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Research Article

Investigating the Mutual Effects Between Economic Growth, Trade Openness and CO_2 Emissions: A Study of OECD Countries Through Panel Simultaneous Equation Modeling

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Abstract
This study examines the relationships between economic growth, CO_2 emissions, and trade openness across OECD countries from 1990 to 2015. Simultaneous equation models are used within a multivariate framework, incorporating variables such as gross fixed capital formation, labor force participation rate (aged 15-24), energy consumption, combustible renewables and waste, foreign direct investments and real effective exchange rate index. Findings indicate that trade openness positively influences economic growth, while CO_2 emissions negatively affect it. Economic growth, in turn, increases CO_2 emissions. However, trade openness has no significant impact on CO_2 emissions. Economic growth positively affects trade openness, whereas CO_2 emissions have a negative impact on it. These results highlight the intricate dynamics among these variables within OECD countries.

Keywords: Trade openness, economic growth, CO_2 emissions, OECD
JEL Classification Codes: C23, Q20, Q30, Q56

Ekonomik Büyüme, Ticari Dışa Açıklık ve CO_2 Emisyonları Arasındaki Karşılıklı Etkilerin İncelenmesi: Panel Eşanlı Denklem Modellemesiyle OECD Ülkelerinin İncelenmesi

Öz
Bu çalışma, 1990'dan 2015'e kadar olan dönemde OECD ülkeleri arasında ekonomik büyüme, CO_2 emisyonları ve ticaret açıklığı arasındaki ilişkileri incelemektedir. Çalışmada çok değişkenli eşzamanlı denklem modelleri kullanılmış olup, analizde gayrisafi sabit sermaye oluşumu, 15-24 yaş arası işgücüne katılım oranı, enerji tüketimi, yanabilir yenilenebilir kaynaklar ve atıklar, doğrudan yabancı yatırımlar ve reel efektif döviz kuru endeksi gibi değişkenler ele alınmıştır. Bulgular, ticaret açıklığının ekonomik büyümeyi olumlu yönde etkilediğini, ancak CO_2 emisyonlarını etkilemediğini göstermektedir. Ekonomik büyüme ise CO_2 emisyonlarını artırmaktadır. Ayrıca, ekonomik büyümenin ticaret açıklığını olumlu yönde etkilediği, ancak CO_2 emisyonlarını olumsuz etkilediği belirlenmiştir. Bu sonuçlar, değişkenler arasındaki karmaşık dinamikleri ve etkileşimleri vurgulamaktadır.

Anahtar kelimeler: Ticari açıklık, ekonomik büyüme, CO_2 emisyonları, OECD
JEL Sınıflandırma Kodları: C23, Q20, Q30, Q56

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1. Introduction

In recent times, one of the most widely discussed concepts is globalization, particularly in the realm of trade. The globalization of trade refers to the increasing prevalence of free trade, driven by growing cross-border exchanges of goods and services among nations, fostering greater interdependence and similarity (Saçık, 2009, p.273). A key indicator of globalization is trade openness, which can spur economic growth but also expose economies to external vulnerabilities. Hence, it is crucial to carefully manage a country's trade policies to maintain balance.

Carbon dioxide (CO_2) is among the greenhouse gases in the atmosphere. These gases trap solar radiation and play a crucial role in regulating the Earth's temperature. However, excessive emissions of greenhouse gases can intensify the greenhouse effect, leading to global warming. CO_2 is particularly significant in discussions on global environmental sustainability and conservation efforts. Scientific consensus underscores that rising CO_2 emissions significantly contribute to the proliferation of greenhouse gases (Mercan & Karakaya, 2015; Mete, 2020, p. 389), which in turn exacerbate global warming and induce shifts in climate patterns (IPCC, 1996; Kaygusuz, 2009, p. 258).

Addressing the urgent challenge of global warming and its impact on the Earth's ecosystem, developed nations collaborated to establish the Kyoto Protocol (Halıcıoğlu, 2009). Economic growth is typically associated with an increase in industrial production and energy demand, which often leads to greater use of fossil fuels (oil, coal, natural gas) and subsequently, an increase in CO_2 emissions. However, economic growth also fosters opportunities for adopting more efficient technologies and developing environmentally friendly practices, which can mitigate the sensitivity of economic growth to CO_2 emissions. Trade openness, characterized by increased international trade and exports, facilitates the reach of products and services to distant markets, thereby promoting the growth of energy-intensive industries and potentially increasing CO_2 emissions.

Economic growth contributes to enhancing a country's wealth, reducing unemployment, and improving living standards. Trade openness measures a country's engagement in international trade, reflecting its activity in exporting and importing goods and services. By participating more actively in global trade, an open economy can exploit the benefits of international markets, fostering economic growth, expanding market access, and enhancing competition.

Understanding the correlations among economic growth, trade openness, and CO_2 emissions is pivotal for comprehending how these factors interrelate and for formulating strategies that support sustainable economic development. Extensive research over recent decades has explored these relationships (Hasson and Masih, 2017; Boateng, 2020; Aydın, 2023), seeking to provide policymakers with insights into balancing economic objectives with environmental concerns.

In summary, the relationship among economic growth, CO_2 emissions, and trade openness is complex and influenced by a myriad of factors. Policymakers must design strategies that harmonize sustainable economic expansion with the imperative goal of reducing CO_2 emissions, aiming to align economic progress with environmental preservation objectives.

The primary aim of this study is to investigate the intricate relationships among CO_2 emissions, trade openness, and economic growth. The key motivation behind this research is to comprehend how economic growth, CO_2 emissions, and trade openness are interconnected within OECD countries. To analyze these relationships, simultaneous equation models and a multivariate framework are employed. Panel data covering OECD countries from 1990 to 2015 are utilized to explore these connections.

There exist complex relationships between economic growth, CO_2 emissions, and trade openness. Understanding and managing these relationships correctly are crucial to achieving environmental sustainability goals and promoting economic growth. The primary aim of this study is to thoroughly examine the relationships between economic growth, CO_2 emissions, and trade openness specifically across OECD countries. The study aims to elucidate these relationships using complex econometric methods such as simultaneous equation models and multivariate analysis. The goal is to translate the findings into directly actionable policy recommendations and implementations for policymakers and decision-makers. In this way, the overarching objective of the study is to provide a scientific foundation for understanding the balance between economic growth and environmental impacts, thereby contributing to achieving sustainable development goals. The study employs simultaneous equation models and a multivariate framework, which proves effective in analyzing complex relationships such as economic growth, CO_2 emissions and trade openness. These methods serve as a reference point for similar studies. The research not only confirms previous findings but also extensively investigates the relationship between economic growth and CO_2 emissions, as well as the impact of trade openness on these dynamics. This adds new perspectives to the literature and helps uncover previously overlooked relationships. The findings of the study may offer policy recommendations on managing factors like economic growth and trade openness to achieve environmental sustainability goals. Such recommendations are valuable resources for decision-makers. Conducted specifically within OECD countries, the study allows for generalization to other regions sharing similar economic and environmental conditions. This positions the study to contribute to global policymaking and implementation efforts. The study employs complex econometric methods such as simultaneous equation models and multivariate analysis to thoroughly examine the relationships between economic growth, CO_2 emissions, and trade openness. This methodology distinguishes it from other studies in the literature focusing on these topics. The research reveals previously overlooked or under-researched relationships, thereby making a novel

contribution to the literature. For example, it provides detailed insights into the impact of trade openness on CO_2 emissions. The study emphasizes converting its findings into direct policy recommendations and practical applications for decision-makers. This proactive approach bridges the gap between theoretical findings and their practical implications. By specifically focusing on OECD countries, the study offers specialized analysis for this group of nations. This facilitates extrapolation to other regions with similar economic and environmental conditions, enhancing its potential contribution to global policymaking. In this manner, the study contributes significantly to the literature by conducting in-depth analyses of fundamental topics such as economic growth, CO_2 emissions, and trade openness, thereby advancing the knowledge base in these domains. The originality of the study lies in its methodological approach and the comprehensive analysis of multiple variables simultaneously within OECD countries. Here are the points highlighted for the originality of the study. The study employs simultaneous equation models that evaluate multiple variables such as gross fixed capital formation, labor force participation rate (aged 15-24), energy consumption, combustible renewables and waste, foreign direct investments, and real effective exchange rate index concurrently. This methodological choice is innovative as it allows for a holistic examination of the interrelationships among these variables. Unlike studies primarily focusing on advanced economies, this research specifically targets OECD countries. It aims to uncover unique dynamics and relationships among these countries, providing insights distinct from research on other groups of nations. The study's in-depth analysis of the relationships between the variables, which are typically treated separately in the literature, allows for a comprehensive understanding. Particularly rare are studies that deeply explore the effects of trade openness on economic growth and CO_2 emissions concurrently. The findings clarify how trade openness influences economic growth and how CO_2 emissions impact economic growth. Such analyses provide crucial insights for policymakers aiming to understand the implications of these relationships on policy decisions. The study's timeframe from 1990 to 2015 and the dataset used are crucial elements determining its originality. The analysis of trends and variations during this period significantly impacts the overall findings and conclusions drawn. In summary, the study's originality stems from its methodological rigor, comprehensive analysis of multiple variables within OECD countries, unique insights into the relationships between these variables, clear findings with policy implications, and the specific timeframe and dataset used for analysis. These factors collectively contribute to its contribution to the literature and relevance for policymakers. The subsequent sections of this paper are structured as follows: Section 2 provides an overview of existing literature concerning the interrelationships among CO_2 emissions, trade openness, and economic growth. Section 3 delineates the specifications of the empirical model, outlines the dataset used, and elucidates the methodology employed in the study. Sections 4 and 5, respectively, present the research findings and draw conclusions based on the analysis conducted.

2. Literature Review

This section outlines the structure of the literature review, following a similar approach as in the introductory paragraph.

2.1. The Connection Between CO_2 Emissions and Economic Growth

The relationship between economic growth and CO_2 emissions is not uniform or universally applicable. It is influenced by various factors and exhibits considerable variation across countries and regions. This topic is complex and multifaceted, with relationships that can vary significantly depending on several determinants, including a country's stage of development, its energy resources, and its policy frameworks. The examination of the interplay between CO_2 emissions and economic growth is marked by diverse studies, each shedding light on different aspects of this complex relationship.

Özturk and Acaravcı (2010) analyzed long-term patterns and causal connections among carbon emissions, economic growth, energy consumption, and employment rates in Turkey from 1968 to 2005. Their investigation revealed that per capita carbon emissions did not exert a substantial influence on per capita real GDP.

Bozkurt and Akan (2014) conducted an in-depth exploration of the intricate relationship between economic growth, CO_2 emissions, and energy consumption within Turkey from 1960 to 2010. Their comprehensive research involved detailed annual data analysis, including metrics such as energy consumption, carbon dioxide emissions, and gross domestic product. A significant finding was the detrimental impact of CO_2 emissions on the trajectory of economic growth.

According to Çetintaş and Sarıkaya (2015), there is a persistent link between economic growth and carbon dioxide (CO_2) emissions in both the United States (USA) and the United Kingdom (UK). In the UK, economic growth positively influences CO_2 emissions in both the short and long terms, suggesting a one-way causal relationship where CO_2 emissions affect economic growth. Conversely, for the USA, their research indicates that economic growth does not significantly impact CO_2 emissions.

Mercan and Karakaya (2015) investigated the relationship between economic growth, energy consumption, and CO_2 emissions across eleven OECD nations and Brazil from 1970 to 2011. Their findings indicated that gross domestic product (GDP) had a modest negative impact on carbon dioxide emissions in OECD countries.

Yıldırım (2017) explored the connection between economic growth and CO_2 emissions among eighteen OECD nations from 1961 to 2011. The study revealed that economic growth was associated with increased energy consumption,

consequently leading to higher CO_2 emissions. This effect was particularly significant in certain developing countries within the OECD.

Tariq, Sun, Haris, Kong, and Nadeem (2018) focused on Pakistan and India, highlighting a positive correlation between GDP and CO_2 emissions over both short-term and long-term periods. This correlation was attributed to increased Foreign Direct Investment (FDI) accompanying GDP growth, which stimulated job creation and subsequently escalated CO_2 emissions, thereby posing environmental challenges.

Majeed, Mazhar, Samreen, and Tauqir (2022) examined the relationship between economic complexity and CO_2 emissions among OECD economies from 1971 to 2018. Their research underscored a substantial positive correlation between economic complexity and CO_2 emissions, particularly notable in OECD nations with lower initial emission levels.

These studies collectively contribute to understanding the nuanced interactions between economic growth, energy consumption, and CO_2 emissions, emphasizing the varying impacts across different countries and regions within the OECD context.

2.2. The Connection Between Trade Openness and CO_2 Emissions

The relationship between CO_2 emissions and trade openness is intricate and contingent upon various factors such as a country's developmental stage, environmental regulations, industrial composition, and technology adoption. Ongoing research aims to deepen understanding of how international trade influences environmental outcomes and how policies can be crafted to foster sustainable development.

Studies on this relationship have yielded significant insights. For instance, Atıcı and Fırat (2007) found that an increase in the trade openness index leads to a rise of 16.52 kg in per capita emissions. This finding strongly supports the Pollution Haven Hypothesis, suggesting that as trade openness expands, pollution tends to worsen. In Turkey's case, particularly since the 1980s, the intensification of production in environmentally polluting sectors has mirrored the growth in trade volume, especially in low-tech product categories. However, it is worth noting that while an increase in the agricultural trade openness index has been observed to have a mitigating effect on CO_2 pollution, this impact is statistically insignificant. These findings underscore the complexity of the relationship between trade openness and CO_2 emissions, highlighting the need for nuanced policy interventions that balance economic growth with environmental sustainability objectives.

Fotros and Maaboudi (2011) undertook an investigation into the potential link between trade openness and environmental degradation in Iran. Their primary

objective was to examine the relationship between trade openness, economic growth, and CO_2 emissions in Iran. They employed a multivariate model and analyzed data spanning from 1971 to 2006. Their analysis revealed a unidirectional relationship, where trade openness exerted a significant influence on CO_2 emissions, leading to notable increases in carbon dioxide emissions.

In their 2016 study, Le, Chang, and Park explored the impact of increased trade openness on environmental degradation using a global sample. Their findings indicated that the outcomes varied depending on the income levels of the countries involved. For high-income nations, trade openness either had a positive effect on the environment or had a neutral impact, suggesting it did not significantly harm environmental conditions. Conversely, for middle- and low-income countries, increased trade openness was associated with environmental harm.

According to Alper (2018), the empirical results identified a long-term relationship among the variables analyzed at a global scale and across different country groups. Specifically, there was an inverse relationship between trade openness and CO_2 emissions for high-income countries, while middle- and low-income countries, as well as the global level, exhibited a positive relationship.

These studies underscore the nuanced relationship between trade openness and CO_2 emissions, highlighting the varying impacts across different economic contexts and emphasizing the importance of tailored environmental policies to mitigate adverse effects on the environment.

2.3. The Connection Between Economic Growth and Trade Openness

Trade openness and economic growth exhibit variability influenced by diverse factors such as a country's unique circumstances, economic policies, and the global economic environment. Although trade openness holds the potential for significant benefits in terms of economic growth, its effective management is crucial to maximize these positive impacts. However, the outcomes of trade openness are not uniform across all countries, highlighting the importance of understanding context-specific dynamics.

Numerous studies have extensively investigated the relationship between trade openness and economic growth. These studies contribute to a nuanced understanding of how trade openness can foster economic development under specific conditions while also revealing the complexities and potential challenges associated with integrating into global trade networks. By examining these relationships, researchers aim to provide insights into optimizing trade policies to enhance economic growth and ensure sustainable development.

Dar and Amirkhalkhali (2003) conducted an empirical study to evaluate the impact of trade openness on the expansion of total and individual factor productivity across

19 OECD countries over the past three decades. Their research underscores significant variability in how trade openness influences economic growth among the studied countries. Moreover, the study reveals that the contributions of capital and labor accumulation to economic growth not only vary across regions but also evolve over time in response to prevailing levels of openness.

Utkulu and Kahyaoğlu (2005) explored the empirical effects of trade and financial openness on economic growth and vulnerability to crises in Turkey from 1990 to 2004. Their findings indicated that while trade openness positively impacted economic growth in Turkey, financial openness contributed to prolonged economic downturns. Interestingly, financial openness acted as a counterforce that mitigated the beneficial effects of trade openness, thereby adversely affecting overall welfare outcomes.

Yapraklı (2011) conducted a research study aimed at investigating the relationship between trade and financial openness and economic growth in Turkey. The analysis revealed that trade openness positively influenced long-term economic growth, whereas financial openness had a negative impact. These findings suggest the existence of a bidirectional causal relationship between trade and financial openness and their respective effects on economic growth.

Mercan and Göçer (2014) conducted research using annual data from the period 1990-2010 to investigate the effects of trade openness on economic growth and inflation in Central Asian countries through panel data analysis. According to the authors, they found that a 100% increase in the level of trade openness leads to a 4.8% increase in economic growth.

Idris, Yusop, Habibullah, and Chin (2018) conducted a comprehensive investigation into the intricate connections between trade openness and economic growth across a diverse dataset of 87 countries, encompassing both developing nations and OECD member states. The results consistently pointed to a robust bidirectional causal link between trade openness and real economic growth, with this causality being statistically significant at the 5% confidence level. These findings underscore the substantial influence of trade openness on economic growth in developing countries, and conversely, the role of improved economic performance in fostering an increase in trade openness.

Özcan, Özmen, and Özcan (2018) conducted an analysis aimed at uncovering the link between trade openness and economic growth within a dataset consisting of 18 emerging market economies. This investigation spanned the period from 1992 to 2015. Their study revealed that, akin to the impact of trade openness on economic growth, the proposition that economic growth contributes to the promotion of trade openness holds true in certain developing countries. However, it's important to note that the degree of statistical significance varies among these countries.

In their 2018 research, Dam and Bakkalcı presented empirical analysis results that indicate a positive and significant long-term influence of trade openness on economic growth. Their findings align with numerous models exploring the relationship between openness and economic growth, emphasizing the existence of a connection between economic growth and trade openness. The study employed unit root tests, cointegration tests, long-term analysis, and error correction models

Belazreg and Mtar (2020) conducted a comprehensive study examining a dataset spanning from 2001 to 2016 across 27 OECD countries. Their empirical investigation aimed to uncover the interplay between trade openness, innovation, financial development, and economic growth. Their findings reveal a reciprocal relationship between economic growth and trade, underscoring the intricate connections among these pivotal variables.

Kesap and Sandalcılar (2021) analyzed the effects of foreign trade policies on economic growth using data from 2009 to 2019 encompassing 20 countries, including developing and rapidly growing economies seeking integration into the global economy. Their analysis indicates that protectionist policies in international trade negatively impact economic growth.

In high-income countries, Tokmak and Sonmez (2021) identified a unilateral causal linkage from trade openness to economic growth. For lower-middle-income countries, their research highlighted two-way causal relationships involving fertility rate, public expenditures, economic growth, exports, imports, inflation, and trade openness. In low-income countries, they found two-way causal relationships between public expenditures, imports, foreign direct investments, economic growth, health expenditures, life expectancy at birth, inflation, and trade openness, illustrating the complex dynamics at play in different economic contexts.

Asım, Kılıç, and Pazarcı (2022) conducted a study exploring the dynamics between trade openness and economic growth across ten Eastern European nations from 1995 to 2020. Their initial analysis using time series techniques revealed a sustained connection between trade openness and economic growth specifically in Latvia, Lithuania, and Slovakia. However, upon shifting to panel data analysis, they found no statistically significant relationship between trade openness and economic growth.

Yenipazarlı, Cambazoğlu, and Begeç (2022) aimed to scrutinize the impact of trade openness on the economic growth of BRICS countries from 1996 to 2020. Their research uncovered a constructive influence of trade openness on the economic growth rates of BRICS nations. Their model consistently highlighted a robust and statistically significant positive relationship between trade openness and economic growth.

Karaca, Güney, and Hopoglu (2022) conducted an in-depth examination of the complex interactions among trade openness, foreign direct investment (FDI), and economic growth within the emerging markets collectively known as BRICS-T. Spanning from 1992 to 2019 and employing panel data analysis techniques, their research revealed a bidirectional causal relationship between trade openness and economic growth among the BRICS-T nations over the study period. Additionally, their findings indicated a one-way causal connection where economic growth influenced FDI in this context.

In a study conducted by Aktop (2023), the primary aim was to investigate the impact of trade openness on economic growth in OECD countries from 1997 to 2020. The research findings reveal a mutual causality relationship between economic growth and trade openness, indicating a two-way cause-and-effect connection. The results of the causality tests consistently emphasize this bidirectional association between trade openness and economic growth. These findings provide robust evidence suggesting that trade openness plays a positive role in driving economic growth across the panel of countries examined.

Jošić (2023) undertook a study to scrutinize the link between trade openness and GDP growth within OECD countries, covering the period from 1988 to 2020. The primary outcomes of this research support the notion that trade openness contributes to fostering economic growth.

2.4. CO_2 emissions, economic growth and trade openness relationship

In a study conducted by Choi, Heshmati, and Cho (2010), an examination was carried out using annual data spanning from 1970 to 2013 to assess the influence of factors such as population density, energy consumption, economic growth, and trade openness on CO_2 emissions in India. Their results demonstrated statistically significant positive impacts in both the short-term and long-term for population density, energy consumption, and economic growth with respect to CO_2 emissions.

In essence, these factors were found to contribute to increased CO_2 emissions over time. In a study conducted by Hossain (2011), the analysis revealed the presence of unidirectional short-run causal relationships among several key variables. Specifically, the study identified short-term causal relationships among economic growth and trade openness, economic growth and energy consumption, trade openness and economic growth, urbanization and economic growth, and even trade openness and urbanization. Interestingly, the findings did not reveal any conclusive evidence supporting sustained panel causal relationships among these variables over the long term. Additionally, notable findings highlighted the substantial and negative impacts of trade openness and urbanization on carbon emissions, suggesting that these factors contributed to a reduction in carbon emissions.

Shahbaz, Hye, Tiwari, and Leitão (2013) investigated the intricate connections among economic growth, trade openness, energy consumption, financial development, and CO_2 emissions in the context of Indonesia. The analysis spanned from 1975Q1 to 2011Q4 and revealed bidirectional causality between economic growth and CO_2 emissions. Additionally, the study highlighted the potential contributions of financial development and trade openness in enhancing environmental quality.

In their 2014 research, Saboori, Sapri, and bin Baba aimed to unravel the intricate and long-term connections between energy consumption in the road transport sector, CO_2 emissions, and economic growth in OECD countries. The study's outcomes illuminated a noteworthy and positive two-way connection that persisted over the long term. Specifically, this connection was evident between CO_2 emissions and energy consumption in the road transport sector, as well as between CO_2 emissions and economic growth across all OECD countries. These findings underscore the substantial impact of energy consumption on the generation of CO_2 emissions from transportation activities.

Kızılkaya, Çoban, and Sofuoğlu (2015) embarked on an investigation into the intricate interplay between carbon dioxide emissions, energy consumption in the transportation sector, economic growth, and trade openness within Turkey. The study encompassed annual data spanning from 1967 to 2010. The outcomes of the analysis shed light on the prolonged association between carbon dioxide emissions and energy consumption in the transport sector, economic growth, and trade openness in the Turkish context. Notably, in Turkey, economic growth, energy consumption in the transportation sector, and trade openness were found to exert a positive influence on carbon dioxide emissions.

Ali, Law, and Zannah (2016) conducted a study to investigate the dynamic effects of urbanization, economic growth, energy consumption, and trade openness on CO_2 emissions in Nigeria. The research outcomes reveal that, based on the coefficients of the long-term findings, urbanization does not exert a substantial influence on CO_2 emissions within Nigeria. Conversely, economic growth and energy consumption were found to have a positive and noteworthy impact on CO_2 emissions, while trade openness was associated with a negative and significant effect on CO_2 emissions.

Doğan and Şeker (2016) examined several factors, including CO_2 emissions, real income, quadratic income, energy consumption, financial development, and openness, which exhibited first-order integration. The study covered data from 1975 to 2011 and utilized panel data methods. Their results highlighted that increased openness and greater financial development were associated with a decrease in emissions. Conversely, the study revealed that energy consumption was a contributing factor to higher carbon emissions.

Jamel and Maktouf (2017) conducted a thorough investigation into the causal relationships among economic growth, CO_2 emissions, financial development, and trade openness. Their analysis involved an extensive dataset comprising 40 European economies over the years from 1985 to 2014. They observed bidirectional Granger causal connections among various pairs of variables within the European economies. These included GDP's bidirectional relationship with both pollution and financial sector development, as well as its bidirectional link with trade openness. Furthermore, the study identified bidirectional causal links between financial sector development and trade openness, and also between trade openness and pollution. The mutual and interdependent relationship between GDP and trade openness, especially in the context of European economies, drew significant attention.

Rahman, Saidi, and Mbarek (2020) conducted an examination into how CO_2 emissions, population density, and trade openness influenced the economic growth of five South Asian countries. Their approach involved utilizing panel co-integration analysis and an extended neoclassical growth model, with data spanning from 1990 to 2017. It was observed that in South Asia, both CO_2 emissions and population density had a positive effect on economic growth. However, in contrast, the study revealed that trade openness had a detrimental impact on the region's economic growth.

Van (2020) conducted a study to explore the impacts of energy consumption, economic growth, and trade openness on environmental pollution, with a particular focus on Vietnam as a developing nation. The research uncovered an interesting pattern in the relationship between various pollutants and per capita income, demonstrating an inverted U-shaped curve. Regarding trade openness, the study found that Vietnam exhibited a noteworthy and positive influence on CO_2 emissions, both in the short term and long term.

Hayaloğlu (2020) undertook a comprehensive study aiming to understand the intricate relationships among economic growth, openness, and environmental pollution within the member states of MERCOSUR. To address the endogeneity issue among the variables, the study employed panel simultaneous equation models, utilizing data from the years 1992 to 2017. The study's outcomes unveiled intriguing insights. Notably, the research revealed a positive and two-way relationship between economic growth and CO_2 emissions, as well as between economic growth and trade openness within the examined countries.

Sun, Samuel, Amissah, Taghizadeh-Hesary, and Mensah (2020) aimed to unravel the dynamic links between carbon emissions, trade, energy consumption, urbanization, and economic growth factors spanning from 1992 to 2015 in OECD countries. The results shed light on the significant role played by various factors, including trade openness, urbanization, and energy consumption, in the recent global increase in carbon emissions. The Granger non-causality estimates provided

substantial evidence of a bidirectional causal relationship among these variables across all three panels over the long term.

Kim (2022) focused on understanding the relationship between the utilization of Information and Communication Technology (ICT) and carbon dioxide (CO_2) emissions within OECD countries. This investigation considered various factors, including economic growth, trade openness, and the presence of renewable electricity, spanning the period from 1990 to 2018. The research outcomes highlighted a notable trend: economic growth was found to lead to an increase in CO_2 emissions, both in the short term and long term. Conversely, the study indicated that the expansion of renewable electricity sources and greater openness to trade had a positive impact by reducing CO_2 emissions over the long run (Türköz, 2023; Chebbi, Olarreaga, and Zitouna, 2011).

The relationship between economic growth and CO_2 emissions is complex and varies significantly across countries and regions. Studies highlight that the impact of CO_2 emissions on economic growth can differ based on developmental stages, energy resources, and policy frameworks. For instance, Özturk and Acaravcı (2010) found in Turkey that per capita carbon emissions did not strongly influence per capita GDP. Similarly, Bozkurt and Akan (2014) noted a detrimental effect of CO_2 emissions on economic growth in Turkey. In contrast, Çetintaş and Sarıkaya (2015) identified a positive influence of economic growth on CO_2 emissions in the UK but not in the USA. Studies like Mercan and Karakaya (2015) observed a negative impact of GDP on CO_2 emissions in OECD countries, indicating a nuanced relationship influenced by specific national contexts. The relationship between CO_2 emissions and trade openness varies based on a country's developmental stage, industrial structure, and environmental regulations. Atıcı and Fırat (2007) found in Turkey that increased trade openness correlated with higher per capita emissions, supporting the Pollution Haven Hypothesis. Fotros and Maaboudi (2011) observed in Iran that trade openness significantly increased CO_2 emissions. Le, Chang, and Park (2016) highlighted that while trade openness had positive effects on environmental outcomes in high-income countries, it had adverse impacts in middle- and low-income countries. Alper (2018) identified a negative relationship between trade openness and CO_2 emissions in high-income countries but a positive one in middle- and low-income countries. Trade openness can positively influence economic growth, but the outcomes vary among countries due to different economic policies and global economic conditions. Studies such as Dar and Amirkhalkhali (2003) and İdris et al. (2018) found bidirectional causal links between trade openness and economic growth across various country groups. Utkulu and Kahyaoğlu (2005) noted in Turkey that trade openness contributed positively to growth, while financial openness had adverse effects. Özcan, Özmen, and Özcan (2018) and Dam and Bakkalcı (2018) explored similar patterns in emerging economies, highlighting the nuanced impacts of trade openness on economic growth across different contexts. The nexus between CO_2 emissions,

economic growth, and trade openness is intricate and varies across different regions and periods. Studies like those by Shahbaz et al. (2013) in Indonesia and Kızılkaya et al. (2015) in Turkey observed complex interactions where economic growth and energy consumption contributed positively to CO_2 emissions, while trade openness sometimes exhibited a mitigating effect. Rahman et al. (2020) highlighted positive effects of CO_2 emissions and population density on economic growth in South Asia, contrasting with negative impacts of trade openness. These studies underscore the need for tailored policies to balance economic growth with environmental sustainability. Overall, the literature reveals diverse findings regarding the relationships between CO_2 emissions, economic growth, and trade openness, emphasizing the importance of contextual factors and policy interventions in achieving sustainable development goals.

3. Methodology

3.1. Simultaneous-Equation Model

A regression model generally includes one or more explanatory variables X(s) and a single dependent variable Y. An implicit assumption in such models is that the cause-effect relationship between Y and X's, if any, is unidirectional (Gujarati and Porter, 2009, p.671). Many economic relationships may have too complex structures to be explained by models that can be reduced to a single equation (Şükrüoğlu, 2018, p.133). However, there are also cases where there is a two-way flow of influence between variables; that is, one variable affects the other variable(s) and is in turn affected by it(s) (Gujarati and Porter, 2009, p.671).

A single equation established to explain economic relations is not sufficient, and more than one equation system must be established. Import and export equations, the Keynesian consumption and income equations model can be given as examples for simultaneous equations models (Yerdelen Tatoğlu, 2012, p.121). In simultaneous equation systems, mutual cause and effect relationships between research variables are investigated. A system of simultaneous equations based on two equations can be given as an example:

$$Y_{1i} = \alpha_{10} + \alpha_{12} Y_{2i} + \alpha_3 X_{1i} + U_{1i} \quad (1)$$

$$Y_{2i} = \beta_{20} + \beta_{21} Y_{1i} + \beta_3 X_{1i} + U_{2i} \quad (2)$$

While the variable Y_1 is the dependent variable in Eq. 1, it is included in Eq. 2 as an explanatory variable. While variable Y_2 is an endogenous variable for Eq. 1, Y_1 is an endogenous variable for Eq. 2. X_1 is an exogenous variable for both equations and U_1, U_2 are error terms. In this simultaneous-equation models system, two equations are evaluated together.

3.2. Data and model

This study aims to analyze the mutual linkage between the trade openness CO_2 emissions and economic growth an indicator of environmental pollution. 24 OECD countries were selected based on data availability. The balanced panel of 24 OECD member countries for the period 1990-2015 was used as the data set in the study. 24 OECD countries[1]. Although there are 37 OECD member countries, countries where data on all study variables can be obtained were included in the analysis.

In this study, GDP per capita (a proxy for economic growth), trade openness (imports (% of GDP) + exports (% of GDP)) and per capita CO_2 emissions (kt) are used as both dependent and explanatory variables. Control variables of labor force participation rate for ages 15-24 (total, %), combustible renewables and waste (% of total energy), real effective exchange rate index (2010=100), gross fixed capital formation, foreign direct investments (% of GDP), and energy consumption (kilogram oil equivalent per capita) are also included in the study models. In the literature, the studies show that there are mutual relationship between economic growth, trade openness and environmental pollution (Hayaloğlu, 2020), there are causal relations among carbon emissions, economic growth, energy consumption (Bozkurt and Akan, 2014; Mercan and Karakaya, 2015), there are mutual relationship between economic growth and trade openness (Shahbaz et. al., 2013; Ben Aissa et al., 2014), there are mutual relationship between environmental pollution and economic growth (Omri et al., 2014; Saidi and Hammami, 2017). The mutual relationships between economic growth, environmental pollution and trade openness mutually affect each other (Hayaloğlu, 2020: 302). Since the variables are mutually affect each other, considering the models based on the variables separately will cause the parameter estimates to be biased.

All data comes from the database of World Bank (WDI, 2023). Natural logarithms of all study variables were used in the analyses. Following Hayaloğlu (2020, p.302), the model structures are as follows:

$$GDP = f(TRADE,\ CO2,\ GCF,\ LABOR) \quad (3)$$

$$CO2 = f(GDP,\ TRADE,\ ENERGY,\ CRW) \quad (4)$$

$$TRADE = f(GDP,\ CO2,\ FDI,\ REERI) \quad (5)$$

where GDP, TRADE, CO_2, GCF, LABOR, ENERGY, CRW, FDI and REERI stand for economic growth, trade openness, carbon emissions, gross fixed capital formation, labor force for ages 15-24, energy consumption, combustible renewables

[1] Australia, Austria, Belgium, Canada, Switzerland, Chile, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Italy, Japan, Korea, Mexico, Netherlands, Norway, New Zealand, Portugal, Sweden, United States.

and waste, foreign direct investments, real effective exchange rate index, respectively.

As three structural equations and nine variables, the system of simultaneous equations to be estimated in practice is as follows.

$$LGDP_{it} = \alpha_0 + \alpha_1 LTRADE_{it} + \alpha_2 LCO2_{it} + \alpha_3 LGCF_{it} + \alpha_4 LLABOR_{it} + U_{1it} \quad (6)$$

$$LCO2_{it} = \beta_0 + \beta_1 LGDP_{it} + \beta_2 LTRADE_{it} + \beta_3 LENERGY_{it} + \beta_4 LCRW_{it} + U_{2it} \quad (7)$$

$$LTRADE_{it} = \gamma_0 + \gamma_1 LGDP_{it} + \gamma_2 LCO2_{it} + \gamma_3 LFDI_{it} + \gamma_4 LREERI_{it} + U_{3it} \quad (8)$$

In Eq. (6), (7) and (8), L indicates that the natural logarithm of the relevant variable is taken. Here t is for time dimension and i is for countries indication and, $\alpha_1,\ \alpha_2,\ \alpha_3,\ \alpha_4,\ \ \beta_1,\ \beta_2,\ \beta_3,\ \beta_4$ and $\gamma_1,\ \gamma_2,\ \gamma_3,\ \gamma_4$ are regression coefficients, $\alpha_0,\ \beta_0,\ \gamma_0$ are the constant terms and U stands for error term ($t = 1,...,T = 26,\ \ i = 1,...,N = 24$). For Eq. (6) the null hypothesis is $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$, for Eq. (7) the null hypothesis is $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$, and for Eq. (8) the null hypothesis is $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$. These hypotheses are tested employing the Wald chi^2 statistic. In the simultaneous equation models (6), (7) and (8), LGDP, LTRADE and LCO_2 are three endogenous variables and, LGCF, LLABOR, LENERGY, LCRW, LFDI and LREERI are six exogenous variables.

4. Results

4.1. Preliminary Results

Some preliminary tests were conducted for each statistical model to check the regression assumptions with panel data. Necessary conditions for the identifiability of a structural equation are order and rank condition. For the order condition of definability, the number of variables excluded from the equation is at least equal to the number of structural equations minus one.

A sufficient and necessary condition is rank condition for the equation to be determined (Koopmans, 1949, p.136). Order requirement is calculated with the formulation K-m≥G-1 where K and G total number of total number of exogenous and endogenous variables, respectively. exogenous variables in the equation examined number is m (Koopmans, 1949; retrieved from Özkurt, 2015, p.50). For each model (4), (5) and (6) K=6, G=3, m=2 and K-m=6-2=4>G-1=3-1=2. Since K-m>G-1 for all three equations in the system. It is concluded that there is over determination according to the order condition (Maddala, 2001; retrieved from Özkurt, 2015, p.51). Thus, the order condition for determination was met in all equations in the equation system. The rank condition is also examined in the

equation system (Şükrüoğlu, 2018, p.138). Eq. (6), (7) and (8) can be written in the form as follow:

$$LGDP_{it} - \alpha_0 - \alpha_1 LTRADE_{it} - \alpha_2 LCO2_{it} - \alpha_3 LGCF_{it} - \alpha_4 LLABOR_{it} = U_{1it} \quad (9)$$

$$LCO2_{it} - \beta_0 - \beta_1 LGDP_{it} - \beta_2 LTRADE_{it} - \beta_3 LENERGY_{it} - \beta_4 LCRW_{it} = U_{2it} \quad (10)$$

$$LTRADE_{it} - \gamma_0 - \gamma_1 LGDP_{it} - \gamma_2 LCO2_{it} - \gamma_3 LFDI_{it} - \gamma_4 LREERI_{it} = U_{3it} \quad (11)$$

According to the coefficients in Eq. (9), Eq. (10) and Eq. (11), the rank table is created as in Table 1.

Table 1: Rank Condition Analysis

Equation	1	LGDP	LCO_2	LTRADE	LGCF	LLABOR	LENERGY	LCRW	LFDI	LREERI
Eq. (9)	$-\alpha_0$	1	$-\alpha_1$	$-\alpha_2$	$-\alpha_3$	$-\alpha_4$	0	0	0	0
Eq. (10)	$-\beta_0$	$-\beta_1$	$-\beta_2$	0	0	0	$-\beta_3$	$-\beta_4$	0	0
Eq. (11)	$-\gamma_0$	$-\gamma_1$	0	$-\gamma_2$	0	0	0	0	$-\gamma_3$	$-\gamma_4$

In Table 1, coefficients are zero for the variables not included in Eq. 9. The coefficients of the Eq. 10 and Eq. 11 under the columns where the 1st column has a zero value are the matrix to be examined in determining the rank of Eq. 9 (Şükrüoğlu, 2018, p.146-148). Accordingly, the Eq. 9 rank condition matrix is determined as follows.

$$A_1 = \begin{bmatrix} -\beta_3 & -\beta_4 & 0 & 0 \\ 0 & 0 & -\gamma_3 & -\gamma_4 \end{bmatrix} \quad rank(A_1) = 2$$

Ranks with a similar structure are determined for Eq. (10) and Eq. (11). For these equations, rank value is also equal to 2. Since $rank(A_1) = rank(A_2) = rank(A_3) = 2 \geq G - 1 = 3 - 1$ is valid for all equations, all equations are determined according to the rank condition (Gujarati and Porter, 2009, p. 702).

Order and rank conditions are met for both models. Therefore, the simultaneous panel data model system will be estimated with the two-stage error components least squares method (Özkurt, 2015, p.53). In panel data analysis, it is investigated whether there is a cross-sectional dependence between the series. This dependence between series is performed with the Breusch-Pagan (1980) LM (Breusch-Pagan LM) test when time dimension is higher than cross-sectional dimension ($T > N$) (Özkurt, 2015, p. 55). In this study (N=24 and T=26). Breusch-Pagan LM test results for all three models are shown in Table 2. The null hypothesis for Breusch-

Pagan LM test is that there is no cross-sectional dependence. It is seen from Table 2 that significance values (p) are less than 0.01 significant level thus the null hypothesis for all equations are rejected. Cross-sectional dependency was determinend between the countries.

Table 2: Breusch-Pagan LM Test of Independence

Eq. (4)	$Chi^2(276) = 1443.237$	p = 0.0000
Eq. (5)	$Chi^2(276) = 1948.360$	p = 0.0000
Eq. (6)	$Chi^2(276) = 1766.778$	p = 0.0000

In panel data simultaneous-equation models, for each variable unit root tests must be performed before constituting a model. Panel unit root test of Pesaran's CADF takes cross-sectional dependencey into account (Yerdelen Tatoğlu, 2012, p. 223). In this regard, Pesaran's CADF tests have been employed for unit roots in the variables. The null hypothesis for Pesaran's CADF test is that there is unit root, the variable is not stationary in its level. This point out that for all variables the null hypothesis of a unit root is rejected. All these variables need to be first-differenced before conducting the analysis. CADF test results applied after first difference for all non-stationary variables are given in Table 3. Since stationarity is achieved at the first differences of the variables, the letter D is added to the beginning of the variables to indicate that the first difference is conducted. It is seen from Table 4 that for all variables the null hypotheses are rejected ($p<0.10$)

Table 3: Pesaran's CADF panel unit root test

Variable	t-bar	Z[t-bar]	p	The order of integration
LGDP	-2.296	-2.729	0.003	I(1)
LCO_2	-2.523	-3.862	0.000	I(1)
LTRADE	-2.025	-1.374	0.085	I(1)
LGCF	-2.261	2.556	0.005	I(1)
LLABOR	-2.202	-2.258	0.012	I(1)
LENERGY	-2.179	-2.145	0.016	I(1)
LCRW	-3.688	-9.689	0.000	I(1)
LFDI	-2.472	-3.609	0.000	I(1)
LREERI	-2.073	-1.615	0.053	I(1)

I(1): Stationary at 1st difference

4.2. Panel Data Simultaneous-Equation Models Results

It is widely believed in the literature that trade openness, CO_2 emissions and economic growth variables mutually affect each other. Therefore, it can be said that these variables are endogenous variables (Hayaloğlu, 2020, p.307). Parameter estimates for the simultaneous equation system were estimated with the error components two-stage least squares method. It was concluded from the results of Hausman test, that the EC2SLS estimator (two-stage error combinations) was the most appropriate method for all three equations.

The null hypotheses in this study for simultaneous-equation models are as follow:

$H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$,
$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$, and $H_0 : \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$.

These joint null hypotheses are tested using the Wald chi^2 statistic. According to the results of Wald chi^2 statistics given in Table 4, it can be concluded that all study hypotheses were rejected at the 1% significance level ($p<0.01$). It can be concluded that the simultaneous-equation models were established as statistically significant. When the R^2 value of the models are compared, it is seen that the determination coefficient value of the second model ($R^2 = 0.555$) is higher than the other two models.

Table 4: Two-stage least squares method parameter estimates of the simultaneous equation model of energy consumption, CO_2 emissions and GDP

	Dependent Variable		
	LGDP	LCO_2	LTRADE
Constant	-5.116076*** (-11.66)	3.995176*** (13.00)	7.304029*** (20.08)
LGDP	_	0.1290673*** (11.65)	0.3426642*** (26.52)
LCO_2	-0.2051197*** (-6.60)	_	-0.1710108** (-6.06)
LTRADE	0.088181** (2.20)	0.0052422 (0.16)	_
LGCF	0.7795563*** (65.80)	_	_
LLABOR	-0.6359844*** (-11.63)	_	_
LENERGY	_	0.8475618*** (23.09)	_
LCRW	_	-0.19007*** (11.21)	_

LFDI	_	_	0.063551*** (4.26)
LREERI	_	_	-1.032895*** -21.7)
R^2 =	0.1616	0.555	0.3886
Wald chi2(4) =	10516.32***	757.22***	1090.93***
Hausman test chi2(4) =	4.48	0.44	2.01

***, ** and ** Denotes significance at 0.01, 0.05 and 0.10 level or better for two-tailed test, respectively.
Note: z values appear in parentheses below the coefficients

From the findings Eq. (6), Eq. (7) and Eq. (8) can be written as follow:

$$LGDP = - 5.116076 - 0.2051197LCO_2 + 0.088181LTRADE + 0.7795563LGCF - 0.6359844LLABOR \quad (12)$$

$$LCO_2 = 3.995176 + 0.1290673LGDP + 0.0052422LTRADE + 0.8475618LENERGY - 0.19007LCRW \quad (13)$$

$$LTRADE = 7.304029 + 0.3426642LGDP - 0.1710108LCO_2 + 0.063551LFDI - 1.032895LREERI \quad (14)$$

The findings are evaluated when all study models are analyzed simultaneously. Since all three models were considered interrelated, simultaneous analysis was performed. Specifically, Table 4 shows that CO_2 emissions, gross fixed capital formation, trade openness and labor force for ages 15-24 have significant effects on economic growth at 5% significance level. Trade openness and gross fixed capital formation have positive impacts on economic growth, whereas the CO_2 emissions and labor force participation rate for ages 15-24 have a negative impact. Implying that a one-unit increase in trade openness increases economic growth by approximately 0.09 units, broadly speaking, for the panel, this means that higher trade openness is a positive indicator of economic growth. Trade openness promotes economic growth. The economic growth negatively effected by CO_2 emissions. A one-unit increase in CO_2 emissions decreases economic growth by approximately 0.205 units.

Energy consumption and economic growth have positively effect CO_2 emissions at the 1% significant level. Economic growth is found to be determinant of CO_2 emissions and one-unit increase in GDP increases CO_2 emissions by 0.129 units. CO_2 emissions has not significantly effected by trade openness. CO_2 emissions are negatively and significantly effected by combustible renewables and waste at the 1% level. The findings indicate that combustible renewables and waste are observed to improve the environment.

Since the effects of the all explanatory and control variables in the model (11) are significant at the 5% level, therefore all variables in the model (11) are determinants of trade openness. Trade openness is positively effected by foreign direct investments and economic growth, and negatively effected by CO_2 emissions and real effective exchange. Any increase in the GDP by one unit generates an increase in trade by 0.34 units. Economic growth increases trade and it is a driving force for trade openness. It is found that CO_2 emissions has negative and significant effect on trade openness at the 5% significant level. A one-unit increase in CO_2 emissions decreases trade by 0.17.

5. Conclusion

This study investigated the mutual impact between trade openness, CO_2 emissions, and economic growth over the period 1990-2015 in a balanced panel of 24 OECD countries. Empirical results showed that economic growth is positively affected by trade openness. It was also found that economic growth is negatively and significantly affected by CO_2 emissions. Additionally, CO_2 emissions are positively and significantly influenced by economic growth. However, trade openness does not drive CO_2 emissions, likely due to the effective use of clean technologies in transportation.

The findings reveal that economic growth has a positive and significant impact on trade openness. Economic growth and trade openness mutually affect each other positively. It was determined that CO_2 emissions have a negative and significant effect on trade openness, possibly because it is not desirable to import food from countries with high CO_2 emissions.

The study highlights the necessity for environmental policies that ensure economic growth while reducing CO_2 emissions. Trade openness expands the economy, and economic progress increases trade openness. Export promotion initiatives can significantly boost economic growth, enabling the country to compete more effectively in the global market. Policies that foster international trade dialogues are recommended.

5.1. Impact of Trade Openness on Economic Growth

The study demonstrates that economic growth in the 24 OECD countries analyzed is positively affected by trade openness. This indicates that increased trade activities and reduced trade barriers contribute to the economic development of these countries. The findings align with previous empirical studies by Utkulu and Kahyaoğlu (2005), Yapraklı (2011), Mercan and Göçer (2014), Özcan, Özmen and Özcan (2018), Dam and Bakkalcı (2018), Hayaloğlu (2020), İdris, Yusop, Habibullah and Chin (2018), Kesap and Sandalcılar (2021), Yenipazarlı et al. (2022), and Aktop (2023), which similarly report a positive relationship between trade openness and economic growth.

5.2. Impact of CO_2 Emissions on Economic Growth

Economic growth is found to be negatively and significantly affected by CO_2 emissions. This suggests that higher levels of CO_2 emissions hinder economic growth, likely due to the adverse effects of environmental degradation on productivity and health. This conclusion supports the findings of Bozkurt and Akan (2014) and Azam et al. (2016), who also observed a negative impact of CO_2 emissions on economic growth.

5.3. Impact of Economic Growth on CO_2 Emissions

The study reveals that CO_2 emissions are positively and significantly influenced by economic growth. As economies grow, industrial activities and energy consumption typically increase, leading to higher CO_2 emissions. This relationship is consistent with findings from Choi et al. (2010), Ohlan (2015), Tariq et al. (2018), Majeed et al. (2022), and Saboori et al. (2014), who also identified a positive correlation between economic growth and CO_2 emissions.

5.4. Impact of Trade Openness on CO_2 Emissions

The empirical results indicate that trade openness does not significantly drive CO_2 emissions in the studied countries. This outcome may be attributed to the effective use of clean technologies in transportation and production processes. Similar results are reported by Ertugrul et al. (2016), who found that trade openness had no significant impact on environmental degradation in Thailand, Brazil, and Korea, and Thuy and Nguyen (2022), who concluded that trade openness does not lead to environmental degradation in developing countries.

5.5. Mutual Impact of Economic Growth and Trade Openness

Economic growth has a positive and significant impact on trade openness, suggesting that as economies expand, they tend to engage more in international trade. Conversely, trade openness also fosters economic growth. This mutual positive relationship is supported by previous studies by Kaushal and Pathak (2015), Ozcan et al. (2018), Idrıs et al. (2018), and Hayaloğlu (2020).

5.6. Impact of CO_2 Emissions on Trade Openness

The study finds that CO_2 emissions have a negative and significant effect on trade openness. High levels of CO_2 emissions may deter countries from engaging in trade, particularly in importing food and other goods from countries with poor environmental standards. While there is limited literature on the impact of CO_2 emissions on trade openness, Hayaloğlu (2020) found that CO_2 emissions did not significantly affect trade openness.

We can explain the study's findings more specifically by examining each country individually. Below are examples of how the findings can be explained for some OECD countries.

5.6.1. United States

Economic Growth and Trade Openness: The US has a large economy and extensive trade networks. Trade openness supports the US's economic growth because international trade facilitates technology transfer, investment, and innovation. CO_2 Emissions and Economic Growth: High CO_2 emissions can negatively impact economic growth by causing environmental pollution and health issues. The US can mitigate these effects by tightening environmental protection policies. Trade Openness and CO_2 Emissions: In the US, the lack of an increase in CO_2 emissions due to trade openness can be attributed to policies promoting the use of clean energy and green technologies.

5.6.2. Germany

Economic Growth and Trade Openness: Germany has an export-oriented economy, so trade openness has a significant impact on economic growth. Germany's strong industrial sector promotes global trade. CO_2 Emissions and Economic Growth: Germany aims to reduce CO_2 emissions and achieve sustainable economic growth by making significant investments in renewable energy sources. Trade Openness and CO_2 Emissions: Germany prevents trade openness from increasing CO_2 emissions through the use of environmentally friendly production techniques and clean energy.

5.6.3. Japan

Economic Growth and Trade Openness: Japan is a key player in global trade with its technological innovations and high-quality products. Trade openness significantly contributes to Japan's economic growth. CO_2 Emissions and Economic Growth: High CO_2 emissions can negatively impact economic growth in Japan by causing environmental and health issues. Japan strives to mitigate these effects by improving energy efficiency. Trade Openness and CO_2 Emissions: Japan ensures that trade openness does not increase CO_2 emissions through advanced technology and environmentally friendly policies.

5.6.4. France

Economic Growth and Trade Openness: France plays an active role in international trade with its extensive agriculture and industrial sectors. Trade openness promotes economic growth. CO_2 Emissions and Economic Growth: France relies heavily on nuclear energy to keep CO_2 emissions low, ensuring sustainable economic growth. Trade Openness and CO_2 Emissions: France prevents trade openness from

increasing CO_2 emissions through environmentally friendly policies and supports this with the use of clean energy.

5.6.5. Canada

Economic Growth and Trade Openness: Canada's economy is based on natural resources and energy exports. Trade openness significantly contributes to Canada's economic growth. CO_2 Emissions and Economic Growth: Despite intensive use of fossil fuels, Canada aims to reduce CO_2 emissions by transitioning to renewable energy sources, thereby minimizing the adverse effects on economic growth. Trade Openness and CO_2 Emissions: Canada prevents trade openness from increasing CO_2 emissions by adopting clean technologies in the energy sector.

5.7. Policy Implications and Recommendations

The findings suggest several policy implications:

1) Promoting Trade Openness: Countries should continue to reduce trade barriers and promote export activities to drive economic growth. Enhanced trade policies can help countries compete more effectively on the global stage.

2) Adopting Green Energy: To ensure sustainable economic growth, countries need to transition to green energy sources. This shift can mitigate the adverse effects of CO_2 emissions on the environment and public health.

3) Environmental Policies: It is crucial to design and implement environmental policies that balance economic growth and CO_2 emission reduction. Such policies can help achieve sustainable development without compromising environmental quality.

4) Reducing CO_2 Emissions: Given the negative impact of CO_2 emissions on economic growth and trade openness, efforts should be made to lower emissions. This can be achieved through stricter environmental regulations and investment in clean technologies.

Overall, the study underscores the importance of trade openness in driving economic growth while highlighting the need for sustainable practices to manage the environmental impact of economic activities.

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