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REVEALING THE ENVIRONMENTAL COST OF GLOBALIZATION: AN EMPIRICAL ANALYSIS ON TRADE OPENNESS, FDI, AND CO_2 EMISSIONS IN THE APEC COUNTRIES

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ABSTRACT

This research aims to examine the influence of trade and FDI on CO2 emissions in APEC countries using the framework of the Environmental Kuznets Curve (EKC). The model includes trade openness and FDI, population and renewable energy as control variables, and economic growth and the square of economic growth to examine the EKC. By conducting a fixed effects panel data analysis of APEC countries' data from 1990 to 2020, the empirical findings of this study reveal that trade openness leads to an increase in CO2 emissions, while FDI has the opposite effect, reducing CO2 emissions. These findings support the EKC hypothesis. As a result, the study suggests several measures to address environmental impacts, including promoting investments in energy efficiency, emission reduction technologies, and waste management. Additionally, the implementation of carbon taxes and green tariffs, as well as the development of international standards, are recommended to mitigate the environmental consequences of economic activities.

Keywords: *CO_2 Emissions, APEC, Panel Data Analysis, Trade Openness, Foreign Direct Investment, Environmental Kuznets Hypothesis.*

JEL Classification Codes: *F18, F64, C23, S27.*

ÖZ

Bu çalışma, Çevresel Kuznets Eğrisi (EKC) yaklaşımını kullanarak APEC ülkelerinde ticaret ve doğrudan yabancı yatırımların CO_2 emisyonları üzerindeki etkisini incelemeyi amaçlamaktadır. Modelde ticarete açıklık ve doğrudan yabancı yatırımların yanı sıra kontrol değişkenleri olarak nüfus, yenilebilir enerji dahil edilmiş, EKC'yi incelemek için ise ekonomik büyüme ve ekonomik büyümenin karesi ele alınmıştır. APEC ülkelerinin 1990-2020 yılları arasındaki verileri üzerinde sabit etkiler panel veri analizi yürüten bu çalışmanın ampirik bulguları, ticari açıklığın CO2 emisyonlarında artışa yol açtığını, DYY'nin ise tam tersi bir etkiye sahip olduğunu ve CO2 emisyonlarını azalttığını ortaya koymaktadır. Bu bulgular EKC hipotezini desteklemektedir. Sonuç olarak, çalışma çevresel etkilerin ele alınması için enerji verimliliği, emisyon azaltma teknolojileri ve atık yönetimi yatırımlarının teşvik edilmesi de dahil olmak üzere çeşitli önlemler önermektedir. Ayrıca, ekonomik faaliyetlerin çevresel

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sonuçlarını azaltmak için karbon vergileri ve yeşil tarifelerin uygulanmasının yanı sıra uluslararası standartların geliştirilmesi de önerilmektedir.

Anahtar Kelimeler: *CO_2 Emisyonları, APEC, Panel Veri Analizi, Ticarete Açıklık, Doğrudan Yabancı Yatırımlar, Çevresel Kuznets Hipotezi.*
JEL Sınıflandırma Kodları: *F18, F64, C23, S27.*

1. INTRODUCTION

Recently, the deterioration of environmental quality and the problems associated with climate change have led to growing concerns about environmental issues. The main source of environmental concern regarding global warming is known as greenhouse gas (GHG) emissions. A significant portion of GHG emissions consists of CO_2 emissions. As a cause of climate change and environmental pollution, CO_2 emissions have become the subject of much research. (Neumayer, 2002; Cole and Elliott, 2003; Dijkgraaf and Vollebergh, 2005; Apergis and Payne, 2010; Apergis and Öztürk, 2015; Shahbaz, Loganathan, Muzaffar, Ahmed and Jabra, 2016; Bento and Moutinho, 2016; Rafindadi and Usman, 2020; Chebbi, Olarreaga, Zitouna, 2011; Fang, Gozgor, Lu and Wu, 2019; Mahmood, Maalel and Zarradet, 2019; Zhang, Jin, Chevallier, and Shen, 2016; Managi, Hibiki and Tsurumi, 2009; Dou, Zhao, Malik and Dong, 2021; Shahbaz, Tiwari and Nasir, 2013; Breitung and Candelon, 2006; Koc and Bulus, 2020).

The main source of CO_2 emissions is human activities, which occur as a result of the burning of various fossil fuels. According to the IEA (2021), approximately 42.1% of the source of global energy-related CO_2 emissions is coal, 29.5% is oil, and 20.6% is natural gas. While CO_2 emissions are crucial for climate change, they do not cause climate change. CO_2 emission first reaches the ozone layer and destroys it. This exposes the Earth's surface to ultraviolet radiation from the sun, and an increase in the Earth's temperature is causing global warming. The significant increase in CO_2 emissions caused by climate change is a global problem and poses threats to every region of the world (Yoro and Daramola, 2020). Various countries are aware of this issue and have signed agreements to prevent this climate change. These are the Geneva Convention signed in 1979, the Montreal Protocol of 1987, the Kyoto Protocol of 1997, the Doha Amendment of 2012 with the amendment of the Kyoto Protocol, and the Paris Agreement of 2015. Many nations have adopted environmental policies to reduce CO_2 emissions, such as carbon taxes; innovative, energy-saving, and efficient technologies; and campaigns to increase awareness of the harmful effects of GHGs. Nevertheless, as stated in the report issued by the IPCC, CO_2 emissions have been on the rise overall. (Usman, Akadiri and Adeshola, 2020; IPCC, 2017).

In many regions of the world, while policies to stop the growth of CO_2 emissions are supported, studies identifying the economic activities that increase CO_2 emissions and designing environmental policies in this context are encouraged. Many macroeconomic variables that affect CO_2 emissions have been identified in the literature. These factors include energy consumption, GDP growth, FDI and financial development (Acaravci and Ozturk, 2010; Charfeddine and Khediri, 2016; Dogan and Seker, 2016; Menyah and Wolde-Rufael, 2010; Ang, 2007; Stern, 2004; Apergis and Payne, 2010; Brammer and Pavelin, 2006; Li, Liang and Huang, 2017; Shafik and Bandyopadhyay, 1992; Wang and Han, 2015; Apergis and Payne 2014; Bölük and Mert, 2015; Gupta, 2019; Shahbaz et al., 2017; Zhang, 2019). In addition, many studies have focused on the relationship between environmental pollution and trade openness, which refers to the share of exports and imports in GDP (Cole and Elliott, 2003; Grossman and Krueger, 1991; Jaffe, Peterson, Portney and Stavins, 1995; Wagner, 2018; Kellenberg and Levinson, 2017; Antweiler, Copeland and Taylor, 2001; Frankel and Rose, 2005; Lee and Roland-Holst, 2009; Tobey, 1990; Caviglia-Harris, Chambers and Kahn, 2021; Fang and Wang, 2021; Lourdes, 2022; Ramasamy, Lo, Xie and Islam, 2021; Wang et al., 2021; Akinosoye, Sanni and Adedeji, 2021; Dong and Wang, 2021; Ghosh, Yadav, and Parhi, 2021; Kordestani and Moshiri, 2021; Muhammad et al., 2021; Burke et al., 2010; Chakraborty, Stark and Yasar, 2020; Gao, 2016; Lee, Strazicich, and Yu, 2014; Shahbaz et al., 2019; Inekwe, Bhattacharya and Guncavdi, 2019; Li, Chen and Liu, 2018; Simplice, 2018; Voss, Stark and Yasar, 2016; Çoban and Özkan, 2022).

The relationship between environmental degradation and trade openness has been examined using two different approaches. The initial approach, known as the Pollution Haven Hypothesis, suggests that firms relocate their polluting production facilities to countries with weaker environmental regulations through trade, financial liberalization, and foreign direct investment. These firms avoid stringent environmental policies aimed at reducing carbon emissions and promoting the use of clean energy (Dauda, Long, Mensah, Salman, Boamah, Ampon-Wireko and Dogbea, 2021). The second approach focuses on the relationship between the volume of international trade and CO_2 emissions. Nevertheless, there is no consensus on this topic. Some studies suggest that international trade may decrease CO_2 emissions through the dissemination of information, indicating a negative correlation between trade openness and CO_2 emissions. However, for some countries, trade openness has been observed to increase CO_2 emissions (Mutascu, 2018).

According to the World Bank (2022), more than half of the global carbon emissions over the past decade originated from APEC countries, particularly China, the United States, the Russian Federation, and Japan. Additionally, APEC countries significantly impact global energy consumption and international trade. Thus, it is crucial to examine the relationships between trade openness and FDI and between trade openness and CO_2 emissions in APEC countries. Therefore, the purpose of this study is to investigate the impact of trade openness and FDI on CO_2 emissions in APEC countries by analyzing the relationships between macroeconomic indicators and environmental degradation based on the EKC framework.

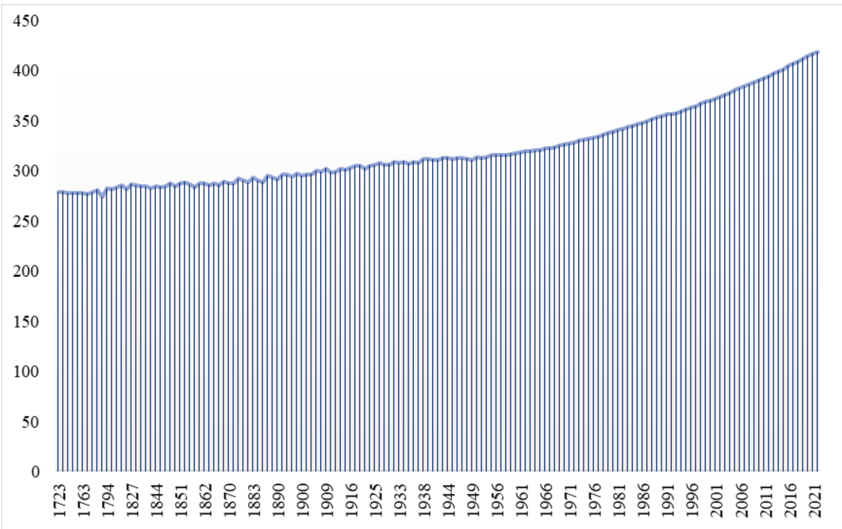
The contribution of this study to the literature is its examination of the effects of trade openness and foreign direct investment (FDI) on CO_2 emissions in APEC member nations. Although the literature widely discusses the macroeconomic factors that influence CO_2 emissions, this study distinctively emphasizes the relationship between environmental degradation and macroeconomic indicators, especially in the context of the EKC framework. This study investigates the impact of trade openness and other macroeconomic indicators on CO_2 emissions within APEC member economies. The inclusion of concrete data and analysis in this research offers valuable policy recommendations aimed at addressing global climate change. The study furnishes empirical data and analyses pertinent to environmental policy design and implementation, thereby providing substantive policy recommendations that are crucial for the nations in this region and that play a pivotal role in global endeavors to combat climate change. As a result, this study reveals knowledge and strategies that will play a critical role in understanding and managing the environmental impacts of trade openness and FDI in APEC countries.

The second section of this study presents a discussion of the relationship between CO_2 emissions and macroeconomic indicators, including an explanation of the theoretical approaches to studying this relationship. The third section describes the empirical methodology of this study. The fourth section presents the empirical findings, exploring the effects of trade openness and other macroeconomic indicators on CO_2 emissions in APEC economies. The fifth and final section discusses the findings and provides policy recommendations.

2. THEORETICAL AND EMPIRICAL LITERATURE

Since industrialization began in 1751, worldwide CO_2 emissions have exceeded 1.5 trillion tons. The goal of implementing global climate change measures is to limit global warming to 1.5°C above pre-industrial levels, which is the main target of the Paris Agreement (UNFCCC, 2015). To achieve this goal, it is necessary to increase the peak cumulative CO_2 emissions and rapidly decrease the annual emissions to match the net-zero emission target.

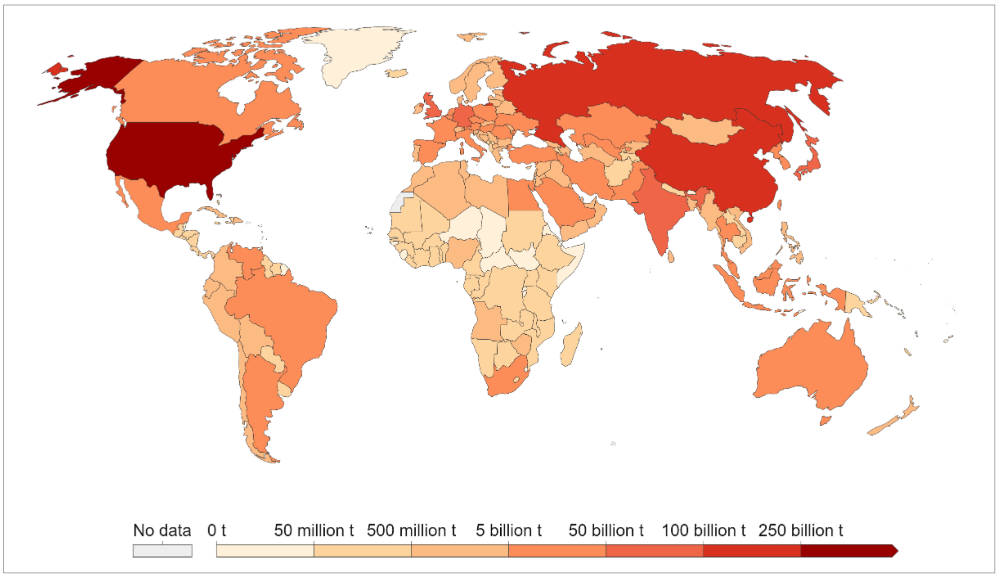
Graph 1. Global Atmospheric CO_2 Concentration, 1723-2020



Source: National Oceanic and Atmospheric Administration (NOAA), 2020

Graph 1 shows the global atmospheric concentration of CO_2. Accordingly, CO_2 emissions have risen steadily since the postindustrial revolution era. This means that CO_2 emissions have yet to peak. To achieve the targets set in the Paris Agreement, the concentrations of greenhouse gases, particularly CO_2 emissions, must be stabilized. However, the prevailing scenario demonstrates an ongoing increase in greenhouse gases.

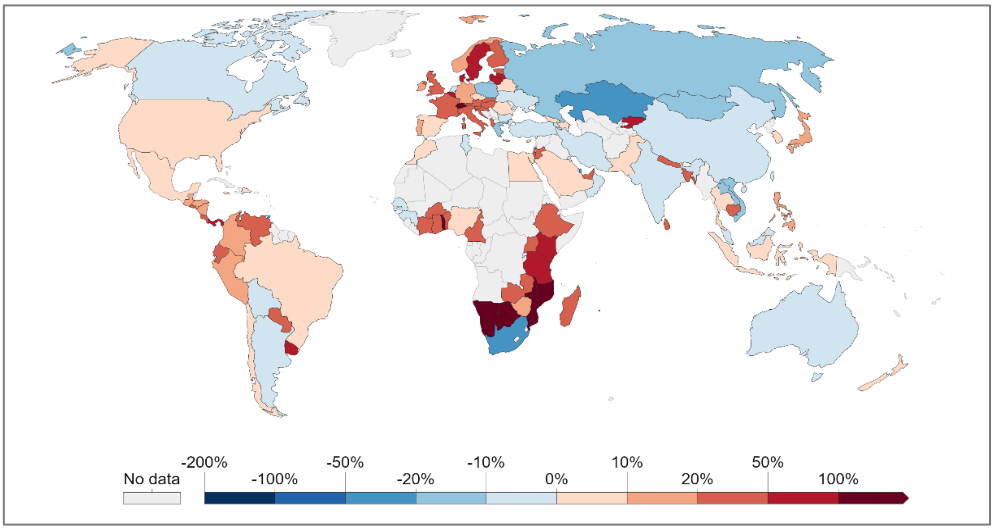
Figure 1. Cumulative CO_2 Emissions (2020)



Source: Our World in Data based on the Global Carbon Project, 2020

Figure 1 shows the cumulative contributions of countries to CO_2 emissions since the Industrial Revolution. In 2020, worldwide carbon emissions reached 1.7 trillion tons. APEC countries are responsible for approximately 63.47% of the total CO_2 emissions (Our World Data, 2020).

Figure 2. CO_2 Emissions Embedded in Trade (2019)



Source: Our World in Data based on the Global Carbon Project, 2019

Figure 2 shows the emissions of traded goods. While red shows the net CO_2 emission importing countries, blue shows the net CO_2 emission exporting countries. This map enables a comparison of consumption-based and production-based emissions. According to 2019 data, CO_2 emissions from the production of export-based products in China, Australia, and Russia from APEC countries are 9.98%, 9.42%, and 14.69%, respectively, more than the CO_2 emissions from import-based products. Therefore, there is likely a relationship between CO_2 emissions and trade in these countries. APEC countries have become the most important contributors to CO_2 emissions as they produce more of the goods they need. On the other hand, the share of global CO_2 emissions in APEC countries has increased from 54% to 60% since the 1980s, making this a serious concern (World Bank, 2021).

There are many studies on the macroeconomic determinants of CO_2 emissions. The theoretical approaches underlying these studies involve two main hypotheses. One of these is the EKC, which was first introduced by Grossman and Krueger (1991) by adapting the Kuznets hypothesis to the environmental pollution model. The other is the Pollution Paradise Hypothesis (PPH) proposed by Copeland and Taylor (1994). The EKC and PPH theories both emphasize the relationship between pollution and trade. However, additional agreement is needed within the current academic studies, as both hypotheses present conflicting perspectives.

The study by Grossman and Krueger (1991) initiated extensive literature on the relationship between economic activities and environmental pollutants. Specifically, the authors investigated the impact of NAFTA-induced commercial liberalization on the environment. For this purpose, they modeled a cubic function of trade intensity and per capita income with smoke, SO2, and SPM. Through this study, it was determined that as income in Mexico increases, various pollutants reach their maximum level at a certain income level but increase in environmental quality during the following periods. This phenomenon is called the Environmental Kuznets Curve (EKC) by Panayotou (1993) due to its similarity to the Kuznets hypothesis, in which Kuznets (1955) advocated the relationship between income inequality and per capita income. The EKC argues that environmental degradation and destruction are inevitable during a specific phase of economic development. However, once a particular income level is reached, it is argued that environmental quality will gradually improve due to the economic progress achieved (Panayotou, 1993).

The EKC investigates the relationship between trade and environmental degradation and explains it in the context of three effects: scale, technical, and composition. The scale effect refers to the pollution created by economic growth that increases market access through trade liberalization. During the phase when the scale effect dominates, GDP growth and environmental degradation change in the same direction, causing the EKC to have an increasing slope. The environmental deterioration resulting from the scale effect improved with the compensatory effect of the technical effects and the composition effects, allowing the EKC to follow a decreasing course over time. The technological effects mentioned here refer to the change in production techniques and such improvements in environmental quality due to economic growth and the adoption of innovative, cleaner, and more efficient technologies. The combined effect results from each country having a comparative advantage in international trade in areas where environmental regulations are not strict. In other words, the income increase resulting from international trade causes a transition toward a technology-intensive structure as the economy becomes predominant in the service sector. The inverted U shape of the EKC, which reflects the relationship between GDP growth and the environment, is explained by scale, technical, and composition effects (Dinda, 2004).

After Grossman and Krueger's 1991 study, Shafik (1994) tested the EKC for ten different environmental indicators through linear, quadratic, and cubic functional forms. The findings indicated that ecological indicators related to water and sanitation were positively associated with income. Moreover, variables related to municipal waste, CO, and river quality were negatively associated with income. Furthermore, research indicates that particulate matter and SO2 concentrations increase with income and decrease after a specific turning point. With the publication of the findings of Shafik and Bandyopadhyay's (1992) study in the 1992 World Development Report, the EKC has aroused significant repercussions on the literature on environmental economics. The Environmental Kuznets Curve (EKC) was first proposed by Grossman and Krueger (1991) and has since been confirmed by many studies (Cole, Rayner, and Bates, 1997; Schmalensee, Josko, Ellerman, Montero and Bailey, 1998; Neumayer, 2002; Cole and Elliott, 2003; Dijkgraaf and Vollebergh, 2005; Apergis and Payne, 2010; Apergis and Öztürk, 2015; Shahbaz et al., Loganathan, Muzaffar, Ahmed and Jabran, 2016; Bento and Moutinho, 2016; Rafindadi and Usman, 2020; Özkan, Çoban, Iortile and Usman, 2023; Çoban and Özkan). Although the EKC has attracted the interest of many researchers, it has been subject to statistical criticism (Narayan and Narayan, 2010). These models add income per capita and income per capita squared as independent variables, which is the cause of the multicollinearity problem. Since multicollinearity leads to the unreliability of t tests, the EKC literature faces methodological unreliability (Stern, 2004).

Copeland and Taylor (1994) proposed the Pollution Haven Hypothesis (PPH) as an alternative approach to investigating the connection between environmental pollution and international trade through a study that analyzed North–South trade within the framework of the North–South Trade Association (NAFTA). The study showed that as a result of trade liberalization, contaminated industries will transfer from developed to developing countries. The fact that developed countries have stricter environmental regulations than developing countries is the basis of this hypothesis. It is argued that trade liberalization may transform developing countries into pollution havens. Inadequate environmental regulations in developing countries are seen as a cost advantage for companies in polluting industries in developed countries. Developed countries specialize in clean sectors and export the goods of these industries to other countries, while developing countries specialize in polluted sectors and typically export the goods of these industries to other countries. (Gill, Viswanathan and Karim, 2018).

Copeland and Taylor (1994) argue that under NAFTA, the difference in the strictness of environmental regulations between North and South regions will result in the concentration of clean industries in the North region and the formation of a pollution haven with the relocation of polluting industries to the South region. According to the PPH, developed countries are expected to import products produced with production techniques instead of continuing to use production techniques that cause pollution. Therefore, developing countries are expected to have a negative correlation between GDP growth and environmental degradation, leading to the production of polluting goods using outdated technology, which is subsequently exported to developed countries. According to the PPH approach, GDP growth in developing countries is expected to increase environmental degradation. Although the PPH logically confirms that strict environmental regulations will affect the competitiveness of firms and change the course of trade, the evidence in the literature does not point to a consensus (Gill et al., 2018).

In addition to the EKC and the PPH, many studies with different approaches in the literature have examined environmental degradation in the context of economic activities. One of these is referred to in the literature as the Porter hypothesis. This approach states that strict environmental regulations will trigger competitiveness in the context of companies. Porter and Linde (1995) argue that stringent environmental regulations promote cleaner technologies, reduce such marginal costs, and increase firms' productivity. The Green Port hypothesis explains another approach in which corporate social responsibility is important in polluting capital-intensive industries. Therefore, to protect the green reputation of polluting industries, companies will contribute to protecting the environment by adopting policies that will protect the ecological balance.

There is extensive evidence in the literature on the relationship between carbon emissions and trade openness. Amin, Aziz and Liu (2020) analyzed 13 Asian countries over the period 1989-2019 and found that trade openness reduces pollution by facilitating technology transfer. Antweiler et al. (2001) analyzed 43 countries and found that trade openness improves environmental quality through technical and economies of scale effects. In a study of trade and CO_2 emissions in EU countries, Park, Meng and Baloch (2018) determined that trade openness is a pollution-increasing factor for Bulgaria, while it reduces pollution in some EU countries, such as France, the Netherlands, Portugal, Finland, and Italy. Chebbi et al. (2011) analyzed the impact of trade on pollution in Tunisia and found that trade openness reduces pollution in both the short and long run. In their study, Özkan, Sharif, Mey, and Tiwari (2023) explore the concept of carbon efficiency as an alternative measure of CO2 emissions. Their findings show that trade openness has a negative impact on carbon efficiency that persists in both the short and long run.

Chen, Jiang and Kitila (2021) examined 64 countries from 2001 to 2019 and found that trade openness increases CO_2 emissions through economic effects while reducing CO_2 emissions through energy substitution and technology effects. Shahzad et al. (2017), who conducted a similar study for Pakistan, found that trade openness increases CO_2 emissions in both the short and long run. Al-Mulali and Sheau-Ting (2014) analyzed 189 countries from six different regions and found a bidirectional causal relationship between these two variables. Pazienza (2015), who analyzed OECD countries, reported a weak negative relationship between trade openness and environmental degradation. Cui et al. (2015) found that trade openness reduces CO_2 emissions at the firm level. They also find that trade openness contributes to firm growth, strengthening the negative relationship. Li and Haneklaus (2022) examined the relationship between trade openness and CO_2 emissions in the case of China. Their study revealed that trade openness reduces CO_2 emissions and that the EKC is valid. By analyzing 55 middle-income countries, Lv and Xu (2018) found that trade openness reduces CO_2 emissions in the short run. Paradoxically, this effect is reversed in the long run. Rahman Saidi and Mbarek (2020) analyzed the relationship between trade openness and CO_2 emissions in South Asian countries within the framework of the neoclassical growth model and found bidirectional causality between trade openness and CO_2 emissions. By analyzing 40 European countries, Jamel and Maktouf (2017) also found a bidirectional causal relationship between trade openness and CO_2 emissions. Çoban (2021) analyzed the long-term and causal relationships between trade openness and environmental degradation in 10 member countries of the Latin American Integration Community (LAIA) from 1960 to 2018. The study revealed that there is a significant long-term relationship between trade openness and CO_2 emissions in these countries and unidirectional causality between trade openness and CO_2 emissions. Alper (2018) analyzed the impact of trade openness on CO_2 emissions in the 1995–2016 period by classifying 64 selected countries according to the World Bank classification into upper-income, middle-income and low-income groups. The findings obtained by Alper (2018) show that there is a negative relationship between trade openness and CO_2 emissions in high-income countries, while there is a positive relationship in middle- and low-income countries.

Research by Hossain (2011) showed that trade openness increased carbon emissions in newly industrializing countries from 1971 to 2007. Salman, Long, Dauda, Mensah and Muhammad (2019) analyzed the relationship between trade and carbon emissions separately for exports and imports. They reported that exports have an increasing effect on carbon emissions in some countries in Asia. Essandoh, Islam, and Kakinaka (2020), in their study examining the relationship between carbon emissions and trade for 52 countries in the period 1991-2014, determined that trade reduces carbon emissions in developed countries and that the diffusion of information and technology from trade has a reducing effect on carbon emissions. Managi et al. (2009) found that trade openness decreases carbon emissions in OECD countries but has an increasing effect on carbon emissions in non-OECD countries. Halıcıoğlu (2009) conducted a similar study for Turkey and concluded that trade openness increased carbon emissions from 1960 to 2005. Another study of Turkey examined the impact of economic growth and openness to foreign trade on environmental pollution in the context of the EKC. Artan, Hayaloğlu and Seyhan (2015) find that the EKC is valid and that openness to foreign trade increased CO_2 emissions in Turkey during the 1981–2012 period.

In the literature, studies dealing with carbon emissions in APEC countries in the context of the EKC are limited. Sinha and Sengupta (2018) evaluated the energy mix and nitrogen oxide emissions of APEC countries in the context of the EKC. The findings suggest that the use of renewable energy in APEC countries has a positive impact on environmental quality by reducing nitrogen emissions. According to another study examining carbon emissions for APEC countries, there is an inverted U-shaped relationship between corruption and carbon emissions (Zhang et al., 2016). However, although the relationship between trade openness and carbon emissions has been investigated for many countries (Chebbi et al., 2011; Fang, et al., 2019; Mahmood et al., 2019; Zhang et al., 2016; Managi et al.,2009; Dou et al., 2021; Shahbaz et al., 2013; Breitung and Candelon; 2006; Koc and Bulus, 2020), to the best of our knowledge, there are no such studies on APEC countries. Therefore, the main motivation of this study is that the relationship between carbon emissions and trade openness has not been investigated for APEC countries.

3. DATA AND METHODOLOGY

This study examines the relationship between trade openness and carbon emissions within the framework of the EKC approach and focuses on APEC countries. The Asia-Pacific Cooperation (APEC) was established in November 1989 to help the states of the Asia-Pacific region guide their local programs for dynamic and increasingly integrated markets (Bisley, 2012). The APEC is the Asia-Pacific region's most influential international economic organization (Zhang et al., 2016). In terms of total carbon emissions in 2019, the five most polluting countries were China, the USA, India, Russia, and Japan. All of these countries except India are members of APEC.

Due to the lack of data from APEC countries, two countries[1] were excluded from the analysis. Australia, Brunei Darussalam, Canada, Chile, China, Indonesia, Japan, South Korea, Malaysia, Mexico, New Zealand, Peru, the Philippines, the Russian Federation, Singapore, Thailand, the United States, and Vietnam were included in the empirical analysis. The dataset of 18 APEC countries, handled annually from 1990 to 2020, was analyzed by panel data analysis. After 2020, since the data for many variables are not available, the data included in the analysis are considered up to 2020.

Panel data analysis can be expressed as a method of controlling the effects of independent variables on a dependent variable by combining time series and cross-sectional dimensions. Panel data analysis offers many advantages, such as (i) incorporating unit variability and unobserved heterogeneity into the model, (ii) reducing estimation bias, (iii) reducing the multicollinearity problem, and (iv) building more comprehensive models (Baltagi, 2021).

In this context, the equation of the model to be created with the panel dataset is expressed as follows:

[1] Hong Kong and Papua New Guinea

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_k X_{kit} + v_{it} \quad (1)$$

$$v_{it} = u_{it} + e_{it} \quad (2)$$

$$i = 1, 2, 3, \ldots, N \quad (3)$$

$$t = 1, 2, 3, \ldots, T \quad (4)$$

Panel datasets can be estimated through the use of pooled OLS, fixed effects, or random effects estimators. However, the pooled OLS method ignores unit and time effects and focuses only on interunit dependencies. Therefore, pooled OLS is unsuitable when unit or time effects exist. Since the OLS method cannot even assume externalities, pooled OLS is not used primarily in panel data analysis (Baltagi, 2021).

The fixed effects estimator is a method that determines the unit effects of the independent variables as a constant over time and can be used when the unobserved effect is correlated with the independent variables. On the other hand, the random effects estimator is an estimation method that determines the unit effects of the independent variables as random variables over time and does not allow the correlation between the unit effect and the independent variables. Accordingly, if there is a correlation between the independent variables and the unit effect, the fixed effects estimator is more consistent. However, the random effects estimator is more efficient in the absence of correlation between the independent variables and the unit effect. The Hausman test allows for a choice between fixed and random effects estimators by analyzing the correlation between unit effects and independent variables. (Baltagi, 2021).

The dependent variable considered in the analysis is CO_2 emissions in metric tons (lnco) per capita to express the CO_2 produced from solid, liquid, and gaseous fuels. The independent variables included in the model for the main purpose of this study are the trade openness ratio (lntrade), which is the ratio of total imports and exports to GDP calculated at constant prices in US dollars based on the base year 2010, and net foreign direct investment inflows as a percentage of GDP (fdi). On the other hand, economic growth (growth) and the square of economic growth (growthsq) were included in the analysis as independent variables to test the validity of the EKC. Furthermore, acknowledging that variations in population across countries and in renewable energy use levels may also influence CO_2 emissions, the population (lnpop) and use of renewable energy (renew) were introduced as control variables in the model. All the data were obtained from the World Bank database. Among the variables in the model, logarithmic values of CO_2 emissions, trade openness and population are considered. These variables are used in logarithmic form because of the scale differences of the variables and the geometric increase in the variables.

When examining the EKC in the literature, one comes across quadratic or cubic models formulated in relation to per capita income. However, it is widely acknowledged that including the square or cube of income per capita in this model as an independent variable result in multicollinearity due to the high correlation between independent variables (Narayan and Narayan, 2010; Stern, 2004).

The variance inflation factor (VIF) measures the multicollinearity problem. Accordingly, the VIF is calculated as follows (Draper and Smith, 1981):

$$VIF = \frac{1}{1-R^2} \tag{5}$$

Although panel data analysis overcomes the issue of multicollinearity, the inclusion of the square of a variable in the model leads to high VIF values. Accordingly, the main criticism of the EKC is toward the model's specification. Relying on the findings of a model suffering from multicollinearity is seen as trying to make sense of a statistically problematic model.

In this study, the average VIF reaches 232 when the square and cube of logarithmically per capita income are included in the model for APEC countries. A high value indicates a serious statistical problem. Therefore, the economic growth variable is included instead of per capita income to avoid the multicollinearity problem in the determination of the model. Thus, this study aims to overcome the multicollinearity problem and generate a statistically robust model. The equation of the panel data model examined in this study is presented as follows:

$$lnco_{it} = \sigma_0 + \lambda lntrade_{it} + \tau fdi_{it} + \beta lnpop_{it} + \psi renew_{it} + \varphi growth_{it} + \Upsilon growth^2_{it} + \varepsilon_{it.} \tag{6}$$

The economic growth (growth) and the square of economic growth (growthsq) variables in the model are included to test whether the EKC is valid. Since the main motivation of this study is to determine the effect of trade openness on carbon emissions for APEC countries, the trade openness (trade) variable is included in the model. On the other hand, foreign firms with strict environmental regulations in their own countries tend to go to countries with lax environmental laws, which are called pollution havens. The foreign direct investment (fdi) variable is included to assess whether APEC countries are pollution havens.

Descriptive statistics of the variables in the model are shown in Table 1.

Table 1. Descriptive Statistics

Variable	Description	Mean	Std. Dev.	Min.	Max.
lnco	*Logarithmic value of CO_2 emissions (metric tons per capita)*	1.71	0.95	-0.76	3.07
lntrade	*Logarithmic value of trade openness rate*	4.22	0.64	2.89	6.08
fdi	*Net foreign direct investment inflows % of GDP)*	3.71	4.59	-3.81	29.76

growth	*Economic growth (%)*	3.56	3.56	-13.12	14.51
growthsq	*Square of economic growth*	25.38	28.98	0.01	210.82
renew	*Renewable energy consumption (% of total energy consumption)*	16.84	14.26	0	62.62
lnpop	*Logarithmic value of the population*	17.5	1.79	12.63	21.06

Source: World Bank (2021).

The diagnostic test statistics are shown in Table 2.

Table 2. Diagnostic Test Statistics

	Test Statistics
VIF	1.57
LR Test: Time Effect	0.01
LR Test: Individual Effect	1310.93*
Cluster-Robust Hausman Test	16.47*
D'Agostino Belanger and D'Agostino – Joint Test (μ)	1.93
D'Agostino Belanger and D'Agostino – Joint Test (u)	1.40
Modified Bhargava et al. Durbin-Watson Test	0.34
Levene, Brown, and Forsythe's Test - W_0	14.11*
Levene, Brown, and Forsythe's Test - W_{50}	9.23*
Levene, Brown, and Forsythe's Test - W_{10}	13.61
Frees's Test of Cross-Sectional Independence	4.103*

* Significant at the 95% confidence level.

According to the Likelihood Ratio (LR) test statistic in Table 2, there is no time effect in the model, but there is an individual effect. In this case, the pooled OLS method cannot be applied. To determine whether there is a correlation between independent variables and unit effects when choosing between fixed effects and random effects estimators, one should examine the Cluster-Robust Hausman test statistic. According to the Hausman test, the random effects estimator is inconsistent. Hence, one-way unit effects and fixed effects estimators are used in the model. According to the D'Agostino Belanger and D'Agostino joint test statistics, which evaluate the normal distribution of error terms and unit effects, both the unit effect and the error terms are normally distributed. Modified Bhargava et al. and Durbin–Watson test statistics indicate autocorrelation in the model. Based on Levene, Brown, and Forsythe's test statistics investigating heteroscedasticity, it appears that the model exhibits heteroscedasticity. Frees's cross-sectional dependency test statistics indicate the presence of cross-sectional dependence.

Diagnostic tests reveal the presence of autocorrelation, heteroscedasticity, and cross-sectional dependence in the model. In this case, the Driscoll–Kraay standard error can be used to estimate the model. This method computes standard errors that are resistant to autocorrelation, heteroskedasticity, and cross-sectional dependence (Driscoll and Kraay, 1998; Baltagi, 2021; Yerdelen, 2020). As a result, Driscoll-Kraay resistant standard errors are used to estimate the problems of autocorrelation, heteroscedasticity, and cross-sectional dependence in the model analysis.

4. EMPIRICAL RESULTS

The model statistics calculated with the Driscoll-Kraay standard errors of the fixed-effects estimator are shown in Table 3.

Table 3. Statistics of the Fixed-Effect Model

Independent variable	Coefficients	Driscoll-Kraay Standard Deviations
lntrade	0.165*	0.045
fdi	-0.008**	0.003
growth	0.002***	0.001
growthsq	-0.001	0.001
lnpop	0.221*	0.031
renew	-0.038*	0.001
constant	-2.207*	0.492
F Test Statistics	899.63*	
Within R-squared	0.761	
Obs.	450	

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

When the findings are evaluated, economic growth and the square of economic growth are statistically significant. Accordingly, the EKC, which is modeled on economic growth in APEC countries, is valid. These findings confirm the inverted U-shaped relationship proposed in the literature. Environmental pollution increases in the early stages of economic growth. However, after reaching a peak at a certain growth level, pollution begins to decrease. Calculating the turning point to determine the growth rate at which pollution reaches its peak reveals a rate of 1.47. When the growth rates of APEC countries from 1990 to 2020 are analyzed, it is seen that in most years, APEC countries have realized growth above this rate. This shows that CO_2 emissions are decreasing in these countries. An analysis of the data sets reveals that CO_2 emissions decrease during periods when the growth rate of most countries shows an upward trend above 1.46%.

According to the findings, there is a positive and statistically significant relationship between trade openness and CO_2 emissions in APEC countries. This finding shows that a 1% increase in the share of total international trade (import + export) in GDP in APEC countries leads to an increase in CO_2 emissions of approximately 0.16% and thus to an increase in environmental degradation. According to the model results, a 1% increase in FDI reduces CO_2 emissions by approximately 0.008%. This result can be explained by the fact that foreign capital entering APEC countries in the form of FDI brings new and clean technologies to these countries, thus reducing CO_2 emissions.

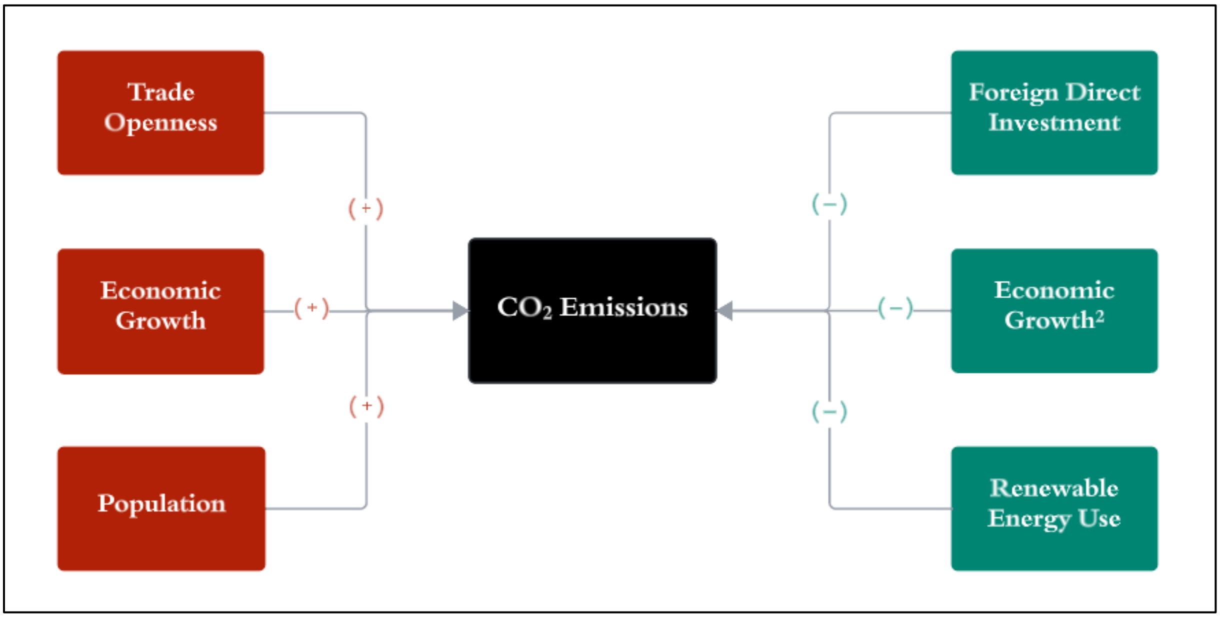
The use of renewable energy, a control variable in the model, decreases CO_2 emissions. A 1% increase in the share of renewable energy in total energy consumption reduces CO_2 emissions by 0.038%. The reduction in CO_2 emissions achieved by using renewable energy sources indicates the need to adopt these sources as alternatives to fossil fuels on a wider scale. This requires a significant transformation of carbon-intensive industries and power generation. Investments in renewable energy sources, improved energy efficiency, and transitioning to sustainable energy technologies have the potential to significantly reduce CO_2 emissions. The population, another control variable, increases CO_2 emissions. Specifically, a 1% population increase leads to a 0.221% increase in CO_2 emissions. The impact of population growth on CO_2 emissions implies that population growth could exacerbate environmental concerns in regions with high population density and rapidly expanding economies. This underscores the significance of devising sustainable solutions for urbanization, transportation, energy utilization, and waste disposal. Additionally, this emphasizes the need for a balanced approach to managing the correlation between population growth and economic growth.

5. CONCLUSION

Today, greenhouse gas emissions and economic activities have become essential areas of research. The main reason for this is that the increase in greenhouse gases accelerated with the industrial revolution and has now reached alarming levels. The greatest threat among greenhouse gases is CO_2 emissions. On the other hand, APEC includes the countries that contribute the most to CO_2 emissions. This study examines the relationships between economic growth, population, renewable energy, trade openness, foreign direct investment, and CO_2 emissions in APEC countries in the context of the EKC. Recently, there has been a focus on trade openness and foreign direct investment, especially in examining the impact of globalization on CO_2 emissions.

Figure 3 shows the graphical summary generated from the results in Table 3.

Figure 3: Graphical Summary of the Results



As shown in Figure 3, CO_2 emissions have a positive relationship with trade openness, economic growth and population. In contrast, there are negative relationships between FDI and the square of economic growth and between the use of renewable energy and CO_2 emissions.

The positive relationship between trade openness and CO2 emissions for APEC countries is similar to the findings of Chen et al. (2021) for 64 countries, Shahzad et al. (2019) for Pakistan, Hassain (2011) for newly industrializing countries, Halıcıoğlu (2009) and Artan et al. (2015) for Turkey. However, these findings contrast with those of studies of Asian countries (Amin et al., 2020), EU countries (Park et al., 2018), OECD countries (Pazienza, 2015; Managi et al., 2009), China (Li and Haneklaus, 2022), Tunisia (Chebbi, 2011) and middle-income countries (Lv and Xu, 2018).

An increase in international trade is often associated with an increase in emission sources such as industrial production, transportation, and energy consumption. In APEC economies, the positive relationship between trade openness and CO_2 emissions demonstrates the environmental impact of economic activities and industrial production. This underscores the importance of effective environmental policies and sustainable production methods, especially in emission-intensive sectors. These findings also point to the need to invest in energy efficiency, waste management and emission reduction technologies to offset the environmental impacts of trade. Carbon taxation and green tariffs are instrumental in increasing the effectiveness of environmental policies. Additionally, promoting international cooperation and developing standards to reduce environmental impacts will contribute to ensuring that trade is conducted sustainably.

The negative relationship between FDI and CO_2 emissions indicates the positive effect of FDI on the environmental performance of these countries. This shows that FDI leads to the transfer and implementation of more modern, efficient and environmentally friendly technologies. Accordingly, foreign capital inflows to APEC countries help reduce CO_2 emissions by bringing in innovative and clean technologies. This finding suggests that FDI is a potentially significant instrument for sustainable development. Moreover, this study emphasizes the importance of directing foreign investment toward environmentally friendly technologies, renewable energy sources and sustainable industrial practices. APEC countries should encourage investment in this area by providing attractive incentives, tax breaks and regulatory relief to foreign investors. Supporting international collaboration and agreements to enhance environmental standards and transfer green technology is also important.

The positive relationship between FDI and CO2 emissions for APEC countries suggests that the PHH is not valid. The positive relationship between FDI and CO2 emissions for APEC countries suggests that the PHH is not valid. The results obtained in this study are consistent with the findings of Chandran et al. (2013), Özkan and Çoban (2022), Zhu, Duan, Guo and Yu (2016), Tang and Tan (2015), Zhang and Zhou (2016), Hakimi and Hamdi (2016), and Amri (2016). However, these findings contrast with those of the studies by Hoffmann, Lee, Ramasamy and Yeung (2005); Al-Mulali and Sab (2012); Shahbaz, Nasir and Roubaud (2018); Seker, Ertugrul and Cetin (2015); Zhang and Zhang (2018); Al-Mulali and Tang (2013); Pao and Tsai (2011); and Jorgenson (2009), who concluded that PHH is valid.

The positive relationship between economic growth and CO_2 emissions shows that an increase in economic activity is directly linked to its environmental impact. Increasing economic growth in APEC economies initially exacerbates environmental pressure in emission-intensive sectors. This emphasizes the importance of sustainable production methods and effective environmental policies. On the other hand, the negative relationship between the square of economic growth and CO_2 emissions indicates that the negative impact of economic growth on the environment may decrease after a certain level is reached. Accordingly, the results show that the Environmental Kuznets Curve (EKC) hypothesis is valid for APEC countries. These findings are consistent with many published studies confirming the EKC (Cole, Rayner, and Bates, 1997; Schmalensee, Josko, Ellerman, Montero and Bailey, 1998; Neumayer, 2002; Cole and Elliott, 2003; Dijkgraaf and Vollebergh, 2005; Apergis and Payne, 2010; Apergis and Öztürk, 2015; Shahbaz et al., Loganathan, Muzaffar, Ahmed and Jabran, 2016; Bento and Moutinho, 2016; Rafindadi and Usman, 2020).

While the Environmental Kuznets Curve suggests that economic growth can lead to a reduction in CO_2 emissions once a certain threshold is reached, it is crucial to integrate economic development and environmental sustainability at all stages. The implementation of policies that focus on increasing environmental standards, investing in green technologies, and promoting sustainable production and consumption patterns are pivotal components of sustainable development. APEC economies should prioritize these policies to ensure a sustainable future.

The positive relationship between population and CO2 emissions in APEC countries is consistent with the findings of Liddle and Lung (2010), Wang, Wu, Zhu and Wei (2013) and Uddin, Alam and Gow (2016). The positive relationship between population growth and CO_2 emissions indicates that increasing population density increases energy demand and thus emissions. This is a significant environmental challenge, especially for APEC countries experiencing rapid population growth. Managing the demand for energy and resources that comes with population growth is a critical factor for these countries to achieve their environmental sustainability goals. To manage the environmental impacts of population growth, APEC countries should improve energy efficiency, expand the use of renewable energy sources and adopt sustainable urbanization policies. This should include reducing environmental impacts in urban planning and infrastructure investments, constructing energy-efficient buildings and improving public transportation systems.

The positive relationship between renewable energy use and CO2 emissions in APEC countries is consistent with the findings of Dong, Hochman, Zhang, Sun, Li and Liao (2018); Salahodjaev, Sharipov, Rakhmanov and Khabirov (2021); Wang, Pham, Sun, Wang, Bui and Hashemizadeh (2022); Zhang (2019); and Apergis, Kuziboev, Abdullaev and Rajabov (2023). The negative relationship between renewable energy use and CO_2 emissions indicates that the adoption of renewable energy sources improves environmental performance in these countries. Investments in renewable energy sources reduce dependence on fossil fuels and lower CO_2 emissions. These findings suggest that promoting renewable energy policies and technologies in APEC countries has the potential to reduce environmental impacts while supporting economic growth. APEC countries should invest in these resources, support research and development activities, and develop policies to facilitate the deployment of renewable energy technologies.

One of the main limitations of this study concerns the data set's scope. The data of many APEC countries are available only up to 2020, resulting in a study period ranging from 1996 to 2020. This limitation presents a significant challenge, especially in examining recent developments over the last three years. It is worth noting that this study does not cover the years impacted by the COVID-19 pandemic. The restrictive measures triggered by the pandemic resulted in reduced foreign trade volume and CO_2 emissions on a global scale. In addition, it is important to consider that capital flows are also affected during the pandemic. For a better understanding of the pandemic's implications, future studies examining the effects of the pandemic before and after the pandemic in APEC nations will be crucial. The use of the fixed-effects estimator in the panel data analysis is another limitation of this study. The fixed effects estimator does not fully account for time series-specific dynamics. In future studies, the use of panel time series methods with a dataset covering a longer period will be critical to better understand how economic and environmental trends change over time. Moreover, the use of panel time series methods allows for a more detailed examination of the different responses to economic and environmental conditions across APEC economies. This methodology will also be an important step in developing country-specific policy recommendations.

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