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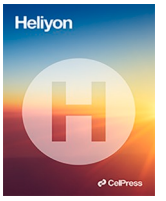

Research article

The Russia-Ukraine conflict, soaring international energy prices, and implications for global economic policies

Mingsong Sun [a], Xinyuan Cao [b], Xuan Liu [c], Tingting Cao [d,e,**], Qirong Zhu [f,*]

[a] School of Economics and Finance, Huaqiao University, Quanzhou, 362021, China
[b] School of Professional Studies, Columbia University, New York, 10027-6902, USA
[c] College of International Economics and Trade, Dongbei University of Finance and Economics, Dalian, China
[d] Postdoctoral Station, Dongbei University of Finance and Economics, Dalian, 116025, China
[e] Postdoctoral Station, Shandong Rural Credit Union, Jinan, 250014, China
[f] Business school, Wuxi Taihu University, Wuxi, 214064, China

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ABSTRACT

This study examines the economic impact of soaring international energy prices during the Russia-Ukraine conflict from February 23, 2022, to May 31, 2022. Notably, by applying a CGE model, this study offers insights into energy policies at both macroeconomic and industrial levels, emphasizing the model's utility in analyzing complex economic interactions under geopolitical stress. Findings indicate that: **(1) Russia, a critical energy-producing country**, faced severe economic setbacks due to sanctions, with its GDP contracting by 5.5 %, household income decreasing by 4 %, and consumer spending dropping by 3.5 %. This was accompanied by a significant reduction in domestic investment by 6 %, a decline in output by 5 %, and a decrease in societal welfare indicators. **(2) Other energy-producing countries or regions**, such as the Middle Eastern oil-producing countries, Australia, Canada, Mexico, and Southeast Asia, experienced economic benefits from the global energy market's "crowding-out effect." These regions saw an increase in GDP ranging from 2 % to 4.5 %, output growth by 3 %–6 %, and household income and consumption improvements by approximately 3 %–5 %. However, these benefits were tempered by a 1 %–2.5 % decline in domestic investment due to rising local energy costs. **(3) Developed and developing regions,** suffered adverse impacts, including the US, UK, EU, Japan, China, South Asia, Middle Eastern non-oil-producing countries, and Africa. These regions reported a decrease in GDP by 0.5 %–3 %, a decline in household income by 2 %–4 %, and lower consumption rates by 1.5 %–3.5 %. The economic strain was further exacerbated by an inflation increase of up to 2 % across these economies. This research offers valuable insights for governments and policymakers globally to address the challenges posed by the Ukraine crisis-induced energy crisis, underscoring the need for strategic energy policy adjustments and economic resilience planning.

* Corresponding author.
** Corresponding author. Postdoctoral Station, Dongbei University of Finance and Economics, Dalian, 116025, China.
E-mail addresses: sunmingsong896@163.com (M. Sun), caoxinyuancolumbia@163.com (X. Cao), liuxuan_0519@163.com (X. Liu), caotingting@dufe.edu.cn (T. Cao), zhuqirong2008@163.com (Q. Zhu).

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List of Abbreviations

- *bbl* Barrel (as a unit of measure for oil)
- *C* global consumption/ Consumption
- *CGE* Computable General Equilibrium
- D_i the energy demand of energy-producing country *i*
- *E* Energy supply
- E_i the energy exports of energy-producing country *i* / Energy supply of sector *i*
- *G* Government spending
- *GDP* Gross Domestic Product
- *I* a global investment/ Investment
- I_i Investment in the sector *i*
- *M* Imports
- M_i the energy imports of energy-producing country *i*
- M_{ij} Quantity imported by sector *i* from sector *i*.
- M^W Total world imports
- *MMBtu* Million British Thermal Units
- *P* global price level
- P_i the energy price of energy-producing country *i* / sector *i*
- P^W Total world price.
- *Q* Quantity of goods
- *USD* United States Dollar
- *X* global energy supply/ Exports
- X_i the output of energy-producing country *i*
- X_{ij} Demand of sector *i* for sector *i*
- *Y* global economic output
- Y_i Output of sector *i*
- Y^W Total world output
- Δ Symbol representing change
- ε Elasticity of demand or supply
- π Inflation rate
- η Efficiency parameter

1. Introduction

On February 24, 2022, a comprehensive military conflict erupted between Russia and Ukraine, leading to a series of sanctions imposed by Western countries, spearheaded by the United States. These sanctions aimed to disrupt Russia's energy exports, culminating in a significant energy crisis [1–3]. Such geopolitical events often have profound and far-reaching consequences, especially in global energy markets [4,5]. Understanding the economic impact of these crises is crucial for policymakers and governments worldwide.

These sanctions sought to impede Russia's energy exports, precipitating a substantial energy crisis [6,7]. On March 8, 2022, President Biden announced a halt to Russia's imports of energy products, including oil, natural gas, and coal. Shortly after that, the United Kingdom also declared its intention to cease imports of energy products from Russia within the same year.[1] Japan followed suit by announcing a ban on exporting refining equipment and technology to Russia [8,9]. In April 2022, the European Union (EU) initiated its fifth round of sanctions against Russia, which included measures like prohibiting Russian vessels from accessing EU member ports, restricting new investments in Russia's energy sector by EU member states, and forbidding the sale, supply, transfer, or export of specific refining products and technologies to Russia [10]. Subsequently, on June 3, 2022, the EU disclosed additional measures as part of its sixth round of sanctions against Russia, which involved imposing an embargo on select petroleum products and sanctions on Russian oil tankers and related financial institutions [11].

These collective actions by Western governments put immense pressure on prominent Western multinational energy corporations, such as BP, Royal Dutch Shell, ExxonMobil, and Equinor, leading them to terminate their economic and technological cooperation with Russian energy enterprises [12,13]. Furthermore, the UK and the EU decided to prohibit domestic insurance companies from providing

[1] Since the outbreak of the Russo-Ukrainian conflict, there has been a sustained increase in global commodity prices, particularly in the prices of oil and natural gas. This has put significant inflationary pressure on countries worldwide and has also impacted global energy trade. The tension in certain geopolitical regions is driving up global crude oil prices, resulting in higher energy expenses for countries and exacerbating the financial burden on businesses, ultimately affecting their national economies. Additionally, in the context of a strong US dollar, localized geopolitical military crises are beneficial to the US dollar and its exports of oil and natural gas.

coverage to vessels transporting Russian oil, effectively obstructing Russia's maritime access to the international oil market [14].

The central focus of these sanctions has been Russia's energy exports, given their critical role in the country's foreign exchange earnings and its heavy reliance on energy markets in Western countries, particularly in Europe and the United States [2,6,7]. In 2021, Russia accounted for 11.4 % of global oil exports, 17.8 % of coal exports, and 19.1 % of natural gas exports. Over recent years, a significant share of Russia's oil, gas, and coal exports has reached Western countries, including the European Union, the United States, and Japan [15]. The imposition of sanctions on Russia by Western nations, spearheaded by the United States, sent shockwaves through the international energy market, resulting in a sharp increase in global energy prices. This energy crisis exposed vulnerabilities in the global energy system and raised questions about its long-term sustainability [7,10,16]. The turbulent fluctuations in international energy supply and demand, driven by the sanctions against Russia and the subsequent substantial price hikes, have had profound and far-reaching impacts on the global economy [8,17].

The German Federal Ministry for Economic Affairs and Climate Protection predicts that Germany's projected economic growth rate in 2022 has decreased by 1.4 % compared to the January forecast, reaching a modest 2.2 %. This decline is primarily attributed to factors such as the Russia-Ukraine military conflict and rising energy prices [8,16]. The rising energy costs have also significantly increased household expenditures. Statistical data from Eurostat, the statistical office of the European Union, reveals that the Eurozone's inflation rate soared to 8.5 % in March 2022. The resulting high cost of living has dramatically burdened citizens [18,19], leading to widespread discontent and protests across multiple European countries. Developing economies have not been spared either [17]. Sri Lanka, heavily reliant on energy imports, experienced severe fuel and electricity shortages, resulting in price surges and exacerbating the economic crisis. This situation has triggered strong public dissatisfaction and protests, contributing to domestic political instability. Carmen Reinhart, Chief Economist at the World Bank, highlights that Sri Lanka's economic predicament is just one example, as more developing countries are likely to face similar challenges [20].

Since the outbreak of the Russia-Ukraine conflict, global commodity prices, especially those of oil and natural gas, have been on a sustained upward trajectory. This trend has exerted significant inflationary pressures on nations worldwide and considerably impacted global energy trade. The localized escalation of geopolitical tensions is poised to increase global crude oil prices, escalating global energy prices, consequently raising energy expenditures for nations, intensifying the cost burden on businesses, and thereby impacting domestic economies. Against a robust US dollar, this localized geopolitical crisis favors the dollar, particularly benefiting US crude oil and natural gas exports.

The instability and sustainability issues in the global energy market are becoming increasingly evident, posing a significant challenge to the United Nations Sustainable Development Goals (SDGs). The complexity of this problem necessitates comprehensive actions by the international community to ensure the stability, sustainability, and accessibility of energy supply while simultaneously achieving sustainable development goals [17,19,21,22]. Therefore, there is an urgent need for research on the Energy Crisis Triggered by the Ukraine Crisis.

This study aims to assess the economic impact of the Ukraine crisis's global energy crisis, analyse its effects on industry output, and provide practical policy recommendations. The study period spans from February 23, 2022, to May 31, 2022. The unique contribution of this research lies in its comprehensive approach, including the establishment of a novel energy price transmission dynamics system, the application of a Computable General Equilibrium (CGE) model, an in-depth analysis of industry output, and the provision of tailored policy recommendations.

As global geopolitical tensions continue to influence international energy markets, this study aims to assess the economic impact of the Ukraine crisis's exacerbation of the global energy crisis, analyse its effects on industry output, and provide actionable policy recommendations. Employing a CGE model from February 23, 2022, to May 31, 2022, this research uniquely contributes by introducing a novel energy price transmission dynamics system. It extensively analyzes the intricate relationships within affected economies and identifies key sectors most significantly impacted by the energy price volatility. This comprehensive approach not only fills existing research gaps but also offers nuanced insights into the macroeconomic implications of international energy price fluctuations, thus aiding policymakers in formulating targeted strategies to mitigate such impacts and foster economic stability.

This study directly addresses the complex global challenge posed by the energy crisis intensified by the ongoing Ukraine conflict. **We have introduced several significant innovations in our research methodology and analysis**.

(1) **Innovative Energy Price Transmission Dynamics System.** We developed a novel system that covers a broad spectrum of economies, including major global players such as China, Japan, the United States, and the European Union. This system fills existing research gaps by enabling a comprehensive analysis of how energy price fluctuations, triggered by geopolitical events, impact global economies.

(2) **Application of a CGE Model.** Our study leverages the CGE model to delve into the macroeconomic implications of international energy price fluctuations. By analyzing parameters such as GDP, household income, consumption, social welfare, investment, and trade, the model provides a detailed perspective on the intricate economic relationships affected by these fluctuations.

(3) **Sector-specific Analysis of Industry Output.** We explored the effects of energy price volatility on industry output across the studied economies. This analysis identifies the sectors and industries most significantly impacted by the energy crisis, which is crucial for developing targeted and effective policy recommendations. The practical implications of identifying these vulnerable sectors are immense, providing policymakers with the insights to formulate strategies that mitigate adverse impacts and enhance economic resilience.

Collectively, these contributions advance the academic understanding of how energy price fluctuations influence global markets

and equip policymakers with actionable insights to enhance stability, sustainability, and accessibility within the global energy market. Our findings and recommendations aim to foster a more profound comprehension among the international community, thereby aiding in effectively managing the economic impacts of geopolitical energy crises.

2. Literature review

The conflict between Russia and Ukraine, initiated on February 24, 2020, triggered a series of sanctions imposed by Western countries, with the United States taking a prominent role. Among these sanctions, energy exports from Russia emerged as a primary target. The EU, a significant importer of Russian energy, relied on Russia for nearly 40 % of its natural gas supply [23]. As Europe's existing energy structure faced significant challenges due to supply restrictions, such as obtaining matching energy supply from other countries or regions, it became evident that geopolitical events like these have profound and far-reaching consequences, especially in global energy markets.

This emphasis on energy in geopolitical conflicts has been introduced previously. Natorski and Surralles [24] argued that many EU member states faced energy supply security challenges influenced by multiple political and economic factors. Disruptions in global energy markets can place enormous pressure on governments [25]. Moreover, countries with strong trade, financial, and migration ties to both Russia and Ukraine would experience direct and substantial impacts [26].

The importance of energy as a foundational pillar supporting economic and social activities cannot be overstated. Rising energy costs directly impact the prices of commodities, making it a critical factor in global economic stability [23], leading to a shortage of crops and cereals in the food market [27]. From a global perspective, rising energy prices would lead to a worldwide cost of living crisis, intensify social conflicts, and cause social unrest [25]. However, the ramifications extend beyond price hikes. The Russia-Ukraine conflict, for instance, resulted in food market disruptions and supply shortages, which contributed to "hunger and food" insecurity in low-income countries [26]. These supply shortages, coupled with security concerns and economic uncertainty driven by volatile energy prices, were described by the International Energy Agency (IEA) as "the first truly global energy crisis, with impacts that will be felt for years to come" [28].

Existing literature on the impact of global energy price fluctuations stemming from geopolitical conflicts has mainly focused on various analytical methods, including partial equilibrium analysis (such as the Vector Autoregression model, or VAR), income-output models, CGE analysis, dynamic stochastic general equilibrium (DSGE) models, cross-quantilogram approaches, and structural vector autoregressive (SVAR) analysis methods.

Partial equilibrium analysis has been pivotal in understanding the influence of international oil price fluctuations. For example, Hamilton [29] employed a VAR model to investigate the effects of oil price fluctuations on major economies' GDP and unemployment rates since World War II. Building upon this research, Cologni and Manera [30] used a VAR model to explore the effects of oil price fluctuations on output and prices in G7 countries. Similarly, Natalia [31] employed a VAR analysis to investigate the repercussions of international oil price changes on the Russian economy. Expanding the scope of inquiry, Abdulrahman [32] employed a VAR model to empirically analyse the ramifications of fluctuating international oil prices on the economic growth of South Sudan, revealing a significant adverse impact of oil price increases on the country's GDP.

Additionally, some studies explored the relationship between energy price shocks and various economic factors. Sokhanvar et al. [33] adopted the cross-quantilogram approach to study the impact of energy price shocks on exchange rate fluctuations, while Emter et al. [34] employed the SVAR analysis method to discuss the influences of energy price shocks on price competitiveness and euro area export performance. Moreover, Podieiachenko [35] conducted a comprehensive analysis of the effects of international oil prices on Chinese prices, elucidating that changes in global oil prices reverberate across multiple domestic production sectors, including oil and gas, chemicals, and food, thereby influencing the overall price levels in China.

The study revealed that an increase in crude oil prices leads to an overall rise in domestic prices. Levent and Mustafa [36] conducted a CGE analysis to examine the effects of rising international oil prices on the Turkish economy. Their research indicated that the increase in international oil prices not only resulted in a decline in output and consumption levels within the country but also worsened its international balance of payments. Wu and Shan [37] utilized a DSGE model to analyse the macroeconomic impact of international oil price volatility on China. Their findings demonstrated that increased international oil prices stimulate domestic inflation, resulting in higher business production costs and reduced domestic output and investment. Through analysis, it could be seen that energy shocks would significantly affect industries with high risk, and the medium-term prospect of euro area competitiveness was not good, exporters' input costs were likely to rise accordingly.

CGE models have been extensively employed within academic discourse to evaluate the ramifications of fluctuating global oil prices on diverse national economies. Xiao [38] investigated the repercussions of escalating international crude oil prices on the Chinese economy. They harnessed a Chinese CGE model to simulate the impact of varying oil price scenarios on distinct economic indicators. The study elucidates the adverse effects of oil price hikes on China's economic landscape and underscores the pivotal role played by technological advancements in mitigating these risks. In a more in-depth exploration, Timilsina et al. [39] delved into the intricate nexus between oil prices, the expansion of biofuels, and their implications for food supply. Their research revealed a significant upsurge in biofuel penetration prompted by oil price hikes, with consequential impacts on agricultural output and global food supply. Timilsina [40], employing a global Computable General Equilibrium model, meticulously examined the economic consequences of rising oil prices. The study accentuated the unequal distribution of these impacts across countries and sectors, emphasizing the imperative consideration of biofuel capacity in addressing oil price volatility. Jia et al. [41] directed their attention to the confluence of the 2020 COVID-19 pandemic and the precipitous decline in international oil prices. Their analysis discerned economic recession and dissected variations in input factors and consumer preferences, subsequently exploring the environmental repercussions

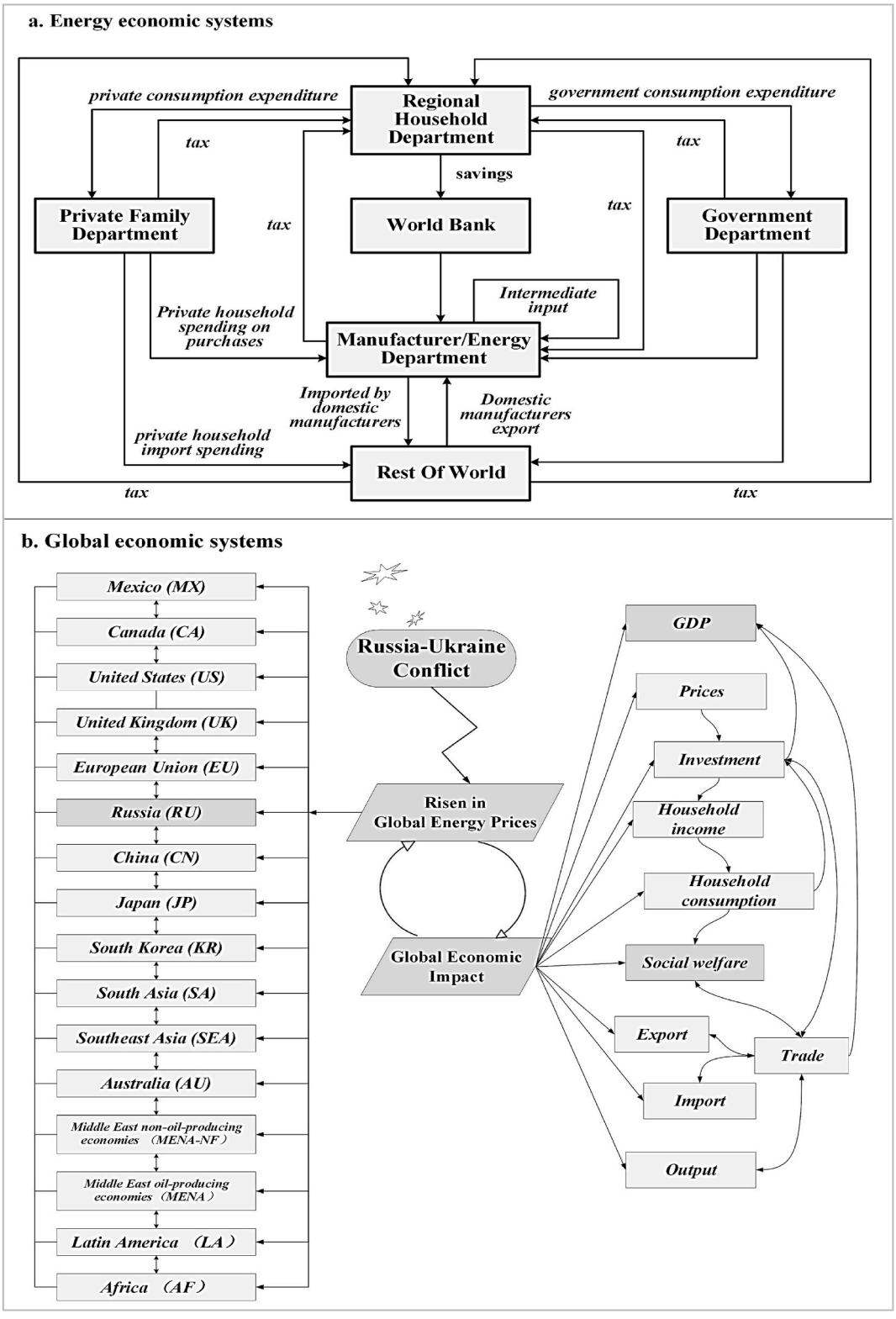

Fig. 1. A CGE model of the Global Energy Economy Supply System.

of these events.

Carbone and Rivers [42] scrutinised the influence of unilateral climate policies on competitiveness, elucidating that such policies are prone to moderate reductions in output and exports from emissions-intensive trade-exposed (EITE) sectors. Babatunde et al. [43] comprehensively reviewed applying CGE models in climate change mitigation. They underscored the vital role of CGE models at different scales in addressing climate change. They highlighted preferences for themes such as carbon taxation, emission reduction targets, and renewable energy within the scope of CGE models. Cui et al. [44] pointed out that the Russia-Ukraine conflict led to short-term sharp fluctuations in energy prices, and the global energy supply chain and economic and trade order were unstable. To explore the influence of the energy disruption caused by the Russia-Ukraine conflict on the macro-economy of the relevant trading countries, they selected the CGE model for empirical analysis. The results showed that the trade disruption would significantly reduce Ukraine's GDP. The energy sanctions adopted by the United States and Europe against Russia would not only have a lot of adverse effects on the Russian economy, but also raise the economic cost of the sanctioning countries and disrupt the global political and economic pattern. In summary, the extant literature underscores the paramount importance of CGE models in comprehending the multifaceted impacts of fluctuating global oil prices on various facets of economic and social domains.

The existing body of literature on the impact of crude oil price fluctuations has undeniably contributed valuable insights to the field. Historically, the focus of research has predominantly been on examining the effects of oil price changes on various economic indicators such as price levels, output, consumption, and international balance of payments. However, a closer inspection reveals discernible limitations in these studies. One notable limitation is that these studies often focus on specific aspects and overlook vital economic indicators like employment, income distribution, and sectoral dynamics. Moreover, there is an evident gap in comprehensively examining potential non-linear effects and asymmetries in the relationship between energy prices and economic variables. While providing depth in some areas, this narrow approach leaves significant aspects of the energy-economic relationship needing to be explored, particularly in the broader context of global economic impacts and specific events like the Russia-Ukraine conflict.

This study aims to provide a more holistic perspective in light of these identified gaps. Our literature review explores various analytical methods to understand the impacts of global energy price fluctuations stemming from geopolitical conflicts. These include partial equilibrium analysis, DSGE models, and SVAR analysis methods. Each offers unique insights but also presents limitations when applied to complex, multi-sectoral global scenarios.

The CGE model, however, stands out due to its comprehensive approach to simulating the economic interrelations and sectoral adjustments across entire economies. Unlike partial equilibrium models, which focus on specific sectors or markets in isolation, CGE models provide a holistic view by encompassing all economic sectors. This allows for assessing both direct and indirect effects of shocks on an economy, capturing the broader economic dynamics better than SVAR models, which often require prior assumptions about the relationships between variables. Furthermore, unlike DSGE models, which are typically tailored to address monetary policy and macroeconomic stability questions, CGE models are specifically adept at analyzing trade policies and their wide-ranging impacts, making them particularly suitable for evaluating the economic consequences of geopolitical events and international policy shifts.

This breadth and integration capability make CGE models particularly valuable for our study, which seeks to comprehensively analyse the ripple effects of energy price fluctuations driven by the Russia-Ukraine conflict across various global economies. By employing a CGE model, we can more effectively simulate the interdependencies of trade, industry output, and macroeconomic indicators such as GDP, household income, and consumption, providing a nuanced understanding critical for formulating robust policy recommendations.

While the academic world has initiated valuable explorations into the impact of energy prices, especially in geopolitical events like the Russia-Ukraine conflict, there remains a substantial research void. This void pertains specifically to the quantitative assessments regarding the repercussions of soaring international energy prices (including oil, gas, and coal) on the global economic landscape. Armed with a comprehensive analytical framework, this study aspires to bridge this gap, fostering a deeper comprehension of the ramifications of the recent international energy price surges on the global economy.

3. Methodology

Fig. 1 presents a simplified framework that improves our comprehension of how energy price fluctuations affect global output, prices, and imports while shedding light on the interplay among different sectors. This framework enhances our understanding of the intricate nature of the global energy market.

3.1. Theoretical basis

According to Walras' theory of general equilibrium, economic activities involve interconnectedness between prices and supply-demand relationships of commodities. Changes in one entity's price influence the costs and supply-demand of others, leading to market equilibrium. In a globalised economy, countries are tightly interconnected. Fluctuations in international energy prices, driven by political and economic shocks, impact the production and export capacities of energy-producing countries. This affects the prices and supply-demand of other commodities. As energy is a vital input, its price fluctuations reverberate through energy-importing countries, influencing production costs, prices, output, and supply-demand of various products. Consequently, global energy price changes cascade through economies, affecting GDP, income, consumption, investment, welfare, trade, and price levels worldwide.

3.2. Mathematical model

Johansen [45] established the CGE model, which analyses price and supply-demand relationships to integrate economic activities in the national economy. Over the past 60 years, the CGE model has been widely used to analyse the impact of economic variables on the national economy. The GTAP model, developed by Hertel [46] and his team at Purdue University, builds upon neoclassical economic theory to analyse the effects of international economic events and policies on multiple economies. Incorporating trade relationships among 141 countries/regions, the GTAP model provides a global CGE model. This paper adopts a CGE framework and mathematical model, both expanded and refined, based on specific requirements and data derived from the GTAP10 database.

3.2.1. Mechanism of domestic prices and import/export prices of commodities in different countries

The offshore price of exporting commodity i from country (region) r to country (region), denoted as $ps^{fob}_{i,r,s}$, can be calculated using Equation (1). Equation (1) expresses the production price (domestic price) of commodity i, $ps^{fob}_{i,r,s}$, in country (region) r, adjusted by the subsidy or tax on the export of item i from country (region) r to country (region) s, represented by $\tau^{e}_{i,r,s}$.

$$ps^{fob}_{i,r,s} = ps_{i,r,s}\left(1+\tau^{e}_{i,r,s}\right) \tag{1}$$

In Equation (2), $pim_{i,r,s}$ represents the import duty-paid price of purchasing commodity i by country (region) r from country (region) s. It can be calculated using the cif price of importing commodity i, $pim^{cif}_{i,r,s}$, adjusted by the tariff imposed on the import of commodity i by country (region) r from a country (region) s, denoted as $\tau^{m}_{i,r,s}$.

$$pim_{i,r,s} = pim^{cif}_{i,r,s}\left(1+\tau^{m}_{i,r,s}\right) \tag{2}$$

Equation (3) defines $pim^{cif}_{i,r,s}$ as the sum of the offshore price of exporting commodity i from country (region) r to country (region) s, $ps^{fob}_{i,r,s}$, and the transportation insurance costs of commodity i trade between country (region) r and country (region) j, represented by $t^{mg}_{i,r,s}$ and $pwmg_{i,r,s}$.

$$pim^{cif}_{i,r,s} = ps^{fob}_{i,r,s} + t^{mg}_{i,r,s}\, pwmg_{i,r,s} \tag{3}$$

Where $pwmg_{i,r,s}$ denotes the sum of transportation and insurance costs associated with the commodity trade between country (region) r and country (region) j. The meanings of other variables are the same as in Equations (1) and (2).

3.2.2. Macro mechanism of the impact of international energy price increases on the global economic system

Here is a simplified model incorporating several vital equations. We assume that global consumption C depends on global output Y and global price level$P$, using a simplified linear consumption function:

$$C = aY - bP \tag{4}$$

Energy supply X equals the sum of output from all energy-producing countries:

$$X = \sum_{i} X_i \tag{5}$$

Energy demand D_i can be represented by a linear demand function, where energy price P_i is a crucial influencing factor:

$$D_i = c - dP_i \tag{6}$$

Energy exports E_i of the energy-producing country i are related to its energy output X_i and energy price P_i:

$$E_i = fX_i + gP_i \tag{7}$$

Energy imports from energy-producing country i are influenced by energy price P_i and global energy demand D:

$$E_i = h\,P_i + kD \tag{8}$$

Finally, we can consider the relationship between price transmission and supply-demand equilibrium. According to the supply-demand relationship, global energy price P can be determined by the supply-demand equilibrium of energy-producing countries:

$$P = \frac{1}{X}\sum_{i}\left(P_iX_i - M_i + E_i\right)_i \tag{9}$$

Based on the model described above, a feedback diagram illustrates the interrelationships between sectors within the global energy CGE model. By defining variables and parameters and establishing production functions, supply-demand relationships, and energy supply, the impacts of energy price increases on the global economy can be revealed.

3.2.3. 2.3Micro mechanism of the impact of international energy price increases on the global economic system

Assuming there are four sectors: the Producer Sector (P), the Consumer Sector (C), the International Trade Sector (T), and the

Energy Sector (E).

- The Producer Sector produces various goods and services.
- The Consumer Sector consumes based on price and income levels.
- The International Trade Sector handles the trade of goods and services between countries.
- The Energy Sector produces and supplies energy products.

The following mathematical formulas illustrate the impact of the international energy price increase caused by the Ukraine crisis on the global economy.

(1). Production function:

$$Y_i = f_i(X_{1i},\ X_{2i}, \ldots, X_{Ni}, K_i, E_i) \tag{10}$$

(2). Supply and demand relationship:

$$Y_i = C_i + I_i + \ X_{1i} + X_{2i} + \ldots + X_{Ni} + X_{1i} + X_{2i} + \ldots + M_{Mi} \tag{11}$$

(3). Energy supply:

$$E_i = g_i\left(\ P_E, Y^W\right) \tag{12}$$

(4). Impact of energy price increase:

$$P_E = P_E^0 + \Delta P_E \tag{13}$$

(5). Global economic impact:

$$\Delta Y^W = h(\ \Delta P_E) \tag{14}$$

$$\Delta P^W = g(\ \Delta P_E) \tag{15}$$

$$\Delta M^W = f(\ \Delta P_E) \tag{16}$$

Where represents the change in global output, ΔP^W represents the change in global price, ΔM^W represents the change in global imports, and ΔP_E represents the change triggered by the increase in energy prices.

This is a simplified GTAP model. If we further define the price shock as:

$$p_m = p_m^0 + \epsilon_m \tag{17}$$

Where p_m is the price of the commodity m, p_m^0 is the base price, and ϵ_m is the exogenous shock.

Output:

$$Y_i = Y_i(\ p_1,\ p_2, \ldots, p_m, L_i, K_i) \tag{18}$$

where Y_i is the output of sector i, $p_1,\ p_2, \ldots, p_m$ are the prices of various commodities, L_i is labour input, and K_i is capital input.

Consumption expenditure:

$$C_i = C_i(\ p_1,\ p_2, \ldots, p_m, Y_i) \tag{19}$$

where C_i is the consumption expenditure of sector i, and Y_i is the output of that sector.

Government expenditure:

$$G_i = G_i(\ p_1,\ p_2, \ldots, p_m) \tag{20}$$

where G_i is the government expenditure of sector i.

Net exports:

$$NX_i = X_i - M_i \tag{21}$$

where NX_i is the net exports of sector i, X_i is the export quantity, and M_i is the import quantity.

Household savings:

$$S_i = Y_i - C_i - T_i \tag{22}$$

where S_i is the savings of sector i, and T_i is the tax revenue.

Market clearance condition:

$$Y_i = C_i + I_i + G_i + NX_i \tag{23}$$

where I_i is the investment expenditure of sector i.

3.3. Data processing

The CGE model facilitates the analysis of the impact of the energy price escalation triggered by the Ukrainian crisis on the global economy. Through parameter and assumption adjustments within the model, diverse scenarios of global economic fluctuations can be simulated, thereby assessing the repercussions of the Ukrainian crisis on energy-producing nations, developed countries, and developing nations.

The GTAPv10 database, released by Purdue University in July 2019, encompasses national economic account data for 141 countries and regions, encompassing production, consumption, investment, taxation, subsidies, and international trade. In this study, the GTAPv10 database is employed to evaluate the influence of international energy price variations on the global economy in the context of the Russia-Ukraine conflict. As the original RunGTAP model treats commodity prices as endogenous variables, it is unsuitable for directly analysing the economic consequences of international energy price fluctuations on individual countries or regions. To overcome this limitation, we employ a variable transformation approach to impose shocks on commodity prices (pm) exogenously [47,48]. Moreover, to satisfy the short-term closure requirements for GTAP model computations, we utilise the GTAPagg software to aggregate the 141 countries and regions covered in the GTAP10 database into 24 sectors, as presented in Table 1, while consolidating the original 65 product sectors of GTAP10 into 24 sectors, as displayed in Table 2.

3.4. Parameter setting

Russia occupies a significant position in global energy production and exports. The outbreak of the Russo-Ukrainian military conflict led Western countries, including the United States and Europe, to impose sanctions on Russia. These actions created expectations among energy producers and traders of rising energy prices, resulting in an ongoing escalation of oil, natural gas, and coal prices in the international market. To mitigate the sharp increase in international oil prices, the member countries of the IEA collectively initiated measures in mid-March 2022, committing to releasing 120 million barrels of oil from their strategic petroleum reserves, thereby alleviating the panic in the energy market. Additionally, as the weather warmed up in April 2022, the demand for energy sources such as gas and coal for residential and commercial use decreased, partially easing the upward trend in international energy prices. Since the initial phase of the Russo-Ukrainian conflict, the volatility of international oil, natural gas, and coal prices has significantly reduced since late May 2022, stabilising to some extent, albeit at relatively high levels. In light of this context, this study aims to analyse the impact of the recent international energy price increase on the global economy by considering the magnitude of price fluctuations in oil, natural gas, and coal in the international market from February 23, 2022, to May 31, 2022, as the shock variable.

Table 1
Country and energy Status.

Country/Region	Country Code	Energy Status
Russia	RU	Energy-producing country
European Union	EU	Energy-consuming country
United Kingdom	UK	Energy-consuming country
United States	US	Energy-consuming country
Canada	CA	Energy-producing country
Mexico	MX	Energy-producing country
China	CN	Energy-consuming country
Japan	JP	Energy-consuming country
South Korea	KR	Energy-consuming country
South Asia	SA	Energy-consuming country
Southeast Asia	SEA	Energy-producing country
Australia	AU	Energy-producing country
Middle East oil-producing countries	MENA	Energy-producing country
Middle East non-oil-producing countries	MENA-NF	Energy-consuming country
Latin America	LA	Energy-consuming country
Africa	AF	Energy-consuming country

Table 2
Sector numbers and names.

No.	Sectors Breakdown Details	No.	Sectors Breakdown Details
1	Grain and other grains	14	Metals and their products
2	Fruits and vegetables and dried fruits	15	Mechanical equipment
3	Oil and sugar	16	Transport equipment
4	Cotton and other plant fibres	17	chemicals
5	Animal products	18	Computer, electronic and optical products
6	Aquatic products	19	Electrical products
7	coal	20	Water, electricity and steam supply services
8	petroleum	21	Traffic and Transportation
9	Natural gas	22	Communication service
10	Food, sugar, drinks and tobacco	23	Financial and insurance services
11	Textiles, clothing and leather goods	24	Other services
12	Wood products such as trees and furniture	25	Overall level
13	Paper and printed matter		

The IEA commonly employs the London Brent crude oil price, the U.S. Henry Hub natural gas price, and the Newcastle Port thermal coal price from Australia as indicators of the international market price levels for these three fossil energy sources [49].

As shown in Table 3, On February 23, 2022, the futures prices for Brent crude oil, Henry Hub natural gas, and Newcastle Port thermal coal were $74.13 per barrel, $4.41 per million British thermal units (MMBtu), and $99.31 per ton, respectively. By May 30, 2022, the prices of these three fuels had risen to $105.32 per barrel, $7.24 per MMBtu, and $230.76 per ton, respectively. Therefore, between February 23, 2022, and May 31, 2022, the prices of these three fuels increased by 42 %, 64 %, and 132 %, respectively. The subsequent sections will assess the impact of these oil, natural gas, and coal price increases on the global economy.

3.5. Selection of Dependent variables

The impact of the international market prices of crude oil, natural gas, and coal on various macroeconomic indicators such as GDP, prices, household income and expenditure, social welfare, and investment across different regions is analysed using the CGE model. These indicators' selection references can be found in Table 4.

4. Results

The model considers the magnitude of the price increases in energy commodities as exogenous shocks. The results provide insights into the effects of the international energy price hikes on macroeconomic indicators (Fig. 2) and industry outputs (Fig. 3) in the context of the Russia-Ukraine conflict.

4.1. Macroeconomics

(1) . ***GDP.*** The international surge in energy prices harms the economic growth of Russia, the United States, the European Union, the South Asian region, China, Japan, South Korea, non-oil-producing Middle Eastern countries, and Africa. Russia faces the most significant blow, potentially reducing its economic growth rate by approximately 5.5 %. Subsequently, South Korea and the South Asian region experienced the second-highest impact, potentially leading to a decrease of around 4 % in their GDP growth rates. Furthermore, there is a substantial economic shock for Africa and non-oil-producing Middle Eastern countries, likely resulting in respective declines of 3.06 % and 2.52 % in their economic growth rates. Additionally, this trend may reduce economic growth rates for China, Japan, and the European Union, ranging from 1.29 % to 1.58 %. In contrast, the adverse effects on the economic growth rates of the United States and the United Kingdom are relatively minor, potentially causing a decline of 0.67 %–0.77 %. Nevertheless, it fosters economic growth in the Middle East oil-producing nations, Australia, Canada, Mexico, Southeast Asia, and Latin America.

(2) . ***Household Income and Consumption.*** The recent surge in international energy prices has adversely affected the income and consumption of residents in Russia, the European Union, the United States, China, Japan, South Korea, South Asia, and non-oil-producing countries in the Middle East and Africa. Among these regions, Russia has experienced the most significant impact, with notable repercussions on income and consumption in Africa. At the same time, the United States and the United Kingdom have been comparatively less affected. Furthermore, our study reveals that the current upswing in international energy prices

Table 3
Parameter Settings for price increases in three energy sources.

Energy types and their prices		23-Feb-22	30-May-22	increment	rangeability
Oil	futures prices for Brent crude oil($/bbl)	74.13	105.32	31.19	**42 %**
Natural Gas	prices for Henry Hub natural gas(MMBtu)	4.41	7.24	2.83	**64 %**
coal	prices for Newcastle Port thermal coal($/ton)	99.31	230.76	131.45	**132 %**

Table 4
Economic indicators selected under the influence of referenced literature.

Variables	Reference
GDP (%)	Xiao(2007) [38]; Timilsina (2015) [40]; Jia et al. (2021) [41]; Babatunde et al. (2017) [43]; Cui et al. (2023) [44]; Liu et al. (2021) [50].
Household income (%)	Xiao(2007) [38]; Cui et al. (2023) [44]; Liu et al. (2021) [50].
Household consumption (%)	Xiao(2007) [38]; Liu et al. (2021) [50].
Investment (%)	Xiao(2007) [38]; Liu et al. (2021) [50].
Export (%)	Xiao(2007) [38]; Timilsina (2015) [40]; Jia et al. (2021) [41]; Carbone and Rivers (2017) [42]; Cui et al. (2023) [44]; Liu et al. (2021) [50].
Import (%)	Xiao(2007) [38]; Timilsina (2015) [40]; Jia et al. (2021) [41]; Carbone and Rivers (2017) [42]; Liu et al. (2021) [50].
Prices (%)	Xiao(2007) [38]; Timilsina et al. (2011) [39]; Timilsina (2015) [40]; Cui et al. (2023) [44].
Social welfare (USD billion)	Xiao(2007) [38]; Carbone and Rivers (2017) [42]; Cui et al. (2023) [44]; Liu et al. (2021) [50].
Industrial output (%)	Xiao(2007) [38]; Jia et al. (2021) [41]; Carbone and Rivers (2017) [42]; Liu et al. (2021) [50].

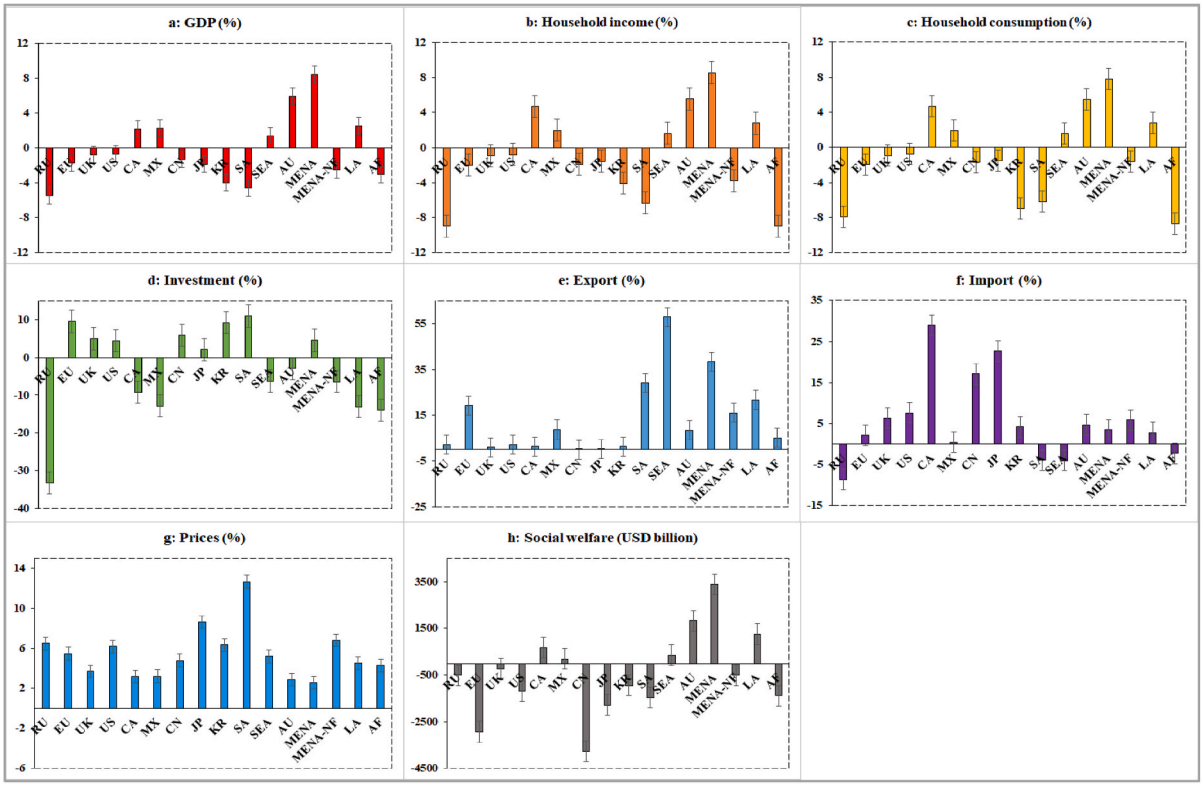

Fig. 2. The macroeconomic impact of international energy price increases on countries or regions.

has contributed positively to the income and consumption of residents in Canada, Mexico, Southeast Asia, Australia, oil-producing countries in the Middle East, and Latin America. Notably, the most substantial improvement has been observed in the income and expenditure of residents in oil-producing countries in the Middle East.

(3) . ***Investment.*** The recent increase in international energy prices has facilitated the enhancement of domestic investments in countries like China, Japan, South Korea, the USA, the EU, the UK, Middle Eastern oil-producing nations, and South Asian regions. However, this surge might have contributed to the decline in investment growth in areas including Russia, Africa, Latin America, Mexico, non-oil-producing Middle Eastern regions, Canada, Southeast Asia, and Australia.

(4) . ***Exports.*** In the context of the recent international surge in energy prices, exports in various countries and regions have notably facilitated. This phenomenon can be attributed to the escalation in energy prices, which has not only stimulated increased energy exports in energy-producing nations, particularly in the Middle East, but has also triggered varying degrees of price hikes across countries and regions (as detailed in the subsequent analysis of price impacts). Consequently, this has led to the amplification of export volumes among different economic entities.

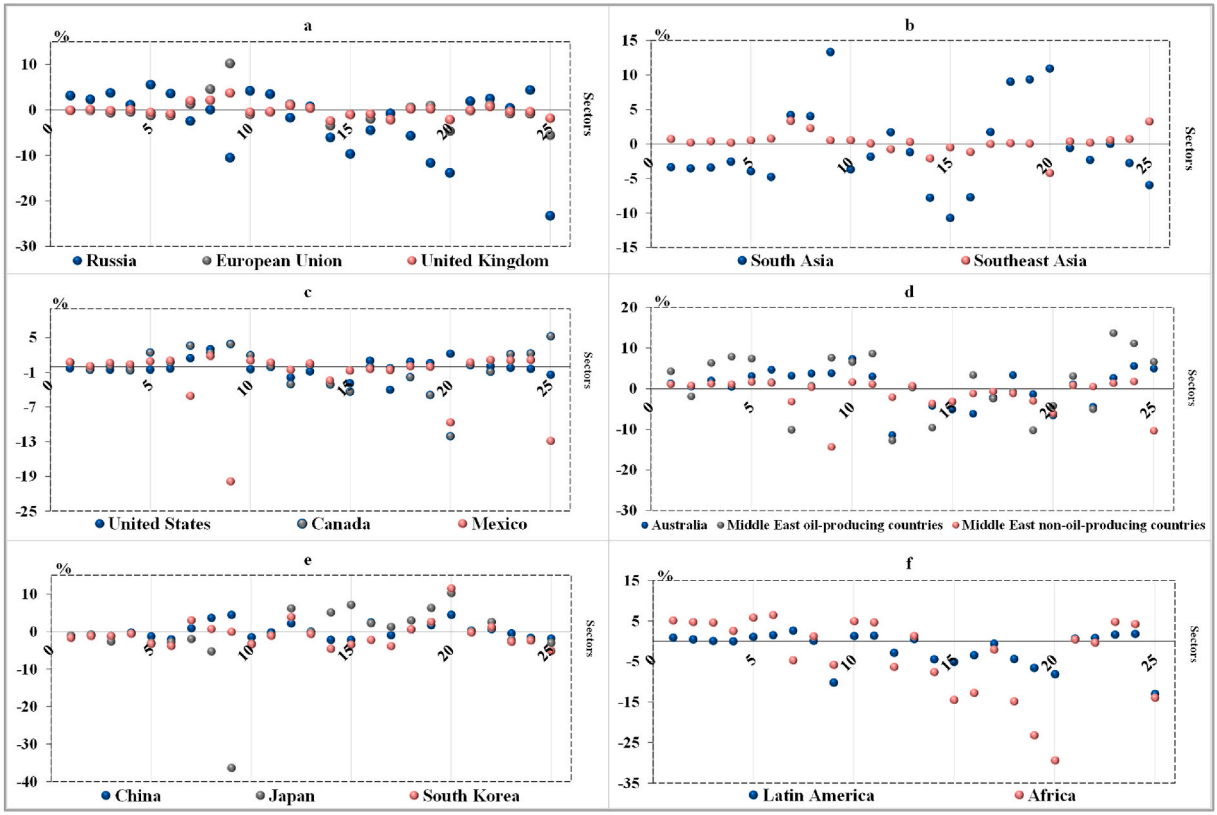

Fig. 3. The impact of rising international energy prices on the industrial economy of the world economy.

Examining the shifts in export patterns across countries and regions, the most substantial boost in exports due to the surge in energy prices has been observed in Southeast Asia and the Middle East, with export volumes increasing by approximately 57.92 % and 38.47 %, respectively. Following closely, there has been a significant promotion of exports in South Asia, Latin America, the non-oil-producing countries in the Middle East, and the European Union, resulting in export growth rates of 29.07 %, 21.67 %, 16.08 %, and 19.27 %, respectively. Furthermore, there has been noticeable export enhancement in Mexico, Australia, and Africa, potentially leading to export growth rates of 8.71 %, 8.4 %, and 5.18 %, respectively.

Conversely, the impact on exports in the United States, Russia, South Korea, and Canada has been relatively modest, resulting in export growth rates ranging from 0.21 % to 2.1 %. Notably, the surge in international energy prices has had the most negligible promotional effect on Chinese exports, with an increase of merely 0.07 %.

(5). **Imports.** Imports from Russia, Southeast Asia, South Asia, and Africa have decreased. Among them, the impact on import trade with Russia is the most significant, potentially leading to an overall import decline of 8.16 %. However, there is a varying degree of promotion effect on imports from other regions of the world. Specifically, the promotion effect is most pronounced for imports from Canada, Japan, and China, potentially resulting in an increased import growth rate of 28.98 %, 22.65 %, and 17.08 %, respectively. The promotion effect on imports from the United States, the United Kingdom, South Korea, Australia, and non-oil-producing countries in the Middle East is also noticeable. In contrast, the effect of promotion on imports from oil-producing countries in the Middle East, Latin America, the European Union, and Mexico is relatively small.

(6). **Price levels.** The most significant change for most of the world's population was the rising price of energy. Among them, the highest price increase was observed in South Asia, reaching 12.68 %. Japan experienced the second-highest rise in prices at 8.64 %. China, South Korea, the United States, the European Union, Russia, and non-oil-producing countries in the Middle East, Southeast Asia, Latin America, and Africa saw noticeable price increases, ranging from 4.27 % to 6.48 %. The impact on the price levels of the United Kingdom, Canada, Mexico, Australia, and oil-producing countries in the Middle East was relatively minor, increasing prices by 2.65 %–3.7 %.

(7). **Social welfare.** The social welfare of Middle Eastern oil-producing countries, Australia, Latin America, Southeast Asia, Canada, and Mexico has increased. Middle Eastern oil-producing countries have experienced the most substantial increase in social welfare, reaching as high as $337.852 billion. Australia and Latin America follow with increases of $182.845 billion and $1256.06 billion, respectively. Additionally, Canada, Mexico, and Southeast Asia have witnessed relatively significant increments in social welfare, with figures of $678.21 billion, $192.87 billion, and $351.76 billion, respectively.

However, this has potentially led to a significant decrease in the levels of social welfare in China, Japan, the United States, the European Union, the United Kingdom, and Russia. Notably, China has suffered the most substantial loss in social welfare, amounting to a staggering $3766.07 billion. The European Union and Japan closely follow, with losses of $2927.44 billion and $1792.17 billion, respectively. Moreover, the decline in social welfare is also substantial in the United States, South Korea, South Asia, and Africa, potentially resulting in losses ranging from $937.6 billion to $1456 billion. Furthermore, Russia, non-oil-producing countries in the Middle East, and the United Kingdom may also experience declines in social welfare.

4.2. Industrial outputs

(1) ***Russia***. Russia's total output decreased by 23.26 %. The country's water and steam supply production experienced the most immense impact, potentially leading to a decline in output by 13.83 %. Additionally, the output of natural gas, coal, wood and furniture sectors, chemical products, machinery and equipment, metals and their products, computer electronics and optical products, electrical products, and transportation equipment decreased. However, there was a slight increase in output in sectors including livestock products and 14 other industries.

(2) ***European Union***. The total output of the European Union decreased by 5.55 %. There was an increase in output in sectors such as cotton and other plant fibres, coal, chemical products, textiles, clothing and leather products, metals and their products, machinery and equipment, computer electronics and optical products, communication services, transportation, and financial and insurance services. However, there was a slight decrease in output in 14 sectors, including grain and other cereals.

(3) ***United Kingdom***. The total output of the United Kingdom decreased by 1.85 %. Most sectors in the UK experienced a decline in output, with chemical products, metals and their products, and water and steam supply services being slightly more prominent, with a decrease of around 2 %. However, there were increases in output levels for sectors such as fruits and vegetables, dried fruits, cotton and other plant fibres, wood and furniture, coal, oil, natural gas, paper and printing, electrical products, computer electronics and optical products, and communication services. Among them, natural gas had the most enormous growth, with an increase of 3.72 %.

(4) ***United States***. The total output of the United States decreased by 1.41 %. There were decreases in output for sectors such as grain and other cereals, fruits and vegetables, dried fruits, oilseeds and sugar crops, livestock products, aquatic products, food, sugar, beverages and tobacco, wood and furniture, paper and printing, chemical products, metals and their products, machinery and equipment, financial and insurance services, and other services. Among them, the decline in chemical product output was the largest at 4 %. However, the output of natural gas, oil, and coal sectors increased. Natural gas and oil had the most significant increases, with growth rates of 3.91 % and 3.02 %, respectively.

(5) ***Canada***. Canada's total output increased by 5.25 %. The water and steam supply services in Canada experienced the most enormous impact, potentially causing a decrease in output by 12.05 % in that sector. The adverse effects on sectors such as wood and furniture, metals and their products, machinery and equipment, and electrical products were also evident, with potential decreases ranging from 3.05 % to 4.91 %. However, there were improvements in output levels for sectors such as petroleum, natural gas, coal, and livestock products.

(6) ***Mexico***. Mexico's total output increased by 4.86 %. However, the output of sectors such as natural gas, coal, wood and furniture, chemical products, metals and their products, machinery and equipment, transportation equipment, electrical products, and water and steam supply services decreased, decreasing the output of other sectors in the country.

(7) ***China***. The total output in China declined by 1.91 %. Decreases in output were observed in sectors such as grain and other cereals, fruits and vegetables, dried fruits, plant fibres, oilseeds and sugar crops, livestock products, aquatic products, food, sugar and beverage, tobacco, textiles, clothing and leather products, paper and printing, chemicals, metals and their products, machinery and equipment, financial and insurance services, and other services. Notably, significant declines in output were observed in the aquatic products, metals and their products, and machinery and equipment sectors, with a reduction of approximately 2 %. However, it is expected that sectors such as natural gas, petroleum, coal, timber and wooden furniture, water, electricity and steam supply services, transportation equipment, electrical appliances, computers, electronics and optical products, communication services, and transportation will experience an increase in output, particularly petroleum, natural gas, and water, electricity and steam supply services with a growth rate of approximately 4 %.

(8) ***Japan***. The total output in Japan decreased by 3.07 %. Decreases in output were observed in sectors such as grain and other cereals, fruits and vegetables, dried fruits, plant fibres, oilseeds and sugar crops, sugar, beverages and tobacco, livestock products, aquatic products, natural gas, petroleum, coal, textiles, clothing and leather products, paper and printing, financial and insurance services, and other services. The impact on natural gas production in Japan was particularly significant, leading to a decline of 36.35 % in this sector. However, there was an increase in output for the remaining ten sectors, notably in timber and wooden furniture, machinery and equipment, electrical appliances, metals and their products, water, electricity and steam supply services, ranging from 5.05 % to 7.08 %.

(9) ***South Korea***. The total output in South Korea declined by 5.21 %. It is expected that sectors such as petroleum, coal, timber and wooden furniture, computers, electronics and optical products, electrical appliances, water, electricity and steam supply services, and communication services will experience an increase in output. However, output decreases were observed in sectors including aquatic products, chemicals, metals and their products, machinery and equipment, and others comprising 17 sectors.

(10) ***South Asia***. The total output in South Asia declined by 5.95 %. Sectors such as timber and wooden furniture, petroleum, natural gas, coal, chemicals, computers, electronics and optical products, electrical appliances, water, electricity and steam supply, and

financial and insurance services experienced increased output. However, output decreases were observed in sectors including metals and their products, machinery and equipment, and transportation equipment, comprising 15 sectors.

(11) ***Southeast Asia***. The total output in Southeast Asia increased by 3.26 %. Output decreases were observed in sectors such as timber and wooden furniture, metals and their products, machinery and equipment, transportation equipment, water, electricity and steam supply services. However, the output level in the remaining sectors of the region slightly increased.

(12) ***Australia***. The total output in Australia increased by 4.93 %. This resulted in a decline in output in sectors such as timber and wooden furniture, chemicals, metals and their products, machinery and equipment, transportation equipment, electric and steam supply services, communication services, water, electricity and steam supply services. However, it is expected that the output in other sectors in Australia will experience growth.

(13) ***Middle East oil-producing countries***. The total output in Middle East oil-producing countries increased by 6.56 %. Decreases in output were observed in sectors such as fruits and vegetables, timber and wooden furniture, coal, chemicals, metals and their products, machinery and equipment, electrical appliances, computers, electronics and optical products, water, electricity and steam supply services, and communication services. However, this helped improve the output level in other regional sectors.

(14) ***Middle East non-oil-producing countries***. The total output in the Middle East non-oil-producing countries declined by 10.4 %. The impact on natural gas production in this region was the most significant, resulting in a decline of 14.38 % in this sector. Additionally, there were slight output decreases in sectors such as coal, timber and wooden furniture, chemicals, metals and their products, machinery and equipment, transportation equipment, electrical appliances, computers, electronics and optical products, water, electricity and steam supply services. However, there were slight increases in output in sectors such as livestock products, food, sugar and beverages, and other 14 sectors.

(15) ***Latin America***. The total output in Latin America declined by 13.03 %. Output decreases were observed in natural gas, plant fibres, timber and wooden furniture, chemicals, metals and their products, machinery and equipment, electrical services, computers, electronics and optical products, transportation equipment, and water, electricity and steam supply services. Among these, the decline in natural gas production was the most significant, with a decrease of 10.22 %. However, there were slight increases in output in 14 sectors, including coal.

(16) ***Africa***. The total output in Africa declined by 13.98 %. There were increases in output in sectors such as coal, petroleum, natural gas, timber and wooden furniture, paper and printing, computers, electronics and optical products, electrical appliances, and communication services. Remarkably, there was a noticeable growth in petroleum and natural gas output. However, output decreased in 16 sectors, including chemicals, metals and their products, water, electricity and steam supply services.

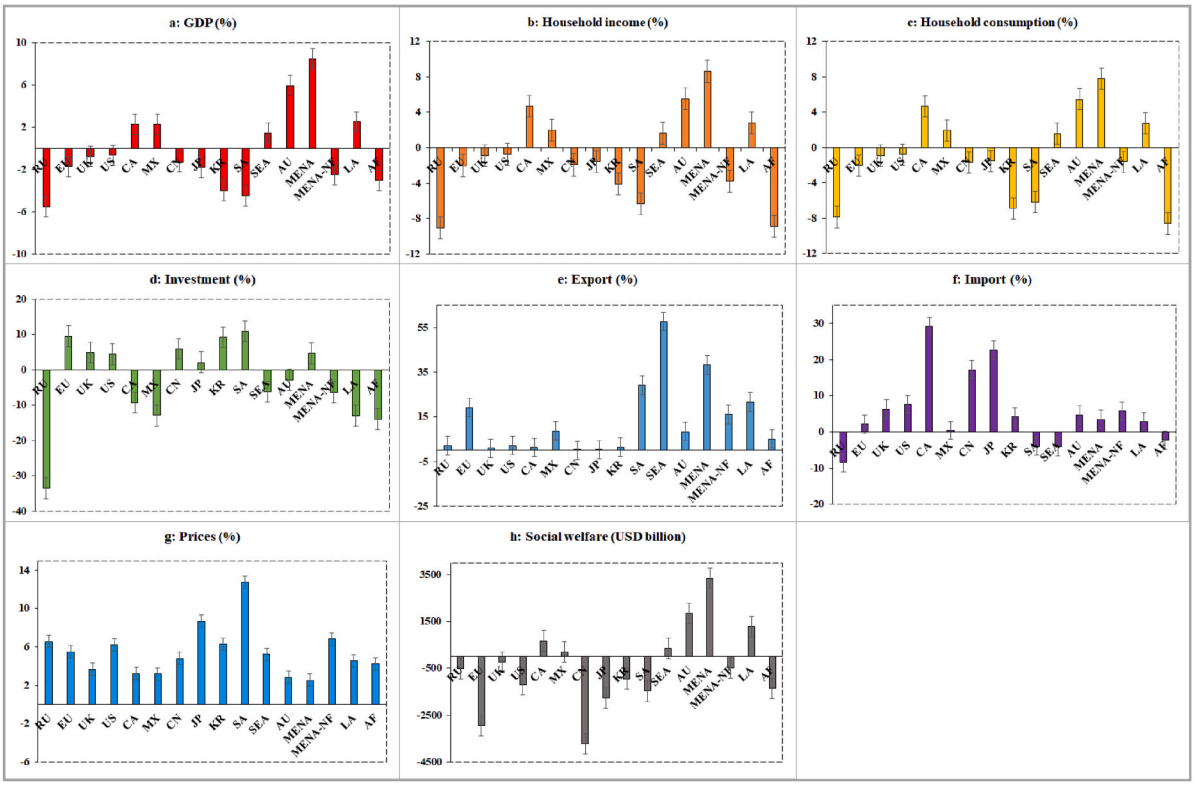

Fig. 4. Robustness test 1 - the macroeconomic impact on countries or regions.

4.3. Sensitive analysis

Building upon the approach proposed by Cui et al. [44] and considering the findings from the preceding analysis, two robustness tests were conducted. The first sensitivity analysis examined variations in Armington elasticities of domestic and imported energy sources (ESBD). A higher ESBD implies greater substitutability between domestic and imported energy sources, and vice versa. To assess the impact of this parameter, ESBD values for three energy sources (coal, crude oil, and natural gas) were increased by 50 %, individually. The results of this sensitivity analysis demonstrated that the numerical discrepancies with the original research findings remained within a negligible range of 1 %, thereby confirming the robustness of the initial conclusions (see Figs. 4 and 5).

The second sensitivity analysis investigated the influence of changes in Armington elasticities on energy source allocation to importing regions (ESBM). This parameter is closely linked to trade diversion effects. A higher ESBM suggests that countries imposing energy sanctions on Russia would find importing energy from other nations easier to compensate for energy import shortages. ESBM values for each energy source type (coal, crude oil, natural gas) were increased by 50 % separately. Similar to the first sensitivity analysis, the results indicated that the numerical discrepancies with the original research findings were within a negligible range of 1 %, thus reaffirming the robustness of the primary conclusions (see Figs. 6 and 7).

However, the EU's heavy dependence on Russian energy implies that ceasing Russian energy imports would significantly raise production costs, eroding its international comparative advantage and export competitiveness. Due to energy sanctions imposed by the United States and the EU, the Russian economy will suffer substantial losses. Nonetheless, the EU will bear a larger share of the costs, while the economic losses for the United States will be limited. These findings remain consistent with the initial research conclusions, further validating the robustness of the study's outcomes.

5. Discussion

The Russia-Ukraine conflict has ignited a series of profound disturbances within the global energy landscape, primarily driven by a surge in international energy prices. This surge has set in motion a cascade of far-reaching consequences that have reverberated across the world stage, encompassing heightened price levels on a global scale, geopolitical instability, sluggish economic growth, mounting inflation, and escalating debt levels, further complicating existing challenges [51,52].

While certain countries, such as Canada, Russia, Mexico, Southeast Asia, Australia, and Middle East oil-producing countries, have experienced positive outcomes in terms of GDP growth, household income, and consumer spending, others, including China, Japan, South Korea, the United States, the United Kingdom, the European Union, South Asia, Middle East non-oil-producing countries, and

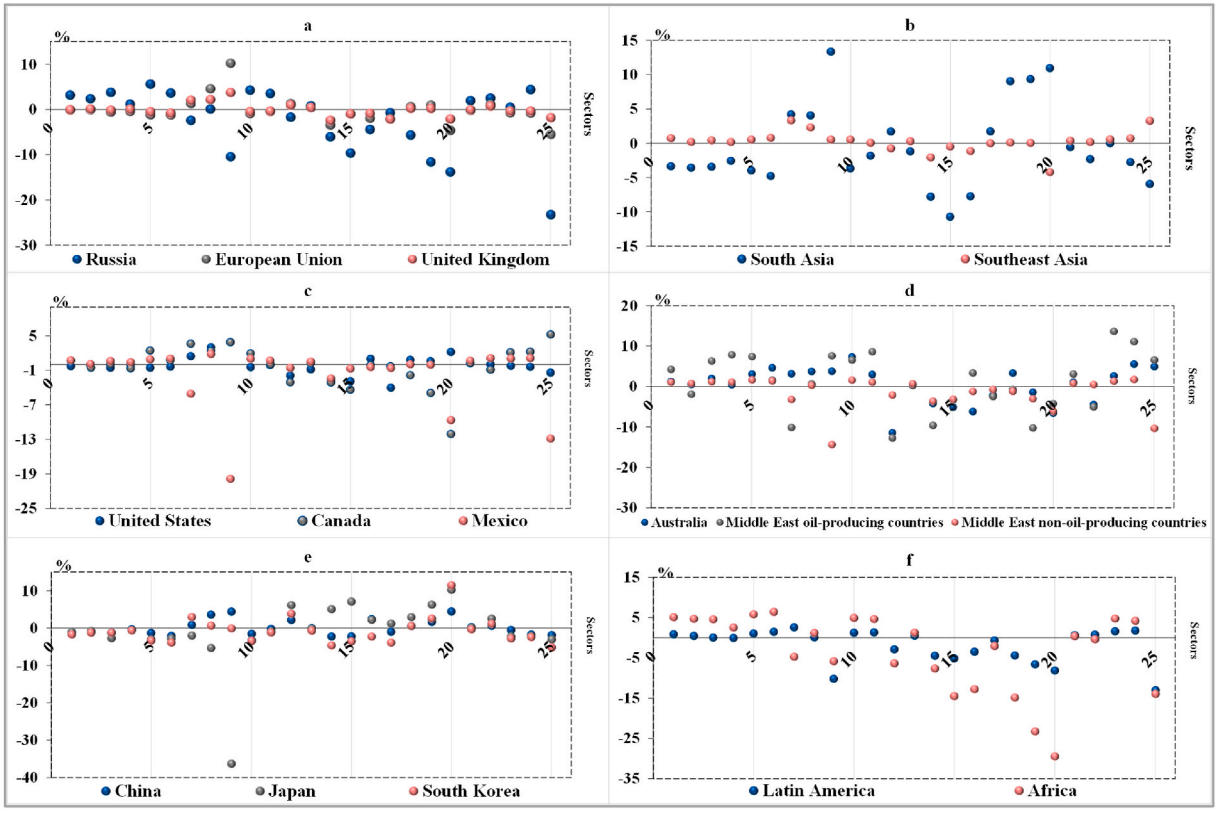

Fig. 5. Robustness test 1 - assessing the influence on the global industrial economy.

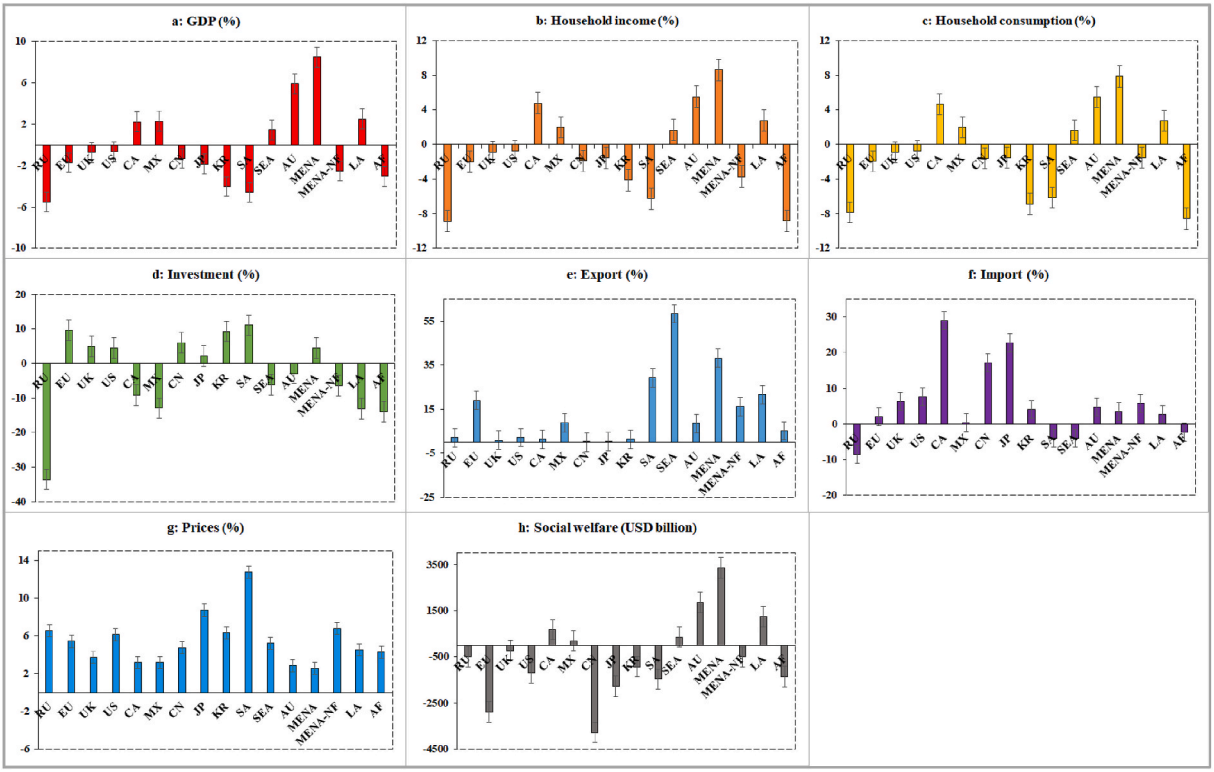

Fig. 6. Robustness test 2 - the macroeconomic impact on countries or regions.

Africa, have encountered substantial negative impacts on their macroeconomic interests. The European Union's predicament is of particular significance, bearing the brunt of these consequences due to its close trade connections with Russia and Ukraine and its reliance on these nations for food and energy supplies [53].

The economic ramifications of the international energy price surge on Russia have been substantial. Although Western countries, notably the United States, have sought to undermine Russia's economic prowess by curbing its oil exports, the actual impact remains a subject of debate. Data from the Finnish Center for Energy and Clean Air Research reveal that Russia's export income from energy surged by 93 billion euros within the first 100 days of the Russia-Ukraine conflict [54]. This paradoxical outcome arises from the European Union's heavy dependence on Russian energy, enabling Russia to circumvent Western sanctions on energy exports by accepting payments in currencies such as the ruble. This avenue provides Russia with a substantial source of foreign exchange income, effectively counteracting the economic repercussions of Western sanctions.

The impact of the international energy price surge on residents' income and consumption closely parallels its effects on GDP, with Middle East oil-producing countries benefiting from energy subsidies, mitigating the impact on household expenses. However, the surge in oil prices is poised to induce significant price increases, particularly in South Asia, potentially fostering inflation and heightening living costs in regions such as Japan, China, and South Korea.

The energy price surge has also exerted an influence on domestic investment patterns. Countries heavily reliant on energy exports, including China, Japan, South Korea, the United States, the European Union, the United Kingdom, Middle East oil-producing countries, and South Asian countries, have witnessed an uptick in domestic investment. Conversely, regions such as Russia, Africa, Latin America, Mexico, Middle East non-oil-producing countries, Canada, Southeast Asia, and Australia have experienced a downturn in investment. Various factors contribute to these patterns, including energy dependence, volatile energy markets, fiscal income, interest rates, capital flows, and geopolitical instability [8,13].

The international energy price surge has spurred increased exports across numerous countries and regions, particularly those with the capacity to expand their energy product sales. This surge has subsequently driven up prices in various regions, amplifying the scale of their exports. Southeast Asia and Middle East oil-producing countries have been at the forefront of export growth, followed by South Asia, Latin America, Middle East non-oil-producing countries, and the European Union. Conversely, certain countries and regions, including Russia, Southeast Asia, South Asia, and Africa, have witnessed decreased imports, primarily due to the need for additional funds to cover the costs of expensive energy imports. Nevertheless, other countries and regions have experienced heightened import demand, driven by increased fiscal income and foreign exchange reserves.

These price surges have had global repercussions, with South Asia bearing the brunt of substantial price hikes, potentially significantly impacting residents' lives. Japan, China, and South Korea have also faced substantial price escalations, potentially leading to inflation and heightened living costs for consumers and businesses.

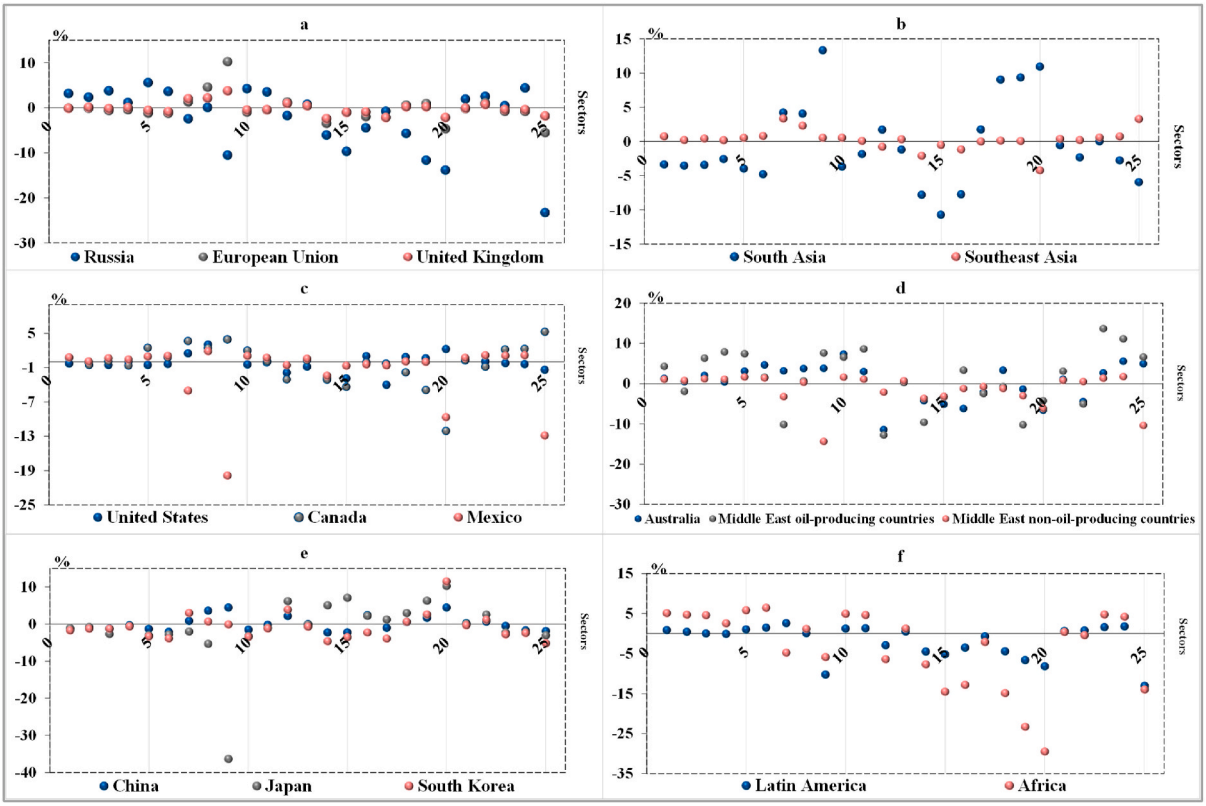

Fig. 7. Robustness test 2 - assessing the influence on the global industrial economy.

The impact on social welfare has varied across countries and regions, with those witnessing reduced income and consumption experiencing a decline in social welfare. In the case of Russia, social welfare has suffered due to rising domestic price levels. Conversely, countries such as Australia and the Middle East oil-producing countries have leveraged the situation, securing a larger share of the energy market and enhancing social welfare [8]. This dichotomy underscores the winners and losers in the global economy arising from changes in resource prices [17].

In terms of industries, the increase in international energy prices amid the Russia-Ukraine conflict is anticipated to depress overall output levels for China, Japan, South Korea, the United States, the European Union, the United Kingdom, Russia, the Middle East non-oil-producing countries, South Asia, and Africa [21]. However, it may result in heightened output levels for Middle East oil-producing countries, Canada, Mexico, Australia, and Southeast Asia, with consequential shifts in output distribution across various sectors within these regions [19,22].

Amidst these dynamics, the United States can reap benefits while pursuing energy sanctions against Russia, with comparatively modest economic losses. Seizing the opportunity presented by the Russia-Ukraine conflict, the United States can advance its strategic objectives of containing Russia and eroding European economic vitality. Consequently, strengthening political and economic bonds between the United States and Europe, coupled with heightened American energy exports to the continent, is a plausible outcome [44, 55].

Looking ahead, the Russia-Ukraine conflict looms large over the global energy trade landscape, poised to profoundly reconfigure the global energy supply map. This conflict is also poised to propel China into deepening its energy and economic collaboration with Russia, driven by containment measures by the United States and the European Union.

Moreover, this conflict could reshape international trade dynamics, necessitating a comprehensive reevaluation of the global value chain. As semi-autonomous regional blocs emerge amidst de-globalization trends, a decentralisation of value chains is expected to take hold [56].

In the aftermath of the Russia-Ukraine military conflict and the subsequent surge in international energy prices resulting from Western-imposed economic sanctions on Russia, the economic interests of both Western and developing countries have been significantly affected. Uncertainties persist as the Russia-Ukraine conflict endures, and Western nations continue to tighten energy export sanctions on Russia. The medium-term outlook for the euro area's competitiveness may further deteriorate, with the European economy still at risk of recession [34]. The European Union's initiatives, including the ban on coal imports from Russia and substantial reductions in oil imports, mainly gas imports, by 2027, pose a considerable challenge to the European economy's energy dependence [55,57]. Russia, as a significant global energy exporter and producer, retains a central role [52]. The further intensification of energy export sanctions by the European Union could trigger another surge in international energy prices, imposing more significant adverse

effects on the global economy, thus warranting deep concerns within the international community.

If the conflict persists, it will not only disrupt the global economy but may also destabilize the global economic equilibrium, posing a threat to global trade. Since trade relies on global maritime transport, maintaining regional stability is imperative. The prolonged Russia-Ukraine conflict will adversely affect energy and trade cooperation in Europe, as well as economic trade relations with Africa. Should an energy or trade crisis ensue, it would introduce uncertainty to the economy and society, giving rise to numerous new issues and potentially fostering additional problems and uncertainties.

6. Conclusion and policy implications

6.1. Conclusion

Geopolitical crises, such as military conflicts, have extensive and far-reaching impacts on a country's economy. They can directly affect economic entities through violence and property destruction and indirectly affect them by disrupting commercial relationships [58]. While existing literature provides ample evidence of the direct effects of the Ukrainian military crisis, the indirect effects remain underexplored.

This paper presents evidence of such indirect effects, specifically the systemic mechanisms of an energy crisis during geopolitical concerns. Using the period from February 23, 2022, to May 31, 2022, as an example, this study employs the CGE model to assess the global economic impact of the international energy price increase during the Russia-Ukraine military conflict. The following conclusions are drawn:

On the macroeconomic level, the current round of international energy price increases has broadly impacted the global economy. The sharp rise in energy prices has pushed global inflation. Compared with NIESR's inflation forecast in early 2022, global inflation could increase by 1 % in 2023 [52]. Firstly, although it contributes to the economic growth, household income, consumption, and social welfare levels of the Middle East non-oil-producing countries, Australia, Canada, Mexico, Southeast Asia, etc., it also triggers inflation in these regions, which is detrimental to domestic investments. Secondly, this round of international energy price increases not only has adverse effects on the economic growth, household income, consumption, and social welfare of developed countries such as the United States, the United Kingdom, the European Union, Japan, and South Korea, exacerbating inflation in these developed countries but also leads to a decline in economic growth, household income, consumption, and social welfare in China, South Asia, Middle East non-oil-producing countries, Africa, and other developing countries, causing price increases in these economies. Thirdly, this current surge in international energy prices is detrimental to the stability of Russia's domestic economic growth, household

Table 5
Targeted Support for affected countries.

National/Regional	Policy Implications
Russia (RU)	Russia should prioritise policies aimed at stabilising domestic inflation and supporting domestic investment. Measures to diversify the economy away from energy dependency are also advisable.
European Union (EU)	While the EU benefits from increased investments and exports, it should simultaneously address the adverse effects on household income and consumption through targeted social welfare programs and income support.
United Kingdom (UK)	The UK should focus on boosting domestic investments and exports to mitigate the negative impacts on GDP and household income.
United States (US)	Policymakers in the US should adopt strategies to promote GDP growth, safeguard household income, and stimulate consumption to counteract the adverse consequences of energy price increases.
Canada (CA)	Canada should concentrate efforts on addressing the decline in investment and improving its trade balance, mainly through diversification of exports.
Mexico (MX)	Mexico should implement policies to counter the adverse effects on investment and household income and ensure they support economic growth.
China (CN)	China should devise measures to stabilise household consumption and increase investments to boost GDP, which energy price increases have impacted.
Japan (JP)	Japan should address the decline in GDP and household income through targeted stimulus programs and strategic investments.
South Korea (KR)	South Korea should prioritise measures to mitigate the significant impacts on household consumption and social welfare while maintaining economic stability.
South Asia (SA)	Policymakers in South Asia should focus on policies that support export growth and social welfare to counteract the adverse effects of rising energy prices.
Southeast Asia (SEA)	Efforts should continue in Southeast Asia to boost exports and address trade imbalances through targeted trade policies and export promotion initiatives.
Australia (AU)	Australia should maintain policies that support the positive impacts on GDP and household income while addressing challenges related to import competition.
Middle East oil-producing countries (MENA)	MENA nations should strengthen policies to manage the positive effects on GDP and household income, while also considering strategies for economic diversification.
Middle East non-oil-producing countries (MENA-NF)	Policies should be designed to address the negative impacts on GDP and household income in MENA non-oil-producing countries, with an emphasis on economic resilience.
Latin America (LA)	Latin American countries should continue to work to boost GDP and household income while addressing challenges related to imports and trade imbalances.
Africa (AF)	Policymakers in Africa should implement strategies to mitigate the negative impacts on GDP and household income, focusing on economic resilience and development.

incomes, and consumption but also results in severe domestic inflation in Russia, leading to a significant decline in domestic investment and social welfare.

On the industry level, total output has shown varying degrees of growth in the Middle East oil-producing countries, Canada, Australia, and Southeast Asia, with the most prominent promotion effect observed in the Middle East oil-producing countries. However, the price increase may lead to a decrease in output levels in China, Japan, South Korea, the United States, the European Union, the United Kingdom, Russia, Mexico, South Asia, Latin America, Middle East non-oil-producing countries, and Africa, with the greatest negative impact on Russia's output and significant adverse effects on Mexico, Latin America, and Middle East non-oil-producing countries. Furthermore, this round of international energy price increases has affected output levels in various sectors of countries and regions to varying degrees.

6.2. Policy implications

6.2.1. Targeted support for affected countries

Given the substantial macroeconomic and industrial repercussions stemming from the escalating international energy prices, policymakers must contemplate a multifaceted array of strategies to mitigate detrimental consequences, bolster economic resilience, and foster sustainable development. This section presents a comprehensive set of policy recommendations meticulously crafted to address the distinctive challenges encountered by diverse countries and regions, as unveiled in the data presented in Table 5.

6.2.2. Targeted Support for affected industry

Therefore, countries worldwide should proactively respond to the challenges posed by rising international energy prices by implementing the measures outlined in Table 6.

Currently, the United States has halted imports of energy products from Russia. Western countries such as the United Kingdom and the European Union have also announced or are gradually reducing their imports of Russian energy products. If the geopolitical conflict escalates further, Western countries will likely strengthen restrictions on Russian energy exports, which could significantly impact global energy trade. To promote long-term sustainable economic and social development, governments should diversify energy sources, ensure energy supply security, actively seek renewable energy to replace imported energy products, and accelerate the energy transition [55]. For example, the European Commission's REPowerEU plan was published in May 2022 [51].

Specifically, efforts should be made to vigorously develop electric vehicles and promote electrification in the transportation sector to reduce overdependence on oil imports. Governments should proactively create incentives to drive a green transition to reduce overdependence on the implications of crucial energy sources such as oil [52]. This not only helps mitigate the impact of international energy price increases on China's economic and social development but also contributes to reducing greenhouse gas emissions and achieving the goals of "carbon neutrality" and "peak carbon emissions." In addition, local governments should simultaneously consider or formulate policies to offset rising energy prices to reduce inflation, supply chain disruptions, and other realistic risks brought about by global economic fluctuations.

These policy recommendations address the diverse impacts of rising international energy prices, ensuring economic stability, energy security, and sustainable development in the face of price fluctuations. Tailoring policies to each country or region's specific needs and challenges is essential for effective implementation and positive outcomes.

6.2.3. Limitations of this study and future research agenda

Acknowledging the study's limitations is crucial. Firstly, the research relies on a CGE modelling approach, which is suitable for macroeconomic analysis but simplifies real-world complexities. Consequently, nuanced effects and behaviours within specific industries or regions may still need to be fully captured.

Additionally, the dynamic nature of energy markets and geopolitical conflicts necessitates ongoing monitoring and analysis. The study offers a snapshot of an evolving situation, and future developments may require adjustments to findings. Building upon insights from this study, several avenues for future research deserve exploration.

(1) Regional Specificity. In-depth region-specific analyses can reveal unique challenges and opportunities in different parts of the world during energy crises, facilitating tailored policies to address regional needs.
(2) Interactions with Other Crises. Exploring connections between energy crises, trade disruptions, food security, and global challenges contributes to a holistic understanding of their collective impact on economies and societies.
(3) Long-Term Effects. Investigating the long-term consequences of energy crises on energy transition, sustainability goals, and global economic stability is crucial for shaping resilient policies.

Table 6
Targeted Support for affected industry.

Policy	Priority
Support for Energy Efficiency	Implementing energy-saving and environmental protection measures is crucial to reducing energy consumption and dependence on energy imports. By investing in energy efficiency, nations can mitigate the impacts of rising energy prices and contribute to environmental sustainability.
Food Security and Price Stability	Ensuring stable food prices is essential for social stability. Policymakers should strengthen agricultural production and supply chains, invest in agricultural technologies, and promote food self-sufficiency to reduce reliance on imported items.
Promoting Green Transition	Accelerating the transition to green and sustainable technologies is essential for reducing dependence on fossil fuels and mitigating the impact of rising energy prices. Governments should provide incentives and support for green initiatives.
Strengthening Financial Resilience	Financial resilience is crucial, especially for small and micro-enterprises facing financial difficulties due to energy price increases. Policymakers should Strengthen Financial Institutions. Focus on strengthening financial institutions and mechanisms to support enterprises, including access to credit and medium-to-long-term loans to alleviate short-term funding needs.
Price Stability Measures	Taking proactive measures to stabilise prices of agricultural and sideline products, such as grains, vegetables, meat, and eggs, is vital for overall price stability and social welfare. Policymakers should consider strategies to: Enhance Agricultural Production. Strengthen agricultural production, supply chains, and circulation of agricultural materials to increase food production in all countries and ensure a good harvest of fruits, vegetables, and livestock products. This will help ease inflation caused by supply-demand imbalances. Reduce Trade Protectionism. Actively work to reduce trade protectionism and support logistics multilaterally to ensure stable supply and demand of commodity prices. Improve residents' consumption power and disposable income by actively reserving coal, stabilising electricity prices, and vigorously developing and utilising non-fossil energy sources.
Collaborative International Efforts	Collaborative efforts among nations can foster a more stable and predictable energy market, mitigating the adverse effects of price volatility and supply disruptions. Policymakers should promote open and constructive dialogue among countries to develop effective strategies and mechanisms for managing energy-related challenges arising from geopolitical tensions.
Energy Source Diversification	To promote long-term sustainable economic and social development, governments should diversify energy sources, ensure energy supply security, actively seek renewable energy to replace imported energy products, and accelerate the energy transition. Specific efforts should be made to vigorously develop electric vehicles and promote electrification in the transportation sector to reduce overdependence on oil imports. Proactive incentives and support for green initiatives are crucial.

Incorporating these considerations into future research agendas contributes to a comprehensive understanding of complex dynamics surrounding energy crises and geopolitical conflicts. We hope such research provides valuable guidance for policymakers and stakeholders navigating challenges posed by these crises in the future. Moving forward, our commitment remains unwavering in enhancing our understanding of these critical issues and contributing to developing effective policies promoting global energy security and economic stability.

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Data availability statement

Most of the data used in this study is derived from the Global Trade Analysis Project (GTAP) Database, Version 10 (GTAPv10), which is extensively utilized for economic model research. The GTAPv10 database encompasses national economic accounting data for 141 countries and regions, including production, consumption, investment, taxation, subsidies, and international trade. This database is published by Purdue University and is accessible through the official GTAP project website. Additionally, this study involves analysis specific to the fluctuations in international energy prices during the Russia-Ukraine conflict period, which may be sourced from various publicly released reports by international energy agencies, news resources, and other economic analysis publications. The data associated with this study will be made available on request.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Consent to Participate

This study did not involve any kind of human participants or human data that requires any kind of approval.

Consent to publish

The study did not use any kind of individual data such as videos and images.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

CRediT authorship contribution statement

Mingsong Sun: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Conceptualization. **Xinyuan Cao:** Writing – review & editing, Validation. **Xuan Liu:** Writing – review & editing. **Tingting Cao:** Writing – review & editing, Supervision, Resources, Project administration. **Qirong Zhu:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology.

Declaration of competing interest

The authors declare no competing interests.

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