, **, and *** denote statistical significance at 10%, 5% and 1% levels, respectively. The numbers in brackets are standard error.

Source: Authors' calculation

Appendix 4. Breusch and Pagan Lagrangian multiplier test

Breusch and Pagan Lagrangian multiplier test for random effects

lnco2per[id,t] = Xb + u[id] + e[id,t]

Estimated results:

	Var	sd = sqrt(Var)
lnco2per	0.799	0.894
e	0.010	0.098
u	0.017	0.129

Test: Var(u) = 0

$chibar^2(01)=146.31$

Prob > $chibar^2 = 0.000$

Source: Authors' calculation

Appendix 5. Hausman test

Hausman fixed random

	Coefficients			
	(b)	**(B)**	**(b-B)**	
	fixed	**random**	**Difference**	**S.E.**
lnpcgni	2.937	3.151	-0.214	.
lnpcgni2	-0.311	-0.347	0.037	.
lnpcgni3	0.011	0.013	-0.002	.
lnenuper	0.709	0.869	-0.160	0.088
lntr	0.168	0.143	0.025	0.022
openxm	-0.245	-0.163	-0.082	0.041

Appendix 5. Hausman test *(continued)*

Hausman fixed random
b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg
Test: Ho: difference in coefficients not systematic
chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 92.82
Prob > chi2 = 0.0000
(V_b-V_B is not positive definite)

Source: Authors' calculation