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Determinants of trade in the palm oil industry between exporting and importing countries: A gravity model analysis in Asia, Oceania and Africa

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Background: The global palm oil industry plays a strategic role in international agricultural trade, particularly for developing economies that depend heavily on crude palm oil (CPO) exports as a major source of foreign exchange.

Aim: This study aims to analyse the determinants of bilateral CPO exports from major producing countries to importing countries in Asia, Oceania and Africa.

Setting: The study is conducted at the bilateral country level, covering 10 leading palm oil exporting countries and a wide range of importing countries across Asia, Oceania and Africa over the period 1995–2023.

Method: This study employs a structural gravity model using panel data with a Poisson Pseudo Maximum Likelihood (PPML) estimator to control for multilateral resistance and unobserved heterogeneity.

Results: The findings show that conventional gravity variables remain important determinants of bilateral CPO exports; however, their effects differ substantially across regions and income groups. Beyond traditional economic factors, carbon emissions and land-use change emerge as significant environmental determinants, highlighting the heterogeneous role of environmental conditions in shaping international palm oil trade.

Conclusion: The findings demonstrate that, beyond traditional economic drivers, environmental conditions play an increasingly important role in shaping global palm oil trade patterns. This highlights the necessity of incorporating environmental considerations into analyses of resource-based commodity trade.

Contribution: This study extends the structural gravity literature by integrating environmental indicators into a commodity-specific gravity model and by providing new empirical evidence on heterogeneous CPO trade patterns across regions and income groups within South–South trade.

Keywords: palm oil industry; gravity model; international trade; environmental indicator; bilateral trade.

Introduction

The increasing interconnectedness of the global economy has reinforced the role of international trade as a central driver of economic growth and structural transformation (Bajo-Rubio & Ramos-Herrera 2024; Park 2025). As global competition intensifies, countries are under growing pressure to strengthen their positions in international markets by stabilising and expanding their export structures (Alkharafi & Alsabah 2025; Fan, Guo & ChenBian 2025). Although global demand has increasingly shifted towards high value-added and technologically sophisticated products (Reviane et al. 2025), many developing economies remain highly dependent on primary commodities and agricultural goods as the backbone of their export baskets (UNCTAD 2019). This reliance reflects structural constraints in productive capacity while simultaneously underscoring the continued importance of resource-based commodities in global trade. Among agricultural commodities, crude palm oil (CPO) occupies a uniquely strategic position in international markets. Palm oil has become the most widely traded vegetable oil globally because of its cost efficiency, versatility and extensive use across food processing, cosmetics, oleochemicals and bioenergy industries (Judijanto 2025; Murphy 2025). Rapid population growth, urbanisation and industrial expansion, particularly in developing regions, have significantly increased global demand for palm oil (Yuslaini, Maulidiah & Harakan 2025). Consequently, CPO exports constitute a major source of foreign exchange, employment and industrial linkage effects for producing countries.

A defining characteristic of the palm oil industry is the high concentration of production and exports in a limited number of countries. A small group of major exporters consistently accounts for the bulk of global palm oil supply, while demand is dispersed across a wide range of importing countries with diverse economic and demographic characteristics (Acobta et al. 2025; Ferreira et al. 2023; Yu et al. 2022). This asymmetry between concentrated supply and geographically dispersed demand generates complex bilateral trade relationships shaped by economic size, population dynamics, geographic distance, institutional arrangements and policy environments (Zhang et al. 2025). In recent decades, Asia, Oceania and Africa have emerged as some of the most dynamic destinations for palm oil exports. Rising incomes, expanding food industries and growing manufacturing activities in these regions have substantially increased palm oil consumption (Alhaji et al. 2024). Moreover, many countries in Asia and Africa have integrated palm oil into both domestic consumption and industrial production processes, reinforcing the importance of South–South trade in the global palm oil market (Lugo-Arias et al. 2024; Schouten, Padfield & Kraamwinkel 2023). Despite this growing relevance, empirical evidence on palm oil trade flows towards these regions remains relatively limited compared to studies focusing on developed economies. Parallel to its economic importance, the expansion of the palm oil industry has intensified concerns regarding environmental sustainability (Ayompe, Schaafsma & Egoh 2021). Large-scale land conversion for oil palm cultivation has been associated with land-use change (Srisunthon & Chawchai 2020), deforestation (De Barros & Chimeli 2025) and increased carbon emissions (Aryapratama & Pauliuk 2022). These environmental dimensions have become central to international policy debates and regulatory frameworks, potentially influencing trade patterns through environmental standards, trade restrictions and consumer preferences. As a result, environmental conditions are increasingly relevant not only as outcomes of palm oil production but also as potential determinants of palm oil trade flows (Dalheimer et al. 2024; Savarese et al. 2022; Syahza 2019). However, existing studies remain fragmented. One stream of literature primarily investigates the environmental consequences of palm oil production, including deforestation, LUCE, certification schemes and sustainability standards (Abdul Majid et al. 2021; Meijaard et al. 2020). Another stream focuses on trade competitiveness and export performance (Tandra et al. 2022). Despite these advances, very few studies explicitly integrate environmental indicators within a structural gravity framework to examine bilateral CPO trade. Consequently, the interaction between environmental sustainability and international trade remains insufficiently understood. The gravity model of international trade provides a well-established theoretical and empirical framework for analysing bilateral trade flows. The gravity model has demonstrated strong explanatory power by linking trade volumes positively to the economic size of trading partners and negatively to trade costs such as geographic distance (Lypko 2022; Tiits et al. 2024). Subsequent theoretical developments emphasised the importance of multilateral resistance terms, highlighting the need to control for country-specific and time-varying trade frictions (Eschmann & Jochem 2025; Pfaffermayr 2020). Gravity models have been widely applied to study trade in agricultural products, natural resources and manufactured goods (Westerlund & Wilhelmsson 2011). Empirical evidence consistently shows that income levels, population size, geographic distance and institutional factors such as trade agreements are key determinants of bilateral trade flows (Freeman & Lewis 2021; Narayan & Nguyen 2016). Nevertheless, most of this literature focuses on aggregate trade flows or manufacturing sectors, while commodity-specific analyses, particularly for palm oil, remain scarce. Although gravity models consistently identify economic size, distance and institutional arrangements as the primary determinants of bilateral trade, recent studies have begun to debate whether environmental performance should also be considered an important trade determinant, particularly for resource-based commodities. While several studies argue that sustainability regulations increasingly shape international market access, empirical evidence remains inconclusive because environmental variables are rarely incorporated directly into gravity specifications. This unresolved debate motivates the present study. When palm oil trade is examined empirically, existing studies typically emphasise comparative advantage, export competitiveness or policy interventions related to sustainability standards. Although these approaches provide valuable insights, they rarely explore the bilateral structure of palm oil trade using a gravity framework that accounts for zero trade flows and unobserved heterogeneity across countries. Moreover, many studies continue to rely on log-linear specifications that may yield biased estimates in the presence of heteroskedasticity and frequent zero trade observations. Another limitation in the literature is the implicit assumption that trade determinants operate uniformly across countries and regions. In practice, importing countries differ substantially in income levels, demographic profiles and regional characteristics. These differences may influence how markets respond to economic size, trade costs and institutional arrangements. Ignoring such heterogeneity risks obscuring important variations in palm oil trade patterns across destination markets. Furthermore, despite the growing relevance of environmental concerns in global commodity markets, environmental indicators such as carbon emissions and LUCE are rarely incorporated as explanatory variables within gravity models of agricultural trade. This omission constrains our understanding of how environmental pressures may influence trade performance in resource-based industries such as palm oil. Overall, the existing literature may be grouped into three broad strands. The first emphasises traditional gravity determinants such as GDP, population and distance; the second focuses on palm oil competitiveness and trade performance; while the third examines environmental consequences of palm oil production. Despite these advances, little empirical attention has been devoted to integrating environmental indicators within a structural gravity framework to explain bilateral CPO trade. Consequently, important interactions between environmental

sustainability and international trade remain insufficiently understood. Against this background, several important research gaps remain. Firstly, there is a lack of commodity-specific gravity model analyses focusing on CPO despite its strategic role in global agricultural trade. Secondly, existing studies rarely integrate environmental variables directly into gravity models to assess their influence on bilateral palm oil trade. Thirdly, empirical evidence on palm oil trade involving Asia, Oceania and Africa remains limited. Fourthly, the heterogeneity of trade determinants across regions and income groups has not been sufficiently explored in the context of palm oil exports. This study aims to address these gaps by examining bilateral exports of CPO from major producing countries to importing countries in Asia, Oceania and Africa. The analysis focuses on 10 leading CPO exporting countries, namely Indonesia, Malaysia, Thailand, Colombia, Nigeria, Papua New Guinea, Guatemala, Honduras, Ecuador and Peru. On the demand side, the study includes 40 importing countries located across Asia, Oceania and Africa. Each bilateral observation therefore represents trade between one exporting country and one importing country in a given year, rather than trade aggregated at the regional level. These countries are selected because of their sustained export capacity and central role in shaping global palm oil trade dynamics. On the demand side, the study includes a diverse set of importing countries across Asia, Oceania and Africa, representing varying income levels, demographic structures and regional characteristics. This diversity provides a suitable context for analysing heterogeneity in palm oil trade patterns across destination markets. Methodologically, the study applies a structural gravity framework incorporating economic size, population, geographic distance, institutional factors and environmental indicators for both exporting and importing countries. The empirical analysis employs the Poisson Pseudo Maximum Likelihood (PPML) estimator, which is consistent with gravity theory and robust to heteroskedasticity and zero trade flows commonly observed in trade data (Martin & Pham 2020; Mnasri & Nechi 2021). Exporter–time and importer–time fixed effects are included to control for multilateral resistance terms and unobserved heterogeneity (Abdi, Zaidi & Karim 2023). Unlike previous gravity model studies that primarily focus on aggregate agricultural trade or export competitiveness, this study simultaneously investigates commodity-specific bilateral CPO trade, incorporates environmental indicators into the structural gravity framework and evaluates heterogeneous trade responses across regional and income classifications. These combined features distinguish the present study from existing empirical literature and provide a more comprehensive understanding of international palm oil trade. This study contributes to the literature in several important ways. Firstly, it provides one of the few commodity-specific gravity model analyses of CPO trade, offering new empirical evidence on the bilateral structure of the palm oil industry. Secondly, it explicitly incorporates environmental indicators carbon emissions and LUCE into a gravity framework, extending traditional trade models to account for environmental pressures in agricultural commodity trade. Thirdly, by focusing on exports to Asia, Oceania and Africa, the study sheds light on the dynamics of South–South trade in palm oil, an area that remains underexplored in existing research. Fourthly, the use of modern PPML estimation with high-dimensional fixed effects enhances the robustness and credibility of the empirical findings.

Methods

This study utilises a bilateral panel dataset covering CPO trade flows from 10 major exporting countries to 40 importing countries across Asia, Oceania and Africa over the period 1995–2023. The exporting countries consist of Indonesia, Malaysia, Thailand, Colombia, Nigeria, Papua New Guinea, Guatemala, Honduras, Ecuador and Peru, which collectively represent the world's major CPO exporters. The importing sample comprises 40 countries distributed across Asia, Oceania and Africa. Each observation represents an exporter–importer–year combination, thereby preserving the bilateral nature of international trade rather than aggregating countries into regional units. This bilateral panel structure enables the analysis to capture variations in trade relationships across countries and over time. The dependent variable is the nominal value of bilateral CPO exports, representing the intensity of trade between exporting and importing countries. Zero trade observations are retained throughout the estimation because excluding them may introduce sample selection bias, particularly in disaggregated commodity trade. The explanatory variables consist of conventional gravity-model variables and environmental indicators. Accordingly, Asia, Oceania and Africa are not treated as single exporting or importing entities. Instead, each country enters the dataset individually, and regional classifications are introduced only for subsample estimations presented in the empirical results. Economic size is proxied by gross domestic product (GDP), while market size and labour availability are captured by total population for both exporting and importing countries. Environmental conditions are represented by carbon dioxide (CO_2) emissions and LUCE. Carbon dioxide emissions capture the intensity of economic and industrial activities that may influence environmental performance, while LUCE reflects changes in land utilisation associated with agricultural expansion and ecosystem transformation. Both variables are incorporated separately for exporting and importing countries to capture environmental conditions that may influence production capacity, sustainability perceptions and bilateral trade relationships. Since LUCE may take negative values because of land restoration, this variable is maintained in level form rather than logarithmic form. In addition, institutional trade integration is captured through a free trade agreement (FTA) dummy variable, which equals one if an FTA is in force between a country pair in a given year and zero otherwise. To explore heterogeneity in trade patterns, importing countries are further classified by income level and geographical region, and these classifications are incorporated directly into the dataset for subsample analysis without altering the underlying data structure. All macroeconomic and demographic data are obtained from internationally recognised sources to ensure consistency and comparability across countries and over time. Bilateral export values are obtained from the World Integrated Trade Solution (WITS). Gross

TABLE 1: Variables used.

Variables	Symbol	Measurement	Data source
Exports of palm oil	CPO	The nominal value of bilateral exports of palm oil	WITS (World Integrated Trade Solution)
Gross domestic product	GDP	Gross domestic product (constant prices)	World Development Indicators (World Bank)
Population	POP	Total population	World Development Indicators (World Bank)
CO_2 emissions	CO_2	Carbon dioxide emissions (MT CO_2)	Global Carbon Budget
Land use changes	LUCE	Land-use change indicator (Ha)	Global Carbon Budget
Distance	DIST	Distance between capital cities of exporting and importing countries (kilometres)	CEPII
Free trade agreement	FTA	Dummy variable: 1 if an FTA is in force between two countries, 0 otherwise	World Trade Organization (WTO)

CPO, crude palm oil; GDP, gross domestic product; LUCE, land-use change; FTA, free trade agreement; DIST, distance; POP, population; CO_2, carbon dioxide; CEPII, Centre d'Études Prospectives et d'Informations Internationales.

domestic product and population data are sourced from the World Development Indicators (World Bank), while carbon emissions and LUCE data are retrieved from the Global Carbon Budget database. Bilateral geographical distance is obtained from the Centre d'Études Prospectives et d'Informations Internationales (CEPII), database, and information on FTAs is collected from the World Trade Organization (WTO). Using internationally harmonised databases enhances consistency and comparability across countries throughout the study period. Table 1 summarises the variables used.

The complete dataset forms an exporter–importer panel observed annually from 1995 to 2023. The regional and income-group classifications are used solely for subsample estimations and do not alter the bilateral structure of the dataset. This approach enables the analysis to identify heterogeneous trade determinants across destination markets while preserving individual country-level trade relationships. Therefore, the exporter sample remains identical across all model specifications, whereas only the composition of importing countries differs according to the respective regional or income-group classification.

This study employs a structural gravity model of international trade, which explains bilateral trade flows as being positively associated with economic size and negatively related to trade costs, following the seminal work of Tinbergen (1966). In its most basic form, the gravity model can be expressed as Equation 1:

$$lnX_{ij} = \beta_0 + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 ln\tau_{ij} + e_{ij} \quad \text{[Eqn 1]}$$

where X_{ij} indicates bilateral CPO exports from the exporter country i to the importer country j, GDP_i and GDP_j is the GDP of the trading countries. The term τ_{ij} captures bilateral trade costs between trading partners, which can be further decomposed as shown in Equation 2:

$$ln\tau_{ij} = lnDIST_{ij} \quad \text{[Eqn 2]}$$

where $DIST_{ij}$ refers to the geographical distance between the capital cities of exporter and importer countries, measured in kilometres, and serves as an observable proxy for trade costs. The error term e_{ij} represents unobserved factors affecting bilateral trade flows. All variables expressed in logarithmic form are transformed using natural logarithms, β_0 denotes the constant term and the remaining β coefficients are parameters to be estimated. Beyond the basic structural gravity framework, the literature has widely extended the gravity model to incorporate additional determinants of trade, including demographic, environmental and policy-related factors. In line with this approach, the present study augments the baseline gravity model by incorporating population size to better reflect market scale effects, as well as environmental indicators that are particularly relevant to palm oil production and trade. Specifically, carbon dioxide emissions (CO_2) and LUCE are included to capture environmental pressures associated with palm oil production and sustainability concerns that may influence international trade patterns. In addition, a dummy variable is introduced to account for the role of FTAs in facilitating bilateral palm oil exports. Accordingly, the extended empirical model is specified as follows (Equation 3):

$$\begin{aligned} lnCPO_{ijt} = {} & \beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnGDP_{jt} \\ & + \beta_3 POP_{it} + \beta_4 POP_{jt} + \beta_5 CO2_{it} \\ & + \beta_6 CO2_{jt} + \beta_7 LUCE_{it} + \beta_8 LUCE_{jt} \\ & + \beta_9 DIST_{ij} + \beta_{10} FTS_{ijt} + \varepsilon_{ijt} \end{aligned} \quad \text{[Eqn 3]}$$

where POP_{it} and POP_{jt} denote the population of exporter and importer countries. The variables $CO2_{jt}$ and $LUCE_{it}$ measure carbon dioxide emissions and land use change in the exporting and importing country, reflecting environmental externalities related to palm oil production. The variable FTA_{ijt} is a binary indicator that takes the value of one if the exporting and importing countries are members of the same FTA in year t and zero otherwise. All continuous variables, except LUCE, are transformed into natural logarithms to facilitate elasticity interpretation and reduce potential scale differences among variables. Land-use change is maintained in level form because the data contain both positive and negative observations, making logarithmic transformation inappropriate.

Given that the number of cross-sectional units in the panel dataset exceeds the time dimension, issues related to non-stationarity and spurious regression are unlikely to arise (Dadakas, Kor & Fargher 2020). To estimate the model, this study employs the PPML estimator, which has been shown to provide consistent and efficient estimates in gravity models of trade, particularly in the presence of heteroskedasticity and zero trade flows (Silva & Tenreyro 2006). As the PPML estimator relies on an exponential conditional mean specification, Equation 4 is estimated in its multiplicative form as follows:

$$lnCPO_{ijt} = \exp(\beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnGDP_{jt} + \beta_3 POP_{it} + \beta_4 POP_{jt} + \beta_5 CO2_{it} + \beta_6 CO2_{jt} + \beta_7 LUCE_{it} + \beta_8 LUCE_{jt} + \beta_9 DIST_{ij} + \beta_{10} FTA_{ijt}) x\, e_{ijt} \quad [Eqn\ 4]$$

Although endogeneity is a common concern in empirical trade analysis, several features of the present specification help mitigate this issue. The inclusion of exporter–time and importer–time fixed effects controls for multilateral resistance terms as well as time-varying country-specific factors that may simultaneously affect trade flows and explanatory variables. Furthermore, the PPML estimator provides consistent parameter estimates in the presence of heteroskedasticity and naturally accommodates zero trade observations. Nevertheless, because the analysis relies on observational macro-level data, the estimated coefficients should be interpreted as conditional associations rather than strict causal relationships.

One limitation of the empirical specification is that environmental indicators such as carbon emissions and LUCE represent macro-level environmental conditions rather than environmental performance specific to the palm oil industry. Consequently, the estimated effects should be interpreted as capturing broad environmental influences on bilateral CPO trade rather than direct firm or plantation-level impacts. Future studies may incorporate commodity-specific environmental indicators or certification measures to provide more detailed evidence.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

Results

This section presents the empirical findings in three stages. Firstly, descriptive statistics are provided to summarise the characteristics of the bilateral trade dataset. Secondly, the structural gravity model is estimated separately by regional groups and income groups to identify heterogeneous determinants of CPO exports. Thirdly, a pooled estimation is conducted using the full sample to provide an overall assessment of the determinants of bilateral CPO trade. The discussion emphasises the economic interpretation of the estimated coefficients rather than merely their statistical significance.

Descriptive statistics

Table 2 presents the descriptive statistics of the variables employed in the gravity model analysis of CPO exports. The summary statistics indicate substantial heterogeneity in bilateral trade flows across country pairs and over time. The distribution of CPO exports is characterised by a large number of zero observations alongside a small number of very large trade flows, reflecting the highly concentrated nature of international palm oil trade. This pattern suggests that while many exporter–importer pairs do not engage in palm oil trade in certain years, a limited number of trading relationships account for a disproportionately large share of total exports. The variables capturing economic size display wide variation across countries in the sample. Both exporter and importer GDP exhibit distributions with pronounced asymmetry, indicating that the dataset includes economies with vastly different levels of economic development. Similarly, population variables for exporters and importers show substantial dispersion, reflecting the coexistence of countries with small populations and those with very large domestic markets. These distributional features highlight the diverse economic and demographic profiles of trading partners involved in the palm oil industry. Environmental variables and trade-cost indicators also exhibit substantial variation across bilateral observations. Carbon emissions and LUCE differ considerably across exporting and importing countries, reflecting heterogeneous environmental conditions associated with palm oil production and economic activities. Likewise, geographical distance and FTA status vary widely across country pairs, confirming the diversity of trade relationships included in the sample. Overall, these descriptive statistics support the application of the PPML estimator, which is well suited to heterogeneous trade data characterised by numerous zero observations.

Gravity model estimates of crude palm oil industry: Regional groups

Table 3 reports the PPML estimates of the structural gravity model across five regional destination groups. The results reveal that the determinants of bilateral CPO exports

TABLE 2: Summary statistics.

Variable	Mean	Variance	SD	Kurtosis	Skewness	Minimum	Maximum
CPO	8492.4697	15 720 986 403	125 383.3578	530.9894	21.69881	0	4 465 022.14
GDP_i	2.22911e[11]	5.3032e[22]	2.302873[11]	3.994474	1.821182	10 200 112 186	1.23824e[12]
GDP_j	5.19974e[11]	2.90188e[24]	1.70349e[12]	50.91176	6.538691	1 953 554 804	1.84881e[13]
POP_i	50 362 760 044	1.19765e[22]	1.09437e[11]	3.0812213	2.073932	4 813 361	4.54722e[11]
POP_j	100 173 809	7.65953e[16]	276 758 643.6	14.80226695	4.022214	298 276	1 450 935 791
$CO2_i$	31.2804109	1532.580917	39.1481817	4.46710148	2.0234493	0.56	208.0670137
$CO2_j$	93.93819909	124 644.578	353.0503902	45.89819346	6.5348155	0.12311605	3322.054865
$LUCE_i$	36.72752576	5837.502861	76.40355267	19.48550102	3.8877241	-39.55547	648.01485
$LUCE_j$	5.97859131	333.9939922	18.27550252	17.6472462	1.472196	-99.1628	160.3614
DIST	10 423.50076	22 081 033.27	499.045996	-0.80993991	−0.237703	315.5433	19812.04
FTA	0.377586207	0.235035125	0.484804213	-1.74518492	0.5050901	0	1

CPO, crude palm oil; GDP, gross domestic product; CO_2, carbon dioxide; LUCE, land-use change; FTA, free trade agreement; DIST, distance; POP, population; SD, standard deviation.

TABLE 3: Gravity model estimates of crude palm oil exports using Poisson Pseudo Maximum Likelihood by region.

Variable	EASAO†		MENA‡		SA§		NEA¶		CSA††	
	p-value	SE	*p*-value	SE	*p*-value	SE	*p*-value	SE	*p*-value	SE
GDP_i	3.848**	1.231	0.653	0.934	-0.231	2.171	-4.212	2.327	-3.039	2.816
GDP_j	1.387***	0.295	-3.121	1.669	-0.355	2.158	19.649***	1.175	-11.447*	5.661
POP_i	0.318***	0.093	0.463***	0.093	0.232**	0.088	0.393*	0.182	0.359**	0.128
POP_j	-0.258*	0.109	5.712***	1.025	-1.226*	0.477	-21.239***	2.103	14.359	11.817
$CO2_i$	-2.501*	1.093	1.276*	0.508	1.441	1.135	5.329***	1.273	3.682*	1.511
$CO2_j$	0.048	0.328	-1.634**	0.508	2.420	1.405	-1.822	1.400	2.959***	0.723
$LUCE_i$	0.011**	0.004	0.009*	0.004	0.008	0.006	0.012**	0.004	0.007	0.006
$LUCE_j$	0.026***	0.005	0.166	0.114	0.012**	0.004	0.228***	0.029	-0.097**	0.034
DIST	-0.0021***	0.0056	-0.0057	0.0013	-0.0037*	0.0012	0.00091	0.0013	0.00028	0.00132
FTA	-5.581**	2.087	-6.985***	1.710	-0.464*	1.273	-5.453***	0.444	-0.172***	0.444

Note: The dependent variable is the bilateral CPO export value from exporter country i to importer country j. The exporter sample is identical across all estimations, while only the importing-country sample differs by regional classification.

EASAO, importing countries located in East Asia, Southeast Asia and Oceania; MENA, Middle East and North Africa; SA, South Asia; NEA, North and East Africa; CSA, Central and Southern Africa; ET, exporter–time; IT, importer–time; CPO, crude palm oil; DIST, distance; GDP, gross domestic product; CO_2, carbon dioxide; LUCE, land-use change; FTA, free trade agreement; POP, population; SE, standard errors.

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

†, EASAO (R^2: 0.6384; Observations: 3770; Fixed Effects: ET, IT); ‡, MENA (R^2: 0.5913; Observations: 2800; Fixed Effects: ET, IT); §, MENA (R^2: 0.7831; Observations: 1450; Fixed Effects: ET, IT); ¶, NEA (R^2: 0.5913; Observations: 1300; Fixed Effects: ET, IT); ††, CSA (R^2: 0.6713; Observations: 1960; Fixed Effects: ET, IT).

differ considerably across regions, indicating that export performance cannot be explained by a single uniform mechanism. Instead, economic, demographic, environmental and institutional factors exhibit heterogeneous effects depending on the characteristics of destination markets. The results show that exporter GDP exhibits a positive and statistically significant association with CPO exports only in the East Asia, Southeast Asia and Oceania (EASAO) region, where a 1% increase in the exporter's GDP is associated with a 3.85% increase in CPO exports. In contrast, exporter GDP is statistically insignificant in MENA and South Asia and negative but insignificant in NEA and CSA. With respect to importer GDP, the estimates indicate a strong positive and significant effect in EASAO and NEA. In particular, importer GDP elasticity is highest in NEA, suggesting that market size on the demand side plays a crucial role in shaping CPO imports in this region. Conversely, importer GDP is negative and significant in CSA while remaining statistically insignificant in MENA and South Asia. Population effects also vary across regions. The exporter's population consistently shows a positive and statistically significant effect on CPO exports across all regions, indicating that countries with larger populations tend to export higher volumes of palm oil. In contrast, the importer's population displays mixed effects. It is negative and statistically significant in EASAO, South Asia and NEA while being strongly positive and significant in MENA. The coefficient for CSA is positive but statistically insignificant, suggesting no robust relationship between importer population size and CPO imports in this region. Environmental variables demonstrate region-specific patterns. Exporter-side CO_2 emissions have a negative and significant effect on CPO exports in EASAO, while they exert positive and significant effects in MENA, NEA and CSA. On the importer side, CO_2 emissions are statistically insignificant in EASAO, South Asia and NEA but show a negative and significant relationship in MENA and a positive and significant association in CSA. These results highlight notable differences in how environmental conditions of trading partners are correlated with CPO trade flows across regions. Land use change also presents heterogeneous effects. Exporter-side land use change is positive and statistically significant in EASAO, MENA and NEA while remaining insignificant in South Asia and CSA. Importer-side land use change is positive and significant in EASAO, South Asia and NEA but negative and significant in CSA. The coefficient for MENA is positive but statistically insignificant, indicating weaker evidence of an association in that region. Geographical distance is found to have a negative and statistically significant effect on CPO exports in EASAO and South Asia, suggesting that distance-related trade costs remain relevant for palm oil trade in these regions. However, distance is statistically insignificant in MENA, NEA and CSA, indicating that spatial frictions play a less prominent role in shaping CPO exports to these regions. The Free Trade Agreement is negative and statistically significant across all regional models. The magnitude of the coefficient varies by region, with the strongest negative effects observed in MENA and NEA. This suggests that, within the estimated specifications and controlling for fixed effects, the presence of FTAs is associated with lower recorded bilateral CPO export values across the examined regions. The models exhibit relatively strong explanatory power, with pseudo-R^2 values ranging from 0.53 to 0.78. All estimations include exporter-time and importer-time fixed effects, ensuring that time-varying multilateral resistance terms are properly controlled for. Overall, the regional estimations indicate that no single determinant consistently explains CPO exports across all destination markets. While economic size and population remain important drivers, their magnitude and direction vary considerably across regions. Likewise, environmental variables exhibit heterogeneous effects, suggesting that sustainability-related factors interact differently with regional market characteristics. These findings highlight the importance of adopting region-specific trade strategies rather than relying on uniform export policies.

Gravity model estimates of crude palm oil industry: Income groups

Table 4 presents the PPML estimates across four income groups to examine whether the determinants of CPO exports

TABLE 4: Gravity model estimates of crude palm oil exports using Poisson Pseudo Maximum Likelihood by income.

Variable	Low income†		Lower middle income‡		Upper middle income§		High income¶	
	p-value	SE	*p*-value	SE	*p*-value	SE	*p*-value	SE
GDP_i	-28.172***	0.005	-2.235*	1.106	0.605	0.821	2.869*	1.304
GDP_j	30.308***	0.008	0.061	0.277	-1.625	2.381	-5.035***	0.611
POP_i	2.857***	0.0111	0.195***	0.045	0.431***	0.080	0.1971	0.107
POP_j	-62.090***	0.0002	0.1954***	0.235	0.288	1.799	0.106	1.099
$CO2_i$	17.503***	0.008	3.481***	0.761	3.028***	0.346	-2.424*	0.954
$CO2_j$	-97.991***	0.005	-0.283	0.207	2.201**	0.765	-4.611***	0.509
$LUCE_i$	0.018***	0.00112	0.0007	0.004	0.0022	0.0002	0.012*	0.005
$LUCE_j$	0.144***	0.00131	-0.004***	0.0011	0.034***	0.0021	-0.0110	0.018
DIST	-0.004***	0.00112	0.0000	0.000	-0.0011	0.000	-0.0011***	0.0000
FTA	-	-	-0.9521	0.574	1.223***	0.437	-1.941*	0.958

Note: Income-group classifications refer only to importing countries, whereas the exporter sample remains unchanged across all estimations. The dependent variable for all models is the CPO export value from country i to j. ET and IT are the importer and exporter time fixed effects included in all models.

CPO, crude palm oil; DIST, distance; GDP, gross domestic product; CO_2, carbon dioxide; LUCE, land-use change; FTA, free trade agreement; ET, exporter–time; IT, importer–time; POP, population; SE, standard errors.

*, ** and *** denote significance at the 10%, 5% and 1% levels.

†, Low income (R^2: 0.552; Observations: 90; Fixed Effects: ET, IT); ‡, Lower middle income (R^2: 0.763; Observations: 6090; Fixed Effects: ET, IT); §, Upper middle income (R^2: 0.594; Observations: 1160; Fixed Effects: ET, IT); ¶, High income (R^2: 0.804; Observations: 3480; Fixed Effects: ET, IT).

differ according to the economic development of importing countries. The results reveal substantial heterogeneity, suggesting that the effects of traditional gravity variables and environmental indicators depend strongly on market income levels. The estimated coefficients for exporter GDP display substantial variation across income groups. Exporter GDP is negative and highly significant for low-income and lower-middle-income countries, indicating that increases in economic size in these economies are associated with lower bilateral CPO exports. In contrast, exporter GDP is positive and statistically significant for high-income countries, suggesting that larger economic scale in these economies supports higher CPO export flows. For upper-middle-income countries, the coefficient on exporter GDP is positive but statistically insignificant. On the importer side, GDP exhibits a strongly positive and significant effect for low-income importers, while it is negative and significant for high-income importers. The coefficient for importer GDP is statistically insignificant for lower-middle-income and upper-middle-income countries. Population effects also differ notably across income categories. The exporter's population has a positive and statistically significant effect on CPO exports for low-income, lower-middle-income and upper-middle-income countries, while it is statistically insignificant for high-income exporters. In contrast, the importer's population exerts a strong negative and significant effect for low-income countries, whereas it is positive and significant only for lower-middle-income countries. For upper-middle-income and high-income importers, the population coefficients are statistically insignificant. Environmental indicators show income-dependent patterns. Exporter-side CO_2 emissions are positive and highly significant for low-income, lower-middle-income and upper-middle-income countries, while they are negative and statistically significant for high-income exporters. On the importer side, CO_2 emissions are negative and significant for low-income and high-income countries, positive and significant for upper-middle-income countries and statistically insignificant for lower-middle-income countries. These results suggest that the relationship between environmental intensity and CPO trade varies systematically with income levels. Land use change variables further reinforce this heterogeneity. Exporter-side land use change is positive and statistically significant for low-income and high-income countries, while it is insignificant for middle-income groups. Importer-side land use change shows a positive and significant effect for low-income and upper-middle-income countries, a negative and significant effect for lower-middle-income countries, and no statistically significant effect for high-income economies. Geographical distance generally exerts a trade-reducing effect although its significance varies across income groups. Distance is negative and statistically significant for low-income and high-income countries, while it is statistically insignificant for lower-middle-income and upper-middle-income groups. This suggests that spatial trade costs are more relevant for CPO exports involving economies at the lower and upper ends of the income distribution. The impact of Free Trade Agreements differs markedly across income levels. The FTA coefficient is positive and statistically significant only for lower-middle-income countries, indicating that trade agreements are associated with higher bilateral CPO exports in this group. In contrast, the FTA effect is negative and statistically significant for high-income countries, while it is statistically insignificant for low-income countries. The estimations demonstrate that the determinants of CPO exports vary substantially across income groups. The models show strong explanatory power, with pseudo-R^2 values ranging from 0.55 to 0.80. All specifications include exporter-time and importer-time fixed effects, ensuring that unobserved time-varying multilateral resistance factors are adequately controlled for. Taken together, the income-group estimations demonstrate that bilateral CPO trade is highly heterogeneous across destination markets. Economic size, environmental conditions and institutional arrangements influence trade differently depending on countries' income levels. Consequently, export promotion strategies should recognise differences in purchasing power, sustainability preferences and market maturity instead of adopting a uniform approach across all destinations.

Gravity model estimates of crude palm oil industry: All groups

To complement the heterogeneous estimations, Table 5 reports the pooled PPML estimates using the complete

bilateral sample. This specification provides an overall assessment of the determinants of international CPO trade while controlling for exporter-time and importer-time fixed effects. The results indicate that exporter GDP has a negative and highly significant effect on bilateral CPO exports. This suggests that, when considering all countries jointly, increases in the economic size of exporting countries are associated with lower CPO export flows. In contrast, importer GDP displays a positive but statistically insignificant coefficient, implying that variations in the income level of destination countries do not systematically influence CPO imports in the pooled sample. Population variables exhibit a positive and statistically significant relationship with CPO exports on both the exporter and importer sides. The exporter's population coefficient is positive and highly significant, indicating that larger population sizes in exporting countries are associated with higher CPO export volumes. Similarly, the importer's population exerts a positive and statistically significant effect, suggesting that more populous destination countries tend to import larger quantities of CPO. Environmental variables also play an important role in shaping CPO trade flows. Exporter-side CO_2 emissions are negative and statistically significant, indicating that higher emission levels in exporting countries are associated with lower CPO exports. Conversely, importer-side CO_2 emissions have a positive and significant effect, implying that countries with higher emission levels tend to import more CPO. Land use change variables show weaker effects: Exporter-side land use change is statistically insignificant, while importer-side land use change is negative and significant at conventional levels. Geographical distance emerges as a strong barrier to CPO trade. The coefficient on distance is negative and highly significant, confirming that greater distance between trading partners substantially reduces bilateral CPO export flows. This result highlights the importance of transportation costs in shaping trade patterns in the palm oil industry. The negative coefficient of the FTA variable deserves particular attention because it differs from the conventional expectation that trade agreements promote bilateral trade. One possible explanation is that many FTAs included in the sample are broad agreements covering numerous commodities but do not specifically facilitate CPO trade. In addition, sustainability regulations, non-tariff measures, certification requirements, and domestic import policies may partially offset the trade-creating effects of tariff reductions. Therefore, the estimated negative association should not be interpreted as evidence that FTAs reduce trade per se but rather that formal trade agreements alone are insufficient to guarantee higher bilateral CPO exports once other economic and institutional factors are controlled for. The pooled model demonstrates a high degree of explanatory power, with a pseudo-R^2 of 0.791 and a total of 9570 observations. The inclusion of exporter-time and importer-time fixed effects ensures that unobserved heterogeneity and time-varying multilateral resistance factors are adequately controlled for, reinforcing the robustness of the estimated results.

TABLE 5: Gravity model estimates of crude palm oil exports using Poisson Pseudo Maximum Likelihood.

Variable	CPO exports all groups†	
	p-value	SE
GDP_i	-7.976***	1.218
GDP_j	0.1101	0.422
POP_i	1.395***	0.232
POP_j	7.935**	3.031
$CO2_i$	-1.097***	0.302
$CO2_j$	1.493**	0.489
$LUCE_i$	0.0013	0.001
$LUCE_j$	-0.0067*	0.003
DIST	-0.0218***	0.00121
FTA	-1.281***	0.074

Notes: The dependent variable for all models is the CPO export value from country i to j. ET and IT are the importer and exporter time fixed effects included in all models.

CPO, crude palm oil; DIST, distance; GDP, gross domestic product; CO_2, carbon dioxide; LUCE, land-use change; FTA, free trade agreement; ET, exporter–time; IT, importer–time; POP, population; SE, standard errors.

*, ** and *** denote significance at the 10%, 5% and 1% levels.

†, R^2: 0.7911; Observations: 9570; Fixed Effects: ET, IT.

Overall, the pooled estimation confirms that bilateral CPO trade is determined by a combination of economic, demographic, environmental and institutional factors. Nevertheless, comparison with the regional and income-group estimations demonstrates that these relationships are far from homogeneous. Consequently, relying solely on pooled estimates may conceal important differences across destination markets, reinforcing the value of heterogeneous gravity-model analyses.

Discussion

The empirical findings extend the structural gravity literature by demonstrating that bilateral CPO trade is influenced not only by conventional economic determinants but also by environmental conditions, with considerable heterogeneity across regions and income groups. Rather than identifying a single universal pattern, the results indicate that the relative importance of economic size, demographic characteristics, environmental factors and institutional arrangements varies according to destination-market characteristics. This evidence supports the view that commodity-specific gravity models provide richer insights than aggregate trade analyses when examining resource-based commodities such as palm oil. The heterogeneous results reported throughout the analysis are obtained from identical exporting countries, whereas heterogeneity is introduced through differences in destination regions and importer income groups. The positive and heterogeneous role of economic size in shaping CPO exports aligns with a broad body of gravity model studies emphasising the importance of income levels in determining trade volumes (Freeman & Lewis 2021; Narayan & Nguyen 2016). This relationship reflects both supply-side capacity in exporting countries and demand-side absorption in importing markets. As global competition intensifies, stabilising export volumes through sustained market access becomes increasingly important for palm oil–producing countries seeking to maintain their positions in international markets (Alkharafi & Alsabah 2025; Fan et al. 2025). The results support the argument that economic expansion in destination markets

continues to underpin demand for palm oil as a key input in food processing and industrial production. The heterogeneous GDP effects also suggest that economic expansion alone does not automatically translate into stronger CPO exports. Market structure, domestic processing capacity, trade policies and consumption patterns differ across destination markets, causing economic growth to generate different trade responses. This finding reinforces the importance of considering market heterogeneity within gravity-model applications. Population dynamics also emerge as an important determinant of CPO trade, underscoring the role of demographic pressure in shaping consumption patterns. Rapid population growth and urbanisation, particularly in Asia and Africa, have significantly increased demand for affordable and versatile vegetable oils (Yuslaini et al. 2025). This finding is consistent with earlier studies suggesting that population size captures both market scale and consumption intensity, especially for staple agricultural commodities (Lugo-Arias et al. 2024). Population-driven demand reinforces South–South trade linkages, as developing regions increasingly rely on imports from major producing countries. Nevertheless, the mixed population effects across regional and income-group estimations indicate that population size should not be interpreted solely as a proxy for market demand. Differences in dietary preferences, industrial utilisation of palm oil and domestic production capacity may weaken or strengthen the relationship between population growth and CPO imports across countries. Geographic distance remains a persistent barrier to bilateral CPO trade, confirming long-standing gravity model predictions that transportation costs and logistical frictions reduce trade flows (Lypko 2022; Tiits et al. 2024). Despite technological advancements in shipping and logistics, distance continues to matter for bulky, low-value-to-weight commodities such as CPO. This result is in line with empirical evidence showing that agricultural and resource-based products are particularly sensitive to trade costs compared to high-value manufactured goods (Westerlund & Wilhelmsson 2011). The findings underscore the importance of infrastructure development and trade facilitation in mitigating distance-related constraints. The persistence of distance effects despite advances in transportation technology also suggests that non-transport logistics, including port efficiency, customs procedures and supply-chain coordination, remain important barriers in international palm oil trade. Institutional factors, captured through FTAs, exhibit mixed effects on CPO exports, reflecting the complex interaction between trade liberalisation and commodity-specific market structures. While trade agreements are generally expected to promote trade by reducing tariffs and non-tariff barriers, their impact on palm oil appears to vary across regions and income groups. This heterogeneity is consistent with previous studies highlighting that the effectiveness of trade agreements depends on complementary domestic policies, regulatory frameworks and market conditions (Eschmann & Jochem 2025; Pfaffermayr 2020). Regulatory concerns and sustainability standards may partially offset the trade-enhancing effects of formal agreements. The heterogeneous and, in several specifications, negative effects of FTAs deserve particular attention because they differ from conventional trade theory. One possible explanation is that many trade agreements reduce tariffs without necessarily addressing non-tariff barriers affecting palm oil, such as sustainability certification, environmental regulations, sanitary requirements and consumer preferences. Consequently, preferential trade agreements alone may be insufficient to increase bilateral CPO exports. This finding suggests that market access for environmentally sensitive commodities depends not only on tariff liberalisation but also on compliance with increasingly stringent sustainability standards. A key contribution of this study lies in the integration of environmental variables into the gravity framework for palm oil trade. The significance of carbon emissions and LUCE indicates that environmental conditions are increasingly intertwined with international trade dynamics. This finding resonates with recent literature emphasising that environmental performance can influence trade outcomes through regulatory pressures, sustainability standards and shifting consumer preferences (Dalheimer et al. 2024; Savarese et al. 2022). Environmental indicators may proxy both production intensity and exposure to sustainability-related scrutiny in global markets. More importantly, the significance of environmental indicators should not be interpreted solely as evidence that environmental degradation promotes trade. Instead, these variables likely capture broader structural conditions associated with agricultural production, industrial development and international sustainability scrutiny. Therefore, environmental performance increasingly represents a component of international competitiveness rather than merely an external consequence of production. The inclusion of environmental dimensions also addresses a notable gap in existing palm oil research, which has often examined environmental impacts and trade patterns as separate issues. While numerous studies focus on deforestation, LUCE and certification schemes (Abdul Majid et al. 2021; Meijaard et al. 2020), relatively few have embedded these factors within a formal empirical trade model. By jointly considering economic and environmental determinants, this study provides a more integrated perspective on how sustainability-related factors interact with traditional trade drivers in shaping CPO exports. This finding also contributes to the growing debate regarding the integration of sustainability considerations into international trade models. While traditional gravity models largely focus on economic determinants, the present study demonstrates that environmental variables provide additional explanatory power in understanding bilateral trade patterns for environmentally sensitive commodities. The regional focus on Asia, Oceania and Africa further enhances the relevance of the findings, as these regions have emerged as some of the most dynamic destinations for palm oil exports in recent decades (Alhaji et al. 2024). The results highlight the growing importance of South–South trade relationships in the global palm oil market, where demand is increasingly driven by developing economies rather than traditional high-income

markets. This observation aligns with recent evidence documenting shifts in global trade patterns towards emerging regions (Lugo-Arias et al. 2024; Schouten et al. 2023). The heterogeneous regional responses further imply that export diversification strategies should account for regional differences in market maturity, regulatory environments and sustainability preferences. Policies that are effective in one destination region may not necessarily produce similar outcomes elsewhere. Overall, the findings demonstrate that bilateral CPO trade cannot be adequately explained using traditional gravity variables alone. Instead, international palm oil trade reflects the interaction of economic development, demographic dynamics, environmental performance, institutional arrangements and destination-market heterogeneity. By integrating environmental indicators within a structural gravity framework and explicitly examining heterogeneous effects across regional and income classifications, this study provides new empirical evidence that advances both the gravity-model literature and research on international agricultural commodity trade. From a policy perspective, the findings suggest that strengthening international competitiveness in the palm oil industry requires a broader strategy than conventional trade liberalisation. Exporting countries should simultaneously improve production efficiency, expand market diversification and strengthen compliance with international sustainability standards. Because trade determinants differ substantially across destination regions and income groups, export promotion policies should be designed according to the specific characteristics of target markets rather than adopting a uniform strategy. In particular, sustainability certification, environmental governance and logistical improvements are likely to become increasingly important sources of comparative advantage in future international palm oil trade.

Conclusion

This study investigates the determinants of bilateral CPO exports from 10 major exporting countries to importing countries across Asia, Oceania and Africa using a structural gravity framework estimated with the PPML approach. By integrating conventional gravity variables with environmental indicators and examining heterogeneous effects across regional and income-group classifications, the study provides a more comprehensive understanding of the factors shaping international CPO trade. The empirical findings confirm that conventional gravity variables remain important determinants of bilateral CPO trade although their effects vary considerably across destination markets. Economic size, population and geographical distance continue to explain bilateral trade patterns, while carbon emissions and LUCE emerge as statistically significant environmental determinants. Furthermore, the heterogeneous responses observed across regional and income-group estimations indicate that bilateral CPO trade cannot be adequately explained using a single uniform specification. From a theoretical perspective, this study extends the structural gravity literature by demonstrating that environmental conditions provide additional explanatory power beyond conventional economic determinants. Unlike most previous gravity-model studies that primarily focus on aggregate trade or manufacturing products, this research explicitly incorporates environmental indicators within a commodity-specific gravity framework and highlights the heterogeneous nature of international palm oil trade. From a policy perspective, the findings suggest that improving international competitiveness in the palm oil industry requires strategies that extend beyond conventional trade liberalisation. Exporting countries should strengthen production efficiency, improve logistics, diversify export destinations and enhance compliance with international sustainability standards. Because environmental indicators significantly influence bilateral trade, sustainability policies should be viewed not only as environmental objectives but also as instruments for maintaining long-term export competitiveness. The heterogeneous results across regions and income groups further indicate that export promotion policies should be tailored to destination-market characteristics. Trade strategies designed for rapidly growing developing markets may differ substantially from those targeting higher-income economies where environmental standards and sustainability requirements play a more prominent role. Consequently, differentiated trade policies are likely to be more effective than uniform export promotion strategies. Despite its contributions, this study has several limitations that provide avenues for future research. Firstly, the analysis focuses on 10 major CPO exporting countries – Indonesia, Malaysia, Thailand, Colombia, Nigeria, Papua New Guinea, Guatemala, Honduras, Ecuador and Peru – which collectively represent a substantial share of global CPO exports during the study period. On the demand side, the study includes 40 importing countries across Asia, Oceania and Africa, representing diverse regional characteristics and income levels. The analysis maintains identical exporting countries across all estimations while allowing importing-country classifications to vary according to region and income group, thereby ensuring that the observed heterogeneity reflects destination-market characteristics rather than changes in the exporter sample. This bilateral country-level structure provides an appropriate setting for examining heterogeneous trade determinants without aggregating countries into regional trading blocs. Secondly, while the study incorporates key environmental indicators, future research could extend the framework by including additional sustainability-related measures, such as certification schemes or environmental regulations. Thirdly, further work could explore firm-level or product-level data to capture micro-level trade dynamics and provide deeper insights into the mechanisms linking environmental performance and international palm oil trade. In addition, the use of macro-level environmental indicators does not fully capture commodity-specific sustainability practices adopted by palm oil producers, which may influence bilateral trade through certification schemes and environmental compliance. Overall, this study provides new empirical evidence that integrating environmental dimensions into

structural gravity models offers a more comprehensive framework for understanding international palm oil trade and supports the development of more targeted and sustainable trade policies.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

CRediT authorship contribution

Fitriwati Djam'an: Conceptualisation, Funding acquisition, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. Abdul H. Paddu: Conceptualisation, Data curation, Formal analysis, Software, Visualisation, Writing – original draft, Writing – review & editing. Indraswati T.A. Reviane: Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. Nur Dwiana S. Saudi: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. Dorojatun Prihandono: Data curation, Resources, Software, Validation, Visualisation, Writing – review & editing. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication and take responsibility for the integrity of its findings.

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Data availability

The data used in this study were obtained from publicly accessible official sources, including the World Bank WDI (https://databank.worldbank.org/source/world-development-indicators), WITS (https://wits.worldbank.org/), Global Carbon Budget (https://globalcarbonbudget.org/datahub/), CEPII GeoDist (https://www.cepii.fr/cepii/en/bdd_modele/bdd_modele_item.asp?id=6), and WTO RTA Database (https://data.wto.org/dataset/ext_rta). All datasets are openly available, and no restrictions apply to their use.

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References

Abdi, A.H., Zaidi, M.A.S. & Karim, Z.A., 2023, 'Economic complexity and bilateral trade flows in selected COMESA and East Asia countries', *Technological and Economic Development of Economy* 29(3), 846–873. https://doi.org/10.3846/tede.2023.18682

Abdul Majid, N., Ramli, Z., Md Sum, S. & Awang, A.H., 2021, 'Sustainable palm oil certification scheme frameworks and impacts: A systematic literature review', *Sustainability* 13(6), 3263. https://doi.org/10.3390/su13063263

Acobta, A.N., Ayompe, L.M., Crook, E.D. & Egoh, B.N., 2025, 'Mapping ecosystem services change under land use change for oil palm expansion', *Cleaner and Circular Bioeconomy* 12, 100176. https://doi.org/10.1016/j.clcb.2025.100176

Alhaji, A.M., Almeida, E.S., Carneiro, C.R., Da Silve, C.A.S., Monteiro, S. & Coimbra, J.S.d.R., 2024, 'Palm oil (*Elaeis guineensis*): A journey through sustainability, processing, and utilization', *Foods* 13(17), 2814. https://doi.org/10.3390/foods13172814

Alkharafi, N. & Alsabah, M., 2025, 'Globalization: An overview of its main characteristics and types, and an exploration of its impacts on individuals, firms, and nations', *Economies* 13(4), 91. https://doi.org/10.3390/economies13040091

Aryapratama, R. & Pauliuk, S., 2022, 'Life cycle carbon emissions of different land conversion and woody biomass utilization scenarios in Indonesia', *Science of the Total Environment* 805, 150226. https://doi.org/10.1016/j.scitotenv.2021.150226

Ayompe, L.M., Schaafsma, M. & Egoh, B.N., 2021, 'Towards sustainable palm oil production: The positive and negative impacts on ecosystem services and human wellbeing', *Journal of Cleaner Production* 278, 123914. https://doi.org/10.1016/j.jclepro.2020.123914

Bajo-Rubio, O. & Ramos-Herrera, M.d.C., 2024, 'Does international trade promote economic growth? Europe, 19th and 20th centuries', *Economic Analysis and Policy* 84, 561–575. https://doi.org/10.1016/j.eap.2024.07.019

Dadakas, D., Kor, S.G. & Fargher, S., 2020, 'Examining the trade potential of the UAE using a gravity model and a poisson pseudo maximum likelihood estimator', *Journal of International Trade & Economic Development* 29(5), 619–646. https://doi.org/10.1080/09638199.2019.1710551

Dalheimer, B., Parikoglou, I., Brambach, F., Yanita, M., Kreft, H. & Brummer, B., 2024, 'On the palm oil-biodiversity trade-off: Environmental performance of smallholder producers', *Journal of Environmental Economics and Management* 125, 102975. https://doi.org/10.1016/j.jeem.2024.102975

De Barros, P.H.B. & Chimeli, A.B., 2025, 'The impacts of palm oil expansion on deforestation and economic activity in the eastern Amazon', *Ecological Economics* 239, 108739. https://doi.org/10.1016/j.ecolecon.2025.108739

Eschmann, J. & Jochem, P., 2025, 'Assessing import dependencies in the accelerating energy transition: A structural gravity model analysis', *Energy Policy* 205, 114697. https://doi.org/10.1016/j.enpol.2025.114697

Fan, Z., Guo, F. & ChenBian, 2025, 'Global uncertainty, macroprudence and export value: "Quality up" or "quantity up"', *International Review of Economics & Finance* 99, 104058. https://doi.org/10.1016/j.iref.2025.104058

Ferreira, S.C.G., Azevedo-Ramos, C., Farias, H.A.B. & Mota, P., 2023, 'Spillover effect of the oil palm boom on the growth of surrounding towns in the eastern Amazon', *Land Use Policy* 133, 106867. https://doi.org/10.1016/j.landusepol.2023.106867

Freeman, R. & Lewis, J., 2021, 'Gravity model estimates of the spatial determinants of trade, migration, and trade-and-migration policies', *Economics Letters* 204, 109873. https://doi.org/10.1016/j.econlet.2021.109873

Judijanto, L., 2025, 'Palm oil: A choice for balancing economic benefits and environmental sustainability', *Growth* 12(1), 33–40. https://doi.org/10.20448/growth.v12i1.6955

Lugo-Arias, E., Lugo-Arias, J., Vargas, S.B., De la Puente Pacheco, M.A., Granados, I.B., Heras, C.B. et al., 2024, 'Determinants of the competitiveness of world palm oil exports: A cointegration analysis', *Transnational Corporations Review* 16(3), 200063. https://doi.org/10.1016/j.tncr.2024.200063

Lypko, N., 2022, 'The gravity model of trade: The case of central and eastern Europe', *Lexonomica* 14(2), 187–212. https://doi.org/10.18690/lexonomica.14.2.187-212.2022

Martin, M. & Pham, C.S., 2020, 'Estimating the gravity model when zero trade flows are frequent and economically determined', *Applied Economics* 52(26), 2766–2779. https://doi.org/10.1080/00036846.2019.1687838

Meijaard, E., Brooks, T., Carlson, K.M., Slade, E.M., Garcia-Ulloa, J. & Gaveau, D.L.A. et al., 2020, 'The environmental impacts of palm oil in context', *Nature Plants* 6(12), 1418–1426. https://doi.org/10.1038/s41477-020-00813-w

Mnasri, A. & Nechi, S., 2021, 'New nonlinear estimators of the gravity equation', *Economic Modelling* 95, 192–202. https://doi.org/10.1016/j.econmod.2020.12.011

Murphy, D.J., 2025, 'Agronomy and environmental sustainability of the four major global vegetable oil crops: Oil palm, soybean, rapeseed, and sunflower', *Agronomy* 15(6), 1465. https://doi.org/10.3390/agronomy15061465

Narayan, S. & Nguyen, T.T., 2016, 'Does the trade gravity model depend on trading partners? Some evidence from Vietnam and her 54 trading partners', *International Review of Economics & Finance* 41, 220–273. https://doi.org/10.1016/j.iref.2015.08.010

Park, S., 2025, 'A disrupted global trading system and the future of multilateralism', *Asia and the Global Economy* 5(2), 100123. https://doi.org/10.1016/j.aglobe.2025.100123

Pfaffermayr, M., 2020, 'Constrained poisson pseudo maximum likelihood estimation of structural gravity models', *International Economics* 161, 188–198. https://doi.org/10.1016/j.inteco.2019.11.014

Reviane, I.T.A., Paddu, A.H., Saudi, N.D.S., Handra, H. & Idris, A., 2025, 'Green trade, economic complexity and green indicators: Evidence in Asia countries with PPML fixed effects model', *Economies* 13(11), 314. https://doi.org/10.3390/economies13110314

Savarese, M., Castellini, G., Paleologo, M. & Graffigna, G., 2022, 'Determinants of palm oil consumption in food products: A systematic review', *Journal of Functional Foods* 96, 105207. https://doi.org/10.1016/j.jff.2022.105207

Schouten, G., Padfield, R. & Kraamwinkel, D., 2023, 'Contested representations: A comparative analysis of palm oil sustainability in Malaysian and Dutch media', *World Development Sustainability* 3, 100075. https://doi.org/10.1016/j.wds.2023.100075

Silva, J.M.C.S. & Tenreyro, S., 2006, 'The log of gravity', *Review of Economics and Statistics* 88(4), 641–658. https://doi.org/10.1162/rest.88.4.641

Srisunthon, P. & Chawchai, S., 2020, 'Land-use changes and the effects of oil palm expansion on a Peatland in Southern Thailand', *Frontiers in Earth Science* 8, 559868. https://doi.org/10.3389/feart.2020.559868

Syahza, A., 2019, 'The potential of environmental impact as a result of the development of palm oil plantation', *Management of Environmental Quality: An International Journal* 30(5), 1072–1094. https://doi.org/10.1108/MEQ-11-2018-0190

Tandra, H., Suroso, A.I., Syaukat, Y. & Najib, M., 2022, 'The determinants of competitiveness in global palm oil trade', *Economies* 10(6), 132. https://doi.org/10.3390/economies10060132

Tiits, M., Kalvet, T., Ounoughi, C. & Yahia, S.B., 2024, 'Relatedness and product complexity meet gravity models of international trade', *Journal of Open Innovation: Technology, Market, and Complexity* 10(2), 100288. https://doi.org/10.1016/j.joitmc.2024.100288

Tinbergen, J., 1966, 'Shaping the world economy: Suggestions for an international economic policy', *Economic Journal* 76(301), 92–95. https://doi.org/10.2307/2229041

United Nations Conference on Trade and Development (UNCTAD), 2019, *Key statistics and trends in international trade 2019*, United Nations, Geneva.

Westerlund, J. & Wilhelmsson, F., 2011, 'Estimating the gravity model without gravity using panel data', *Applied Economics* 43(6), 641–649. https://doi.org/10.1080/00036840802599784

Yu, L., Cao, Y., Cheng, Y., Zhao, Q., Xu, Y., Kanniah, K.D. et al., 2022, 'A study of the serious conflicts between oil palm expansion and biodiversity conservation using high-resolution remote sensing', *Remote Sensing Letters* 14(6), 654–668. https://doi.org/10.1080/2150704X.2022.2063701

Yuslaini, N., Maulidiah, S. & Harakan, A., 2025, 'Palm oil fluctuations and urban vulnerability in pursuit of sustainable industrial cities of the global south', *Frontiers in Sustainable Cities* 7, 1580197. https://doi.org/10.3389/frsc.2025.1580197

Zhang, S., Chen, Z., Chen, Y. & Yang, S., 2025, 'The structure and influencing mechanisms of the global palm oil trade: A complex network perspective', *Sustainability* 17(7), 3062. https://doi.org/10.3390/su17073062