Analyzing the Impact of Export Share to the United States and China on Carbon Dioxide Emissions

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Abstract

This paper examines the relationship between export share and carbon emissions. In particular, this study investigates whether exporting to different countries, such as the United States and China, leads to distinct environmental impacts. It also analyzes the influence of COVID-19 and climate change negotiations, such as the Paris Agreement, on carbon emissions, using data from 52 countries spanning 2003 to 2022 and controlling for variables including GDP per capita, export-to-GDP ratio, and agricultural land. The analysis employs fixed effects and System Generalized Method of Moments (system GMM) estimation techniques to address unobserved heterogeneity and potential endogeneity. The findings indicate a meaningful relationship between export share and carbon dioxide emissions. Specifically, a 1% increase in export share to the United States is associated with a 0.0021% decrease in per capita carbon emissions ($p < 0.10$), whereas a 1% increase in exports to China corresponds to a 0.0036% increase in emissions ($p < 0.10$). Furthermore, the analysis demonstrates that COVID-19 played a role in reducing emissions during the pandemic. However, the Paris Agreement has not yielded the anticipated reductions. Nonetheless, country-specific factors, including those related to climate change negotiations, continue contributing to variation in emissions outcomes.

Keywords: 1) Carbon Emissions 2) Export Share 3) International Trade 4) Climate Policy 5) Fixed Effects

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Introduction

International trade plays a crucial role in shaping global carbon dioxide (CO_2) emissions. As countries engage in export-driven economic growth, the environmental consequences of trade have become a critical area of study. While exports are essential for economic development, their impact on carbon emissions varies depending on the destination country, production processes, and regulatory frameworks. This study explores how export destinations, particularly China and the United States, influence carbon emissions in exporting countries.

Carbon dioxide emissions have been rising consistently over the past two decades, largely due to fossil fuel consumption. Many studies have focused on the impact of domestic energy policies, industrialization, and economic growth on emissions. However, the role of international trade—specifically, the effect of export destinations on carbon emissions remains underexplored. Understanding how different trade relationships contribute to global carbon emissions is essential for shaping effective climate policies and trade agreement

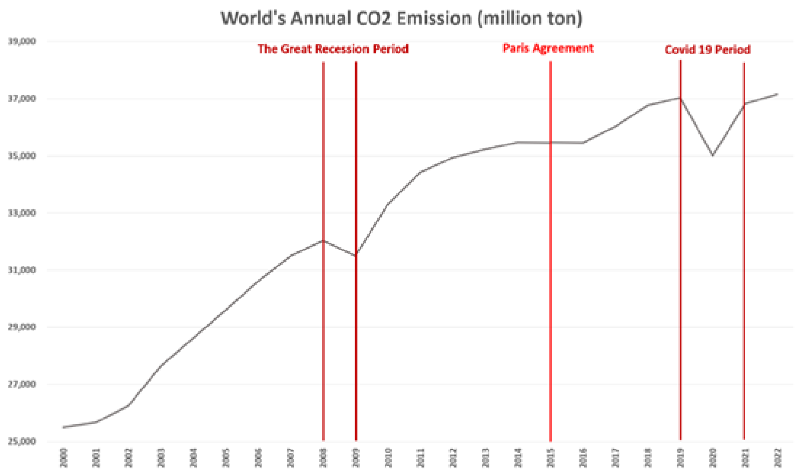

Figure 1 World’s Annual CO2 Emission (Data source from Our World in Data)

Total carbon dioxide emissions have been increasing every year since 2000. Figure 1 illustrates the annual global carbon dioxide emissions. However, there have been periods of significant decline. For example, the 2008–2009 global recession disrupted industries worldwide, leading to factory shutdowns. GDP declined by 4.3 percent, and unemployment neared 10 percent—a crisis known as "The Great Recession" (HISTORY, 2017). A similar pattern occurred during the COVID-19 pandemic from 2019 to 2021, when lockdowns forced businesses to halt operations. In both cases, emission reductions were indirect results of economic slowdowns, not deliberate efforts. Consequently, emissions soon returned to pre-crisis levels, highlighting the need for structural changes for lasting impact.

A critical point to consider is the Paris Agreement, an international treaty enacted in 2015 to combat climate change. Its main goal is to limit the global temperature increase to 1.5°C (United Nations, n.d.). While the agreement lacks strict enforcement, it reflects a collective commitment to reducing greenhouse gas emissions. However, as shown in Figure 1, it has not led to a significant drop in carbon emissions. Instead, global emissions have continued to rise

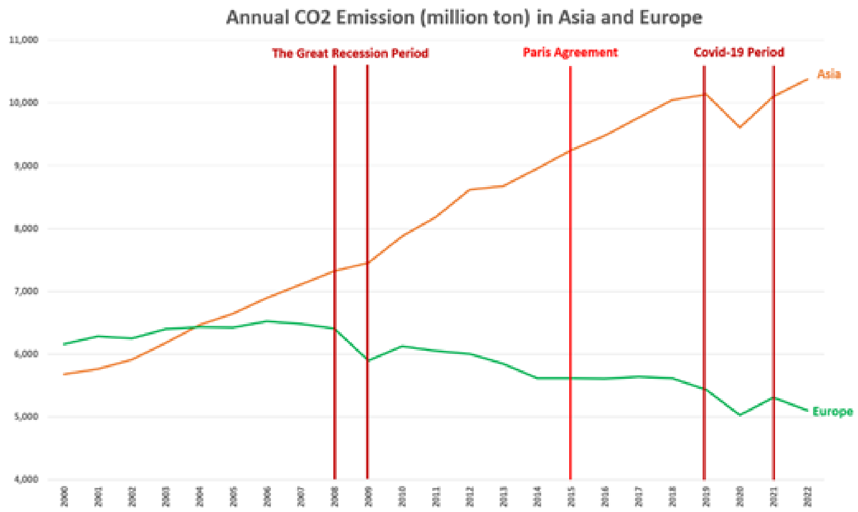

Figure 2 Annual CO2 Emission in Asia and Europe (Data source from Our World in Data)

Regional differences in carbon emissions also provide important insights. Figure 2 further explores the variation in CO_2 emissions between Asia and Europe. Asia increases carbon emissions annually, remaining a large emitter even without China. In contrast, Europe has successfully reduced emissions, highlighting potential differences in environmental policies, energy consumption patterns, and industrial activities. Moreover, it shows that the impact of global economic events differs across regions. In Europe, the economic downturn led to a sharp decline in carbon emissions, while emissions in Asia remained largely unaffected. This suggests economic structure plays a major role in shaping carbon footprints. Similarly, the Paris Agreement appears to have been more effective in Europe, compared to Asia where emissions continue to rise despite international climate commitments. This raises an important question: If countries in both regions have committed to the agreement, why are the outcomes so different?

Exports and carbon dioxide emissions are closely linked, depending on the characteristics of a country's economy and products, including the energy intensity of production, the emissions profile of exported goods, and transportation logistics. Thus, exports have both direct and indirect effects on carbon emissions (Dissanayake, et al., 2023, pp. 1-23). Research suggests that export destinations with stricter environmental regulations, such as the United States, may encourage cleaner production practices, while exports to countries with weaker environmental policies, such as China, may lead to increased emissions.

China has historically been a major export market for many countries. However, in recent years, this trend has shifted. Currently, several countries export more to the United States, this may be due to reasons, such as the trade war between China and the U.S., the noteworthy progress of the U.S. economy, and the export policy of each country. These several reasons have supported many countries in exporting more goods to the U.S.

Specifically, the US-China trade war has changed export patterns. Research indicates that companies focusing on the Chinese market experienced lower revenues, whereas those targeting the U.S. market saw higher revenues. This shift also made Chinese goods more expensive in the U.S., prompting many countries to redirect their exports to the U.S. market and reduce their dependence on China (Fajgelbaum, et al., 2023, pp. 1-12; Benguria, 2023, pp. 20-32). The redirection of exports to the U.S. raises an important question: does exporting to environmentally stringent markets result in lower carbon emissions? Conversely, does trade with countries with lenient environmental policies contribute to higher emissions? This paper investigates these questions by analyzing the impact of export destinations on carbon emissions.

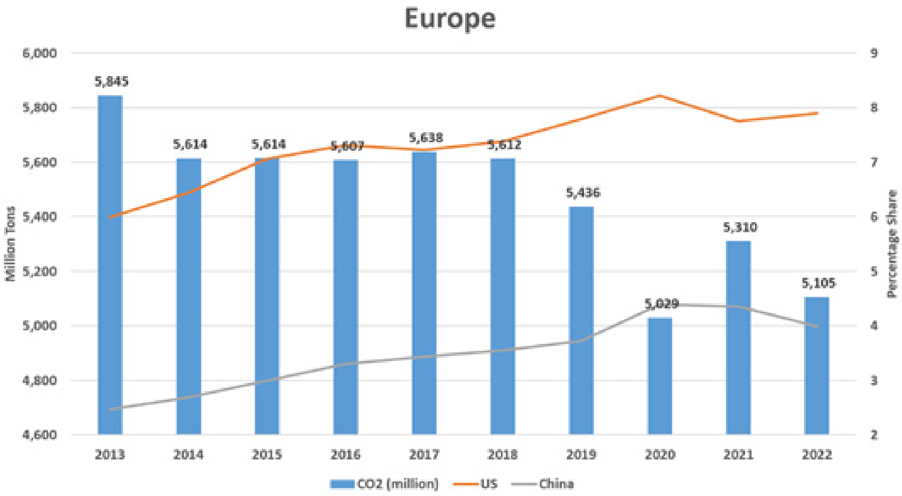

Figure 3 The relationship between China and U.S. export share and carbon emissions in Europe (Data source from World Integrated Trade Solution, Our World in Data)

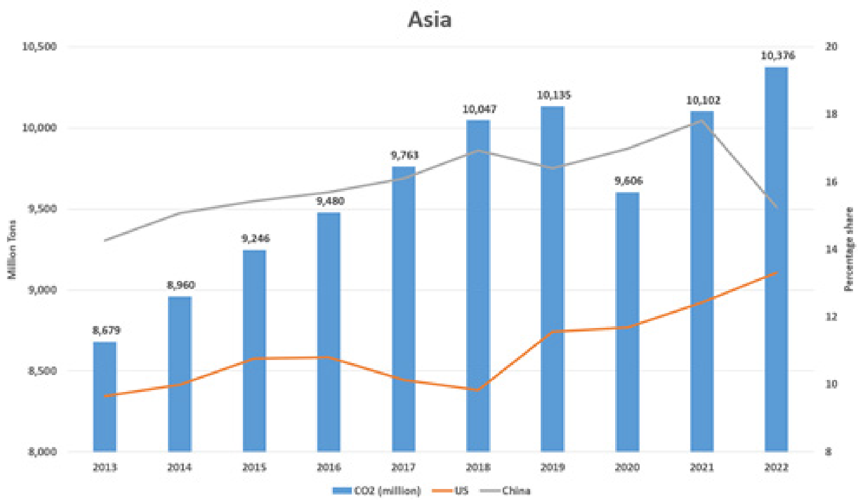

Figure 4 The relationship between China and U.S. export share and carbon emissions in Asia (Data source from World Integrated Trade Solution, Our World in Data)

Figures 3 and 4 illustrate the relationship between export shares to China and the U.S. and carbon dioxide emissions in Europe and Asia, respectively. Figure 3 shows that, despite an increasing export share to both China and the U.S. from 2013 to 2022, Europe's carbon emissions have steadily declined. This suggests that exporting to the U.S. may have encouraged European countries to adopt cleaner production methods. Conversely, Figure 4 shows a different trend for Asia, where carbon emissions have continued to rise. In Asia, exports to China account for approximately 10-18% of total trade, while exports to the U.S. range from 10-13%. This pattern reinforces the hypothesis that exporting to China is associated with higher emissions while exporting to the United States is linked to lower emissions.

This study aims to examine whether export share to different destination countries (e.g., the United States and China) affects carbon emissions in exporting nations. Using data from 52 countries over 20 years, the analysis explores whether trading with environmentally conscious nations leads to lower emissions, while exports to high-emission economies contribute to increased carbon output.

The United States and China were selected as focal export destinations due to their contrasting environmental standards and influence in global trade. The U.S. maintains relatively stringent environmental regulations and has introduced import-related climate policies such as carbon disclosure requirements and sustainable sourcing standards, encouraging exporters to adopt cleaner practices. In contrast, China's rapid industrial growth has often been supported by more lenient environmental enforcement, particularly in heavy manufacturing sectors. These structural differences make the two countries ideal for examining how export destinations with differing environmental expectations influence the carbon intensity of trade.

The findings provide insights into the intersection of international trade and environmental policy, offering guidance for policymakers seeking to balance economic growth with sustainability.

Literature Review

Carbon dioxide emissions have received growing academic attention, particularly in relation to exports. Al-Mulali and Sheau-Ting (2014, pp. 484–498) found a positive link between exports and emissions in countries with high export-to-GDP ratios and developed economies. Their study of 189 countries (1990–2011) shows that exports significantly raise emissions in large export-oriented and advanced nations, but the effect is minimal in less export-dependent or developing countries. However, more recent studies show a different perspective. Dissanayake, et al. (2023, pp. 1-23) found that in 152 countries from 1990 to 2019, exports significantly affect emissions, especially in developing economies. While exports in these countries increase emissions, developed countries, which often export by using renewable energy, help mitigate them. Additionally, transport mode and distance also influence pollution levels.

Further complicating this relationship, Gao, et al. (2020, pp. 1-8) noted that while exports raise carbon emissions, they also support economic growth. Thus, countries must balance emissions reduction with development goals. The study presents two views: exports can reduce emissions—such as during the U.S.–China trade war—or increase them through production and transport. These outcomes vary by region and time, influenced by differing economic structures and behaviors.

At the firm level, Richter and Schiersch (2016, pp. 373–391) found that exporting companies tend to have lower carbon emissions than non-exporters. Using data from German manufacturing firms (2003–2011), they observed that while export intensity increased emissions by 0.21%, export-driven firms also generated higher revenues. As a result, these firms produced fewer goods to meet revenue targets, leading to lower overall emissions. While the country-level research suggests a general increase in carbon emissions with exports, firm-level data presents a different picture, especially regarding efficiency and economic returns.

Next, Shahzad, Ferraz and Dogan (2020, pp. 124–146) examined the relationship between export product diversification and CO_2 emissions. Analyzing data from 63 countries from 1971 to 2014, they utilized the Chow test, fixed effects, and System Generalized Method of Moments (system GMM) to explore the diversification-carbon nexus. Their findings suggest that product diversification in exports negatively impacts carbon emissions, and this aligns with the earlier argument by Dissanayake, et al. (2023, pp. 1-23) regarding how export composition (e.g., renewable energy vs. fossil fuels) influences environmental outcomes. Moreover, the selection of export management policies in developing and developed countries should be tailored to their unique economic and ecological conditions.

In addition to export-related variables, previous research has identified several control variables that influence carbon dioxide emissions. GDP per capita is frequently used to account for economic development levels and energy consumption patterns, as seen in Al-Mulali and Sheau-Ting (2014, pp. 484–498) and Gao, et al. (2020, pp. 1-8). Export-to-GDP ratio captures trade openness, which has also been shown to correlate with emission intensity (Dissanayake, et al., 2023, pp. 1-23). Agricultural land, while less frequently used, has been included in some studies to examine the role of land use in emission outcomes. Agricultural land may act as either a source or sink of emissions, depending on farming practices, mechanization, and fertilizer use. For instance, Gao, et al. (2020, pp. 1-8) emphasize the dual role of agriculture in contributing to or mitigating emissions. Although industrial and transportation factors are acknowledged as major contributors to emissions, many cross-country panel studies omit them due to data availability, lack of consistent time-series information across countries, or multicollinearity with GDP-related variables. As such, this study follows prior literature in selecting control variables that are widely available and have demonstrated relevance in empirical emissions research.

Research Gaps and Contribution

While existing research covers the issue of export intensity, energy consumption, firm behavior, and product diversity, the impact of export destination on carbon dioxide emissions still needs to be explored. Existing studies focus primarily on the total volume of exports but do not differentiate between exporting to high-emission versus low-emission countries. This study fills this gap by analyzing how the selection of export destinations (e.g., China vs. the U.S.) influences CO_2 emissions across exporting nations. This paper makes three key contributions:

1. It shifts the focus from export intensity to export destination, revealing whether exporting to countries with stricter environmental policies leads to lower emissions.

2. It incorporates a panel dataset spanning 52 countries over 20 years, controlling external factors such as the Paris Agreement and the COVID-19 pandemic, to assess how global events affect trade-emission dynamics.

3. It employs Fixed Effects and System GMM to address potential endogeneity issues, providing a robust methodology for evaluating the long-term effects of export on emissions.

Such differences may be based on environmental standards, regulations, trade relationships, and the economic conditions of importing countries. In addition, since the type of data to be used in the analysis is panel data covering 52 countries over two decades, the use of Fixed Effects and System GMM appears to be appropriate methodology for this research, consistent with the approach taken by Shahzad, Ferraz, and Dogan (2020, pp. 124–146).

Research Objectives

This study aims to examine the relationship between export share and carbon dioxide emissions, considering environmental policies and economic development levels.

1. Examine the impact of export share to different destination countries (e.g., the United States and China) on CO_2 emissions in exporting nations.

2. Investigate whether exporting to environmentally stringent countries, such as the United States, is associated with lower CO_2 emissions in the exporting country.

3. Assess whether exporting to environmentally lenient countries, such as China, is linked to higher CO_2 emissions in the exporting country.

4. Evaluate the influence of external factors, including the COVID-19 pandemic and the Paris Agreement, on the relationship between export share and CO_2 emissions.

The findings will provide insights for policymakers to balance trade growth and environmental sustainability.

Methods

Data and Sample Selection

This study employs an annual panel dataset spanning 52 countries from 2003 to 2022 to examine the impact of export destinations on carbon dioxide (CO2) emissions. The sample includes 52 countries selected based on three main criteria: (1) availability of consistent annual data for key variables (e.g., carbon emissions per capita, export-to-GDP ratio, export destinations) from 2003 to 2022,

(2) representation of both developed and developing countries across major regions (Asia, Europe, North America, etc.), and (3) diversity in trade patterns and environmental policy frameworks. Countries were drawn from publicly available databases such as Our World in Data, World Bank, and WITS (World Integrated Trade Solution). Nations with large data gaps or unreliable records were excluded.

The dataset incorporates key economic and environmental indicators, including carbon emissions per capita, export-to-GDP ratios, sectoral trade composition, and policy interventions such as the Paris Agreement and COVID-19 lockdowns. The inclusion of countries with varying levels of environmental stringency allows for a nuanced understanding of the relationship between international trade and carbon emissions.

Econometric Model Specification

To evaluate the impact of export destinations on carbon emissions, the study employs a three-stage econometric approach:

1. Baseline Estimation using Ordinary Least Squares (OLS): Provides an initial assessment of the relationship between carbon emissions and trade variables but does not account for potential endogeneity or unobserved heterogeneity.

2. Fixed Effects (FE) Regression: Controls of time-invariant country-specific characteristics, such as industrial composition and historical energy policies. It helps mitigate omitted variable bias from unobserved heterogeneity, ensuring that the estimated relationships reflect within-country variations rather than cross-country differences. However, FE models cannot fully address endogeneity concerns stemming from reverse causality between trade and emissions.

3. System Generalized Method of Moments (System GMM): Addresses potential endogeneity by instrumenting lagged values of trade variables to mitigate simultaneity bias. Second, this model can correct dynamic panel bias, ensuring robust estimates when emissions exhibit strong persistence over time. Last, System GMM accounts for autoregressive behavior in emissions, where past emissions influence current levels, improving causal inference.

By integrating these estimation techniques, the study ensures robustness and cross-validate results across multiple econometric specifications.

Empirical Model

After considering the data and model from the literature and analysis, the researcher created an equation to analyze the empirical results by considering carbon emissions per capita and the determinants of emissions that vary across time and countries, as shown in the equation below:

$$\begin{aligned} \ln CarbonPerCapita_{it} = {} & \beta_0 + \beta_1 * \ln CarbonPerCapita_{it-1} + \\ & \beta_2 * ParisAgreement_t + \beta_3 * Covid19_t + \\ & \beta_4 * \ln GDPperCapita_{it} + \\ & \beta_5 * ExportToGDP_{it} + \\ & \beta_6 * AgriculturalLand_{it} + \\ & \beta_7 * UnitedStates_{it} + \\ & \beta_8 * China_{it} + \epsilon \end{aligned} \quad (1)$$

Where:

$CarbonPerCapita_{it}$ = Annual $C0_2$ emissions per capita (log-transformed) for country i at year t (million ton)

$CarbonPerCapita_{it-1}$ = Lagged $C0_2$ emissions per capita (log-transformed) for country i at year t (million ton)

$ParisAgreement_t$ = Dummy variable for the Paris Agreement (2015 – 2022) at year t (equal to 1 for years after 2015 (post-Paris Agreement); 0 otherwise)

$Covid19_t$ = Dummy variable for the COVID-19 period (2019 – 2021) at year t (equal to 1 for years 2019–2021 (COVID-19 pandemic period); 0 otherwise)

$GDPperCapita_{it}$ = GDP per capita (log-transformed, PPP-adjusted) for country i at year t (USD)

$ExportToGDP_{it}$ = Total exports as a percentage of GDP for country i at year t (percent)

$AgriculturalLand_{it}$ = Share of agricultural land in total land area for country i at year t (percent)

$UnitedStates_{it}$ = Share of total export from country i directed to U.S. at year t (percent)

$China_{it}$ = Share of total export from country i directed to China at year t (percent)

The dependent variable is annual carbon emissions per capita rather than total yearly carbon emissions. This approach ensures fairness in comparability between countries, as different nations have different populations. Using carbon emissions per capita accounts for this difference, ensuring that the measurement reflects true emission intensity rather than aggregate output. Additionally, the variable is expressed in logarithmic form, allowing changes to be interpreted in percentage terms. This transformation facilitates easier interpretation of elasticities and allows for meaningful cross-country comparisons.

The lagged dependent variable, carbon emissions per capita, is included to capture persistence over time. Since emission patterns tend to follow historical trajectories, this variable is expected to have a positive relationship with carbon per capita, meaning that if countries emitted more carbon last year, they are likely to emit more in the following year. This lagged term is also logarithmic to reflect percentage changes rather than absolute differences.

Dummy variables for the Paris Agreement and COVID-19 are included to indicate periods that may have influenced carbon emissions per capita. As shown in Figure 1, COVID-19 had a negative impact on carbon emissions per capita due to the economic downturn. Regarding the Paris Agreement, although its direct impact cannot be determined from Figures 1 and 2, global efforts to combat climate change suggest that the agreement should have a negative relationship with the dependent variable. Note that the Great Recession is excluded. Unlike COVID-19, the Great Recession had an uneven impact on emissions across regions and industries. The financial crisis primarily affected financial markets rather than industrial emissions, making their inclusion less relevant for analyzing trade-driven environmental effects. Therefore, this study focuses on recent global policy events (Paris Agreement, COVID-19) with clearer links to carbon emissions.

GDP per capita is added to indicate the economic status of each country. This variable is in logarithmic form, which helps in interpreting changes in percentage terms rather than absolute values. The GDP per capita used in this study is based on purchasing power parity (PPP), which is more suitable for cross-country comparisons. This adjustment ensures that economic status is not directly influenced by exchange rate fluctuations, allowing for a more accurate comparison of living standards. However, the relationship between GDP and carbon emissions remains inconclusive. Some studies link higher GDP to increased emissions due to greater energy use and industrial activity, while others suggest that economic growth fosters cleaner technologies and energy efficiency. This debate underscores the complexity of the issue and the importance of considering factors like economic structure, energy policies, and technological progress.

The export-to-GDP ratio is another important variable. It measures the proportion of a country’s total economic output that comes from exports, providing insight into how dependent a country is on international trade. Al-Mulali and Sheau-Ting (2014, pp. 484–498) argued that there is a positive relationship between exports and carbon emissions, especially in countries where exports play a key role in the economy. This is because export-driven economies often rely heavily on manufacturing and industrial production, both of which contribute to higher carbon emissions due to resources and energy consumption.

Another key variable is agricultural land, which represents the percentage of a country’s total land area used for agriculture. Agricultural land is generally expected to have a negative relationship with carbon emissions. Traditional farming practices and the presence of green spaces may act as carbon sinks. However, agricultural land can also be a source of emissions, especially when characterized by mechanization, fertilizer use, and deforestation. As Gao, et al. (2020, pp. 1-8) point out, the relationship between agricultural land and carbon emissions can vary by region —intensive and industrialized agriculture may lead to higher emissions. Therefore, while agricultural land is expected to reduce emissions, its actual impact depends on how it is utilized and managed within different regions.

The last two variables entered in the model are the most important ones in this study, the export share of the United States and China. These variables represent the percentage of each country's exports that are directed to the United States and China. They are critical because they capture how major trading partners influence carbon emissions in each country. Although the relationship between these two variables and carbon emissions per capita may vary depending on each country's economic structure and its specific trade dynamics with these destination countries, the analysis indicates clear patterns. It is expected that exports to the United States should have a negative relationship with emissions, potentially due to stricter environmental standards or a greater demand for cleaner production processes by U.S. importers. In contrast, exports to China are expected to have a positive relationship with carbon dioxide emissions, reflecting differences in production practices or regulatory frameworks. These insights provide a better understanding of how the destination of exports can impact environmental outcomes, making these variables central to the study's analysis.

Results

This section estimates the empirical model based on equation (1) using different estimation techniques. The study examines whether the magnitude of a country's export share affects its carbon emissions. The regression focuses on the percentage change in carbon emissions per capita as a function of the previous year's per capita carbon emissions, the Paris Agreement, COVID-19, GDP per capita, the export-to-GDP ratio, agricultural land, export share of the United States and China.

Table 1 World's Regression results of different estimation techniques

VARIABLES	Models		
	OLS	Fixed effects	System GMM
Ln Carbon per Capita (t-1)	0.979*** (0.00635)	0.886*** (0.0348)	0.967*** (0.0210)
Paris Agreement	0.0129* (0.00697)	0.0146 (0.0105)	0.00805 (0.00880)
COVID-19	-0.0241*** (0.00867)	-0.0223*** (0.00763)	-0.0209** (0.00861)
Ln GDP per Capita (PPP)	-0.0123* (0.00737)	-0.0282 (0.0254)	-0.000958 (0.0205)
Export to GDP	0.000150 (9.67e-05)	0.000585* (0.000343)	0.000182 (0.000124)
Agricultural land	-0.00429*** (0.00139)	0.00771*** (0.00220)	-0.000346 (0.000273)
United States	-0.000260* (0.000153)	-0.00208* (0.00105)	-0.000370 (0.000321)
China	0.000924*** (0.000280)	0.00357 (0.00228)	0.00111* (0.000583)
Constant	0.163** (0.0655)	0.133 (0.219)	0.0627 (0.176)
Observations	876	876	876

*** p<0.01, ** p<0.05, * p<0.1

Table 1 below presents the regression results of OLS, fixed effects, and System GMM. As expected, the previous year's carbon dioxide emissions per capita are positively related to current carbon emissions per capita. In other words, if a country had higher emissions in the past year, it is likely to continue having higher emissions in the current year. All three models show a significant coefficient level at the 1% level for the lagged dependent variable, meaning that the statistical significance is exceptionally strong. Moreover, the coefficients are all greater than 80%, indicating that more than 80% of last year's emissions were carried over to this year. This finding suggests that the factors driving emissions tend to change slowly over time.

For the Paris Agreement, only the coefficient of the OLS model shows a statistically significant effect on carbon emissions per capita at the 10% level of significance. However, all models indicate the same direction of the relationship. Surprisingly, the relationship between the Paris Agreement and carbon emissions per capita is positive, contrary to expectations. This unexpected result may be due to several factors. One possible explanation is the level of commitment and actual enforcement of emission reduction policies vary significantly in each country. Many countries may have not taken strong enough actions to achieve meaningful reductions. Additionally, regional differences could contribute to variations in how countries implement climate policies. Furthermore, the Paris Agreement serves primarily as a cooperative framework rather than a legally binding mandate, meaning that compliance depends on each country's voluntary efforts. These factors may explain why the policy does not show the expected negative relationship with carbon emissions in this study.

However, this uncertainty does not hold for the COVID-19 outcome. This dummy variable has a clear negative relationship with carbon emissions per capita. In addition, two models, OLS and fixed effects, show a significant coefficient at the 1% level, while the System GMM model shows significance at the 5% level. This consistent result suggests that the impact of COVID-19 is robust across different models. As mentioned earlier, the COVID-19 period severely impacted economic operations, leading to a decrease in production, which in turn reduced emissions.

Next is the export-to-GDP ratio. It shows a positive relationship with carbon emissions per capita, indicating that countries that export a large volume of goods also tend to emit more carbon. This is likely because producing goods for export requires energy-intensive manufacturing processes, and transporting to destination countries adds further emissions from logistics and fuel consumption. Although only the fixed effect models have significant coefficients, the results of the relationship with the dependent variable are as expected. In other words, the more a country relies on exports, the higher its carbon emissions tend to be, supporting the notion that increased export activities contribute to greater energy use and carbon output.

Only OLS and fixed effect models show a statistically significant coefficient at the 1% level for agricultural land. However, the two models yield opposite results, with a negative relationship in the OLS model and a positive relationship in the fixed effects model. The significant differences between these results indicate that the overall direction and trend for agricultural land's impact on carbon emissions remains inconclusive. Even so, these differences will be further examined in other models.

Moreover, the effect of export share to the U.S. is negative, in the OLS and fixed effects models, with a significant coefficient at the 10% level. This means that higher export volumes to the U.S. tend to reduce a country's overall carbon emissions, which may be attributed to U.S. policy initiatives and the fact that the U.S. is a global leader in reducing emissions through international agreements. However, the effect is not as strong as expected, because, at the time of the study, the U.S. did not have comprehensive regulations to reduce carbon emissions from goods exported to the country.

Finally, choosing China as the primary export destination has the opposite effect, significantly increasing carbon emissions in all three models, with coefficients significant at the 1% and 10% levels for OLS and System GMM, respectively. The positive impact of exporting to China may be explained by the fact that many goods produced for the Chinese market are manufactured using more energy-intensive methods. This may be due to less stringent environmental regulations, differences in production standards, or a higher reliance on fossil fuels, all of which contribute to increased carbon emissions.

To illustrate the potential regional variations in the impact of these variables on carbon emissions per capita, Table 2 presents regression results for Asia and Europe using fixed effects models. Since the primary analysis of this study focuses on within-country changes, the fixed effects model is the most appropriate, yielding the following results.

Table 2 Asia's & Europe's Regression results on fixed effects model

VARIABLES	Models	
	Asia Fixed effects	Europe Fixed effects
Ln Carbon per Capita (t-1)	0.786*** (0.0900)	0.910*** (0.0197)
Paris Agreement	0.0353 (0.0218)	0.0175* (0.00898)
COVID-19	-0.0357*** (0.0215)	-0.0144* (0.00749)
Ln GDP per Capita (PPP)	0.0549 (0.0695)	-0.0628* (0.0324)
Export to GDP	0.00216* (0.00109)	0.000964 (0.000626)
Agricultural land	0.00916 (0.00553)	0.00335* (0.00190)
United States	-0.00244 (0.00317)	-0.000570** (0.00161)
China	0.00665* (0.00359)	-0.00218 (0.00302)
Constant	-0.757 (0.616)	0.640** (0.289)
Observations	292	378

*** p<0.01, ** p<0.05, * p<0.1

When splitting the analysis into Asia and Europe, the overall results are similar to the results from the previous regression, for example, last year's carbon emissions per capita and the impact of COVID-19. However, some variables show different results or exhibit regional variations despite their similarities.

The Paris Agreement and the export-to-GDP ratio are similar to the previous model but have different effects when separated by region. The Paris Agreement still has a positive relationship with carbon per capita. However, this policy has a significant impact only in Europe. Conversely, other variables, such as the export-to-GDP ratio, have a positive relationship with the dependent variable and are significant only in Asia.

Agricultural land in both regions is positively associated with carbon per capita. However, only in Europe is the coefficient statistically significant, meaning that an increase in agricultural land contributes to higher carbon emissions in Europe.

A notable difference between regions is GDP per capita. Although Europe exhibits the same results as the previous model—where an increase in GDP leads to a decrease in carbon emissions, Asia presents a different pattern.

Although the coefficient of GDP per capita in Asia is not significant, it suggests a general trend in the relationship. Specifically, an increase in GDP per capita in Asia is associated with a rise in carbon emissions. This finding highlights the structural differences between Asian and European economies.

Another key difference concerns the export share of the U.S. and China. The results differ significantly between the two continents. Starting with the export share to the U.S., the variable's coefficient is significant at the 5% level only for Europe. Exports to the U.S. are negatively related to carbon per capita, meaning that when European countries export goods to the U.S., their emissions decrease. This may be due to transportation distance and European environmental policies at the time. Conversely, the export share to China is significant at the 10% level for Asia, indicating a rising impact on carbon per capita. In Europe, exports to China tend to reduce carbon per capita, but this relationship is not statistically significant.

Table 3 Regression result of using the interaction term of the Paris Agreement on export share

VARIABLES	Paris Agreement		
	World Fixed effects	Asia Fixed effects	Europe Fixed effects
Ln Carbon per Capita (t-1)	0.884*** (0.0368)	0.779*** (0.0892)	0.915*** (0.0219)
Paris Agreement	0.00314 (0.0124)	0.0211 (0.0430)	0.0228 (0.0173)
Ln GDP per Capita (PPP)	-0.0366 (0.0276)	0.0398 (0.0700)	-0.0753** (0.0340)
Export to GDP	0.000748** (0.000325)	0.00219** (0.000965)	0.00114* (0.000647)
Agricultural Land	0.00804*** (0.00227)	0.00801 (0.00606)	0.00358 (0.00214)
United States	-0.00245** (0.000992)	-0.00321 (0.00295)	-0.000306 (0.00302)
United States * Agreement	0.000124 (0.000226)	0.00101 (0.00306)	-0.000333 (0.00208)
China	0.00267 (0.00221)	0.00686* (0.00342)	-0.000436 (0.00593)
China * Agreement	0.000764** (0.000364)	-0.000197 (0.000719)	-0.00197* (0.00397)
Constant	0.210 (0.236)	-0.564 (0.606)	0.739** (0.304)
Observations	876	292	378

*** p<0.01, ** p<0.05, * p<0.1

Table 4 Regression result of using the interaction term of the COVID-19 on export share

VARIABLES	COVID-19		
	World Fixed effects	Asia Fixed effects	Europe Fixed effects
Ln Carbon per Capita (t-1)	0.884*** (0.0338)	0.780*** (0.0868)	0.895*** (0.0206)
COVID-19	-0.0193** (0.00869)	-0.0711* (0.0356)	-0.0159*** (0.0154)
Ln GDP per Capita (PPP)	-0.00754 (0.0143)	0.0976 (0.0568)	-0.0390 (0.0283)

VARIABLES	COVID-19		
	World Fixed effects	Asia Fixed effects	Europe Fixed effects
Export to GDP	0.000455 (0.000342)	0.00160 (0.00108)	0.000905 (0.000649)
Agricultural land	0.00710*** (0.00222)	0.00668 (0.00532)	0.00283 (0.00176)
United States	-0.00177 (0.00109)	-0.00202 (0.00353)	0.000328 (0.00202)
United States * COVID-19	0.000329 (0.000298)	0.00346 (0.00182)	-0.000917 (0.000962)
China	0.00395 (0.00238)	0.00736* (0.00368)	-0.00261 (0.00358)
China * COVID-19	-0.000667 (0.000528)	-0.000358 (0.000887)	0.00244 (0.00234)
Constant	-0.0422 (0.136)	-1.041* (0.535)	0.443* (0.255)
Observations	876	292	378

*** p<0.01, ** p<0.05, * p<0.1

Tables 3 and 4 present the regression results, with interaction terms introduced into the equation (1) to observe how the Paris Agreement and COVID-19 influence export share and its impact on carbon per capita.

Starting with the Paris Agreement in Table 3, as in the results from Tables 1 and 2, the variable has a positive relationship with carbon per capita, but it is not significant in the world, Asia, or Europe models. Additionally, the export share of countries to the U.S. remains insignificant in other except the world model, but all models still indicate a tendency for the relationship with pollution to be negative. Moreover, even after the Paris Agreement, the results remain unchanged. None of the three models show a significant effect of exporting to the U.S.

In terms of exports to China, only the Asian model shows that a higher export share correlates with an increase in carbon per capita, with the significant at the 10% level. But after the Paris Agreement, Asian exports to China were not significantly affected. In contrast, for Europe, which comprises many developed countries, the policy appears to have contributed to a reduction in carbon emissions through exports to China. This may be due to increased awareness of emissions and improvements in the structure for goods exported to China.

Next is Table 4, which describes the impact of the interaction term between COVID-19 and export share. Consistent with previous findings, COVID-19 has a negative impact on carbon per capita. The proportion of goods export to the U.S. and its interaction term is not significant in any models, as is the case for goods export to China. The only exception is COVID-19 effect on Asian exports to China, which show a significant and positive relationship with emissions.

These findings suggest that while COVID-19 significantly affected carbon emissions, it does not appear to be linked to export destination choices. Therefore, the interaction term does not have a significant impact on carbon dioxide emissions in any of the models evaluated.

Beyond continental differences, analyzing differences between developing and developed countries provides another interesting perspective. Table 5 presents the regression results using a fixed effects model to compare these two groups of countries.

Table 5 Regression results of fixed effects for different specifications

VARIABLES	Developing country Fixed effects	Developed country Fixed effects
Ln Carbon per Capita (t-1)	0.846*** (0.0519)	0.762*** (0.104)
Paris Agreement	0.0247 (0.0181)	-0.0359* (0.0204)
COVID-19	-0.0262* (0.0134)	-0.0297*** (0.00564)
Ln GDP per Capita (PPP)	0.0110* (0.0726)	0.114** (0.0503)
Export to GDP	0.000764 (0.000608)	-0.000392 (0.000263)
Agricultural land	-0.00506 (0.00444)	0.00294 (0.00270)
United States	-0.00115 (0.00171)	0.00112 (0.00153)
China	0.00626* (0.00311)	-0.00191** (0.000887)
Constant	-0.221 (0.625)	-0.791* (0.445)
Observations	439	437

*** p<0.01, ** p<0.05, * p<0.1

The overall results are quite similar to those of previous models. However, some variables' relationships should be further discussed due to differences between the two groups.

In many previous models, the Paris Agreement has been frequently mentioned in this study because it has a positive relationship with carbon emissions, which contradicts expectations. However, in developed countries, the Paris Agreement has a significant negative impact on carbon per capita, indicating that these countries are strongly committed to this policy. This suggests that the Paris Agreement has played a key role only for developed countries.

Next is GDP per capita, which positively affects pollution in both type of countries. In this regard, there is no significant difference between the two groups. However, for the export-to-GDP ratio and carbon emissions, the results differ. In developing countries, higher export intensity is associated with increased domestic carbon emissions, whereas in developed countries, the reverse is true. Although both models show insignificant effects on the dependent variable, these relationships still provide insights for drawing conclusions.

Another noteworthy point is agricultural land. Although the results of both models are not statistically significant, their relationships offer valuable insights for the analysis. In developing countries, a higher percentage of agricultural land tends to reduce carbon per capita, whereas in developed countries, it has the opposite effect. This trend may be due to differences in agricultural land use. For instance, developing countries often rely on human labor and focus on staple crops that require fewer inputs, relying more on natural resources. In contrast, developed countries typically adopt mechanized, energy-intensive farming methods—such as large-scale livestock and cash crop production—which demand heavy use of chemical fertilizers and generate higher emissions. Notably, livestock farming is among the primary contributors to agricultural carbon emissions. Thus, it can be concluded that agricultural land use in developed countries contributes to higher carbon emissions, whereas in developing countries, an increase in agricultural land corresponds to lower carbon emissions.

Unfortunately, the export share to the United States does not have a significant impact in either group, and the differences between the two groups make interpretation challenging. However, exports to China have a significant impact on carbon emissions in developing countries, with a significant at the 10% level. This contrasts with developed countries, where exports to China are associated with lower carbon emissions, with a significant at the 5% level.

Conclusion and Discussion

The purpose of this study was to explore the impact of different export shares to destination countries on carbon per capita. To achieve this, several specifications of export share and its relationship with per capita income growth were analyzed. Additionally, the impact of other factors, including regional analysis and different economic models, was investigated.

Using OLS, System GMM, and especially fixed effects to control for time-invariant characteristics and focus on endogenous variation within each country, the results suggest that while exports to China are associated with a statistically significant increase in carbon emissions, exports to the U.S. are significantly associated with lower carbon emissions. For instance, in the Fixed Effects model (Table 1), a 1% increase in export share to the U.S. is linked to a 0.0021% decrease in per capita carbon emissions, while a 1% increase in exports to China corresponds to a 0.0036% increase in emissions. The results become more nuanced when broken down by continent. For Asian countries, higher exports to China are significantly associated with increased carbon emissions. However, for European countries, this is not the case, as only exports to the U.S. have a significant effect, showing a negative relationship with carbon dioxide emissions.

These findings complement previous research linking trade and environmental outcomes. For instance, Al-Mulali and Sheau-Ting (2014, pp. 484–498) found a positive association between exports and carbon emissions, particularly in countries with large export sectors, supporting the result that exports to China raise emissions. However, this study diverges from broader literature by highlighting how export destination, not just volume matters. Dissanayake, et al. (2023, pp. 1-23) also emphasize the importance of trade composition and export partner characteristics, suggesting that environmentally stringent markets can influence cleaner production behavior. While much prior research examines aggregate trade effects, this study adds nuance by demonstrating the role of trade partners' environmental standards in shaping emissions trajectories.

The contrasting effects of exports to the United States and China on carbon emissions can be explained by differences in importing countries' environmental regulations, market expectations, and supply chain transparency. The United States enforces stricter environmental and labor standards for imported goods, including mechanisms such as carbon labeling, ESG-related screening, and potential carbon border adjustments. Exporters aiming to maintain access to U.S. markets may thus adopt cleaner production technologies, invest in compliance, or shift toward low-emission sectors. In contrast, China has prioritized cost competitiveness and rapid industrial scaling, often relying on energy-intensive industries and maintaining weaker enforcement of environmental standards at the local level. As a result, exporting to China typically reinforces carbon-intensive production processes, especially in developing countries with limited environmental oversight.

Events that occurred during the study period, such as the Paris Agreement and COVID-19, yielded notable findings. The Paris Agreement, a policy aimed at addressing climate change through carbon reduction, had little to no effect on reducing emissions. This can be explained by the agreement's bottom-up structure, which allows countries to submit Nationally Determined Contributions (NDCs) voluntarily, without legally binding targets or penalties for non-compliance. Such a framework results in widely varying levels of ambition, particularly between developed and developing countries. Many developing countries lack the financial and technological capacity to implement deep decarbonization policies, and even among signatories, climate commitments often conflict with economic growth priorities. As a result, emissions have continued to rise in many countries despite their participation. These findings align with Nascimento et al. (2021, pp. 158–174), who highlight inconsistencies in climate policies across nations. Only developed countries appeared to implement policies in response to the agreement, resulting in significant reductions in carbon per capita. Additionally, the Paris Agreement only influenced the export share of European countries. Following the agreement, European exports to China significantly reduced pollution.

Since international agreements have had limited success in reducing carbon emissions, countries have recently begun implementing more stringent carbon emissions controls on exports. The impact of COVID-19, however, was as expected. The pandemic caused a significant reduction in emissions during that period, but it had no relationship with export share. Thus, the choice of export destinations was not affected by COVID-19.

Empirical results also show that carbon emissions are affected by other variables. Previous years' carbon emissions have had a significant effect on current emissions. GDP per capita is negatively correlated with carbon emissions, whereas the export-to-GDP ratio has a positive relationship with carbon emissions per capita. The impact of agricultural land varies, exhibiting both positive and negative effects on emissions depending on how the land is utilized.

Policy Recommendation

1. Strengthen domestic environmental regulations: Although exports to the United States have been observed to impact greenhouse gas emissions, the effect has not been as strong as anticipated. Enhancing domestic environmental policies and enforcing stricter emissions standards could encourage industries to reduce their carbon footprint, regardless of export destinations.

2. Review international climate commitments: The unexpected positive correlation between the Paris Agreement and carbon emissions suggests that current international agreements may not be effective in achieving emission reductions at the national level. Strengthening mechanisms for monitoring, accountability, and enforcement could improve the effectiveness of global climate commitments.

3. Green Export Compliance and Incentive Policy for developing countries: The policy should focus on incentivizing green infrastructure in export industries by providing tax benefits and subsidies for firms adopting clean energy technologies and improving production efficiency. Since the results show that exports to China are positively related to carbon emissions, this may be because export production still relies on fossil energy sources. Governments should also establish environmental standards for export-oriented industries to align with global sustainability goals.

4. Green Export Compliance and Incentive Policy for developed countries: The policy should incorporate Carbon Border Adjustment Mechanisms (CBAM) to impose tariffs on imported goods with high carbon footprints while offering tax incentives for companies sourcing from environmentally responsible suppliers. Additionally, minimum carbon standards for imported products should be enforced to encourage exporters to transition toward low-carbon production. This policy ensures that international trade contributes to carbon reduction rather than exacerbating emissions.

Limitation and Suggestion

There are several limitations that should be considered when interpreting the results:

First, the study period may not cover all relevant events and trends. The data spans from 2003 to 2022. However, many countries have introduced carbon regulations that directly impact exports. Some of these regulations are yet to be fully implemented, while others have only recently been introduced, meaning their effects are not captured within the analysis period. Therefore, incorporating more recent data where possible would enhance the study's relevance and validity. Expanding the data set would also allow for the inclusion of recent policy changes and market trends that may influence the relationship between exports and carbon emissions.

Second, although the dataset includes 52 countries with diverse economic and environmental profiles, it may not fully represent the global picture. Furthermore, the study only uses the United States and China as destination countries, which excludes other major destinations, and this study did not separate the types of exported products (e.g. agricultural vs. industrial products), which may not reveal differences in impact. Future research could address these limitations by expanding the scope of destination countries and exploring sector-specific trade data.

Third, unexpected findings regarding the Paris Agreement's limited impact on emissions may reflect broader limitations in implementation of global policy. Although the agreement aims to reduce emissions, its broad framework allows countries to set their own policies, often leading to inconsistencies—some support clean energy while still subsidizing fossil fuels (Nascimento et al., 2021, pp. 158–174). In addition, delays or incomplete implementation of policies can reduce short-term effectiveness. Even with existing commitments, projections still indicate a potential temperature rise of 2.6–3.1°C by 2100 (Rogelj et al., 2016, pp. 631–639).

Last, the inclusion of more comprehensive and detailed control variables is necessary. Although this study yields valuable insights, further research is needed to improve the accuracy and robustness of the results. Incorporating additional control variables, such as specific industry characteristics, energy consumption patterns, and regional policy differences, could help isolate the effect of export activities on carbon emissions more clearly. By doing so, future research could provide a deeper understanding of the observed variations and offer stronger evidence for policy recommendations.

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