Energy Mix, Energy Trade, and Trade Balance- A Causality Study of Short-run Interconnectedness and Long-run Equilibrium of 24 High-Income Countries

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The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript, and there is no financial interest to report.

The views expressed in this article are purely personal views of the authors and not those of the Reserve Bank of India.

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Abstract

Energy mix, climatic policy, and sustainable development have not only formed a reciprocatory troika but also influenced the energy trade of the nations, contributing to the overall balance of trade. Researchers explored the causality and contemporaneous relationships between these factors to figure out sector-specific interdependencies for countries across the world. However, a focused empirical examination of the short-run interconnectedness and long-run equilibrium between alterations in energy mix composition and impact on energy and the overall trade balance is yet to be conducted. By deploying a novel instrumental variable regression strategy and Granger Causality design for 24 high-income countries from 1990-2023, we establish a robust causal relationship between the energy balance of trade and the total trade balance. Additionally, this study uses cointegration techniques and an optimum lag-based Pooled Mean Group (PMG) estimation method to formulate a long-run equilibrium model of the total trade balance due to changes in the energy mix. We also examine the heterogeneity of energy component-specific and country-specific trade dynamics in light of the total trade balance within high-income groups. Finally, this study details the plausible reasons for such short-run and long-run dependencies of the energy mix and associated trade factors.

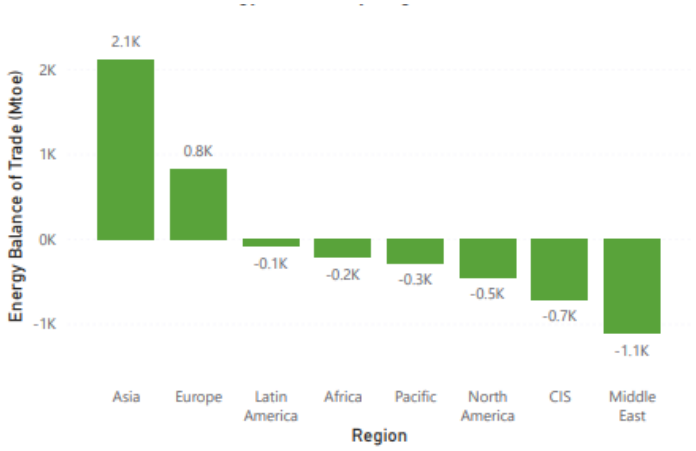
Keywords: Energy Trade, Energy Mix, Instrumental Variable, Long-run Equilibrium, Pooled Mean Group Estimator

JEL Codes: F14, Q43, C23, C36

Introduction

The global disparity between consumption and production has transformed energy products into the world's most extensively traded commodities, with nearly every country importing or exporting significant volumes of energy. Regions and countries with substantial energy consumption often lack sufficient domestic energy resources to fulfill their sizeable and expanding energy needs (Chart 1 depicts the regional variation of Energy Balance of Trade). At the same time, the primary energy-producing nations utilize only a minor fraction of their energy resources (Bahgat, 2013).

Chart 1: Energy Balance by Region (Mtoe)



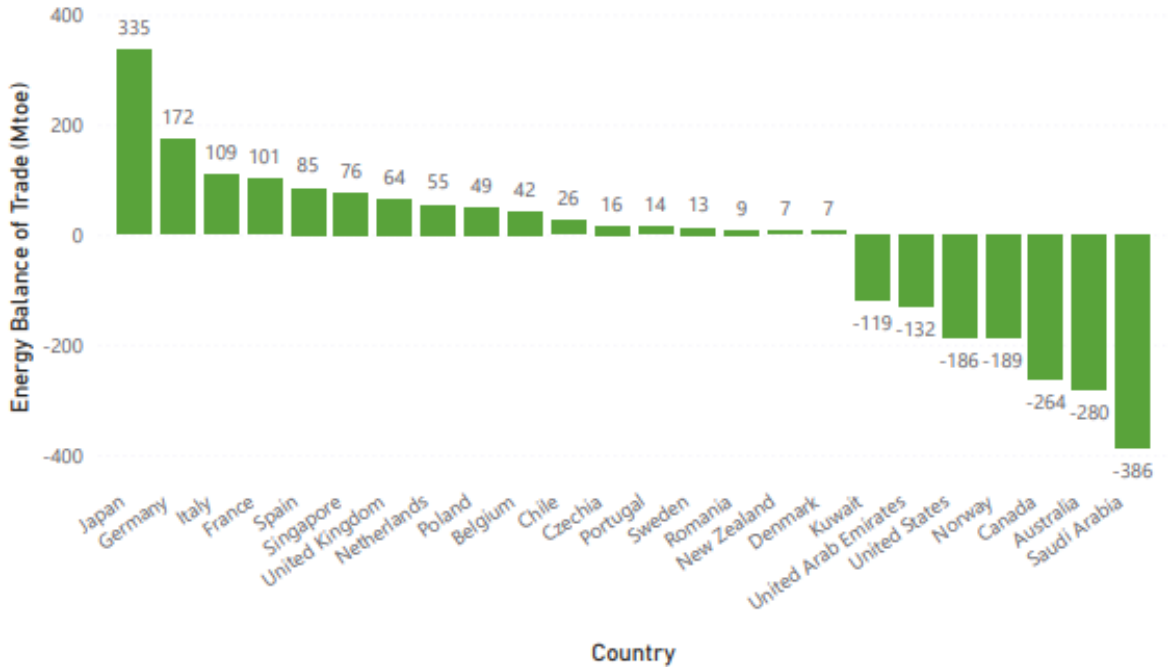
Note: In the energy balance format utilized by the United Nations Statistics Division, imports are positive numbers, and exports are negative numbers and carry a negative sign (-).

Source: Enerdata Yearbook 2023, Authors' construct

Fossil fuels still account for a significant portion of the energy mix in many developing economies, contributing to a negative energy balance of trade due to the reliance on imports to meet growing energy demand (Keeley & Matsumoto, 2018). The geographic distribution of the world's proven fossil fuel reserves is highly skewed, with Saudi Arabia, Kuwait, Canada, Norway, and the United Arab Emirates collectively accounting for nearly 83 percent of the global total (Abdelrashied & Bhattacharya, 2021). Conversely, the United States, Germany,

Japan, and the United Kingdom dominate global energy consumption, responsible for 66 percent of worldwide energy production (Hassan, 2020; Paundra & Nurdin, 2022). This disparity in the concentration of energy resources (Chart 2) and consumption patterns across nations is a significant factor in shaping international trade dynamics, with energy trade representing a major component of the overall trade balance for many countries.

Chart 2: Energy Balance by Country (Mtoe)



Note: In the energy balance format utilized by the United Nations Statistics Division, imports are positive numbers, and exports are negative numbers and carry a negative sign (-).

Source: Enerdata Yearbook 2023, Authors' construct

Trade balances influenced by various factors, including energy resources and trade dynamics, are critical indicators of economic well-being (Krugman, 1992). The literature suggests that the assignment of responsibility for reducing energy-related emissions can be influenced by the dynamics of international trade flows and the associated energy use patterns (Jebli & Youssef, 2015; Jiang et al., 2020; Sadorsky, 2011; Wu & Chen, 2017). A country's energy mix significantly impacts its trade balance, particularly its energy balance of trade. Adopting

renewable energy technologies can improve energy security and reduce the balance of payment burden for the economy.

The literature often discusses the energy balance of trade, total trade balance, and energy mix. Researchers explored the causality and contemporaneous relationships between these determinants to figure out sectoral-level interdependencies for countries across the world. In general terms, countries with unfavorable energy trade balances also show unfavorable total trade balances. Developed nations with high crude oil import volumes have their own idiosyncrasies (Bahgat, 2013). OECD[1] nations with a focused approach towards non-conservative energy production have witnessed either an improvement in trade balance or a transformation towards a conducive carbon credit regime (Alam & Murad, 2019). Emerging countries, heavily dependent on crude oil imports, have also displayed a pressing need for a climate-friendly energy mix to achieve the SDGs.

This study is unique due to its contribution to formulating a robust long-run equilibrium model in explaining the impact of energy mix on trade balance for 24 high-income countries[2,3] for a reasonably long duration of 34 years. Firstly, this study delves into examining the heterogeneous relationship between various components of the energy balance of trade and the total trade balance. By deploying a fixed effect panel regression strategy and instrumenting the dependent variable with its key contributors, we prove a short-run relationship between the

[1] The Organization for Economic Cooperation and Development (OECD) is an international organization consisting of 38 member nations.

[2] Australia, Belgium, Canada, Chile, Czechia, Denmark, France, Germany, Italy, Japan, Kuwait, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Saudi Arabia, Singapore, Spain, Sweden, United Arab Emirates, United Kingdom, United States

[3] **Source: World Bank** - Low-income economies are those with a GNI per capita of $1,145 or less in 2023; Lower middle-income economies are those with a GNI per capita between $1,146 and $4,515; Upper middle-income economies are those with a GNI per capita between $4,516 and $14,005; High-income economies are those with more than a GNI per capita of $14,005.

energy and total trade balances. We also deploy the Granger causality design to examine the causal relationships. However, we determine a componential heterogeneity across energy trade constituents: coal, crude oil, petroleum products, and natural gas.

Secondly, we incorporate energy mix components as determinants for the balance of energy trade and total trade. While we assess the short-run dependency of the energy balance of trade with energy mix, we examine the long-run equilibrium between total trade balance and energy mix determinants. Using the novel Pedroni's panel cointegration and Westerlund error-correction-based cointegration techniques, we discuss the long-run influence of energy mix factors on total trade balance.

Thirdly, we formulate an optimum lag-based Pooled Mean-Group long-run equilibrium estimation equation to examine the error correction terms and autoregressive coefficients. The uniqueness of this paper lies in the comprehensive coverage of short-run and long-run relationships among the energy trade, energy mix, and total trade balance components of the 24 high-income countries. At the end of the study, we negate the long-term dependency of the energy trade balance on the energy mix, reflecting a shift in the componential structure of the energy trade balance. We detail the plausible reasons for such transformation in the long-run policy transmission channels affecting energy trade. We also uniquely contribute to elaborating the policy-level interventions and changes in trade policy dynamics to influence the total trade balance in the long run by repositioning the energy mix. Lastly, we conduct a heterogeneity study amongst the European Union (EU)[4] and the non-EU nations to zero in on the existence and prevalence of decisive energy mix factors exhibiting divergence in the long-run trade balance.

[4] The European Union (EU) is a unique partnership of 27 European countries known as Member States or EU countries. Together, they cover much of the European continent.

Literature Review

A country's trade balance is defined as the country's total exports to the world minus total imports. Trade balance also indicates the country's involvement in the international marketplace. It is a surplus when exports exceed imports and a deficit when imports exceed exports (Keho, 2021; WITS - Trade Outcomes, 2024). Trade Balance is a significant component of the balance of payment and indicates the country's economic well-being. The year-on-year variations of the balance of payment are a significant concern, especially for developing economies; hence, determining its driving factors is critical for assessment and path correction.

Energy trade is a significant component of the overall trade balance, with profound implications for importing and exporting nations. Variations in energy export type and volume among exporter countries can lead to divergence in their trade patterns and influence the global energy landscape (Wu & Chen, 2017). OECD and high-income countries exhibit distinct energy trade patterns and associated impacts on their overall trade balances, contrasting with developing economies that tend to rely more heavily on energy imports to support economic growth and industrialization, resulting in more significant trade deficits linked to energy trade.

For high-income countries, energy trade constitutes a relatively small fraction of their overall trade, approximately 15 percent, whereas for developing economies, this proportion is often substantially higher, sometimes exceeding 50 percent. This divergent impact of energy trade on the aggregate trade balance underscores the need for nuanced policy approaches that account for the heterogeneity across countries and their distinct energy trade dynamics. This heterogeneity further influences both the short-term and long-term balance of payments position.

The European Union and non-EU countries exhibit distinct energy mixes and energy balances, reflecting their respective geographic, economic, and political landscapes. The EU, in particular, grapples with a substantial reliance on imported fuels, with approximately 70 percent of its oil, 43 percent of its natural gas, and 50 percent of its coal supply coming from foreign sources (Afgan & Carvalho, 2008; Hsieh et al., 2019; Lucas & Chondrogiannis, 2016; Ruan, 2023). In contrast, non-EU nations such as Kuwait, Saudi Arabia, Canada, New Zealand, Australia, Chile, the United States, and Brazil maintain a relatively higher proportion of domestic energy production and consumption than the EU. The EU's energy mix encompasses a variety of sources, including natural gas, oil, coal, nuclear power, hydropower, and other renewable energy options. Within the European Union, a disparity exists between particular nations, such as Russia, Norway, and the United Kingdom, that are net energy exporters. In contrast, others, including Germany, France, and Italy, are net energy importers (Lucas & Chondrogiannis, 2016; Bahgat, 2013). Similarly, Canada is a prominent energy exporter, shipping significant crude oil and natural gas volumes to the United States (Wu & Chen, 2017). The economies of OPEC[5] countries demonstrate a distinctive economic structure centered around energy export revenues, constituting a substantial portion of their GDP and overall trade (Demirbaş et al., 2017).

There are distinct differences in the energy trade dynamics of production-oriented and consumption-oriented economies. The asymmetry in energy trade flows creates imbalances in their overall trade balances. This leads us to formulate our first hypothesis to empirically investigate and quantify the distinct impact of energy trade on the overall trade balance.

H1: Energy trade has a significant but heterogeneous impact on the overall trade balance.

[5] The Organization of the Petroleum Exporting Countries (OPEC) is a permanent intergovernmental organization of 12 oil-exporting developing nations that coordinates and unifies the petroleum policies of its Member Countries.

Driven by new resources, innovative technologies, and international and national commitments towards greener energy, the global energy mix is undergoing significant transformation. The transition from a non-renewable energy mix towards renewable energy sources impacts the energy balance of trade and the overall trade balance over time (Araújo, 2014). The shift towards renewable sources will reduce the impact of oil and gas prices on trade balances and improve the economics of domestic renewable energy projects (Fattouh et al., 2019).

Different economies have different energy mix and energy balances based on their natural resource endowments, technological capabilities, and policy priorities (Schiffer et al., 2022). The energy mix and trade relationship are multifaceted, with short-term and long-term implications for trade balances. In the short run, a change in the energy mix affects the import-export dynamics of the associated economies (Araújo, 2014; Li et al., 2020; Sadorsky, 2011). In the long run, global supply chains are reshaped with sustained changes in the trade balances of both exporter and importer economies (Li et al., 2020; Sadorsky, 2011; Wu & Chen, 2017). Further, the introduction of renewable energy adoption policies by the importer countries[6] will improve energy self-sufficiency and trade balances in the long run (IRENA, 2021). Many countries are undergoing an energy transition by introducing clean alternatives in their energy mix and conservation efforts based on energy security, affordability, climate change mitigation, and environmental protection (Naqbi et al., 2019). On the other side, energy exporter countries, like members of the Organization of the Petroleum Exporting Countries (OPEC), will require realigning and diversification of their economies to cope with the change in trade dynamics due to the shift towards renewable sources (Brini et al., 2017).

Nonetheless, a rushed energy transition without securing sufficient energy supply through domestic production or international imports and shifting towards an imbalanced energy mix

[6] Countries meeting their energy requirement primarily through the import of fossil fuels like coal, petroleum, and other petroleum products.

dominated by a limited number of sources may introduce vulnerabilities to supply-side risks and negatively affect the energy import dependencies[7] and trade balances. The shift towards a more balanced energy mix coupled with domestic production capabilities provides energy security and reduces susceptibility towards supply shocks (Berdysheva & Ikonnikova, 2021; Jebli & Youssef, 2015).

Alam and Murad (2019) concluded that economic growth, technological progress, and trade openness have influenced the use of renewable energy in OECD countries over a long period. The long-term dynamics for the OECD countries were consistent for all economies under study (i.e., no country-specific heterogeneity was observed). However, for short-term dynamics, country-specific heterogeneity was observed. Further, the shift towards renewable energy consumption negatively affects the trade balance in the short run and positively in the long run (Idris et al., 2022).

The impact of renewable energy on the energy mix of the trade balance is still an open research question, as some studies suggest that increased reliance on renewable energy sources can potentially reduce energy import dependency and improve trade balances for energy-importing countries, while others note that the effect may depend on the specific characteristics of the renewable energy technologies and the broader economic context (Bahgat, 2013; Li et al., 2020; Wu & Chen, 2017). The correlation between the energy mix, energy balance of trade, and total trade balance is significant, but it is an understudied area (Sadorsky, 2011). An empirical examination of the relationship between alterations in energy mix composition and its influence on both energy balances and the overall trade balance is essential, given the research findings from prior studies and the identified gaps in the existing literature. This leads us to our second hypothesis:

[7] The percentage of a country's total energy needs that are met by imports from other countries.

H2: The shift in the energy mix has a short-run immediate influence on the energy trade and a long-term impact on the overall trade balance.

Importer economies relying heavily on non-renewable energy sources face significant trade deficits, mainly due to fossil fuel imports. These economies are particularly vulnerable to price shocks, destabilizing their trade balances and economic stability (Friedrichs, 2010; Hamilton, 2009; Kilian, 2009). In contrast, economies primarily using renewable energy exhibit lower dependencies on imports and international prices, resulting in stable trade balances (Mazzucato & Perez, 2015). Additionally, their trade balances are often bolstered by the export of green technologies to other economies. Economies with a balanced energy mix show varied outcomes, as the mitigated supply and price risks do not necessarily lead to trade balance surpluses.

Trade in energy products accounts for a significant portion of the overall trade balance for many nations, with energy trade surpluses or deficits significantly determining a country's overall trade position (Bahgat, 2013; Li et al., 2020; Wu & Chen, 2017). The impact of domestic generation capabilities, available technology, energy mix, and import sources determines the trade positions and balances across the global economy.

Wind and biomass predominantly meet Denmark's energy needs, leading to a significant energy trade surplus. In contrast, France relies heavily on nuclear power and maintains a slightly positive energy trade balance (Bahgat, 2013). The United Kingdom's energy mix includes oil, gas, coal, and renewables, resulting in an energy trade deficit (Li et al., 2020; Wu & Chen, 2017). Germany has reduced its trade deficit in recent years through the growth of renewable energy but remains a net energy importer. Italy has decreased its energy trade deficit over the past decade by increasing renewable energy generation and natural gas production. Australia is a major energy exporter, with trade surpluses driven by coal and liquefied natural gas exports

(Fattouh et al., 2019). New Zealand is energy self-sufficient, maintaining a neutral energy trade balance. Portugal and Spain are net energy importers, with trade deficits stemming from heavy reliance on fossil fuel imports (Tuğcu et al., 2020). Romania has transitioned from a net energy importer to a modest net exporter due to growth in the domestic production of fossil fuels. Chile is a net energy importer, with its trade deficit driven by dependence on imported fossil fuels (Green et al., 2016). Belgium is a net energy importer, with trade deficits stemming from reliance on nuclear and fossil fuels. Norway is a significant oil and natural gas exporter, with large trade surpluses driven by these energy exports.

Overall, the diversity in national energy mixes and the corresponding trade patterns underscores the importance of understanding the economic implications of a country's energy portfolio choices (Bahgat, 2013; Green et al., 2016; Kan et al., 2022). The dynamics of energy trade and its impact on trade balances are further complicated because the energy sector is often intertwined with geopolitical considerations, with energy resources and technologies being leveraged as strategic assets in international relations (Li et al., 2020; Wu & Chen, 2017), which has become even more evident in the wake of Russia-Ukraine crisis.

The country-wise heterogeneity observed in the energy trading pattern in high-income countries indicates the need to explore further the intricate connections between a nation's energy mix, energy trade dynamics, and broader economic performance, leading us to our third hypothesis:

H3: There is a country-level heterogeneity in the impact of energy mix and energy trade on the pattern of trade surpluses and deficits across nations.

Data and Variables

This study examines 24 high-income nations, which were carefully selected based on their substantial involvement and key role in the global energy trade, the availability of necessary data to conduct the analysis, and the World Bank's established income-based country classification system, which is regularly updated using the robust Atlas Method[8]. The rationale for selecting these specific countries is their significance and influence in global energy trade, both in terms of the high volume and value of their energy-related transactions. Additionally, the combined Gross Domestic Product of these 24 nations accounts for more than 50 percent of the world's GDP, underscoring their economic weight and importance in the global economy. Furthermore, these countries have experienced a notable shift in their energy balance in recent years, driven by the increasing adoption of renewable energy sources as part of their evolving energy mix.

The data for this analysis is obtained from two sources. First, we utilize the World Bank's World Development Indicators Database for crucial macroeconomic metrics, including GDP per capita, GNI per capita, inflation, unemployment, and various trade and climatic variables. These macroeconomic variables are taken as control variables for our study. Second, we utilize Enerdata's[9] datasets, which provide information on the components of the energy balance of trade (Crude Oil, Coal and Lignite, Oil Products, and Natural Gas account for 99.8 percent of

[8] **Source: World Bank** - The Atlas method smooths exchange rate fluctuations using a three-year moving average, price-adjusted conversion factor. The USD estimate of GNI per capita is derived by applying the Atlas conversion factor to estimates measured in LCU (Metreau et al., 2024).

[9] **Enerdata** is an independent research company specializing in analyzing and forecasting energy and climate issues.

the energy balance of trade), energy balance[10], energy intensity[11]Additionally, we have taken the share of renewable energy in electricity generation, the share of wind and solar sources in electricity generation, and CO_2 emissions as the determinants of energy mix from Enerdata. Trade balance, imports, and exports are taken as dependant variables. Table 1 summarizes the variables utilized for the study.

Table 1: Summary Table of Variables

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Year	Years for this study (1990-2023)	816	2006.5	9.817	1990	2023
EBT	Energy balance of trade (Mtoe)	816	21.131	175.923	-437.805	729.539
EINT	Energy intensity of GDP at constant purchasing power parities (koe/$15p)	816	0.118	0.044	0.045	0.261
CLPBT	Coal and lignite balance of trade (Mt)	816	-1.416	68.957	-393.037	196.555
COBT	Crude oil balance of trade (Mt)	816	17.891	128.308	-377.653	580.428
OPBT	Oil products balance of trade (Mt)	816	-2.924	23.176	-153.797	57.114
NGBT	Natural gas balance of trade (bcm)	816	8.78	43.89	-137.265	127.662
SREP	Share of renewables in electricity production (%)	816	26.3	27.229	0	99.77
SWSEP	Share of wind and solar in electricity production (%)	816	5.872	9.673	0	67.44
ACO	Average CO2 emission factor (tCO2/toe)	816	2.256	0.564	0.73	3.638
lnGDPPC	Log of GDP per capita (constant 2015 US$)	816	10.294	0.616	8.308	11.283
lnGNIPC	Log of GNI per capita (constant 2015 US$)	816	10.286	0.637	8.307	11.562
UNEMP	Unemployment, total (% of total labor force) (modeled ILO estimate)	816	6.688	3.711	0.694	26.094
INF	Inflation, consumer prices (annual %)	816	5.325	26.129	-2.093	567.879
FDIB	Foreign direct investment, net balance (% of GDP) (Inflow-Outflow)	816	0.331	3.758	-20.186	22.385
IMPGS1	Imports of goods and services (% of GDP)	816	40.884	30.531	6.809	208.333
EXPGS2	Exports of goods and services (% of GDP)	816	44.652	35.538	8.816	228.994
TB	Trade Balance of goods and services (% of GDP)	816	-3.648	9.655	-48.452	108.809
COE	CO2 emissions (kg per 2015 US$ of GDP)	816	0.384	0.28	0.062	1.941
Europe	EU countries (1 if is a part of EU, else 0)	816	0.583	0.493	0	1

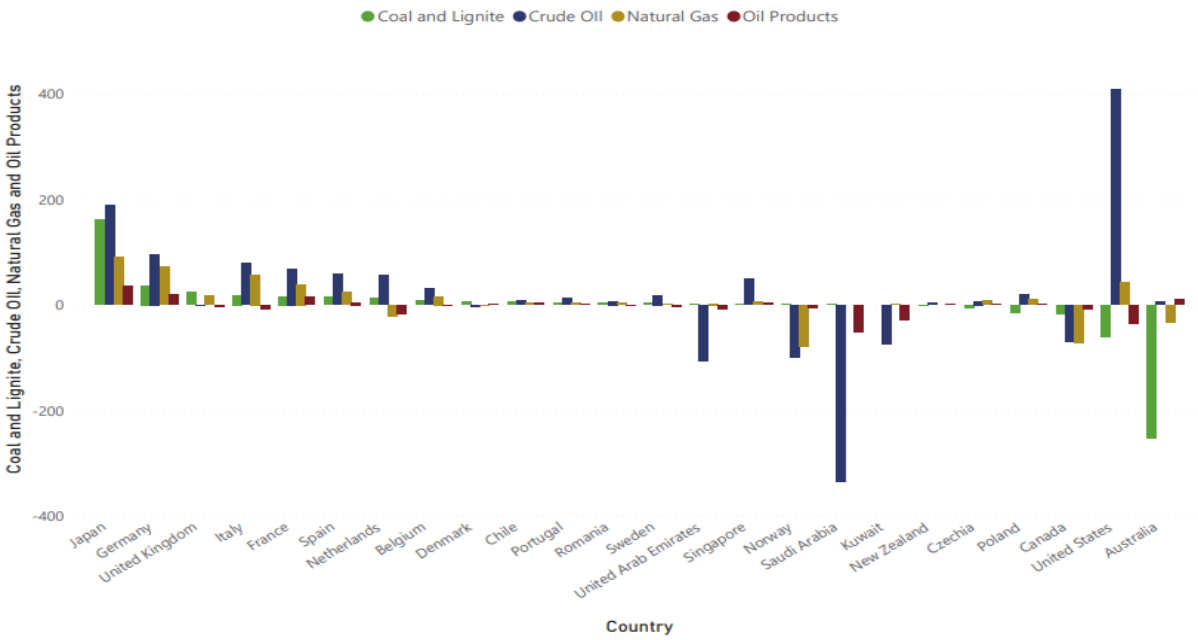
Source: Authors' calculations

[10] In the energy balance format utilized by the **United Nations Statistics Division**, imports are positive numbers, and exports are negative numbers and carry a negative sign (-).

[11] **Energy intensity** refers to the total primary energy supply (TPES) per thousand US dollars of GDP (OECD, 2016).

Preliminary data analysis reveals that Australia is the world's largest exporter of coal and lignite. Similarly, Saudi Arabia, followed by the UAE, Norway, Kuwait, and Canada, is identified as the leading exporter of crude oil. Furthermore, Norway, followed by Canada and Australia, is the top natural gas exporter. Conversely, the United States, Japan, and Germany are recognized as the top three importers of crude oil globally (Chart 3).

Chart 3: Components of Energy Mix by Country



Source: Enerdata Yearbook 2023, Authors' construct

The United States occupies a distinctive position in the global energy market, simultaneously exporting coal, lignite, and oil products while importing crude and natural gas. In contrast, countries like Saudi Arabia, Kuwait, the UAE, Norway, and New Zealand are predominantly energy exporters, while Japan, Germany, France, and Spain are net energy importers. These divergent energy profiles prompt the need to investigate the impact of their unique energy mixes and trade balances on overall trade balances in both the short-term and long-term.

Empirical Strategy

In this paper, we deploy the empirical models primarily to establish short-run and long-run relationships among the targeted variables. We start by testing short-run relationships and causality studies by incorporating the base model, the fixed-effect panel regression strategy. We also use the instrumental variable technique to obviate the plausible endogeneity of the independent variables. Further, we follow all necessary steps to establish a long-term relationship. This includes various cointegration tests, stationarity analysis, and formulating the long-run equilibrium model.

i) Short-run relationship

a) Base Model- Fixed Effect Strategy

To test our first hypothesis, we deploy a fixed-effect (FE) regression strategy as follows:

$$Y_{it} = \beta_1 X_{it} + \beta_2 W_{it} + \theta\, t + \alpha_i + \mu_t + \varepsilon_{it} \quad (1)$$

Here, Y_{it} is the outcome variable, i.e., the total trade balance (as % of GDP) of the ith country in the tth year. X_{it} is the key regressor/independent variable. Here, we consider the energy balance of trade in million tons of oil equivalent as the predictor variable. W_{it} consists of all the control variables in this analysis- GDP per capita, total unemployment, consumer price inflation, and net balance of foreign direct investment. α_i is the state-fixed effect. μ_t is the time-fixed effect. θ is the time trend coefficient incorporated to incorporate probable linearity and unobserved heterogeneities in the model (Stock & Watson, 1988). We run the regression six times by deploying both Pooled OLS (ordinary least square) and FE estimators for import, export, and total trade balance as outcome variables. Further, for a componential heterogeneity study amongst energy trade balance variables, we run Eq. 1 four times- once each for the coal and lignite balance of trade (CLPBT), crude oil balance of trade (COBT), oil products balance

of trade (OPBT), and natural gas balance of trade (NGBT). We also run Eq. 1 six times to examine the short-run impact of three energy mix determinants on the energy balance of trade.

b) Instrumental Variable Strategy

The predictors in Eq. 1 are primarily the energy balance of trade. Considering the overall volume of the energy trade balance and its various components, a plausible endogeneity is evident (Murshed, 2019). We deploy multiple Instrumental Variable (IV) regression techniques to obviate the endogeneity and the omitted variable biases. We deploy two-stage least squares (2SLS), limited-information maximum likelihood (LIML), and generalized method of moments (GMM) IV strategies to test our hypotheses. The energy balance of trade (EBT) variable is instrumented by the energy intensity of GDP (EINT), CLPBT, COBT, OPBT, and NGBT variables. The first stage of the equation is:

$$X_{it} = \alpha_i + \delta_t + \delta_1 EINT_{it} + \delta_2 CLPBT_{it} + \delta_3 COBT_{it} + \delta_4 OPBT_{it} + \delta_5 NGBT_{it} + \varepsilon_{it} \quad (2)$$

We use the first-stage regression results in Eq. 1 to determine the relationship between the total trade balance and energy balance of trade when the possible related variables instrument the latter. We further deploy the maximum likelihood counterpart of 2SLS techniques, i.e., the LIML estimator. Although it does not contain defined moments for any specific number of instruments (Dhrymes, 1994), we use it to check the robustness of the 2SLS estimator.

GMM estimator is used in IV techniques to reduce parameter estimation bias when predictor variables correlate with the error terms. Considering the consistency and higher efficiency of GMM estimators in the presence of heteroskedasticity (Qian & Schmidt, 1999), we deploy it as a further robustness check of our first hypothesis. Objective Function for GMM estimator:

$$Q[\beta_1, \beta_2] = \left(\frac{1}{N}\Sigma z_i u_i\right)' W \left(\frac{1}{N}\Sigma z_i u_i\right) \quad (3)$$

Here, z_i is the instrument vector. $u_i = y_i - Y_i\beta_1 - X_i\beta_2$, where y_i is the dependent variable, Y_i are the endogenous regressors, X_i represents the exogenous regressors. W is a positive-definite matrix (also known as weighting matrix) with the same number of rows and columns as the number of columns of z_i. The GMM estimator of (β_1, β_2) minimizes $Q[\beta_1, \beta_2]$.

c) Causality Analysis

As the short-run relationship among the variables depicts an associational coherence, the need to check the causal impact of the predictors on the outcome variable is needed. We check the causality by deploying a simple linear dynamic panel data model with a single covariate X_{it}. This method offers higher efficiency and lower bias due to using a pooled estimator with an optimized rate of convergence that caters to heterogeneous panel-level clusters (Xiao et al., 2023). It also incorporates cross-sectional dependence and cross-sectional heteroskedasticity. Following (Juodis et al., 2020), we deploy the following equation to perform a half-panel jackknife (HPJ) Wald-type test for Granger non-causality:

$$\mathrm{Y_{i,t}} = \phi_{0,\mathrm{i}} + \sum_{\mathrm{p=1}}^{\mathrm{p}} \phi_{\mathrm{p,i}}\, \mathrm{Y_{i,t-p}} + \sum_{\mathrm{q=1}}^{\mathrm{Q}} \beta_{\mathrm{q,i}}\, \mathrm{X_{i,t-q}} + \varepsilon_{it} \;\; ; \quad t = 1,2,\dots,T \qquad (4)$$

Here, Y_{it} is the outcome variable, i.e., total trade balance; $\mathrm{X_{i,t}}$ are the variables tested to observe a causal relationship with all the outcome variables- EBT, CLPBT, COBT, OPBT, and NGBT.

ii) Long-run Relationship

a) Cointegration test

Before deploying empirical methods to examine long-run relationships, we check the stationarity of the variables, as some of the tests require one or more nonstationary regressors (Pedroni, 2001). We check the plausible presence of unit roots in the variables by estimating a

basic autoregressive model with the lag effect of predictor variables when the serial correlation is present:

$$\Delta Y_{it} = \varphi_i Y_{i,t-1} + z'_{it}\lambda_i + \sum_{j=1}^{p} \Delta Y_{i,t-j} + \varepsilon_{it} \qquad (5)$$

Here, i = 1, . . ., N represents 24 countries in the panel; t = 1, . . ., T_i indicates a period of 34 years; p is the number of lags, and Y_{it} is the dependent variable being tested for the presence of unit roots. ε_{it} is a stationary error value. The z_{it} term indicates either only an entity-specific mean or the existence of a mean with a fixed time trend. We hypothesize null hypothesis H_0: φ_i=0 for all i and alternate hypothesis H_1: φ_i< 0 for all i. Following Eq. 5, we perform four different estimation strategies to examine stationarity. By following Levin et al. (2002), we assume that all panels have identical autoregressive components. In contrast, we also deploy a strategy that considers a fixed period (T) for estimation (Harris & Tzavalis, 1999). We follow Breitung (2004) with the standardized data for a strongly balanced panel. We check the veracity of our findings in the case of an unbalanced panel where autoregressive coefficients are not constant across panels (Im et al., 2003).

While testing our second hypothesis, we rely on energy mix variables and aim to establish a long-run relationship between the shift in energy mix and the total trade balance. We perform various panel-level cointegration tests to determine such long-run relationships. Considering the basic regression model in Eq. 1, we deploy multiple estimators to determine various test statistics. Pedroni (1999) calculates test statistics using a model where the autoregression (AR) parameter is either panel-specific or unchanged across panels. Pedroni (1999, 2004) termed the panel-specific-test statistics "group-mean statistics" and the unchanged test statistics "panel cointegration statistics." The panel-specific-AR test statistics are:

$$\text{Modified variance ratio (v)} = \mathrm{T}^2\mathrm{N}^{3/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{L}_{11i}^{-2}\ \hat{\mathrm{e}}_{\mathrm{i,t-1}}^{2} \right)^{-1} \qquad (6)$$

Modified Phillips-Perron t (rho) = $\mathrm{TN}^{-1/2}\ \sum_{i=1}^{N}(\ \sum_{t=1}^{T}\hat{\mathrm{e}}_{\mathrm{i,t-1}}^{2})^{-1}\ \sum_{t=1}^{T}(\hat{\mathrm{e}}_{\mathrm{i,t-1}}\Delta\hat{\mathrm{e}}_{\mathrm{i,t}}-\hat{\lambda}_{i})$ (7)

Phillips-Perron t (t) = $\mathrm{N}^{-\frac{1}{2}}\sum_{i=1}^{N}\widehat{\sigma_{i}^{2}}(\sum_{t=1}^{T}\hat{\mathrm{e}}_{\mathrm{i,t-1}}^{2})^{-\frac{1}{2}}\sum_{t=1}^{T}(\hat{\mathrm{e}}_{\mathrm{i,t-1}}\Delta\hat{\mathrm{e}}_{\mathrm{i,t}}-\hat{\lambda}_{i})$ (8)

Augmented Dickey-Fuller t (ADF) = $\mathrm{N}^{-1/2}\ \sum_{i=1}^{N}(\sum_{t=1}^{T}\widehat{s_{i}^{2}}\ \hat{\mathrm{e}}_{\mathrm{i,t-1}}^{2})^{-\frac{1}{2}}\ \sum_{t=1}^{T}\hat{\mathrm{e}}_{\mathrm{i,t-1}}\Delta\hat{\mathrm{e}}_{\mathrm{i,t}}$ (9)

Here, $\hat{\mathrm{e}}_{\mathrm{i,t}}$ is the residual obtained from the base panel data regression model. We evaluate $\hat{\lambda}_{i}=\frac{1}{2}(\widehat{\sigma_{i}^{2}}-\widehat{s_{i}^{2}})$, where $\widehat{\sigma_{i}^{2}}$ and $\widehat{s_{i}^{2}}$ are long-run and the individual contemporaneous variances of the residuals from the AR-test regression: $\hat{\mathrm{e}}_{\mathrm{i,t}}=\rho_{i}\ \hat{\mathrm{e}}_{\mathrm{i,t-1}}+v_{it}$, where ρ_{i} is a panel-specific autoregressive parameter and v_{it} is a stationary error term. We perform cointegration tests for all the energy mix determinants (as detailed in the data section) with the balance of total trade and energy trade variables.

Westerlund (2005) considered panel-specific cointegrating vectors as in the basic panel data model in Eq. 1, where all panels have heterogeneous regression coefficients. We calculate group-specific and panel-specific variances by deploying the AR-test regression equation, as mentioned earlier, and by estimating:

Panel-specific test statistics= $\sum_{\mathrm{i=1}}^{\mathrm{N}}\sum_{\mathrm{t=1}}^{\mathrm{T}}\widehat{E_{it}^{2}}\ \widehat{R_{i}^{-1}}$ (10)

Group-specific test statistics= $\sum_{\mathrm{i=1}}^{\mathrm{N}}\sum_{\mathrm{t=1}}^{\mathrm{T}}\widehat{E_{it}^{2}}\left(\sum_{i=1}^{N}\hat{R}_{i}\right)^{-1}$ (11)

All these cointegration tests have been deployed for the energy balance of trade (EBT) and total trade balance (TB) as the outcome variables, whereas the energy mix determinants are the predictor variables.

b) Long-Run Equilibrium Model

We conduct the required empirical investigations before deploying the long-run error correction model for this study. We test the optimal lags for all the dependent and independent variables before formulating the long-run model. Once the cointegration tests and stationarity assessments provide conducive results, we deploy the long-run equilibrium equation to ascertain the relationship between energy mix and trade balance. Following Islam (2021) and Otim et al. (2023), we deploy three different long-run models with cointegrating vectors- Pooled Mean-Group (PMG), Mean-Group (MG), and Dynamic Fixed Effects (DFE) Models. With this, we examine short-run coefficients as well as both constrained and unconstrained heterogeneous long-run coefficients. We specify the equilibrium model as follows:

$$\Delta Y_{it} = \theta_i\left[Y_{i,t-1} - \lambda'_{i1}X_{1,it} - \cdots - \lambda'_{in}X_{n,it}\right] + \sum_{j=1}^{p-1} \zeta_{ij}\,\Delta Y_{i,t-j} + \sum_{j=0}^{q_1-1} \beta'_{1,ij}\,\Delta X_{1,i,t-j} + \cdots$$

$$+ \sum_{j=0}^{q_n-1} \beta'_{n,ij}\,\Delta X_{n,i,t-j} + \varphi_i + \varepsilon_{it} \qquad (12)$$

Here, $\theta_i = -(1-\varphi_i)$ is the entity-specific speed adjustment coefficient where φ_i is the coefficient of the lagged dependent variable in Eq. 5. $\lambda'_{in}$is the vector of long-run relationships of predictor variable X_n for the i[th] country. $\left[Y_{i,t-1} - \lambda'_{i1}X_{1,it} - \cdots - \lambda'_{in}X_{n,it}\right]$ is the error correction term. ζ_{ij} and β'_{ij} are the short-run dynamic coefficients. We consider these three models to assess the best fit for our study. We perform the Hausman test to determine the best-fit long-run model. Deploying Eq. 12, we also check the long-term heterogeneity at the country level amongst the 24 nations considered for the study.

Results

We present the results in three sections- the impact of energy trade on the trade balance, the impact of energy mix on both energy trade and total trade balance, and the country-level heterogeneity in the impact of the energy mix and energy trade on the pattern of trade balances amongst EU and non-EU countries.

Energy Trade and Trade Balance

As we elaborate on the role of energy in determining the trade dynamics of the nations due to their overdependence on the import or export of crude oil or related petroleum products, the energy balance of trade influences the total trade balance. Deploying a Pooled OLS mode in Eq. 1, we find that unit change in the energy balance of trade (here, the balance of trade is calculated as the gap between import and export) affects the total trade balance of the countries by 1.02% in the same direction (Table 2). Although the exports do not show any significant change, imports rise by 1.14% with a unit increase in the energy balance of trade, signifying the import dependence and import-driven trade dynamics of the selected high-income countries. While deploying the Fixed-effect regression strategy, we observe quantitatively similar results. A unit change in energy trade balance changes the total trade balance (as % of GDP) by 1.06%, driven mainly by the imports that change by a significant 1.19%.

Table 2: Pooled OLS and Fixed Effect Regression Results

	Import	Export	Trade Balance	Import	Export	Trade Balance
Energy balance of trade	0.0114***	0.0017	0.0102***	0.0119***	0.0018	0.0106***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
GDP per capita	-2.8742	17.8324***	-12.1794***	-3.2737	18.4776***	-22.3021***
	(2.59)	(2.57)	(1.62)	(2.67)	(2.62)	(2.37)
Total Unemployment	-0.4434***	0.1761	-0.3925***	-0.4372***	0.1963	-0.6287***
	(0.13)	(0.12)	(0.11)	(0.13)	(0.12)	(0.12)
Inflation, consumer prices	-0.0260	0.0281	-0.0404**	-0.0268	0.0292	-0.0618***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)

Foreign direct investment, net balance	-0.1671*	-0.3388***	0.0843	-0.1770**	-0.3509***	0.1629**
	(0.09)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)
Time Trend	0.4048***	0.2513***	0.0589*	0.4112***	0.2427***	0.1966***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.04)
constant	-738.5223***	-643.4272***	5.6932	-747.7874***	-634.0041***	-164.7491**
	(75.65)	(74.68)	(61.76)	(76.30)	(74.79)	(68.62)
Estimation Method	Pooled OLS	Pooled OLS	Pooled OLS	Fixed Effect	Fixed Effect	Fixed Effect
Hausman test				13.87**	11.91**	86.30***
Modified wald test for heteroskedasticity (χ-sq)				8800.56***	22279.68***	51414.57***
R-squared	0.236	0.373	0.120	0.237	0.373	0.132
Obs	760	760	773	760	760	773

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

We perform instrumental variable strategies to check our findings' robustness through Pooled OLS and FE panel regression strategies. Eq. 2 provides the results for two-stage least squares and limited-information maximum likelihood strategies. These two models represent a rise in trade balance by 0.44% with a rise in the energy balance of trade (Table 3). The generalized method of moments strategy, as formulated in Eq. 3, shows a quantitatively similar result to the other two IV strategies. GMM model shows a 0.61% rise in the trade balance with a unit rise in the energy balance of trade. With this, we establish that the energy balance of trade influences the total trade balance. Further, we run the regression models with the components of the energy trade and find that only the crude oil balance of trade (at a minimum 5% level) significantly affects the total trade balance. With a unit change in the crude oil trade balance, the total trade balance changes by 2.15% in the same direction (Table 4). Further, Coal and lignite, as well as the natural gas balance of trade, do not significantly influence the total trade balance. For oil products, the percentage impact is 2.68% at a 1% significant level, reiterating the component-specific heterogeneity.

Table 3: Instrumental Variable Regression Results

	Trade Balance	Trade Balance	Trade Balance	Trade Balance
Energy balance of trade	0.0044***	0.0061***	0.0044***	0.0044***
	(0.002)	(0.001)	(0.002)	(0.001)
GDP per capita	-5.0802***	-4.8583***	-5.0803***	-5.0802***
	(0.481)	(0.532)	(0.481)	(0.530)
Total Unemployment	0.3076***	0.2822***	0.3076***	0.3076***
	(0.073)	(0.056)	(0.073)	(0.064)
Inflation, consumer prices	-0.0067	-0.0050	-0.0067	-0.0067
	(0.015)	(0.008)	(0.015)	(0.009)
Foreign direct investment, net balance	-0.5575***	-0.4456***	-0.5575***	-0.5575***
	(0.069)	(0.130)	(0.069)	(0.129)
Time Trend	-0.0108	-0.0070	-0.0108	-0.0108
	(0.028)	(0.022)	(0.028)	(0.023)
constant	68.8404	59.1685	68.8574	68.8404
	(55.355)	(45.497)	(55.355)	(47.101)
Estimation Method	Instrumental Variable	Instrumental Variable	Instrumental Variable	Instrumental Variable
Instrument Type	2SLS	GMM	LIML	2SLS
Variance Estimators	Unadjusted	Unadjusted	Unadjusted	Robust
Wu-Hausman/Robust F	15.9031***			16.155***
Durbin (score)/Robust (χ-sq)	15.7188***			14.6519***
GMM C statistic (χ-sq)		18.4666***		
Anderson-Rubin (χ-sq)			42.8214***	
Basmann F			10.5306***	
First-stage regression F	807584***	991557***	807584***	991557***
adjusted R-squared	0.269	0.265	0.269	0.269
Obs	674	674	674	674

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Table 4: Fixed Effect Regression Results- Energy Trade Components

	Trade Balance	Trade Balance	Trade Balance	Trade Balance
Coal and lignite balance of trade	0.0037			
	(0.01)			
Crude oil balance of trade		0.0215***		
		(0.01)		
Oil products balance of trade			0.0268*	
			(0.02)	
Natural gas balance of trade				0.0162
				(0.01)
GDP per capita	-7.0989***	-22.5556***	-21.9152***	-23.3584***
	(1.59)	(2.38)	(2.38)	(2.37)
Total Unemployment	-0.2751***	-0.6300***	-0.6145***	-0.6551***
	(0.07)	(0.12)	(0.12)	(0.12)
Inflation, consumer prices	-0.0261**	-0.0618***	-0.0626***	-0.0661***
	(0.01)	(0.02)	(0.02)	(0.02)
Foreign direct investment, net balance	-0.1054**	0.1587**	0.1566*	0.1721**
	(0.05)	(0.08)	(0.08)	(0.08)
Time Trend	0.0145	0.2044***	0.1831***	0.1921***
	(0.03)	(0.04)	(0.04)	(0.04)
constant	42.6483	-177.8309**	-141.2798**	-143.7893**
	(44.36)	(69.50)	(67.71)	(69.26)
Estimation Method	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect
Log likelihood	-2049.211	-2533.895	-2536.405	-2307.340
F statistic	9.326	19.065	18.140	21.186
R-squared	0.073	0.133	0.128	0.158
Obs	740	773	773	707

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

To check the causality among the variables, we deploy Eq. 4 and examine the relationships between the total trade balance and the energy balance of trade, as well as the components of energy trade. All the test statistics show quantitatively similar results. We find that the energy balance of trade has a causal relationship with the total trade balance (Table 5). However, of the four major components, we find only two Granger cause the total trade balance- crude oil and oil products balance of trade. The causality study affirms that the energy balance of trade Granger causes the total trade balance. With the causality test results, we conclude that the energy trade has a significant but heterogeneous causal impact on the overall trade balance.

Table 5: Causality Statistics- Total Trade and Energy Trade Components

	HPJ Wald statistic	Wald statistic	Z-bar statistic	Z-bar tilde statistic
Energy balance of trade	6.9627***	8.3541***	7.5415***	5.2989***
Coal and lignite balance of trade	2.6046	1.0322	0.1991	-0.0411
Crude oil balance of trade	7.8821***	5.937***	3.3549***	2.0423***
Oil products balance of trade	8.5312***	6.9049***	5.0314***	3.3464***
Natural gas balance of trade	2.1224	1.0607	0.2102	-0.0329

Source: Authors' calculations

Energy Mix and Trade Balance

While incorporating energy mix as a component for this study, we consider three different determinants that could impact the energy balance of trade. Deploying Eq. 1 for these energy mix determinants as independent variables, we find that an increase in the share of renewable energy in the total electricity production increases the energy balance of trade, indicating that energy imports outperform energy exports. Similarly, an increase in the average CO2 emission factor (CO2 emission per tonne of oil equivalent energy consumed) reduces the energy balance of trade by 23.14%, indicating a substantial increase in energy exports (Table 6). These results are counterintuitive, and we discuss the plausible reasons in the discussion section. Further, we consider the crude oil trade balance, the most significant component of the energy balance of trade, as the dependent variable and observe quantitatively similar results. A 1% rise in the share of renewables in electricity production increases the crude oil balance of trade by 0.61%, whereas the CO2 emission factor affects it by 19.72%.

Table 6: Regression Results- Energy Mix and Energy Balance of Trade

	Energy balance of trade	Energy balance of trade	Energy balance of trade	Crude oil balance of trade	Crude oil balance of trade	Crude oil balance of trade
Share of renewables in electricity production	1.0156***			0.6157***		
	(0.29)			(0.15)		
Share of wind and solar in electricity production		1.4608***			1.1025***	
		(0.43)			(0.23)	
Average CO2 emission factor (tCO2/toe)			-23.1476***			-19.7249**
			(2.65)			(6.19)
GDP per capita	92.3487***	84.5569***	49.9959	57.5432***	53.3929***	37.2694**
	(22.39)	(22.18)	(36.17)	(11.86)	(11.69)	(15.48)
Total Unemployment	1.8108	1.4182	1.2574	0.9229	0.6583	0.6626
	(1.13)	(1.13)	(1.53)	(0.60)	(0.59)	(0.52)
Inflation, consumer prices	0.1278	0.0871	0.0111	0.0690	0.0443	0.0176
	(0.16)	(0.16)	(0.15)	(0.08)	(0.08)	(0.06)
Foreign direct investment, net balance	-0.8654	-0.8909	-1.0726	-0.1984	-0.2085	-0.4005
	(0.74)	(0.74)	(1.24)	(0.39)	(0.39)	(0.46)
Time Trend	-3.3208***	-3.5534***	-3.0911***	-2.0241***	-2.3276***	-2.1661***
	(0.69)	(0.72)	(0.67)	(0.36)	(0.38)	(0.31)
constant	5681.5042***	6248.1083***	-428.1163	3458.1256***	4119.5726***	-309.1664*
	(1279.83)	(1354.99)	(362.65)	(678.26)	(714.04)	(154.64)
Estimation Method	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect
Log-likelihood	-4222.214	-4222.582	-4324.285	-3731.393	-3727.388	-3819.874
F statistic	2.306	2.285	2.112	2.994	3.226	2.665
R-squared	0.107	0.106	0.090	0.135	0.144	0.126
Obs	773	773	792	773	773	792

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

As we find a robust and counterintuitive dependence of energy trade on energy mix, we ascertain the plausible long-run association among them. Following Eq. 5, we deploy a cointegration test of energy mix determinants with energy balance of trade. By deploying Eq. 6 to Eq. 9 to calculate various test statistics of Pedroni's panel cointegration tests, we find no long-run dependency of the energy balance of trade on energy mix factors. We observe no long-run relationships with Eq. 10 and Eq. 11 for Westerlund error-correction-based panel cointegration test statistics (Table 7). This finding makes us consider that the previously established significant regression results are short-run and do not stand well in the long run. The cointegration tests verify the similar long-run associations of the energy mix determinants with the total trade balance. We observe a significant long-run association of total trade balance

with the energy mix determinants (Table 8). We delve into finding the long-run model with total trade balance as the dependent variable and energy mix factors as predictors.

Table 7: Cointegration of Energy Mix Determinants with Energy Balance of Trade

Sdrs Rs`shrshbr	V drsdqkt mc dqpnq, bnqqdbshnm,a`rdc o`mdlk bnlmsdfq`shnmsdrsr	Sdrs Rs`shrshbr	Odcqnmhb&o`mdlk bnlmsdfq`shnmsdrsr, O`mdlkKdudk
Fqnto l d`m sdrsr, Fs	,0-/6	L nclehdc u`qh`mbd q`shn 'u(	/-/47/5
Y,u`kt d	*2-/5*	*Fqnto Kdudk*	
Fqnto l d`m sdrsr, F`	,1-237	L nclehdc Oghkkhor, Odqqnms 'qgn(	0-35
Y,u`kt d	*3-174*	*Fqnto Kdudk*	1-156))
O`mdlkl d`m sdrsr, Os	,4-2/2	Oghkkhor,Odqqnms 's(	0-/28
Y,u`kt d	*/-765*	*Fqnto Kdudk*	/-8423
O`mdlkl d`m sdrsr, O`	,0-417	@tfl dmsdc Clbj dx, Etkkdqs'@CE(	0-543)
Y,u`kt d	*1-016*	*Fqnto Kdudk*	0-143

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Table 8: Cointegration of Energy Mix Determinants with Total Trade Balance

Sdrs Rs`shrshbr	V drsdqkt mc dqpnq, bnqqdbshnm,a`rdc o`mdlk bnlmsdfq`shnmsdrsr	Sdrs Rs`shrshbr	Odcqnmhb&o`mdlk bnlmsdfq`shnmsdrsr, O`mdlkKdudk
Fqnto l d`m sdrsr, Fs	,1-/81))	L nclehdc u`qh`mbd q`shn 'u(	0-071
Y,u`kt d	*,0-718*	*Fqnto Kdudk*	
Fqnto l d`m sdrsr, F`	,4-750	L nclehdc Oghkkhor,Odqqnms 'qgn(	,0-534)
Y,u`kt d	*0-418*	*Fqnto Kdudk*	,-1387
O`mdlkl d`m sdrsr, Os	,06-075)))	Oghkkhor,Odqqnms 's(	,3-742)))
Y,u`kt d	*,7-08*	*Fqnto Kdudk*	,3-4/7)))
O`mdlkl d`m sdrsr, O`	,3-350	@tfl dmsdc Clbj dx,Etkkdq s'@CE(	,2-784)))
Y,u`kt d	*,/-037*	*Fqnto Kdudk*	,2-52)))

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

To examine the possible existence of unit roots and stationarity of the model variables, we deploy Eq. 5 and perform Im-Pesaran-Shin (IPS), Levin-Lin-Chu (LLC), Breitung, and Harris-

Tzavalis (HT) tests. Table 9 summarizes the results. The test results establish that the total trade balance is stationary at the level, whereas the energy mix determinants are stationary at the first difference. With an aim to obtain the correct lag order, we then test all the variables up to 2 lag orders by performing a basic Autoregressive Distributive Lag (ARDL) model. Table 10 represents country-specific optimum lag orders, where 16 out of 24 countries show (1, 0, 0, 0) as the optimum lag order. Finally, we deploy Eq. 12 and obtain the long-run equilibrium model. Although we use the PMG, MG, and DFE models, the significance of the coefficients indicates that PMG is applicable in our study. The coefficients represented in Table 11 tell an exciting story. Firstly, the counterintuitive short-run results get reversed in the long run, where the rise in the share of renewables in electricity production decreases the total trade balance, indicating a lowering of the gap between imports and exports. The coefficient is similar for the share of wind and solar in electricity production as predictor variable. The average CO2 emission factor has a positive coefficient, reiterating the results obtained for the share of renewables (an increase in renewable share reduces the CO2 emission factor). Secondly, all the long-run coefficients are significant. Thirdly, the error correction term in the long-run equilibrium model is significant, highlighting the convergence of the model to equilibrium in case of a short-term disequilibrium. We conclude that the shift in the energy mix has a short-run immediate influence on the energy trade and a long-term impact on the overall trade balance.

Table 9: Unit Root Test Results

Variables for Long-run Relationship	Im-Pesaran-Shin (IPS) Test Stat	Levin-Lin-Chu (LLC) Test Stat	Breitung Test Stat	Harris-Tzavalis (HT) Test Stat
Total Trade Balance	-1.9273**	-8.7371***	-2.5773***	0.6533***
Share of renewables in electricity production	14.2747	6.2968	7.6737	0.9986
Share of renewables in electricity production- First Difference	-10.9922***	-15.3947***	-6.1879***	-0.2062***
Share of wind and solar in electricity production	21.2014	8.2337	8.4694	1.0794
Share of wind and solar in electricity production- First Difference	-22.4195***	-25.2963***	-2.7430***	0.1786***

Average CO2 emission factor	4.0145	-3.9150**	7.8770	0.9510
Average CO2 emission factor- First Difference	-14.8252***	-21.0245***	-5.1625***	-0.1381***

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Table 10: Optimum Lag Order Identification

Countries	Trade Balance	Share of renewables	Share of wind and solar	CO2 emission factor
Australia	1	0	0	0
Belgium	1	0	1	0
Canada	1	0	0	0
Chile	1	1	0	0
Czechia	1	0	0	0
Denmark	1	0	0	0
France	1	0	0	0
Germany	1	0	0	0
Italy	1	2	0	0
Japan	1	0	1	0
Kuwait	1	0	0	0
Netherlands	1	0	0	0
New Zealand	2	1	0	0
Norway	1	0	0	0
Poland	1	0	0	0
Portugal	2	0	1	1
Romania	1	0	0	0
Saudi Arabia	1	0	0	0
Singapore	1	0	0	0
Spain	1	0	0	0
Sweden	1	0	0	1
United Arab Emirates	1	0	0	0
United Kingdom	1	0	0	0
United States	1	0	0	0

Source: Authors' calculations

Table 11: Regression Results- Long-run Equilibrium Model

	Crude Oil balance of trade	**Crude Oil balance of trade**	**Crude Oil balance of trade**
Long Run Coefficients			
Share of renewables in electricity production	-0.2911**	817.3505	0.4671
	(0.11)	(778.14)	(0.73)
Share of wind and solar in electricity production	-0.4557**	-781.6261	-1.2611
	(0.21)	(779.50)	(1.05)

Average CO2 emission factor	109.3033***	127.7888	21.9025
	(30.05)	(130.42)	(24.47)
Short Run Coefficients			
Error Correction Term	-0.3044**	0.1976	-0.1349**
	(0.13)	(0.26)	(0.05)
Δ (Share of renewables in electricity production)	42.3316	139.6264	-0.0944
	(30.23)	(109.73)	(0.13)
Δ (Share of wind and solar in electricity production)	-29.7461	-103.9686	-0.2010
	(28.66)	(105.63)	(0.40)
Δ (Average CO2 emission factor)	3.6925	20.1131	2.2269
	(41.08)	(59.86)	(13.23)
constant	-7.7378**	-5.3546	-3.1528
	(3.56)	(13.06)	(2.44)
Model Type	Pooled Mean-Group (PMG)	Mean-Group	Dynamic Fixed Effects
Long-run Cointegrating vector	YES	YES	YES
Error Correction Term	YES	YES	YES
Hausman test with PMG (χ-sq)	-	26.29***	24.40***
Obs	720	720	720

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Country-level Heterogeneity

As we examine the relationships between energy trade and total trade in high-income countries, we also determine their country-specific heterogeneity to further deliberate on the plausible reasons. Table 12 indicates a substantial divergence between the EU and the non-EU nations. The coefficients are more than double for the EU countries. As the EU countries witness a 2.48% and 1.5% rise in total trade balance (as a percentage of GDP) due to unit rise in energy balance of trade for FE and IV regression strategies, respectively, the results are 1.21% and 0.7% for the non-EU countries. In the case of the USA, a unit rise in the energy balance of trade affects the total trade balance by a meager 0.22%. Similarly, Table 13 summarizes the regression results for the short-term impact of the energy mix on the energy balance of trade.

The country groups show firm heterogeneity. The regression coefficients are positive for EU countries; however, they are negative for the non-EU nations and the USA. This finding enables us to assess that the counterintuitive argument of a rise in the share of renewables in electricity production increases the gap between imports and exports, which is primarily dominated by the EU countries. In contrast, the others show the expected opposite relationship. All these findings raise some intriguing questions that we uniquely answer in this paper. Why do the components of the energy balance of trade have a heterogeneous relationship with the total trade balance? How do EU countries differ from non-EU countries regarding the interlinkage dynamics of energy trade, energy mix, and total trade? Why is there no long-run relationship between energy mix and energy balance of trade? We elaborate on the answers in the discussion section.

Table 12: Regression Results- Country Specific Heterogeneity (Energy trade and total trade)

	EU Countries	Non-EU Countries	EU Countries	Non-EU Countries	USA
Energy balance of trade	0.0248***	0.0121**	0.0150***	0.0070***	0.0022***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
GDP per capita	-5.6473***	-17.4310***	-4.1633***	0.2311	4.5605***
	(1.06)	(3.48)	(0.38)	(1.20)	(1.25)
Total Unemployment	-0.2322***	-0.6278	-0.0233	1.7348***	-0.1377
	(0.05)	(0.40)	(0.05)	(0.25)	(0.09)
Inflation, consumer prices	-0.0240***	-0.0732	-0.0076	0.5775***	0.1919***
	(0.01)	(0.26)	(0.01)	(0.22)	(0.07)
Foreign direct investment, net balance	0.0552	0.1752	0.2093***	-1.2930***	0.0414
	(0.05)	(0.18)	(0.06)	(0.12)	(0.03)
Time Trend	-0.0386*	0.1376*	-0.0317	0.0679	0.0544
	(0.02)	(0.08)	(0.02)	(0.06)	(0.05)
constant	134.6598***	-99.9564	104.2952**	-154.1798	-47.7674***
	(33.48)	(149.22)	(42.65)	(121.93)	(13.74)
Estimation Method	Fixed Effect	Fixed Effect	Instrumental Variable	Instrumental Variable	Instrumental Variable
Instrument Type	-	-	2SLS	2SLS	2SLS
Variance Estimators	Robust	Robust	Robust	Robust	Robust
Wu-Hausman/Robust F	-	-	15.1695***	3.9169**	4.1109**

First-stage regression F	-	-	144986***	1.6e+06***	117098***
adjusted R-squared	0.171	0.174	-	-	-
Obs	461	312	461	312	33

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Table 13: Regression Results- Country Specific Heterogeneity (Energy Mix and Energy Trade)

	EU Countries	Non-EU Countries	EU Countries	Non-EU Countries	USA	USA
Share of renewables in electricity production	0.2148**	-2.5994**			-35.6168***	
	(0.11)	(1.22)			(11.17)	
Share of wind and solar in electricity production			0.3318**	-3.6593**		-57.6746***
			(0.16)	(1.60)		(15.57)
GDP per capita	30.6942***	68.7871	33.5157***	114.3040**	2106.0903***	1528.4122**
	(8.94)	(47.00)	(9.11)	(47.17)	(568.88)	(642.35)
Total Unemployment	-0.4446	7.7910*	-0.4666	8.0996**	20.6931	2.9455
	(0.38)	(4.04)	(0.38)	(4.00)	(12.46)	(14.92)
Inflation, consumer prices	0.1177**	0.9613	0.1196**	-1.6120	-3.9301	4.4417
	(0.05)	(3.25)	(0.05)	(3.00)	(7.29)	(8.00)
Foreign direct investment, net balance	0.0752	-1.2091	0.0529	-1.9023	2.1270	-0.9475
	(0.29)	(1.65)	(0.29)	(1.67)	(3.19)	(3.32)
Time Trend	-0.6181**	-3.4442**	-0.7408**	-3.3760**	-31.7294***	-14.3467
	(0.27)	(1.54)	(0.29)	(1.54)	(9.58)	(12.86)
constant	958.1081*	6193.7836**	1178.6538**	5557.0060*	42057.7010***	13160.0385
	(503.16)	(2891.85)	(543.88)	(2955.71)	(13254.14)	(19074.89)
Estimation Method	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Pooled OLS	Pooled OLS
Log likelihood	-	-	-	-	-176.098	-174.554
F statistic	-	-	-	-	116.459	128.308
R-squared	0.141	0.251	0.138	0.252	-	-
Obs	461	312	461	312	33	33

* p<0.10, ** p<0.05, *** p<0.010

Source: Authors' calculations

Discussion and Conclusion

We find a robust causal relationship between the energy balance of trade and the total trade balance, primarily due to the share of energy trade in the total trade. Our study shows that the

relationship between the two is primarily import-driven. 18 out of 24 countries under this study are net energy importers. Further, we observe reasonably higher coefficients for the EU nations, signifying the EU countries driving the positive causal and correlational impact of the energy trade balance on the total trade balance. This is attributed to the fact that 13 out of 14 high-income EU countries in this study are net energy importers. In 2022, the EU imported 97.7% of its oil and petroleum products and 97.6% of its natural gas (Eurostat, 2023). The energy trade balance composition is extremely lopsided towards the crude oil trade balance (84.67% of the energy balance of trade in these 24 countries is contributed by crude oil), indicating a solid energy trade composition-specific heterogeneity in the total trade balance. For the pool of 24 countries, a rise in renewable energy use portrays more imports and a less favorable trade balance. Although all the EU countries except Norway in this study are net energy importers, higher use of non-conservative energy sources encourages the nations to import non-petroleum energy products, affecting the energy balance of trade. Researchers found this to be a short-term phenomenon as the shift towards a climate-friendly energy mix requires conducive infrastructure development (Zeren & Akkuş, 2019), immediate source substitution, and alternate short-run high-intensity bulk energy backups (Ilechukwu & Lahiri, 2022). All these incur short-term unfavorable energy balance of trade. However, non-EU nations in this research are primarily large energy exporters, and a shift in the energy mix anyway improves the trade balance. However, the case of the USA is idiosyncratic. Although a net energy importer, other energy trade components compensate for the highly unfavorable crude oil balance of trade in the USA (105% of the average energy balance of trade for the 34 years of study). A favorable energy mix reduces energy import, and with the other energy trade components already having a favorable trade balance, it improves the overall trade balance (Ahmad & Zhang, 2020). However, the relationship with the total trade balance is long-run, and the equilibrium exists due to the steady and sustainable systemic impact of the energy mix in tweaking the energy

types as well as the industry production composition of the countries (J. S. Islam et al., 2018; Lin et al., 2022). For the 24 high-income nations, the favorable energy mix with a better CO2 emission factor exhibits an improved trade structure. It further enables them to shift their trade dynamics systematically towards sustainable and less energy import-driven favorable trade space.

These observations are unique in the energy trade domain and can substantially contribute to policymaking to promote the optimum energy mix and enable the smooth integration of renewable energy technologies for improved trade balance (Ouédraogo, 2017). We focus on the select 24 countries due to their commonalities in economic strength and spending capacity. However, considering the role of emerging economies in the changing space of energy trade dynamics, future studies may focus on empirical analysis of geopolitical risks and their impact on the energy trade patterns of emerging countries (Li et al., 2021).

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