Carbon emissions and economic impact of EU's embargoing Russian fossil fuels

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Abstract

The war in Ukraine lays bar EU's dependence of fossil fuel imports from Russia. Here, we use a global computable equilibrium model, C3IAM/GEEPA, to estimate CO2 emission and GDP impact of embargoing fossil fuels from Russia. We find that embargoes induce more than 10% reduction of CO2 emissions in the EU, and slight increases of emissions in Russia, while both regions experience GDP losses (around 2% for the EU, and about 5% for Russia, ignoring the relative impact of other sanctions). Reacting to increasing energy prices with demand-side response inside the EU would increase CO2 emission savings, while turning GDP losses into gains. Implementing a partial embargo with tariffs largely compensates for lost government revenue.

Full Text

The Russia-Ukraine conflict has intensified geopolitical frictions, created turmoil in global energy markets, and laid blank Europe's dependence on Russia's fossil fuels. Russia is one of the world's top three oil producers, vying for the top spot with Saudi Arabia and the United States, and is the second-largest producer of natural gas, behind the United States [1]. Russia also has extensive oil export pipeline capacity and a wide-reaching gas export pipeline network, in particular to Europe. It is the world's largest natural gas exporter, the second-largest crude oil and condensate exporter after Saudi Arabia, and the third-largest coal exporter after Indonesia and Australia in 2021. Europe is a key destination for Russia's energy exports. Almost 50% of oil exports, 70% of natural gas exports, and one-third of coal exports from Russia are sent to Europe [2]. Germany, the Netherlands, and Turkey are the main importers.

Given Russia's important position in global energy markets, concerns about future disruptions in Russian energy supply have increased. Since carbon dioxide (CO_2) emissions come mainly from the burning of fossil fuels, a disruption in Russian energy supply not only threatens energy security and economic stability but also has implications for resulting fossil fuel combustion and greenhouse gas (GHG) emissions. In this situation, large scale geopolitical disruption align with the last possible timing to rapidly reduce GHG emissions in alignment with the goals of the Paris agreement [3].

Considering the close relations and possible disruptions between Russia and European Union (EU), we here use the Global Energy and Environmental Policy Analysis model in the China's Climate Change Integrated Assessment Model (C^3IAM/GEEPA), a global computable equilibrium model, to simulate and analyze the potential effects of a disruption of Russia's exports to the EU, e.g., as a result of a comprehensive embargo, and of possible response measures.

We develop two disruption scenarios: (1) Moderate Disruption. Considering the difficulty of all EU countries in imposing sanctions on Russia, and the possibility that economic sanctions will have a substantial deterrent effect, we assume that the main importing countries (3−5 countries) of EU are more likely to implement the embargo, and set the corresponding ratio accordingly. In detail, the main oil importers include the Netherlands, Germany and Poland (total 61%); The main natural gas importers

include Germany, Turkey, France and Poland (total 70%); The main coal importers include Germany, the Netherlands and Turkey (total 64%)[2,4]. (2) Strong Disruption. A stronger disruption with 90% fossil fuels trade between Russia and EU has been designed. Under both disruption scenarios, we prohibit immediate world market alignments in natural gas trade as natural gas is mostly transported via pipelines; similarly, because near all oil exports are depended on ships and 80% of oil tank ships insurances are issued in London, a substitution limit on oil's exports to other regions for Russia has been considered, and the model assumes that oil imports of other regions from Russia can only increase by at most 20%.

Under above disruption scenarios, production and consumption in EU, especially electricity and energy-intensive sectors will be negatively affected, and its GDP would fall by 1.6%-2.6% in 2022 (Fig. 1). Aiming for energy substitution, EU will increase its imports from other regions except for Russia, especially Middle East and Africa (MAF) for oil and natural gas by about 12%-21% and 15%-25%, respectively (see Extended data Fig. 1). Even so, EU's total fossil fuel consumption will decrease significantly due to the significant rise in domestic fossil energy prices, causing 13.3%-19.3% (610-885MtCO_2) of CO_2 emissions decline (Fig. 1). Also, EU's trade dependence on fossil energy would decrease moderately, natural gas seeing the biggest drop of about 8.7 to 13.4 percentage points.

However, because Russia relies heavily on revenues from oil and natural gas, which in 2021 made up 45% of Russia's federal budget [5], the decreasing exports of Russia would hurt its own economy more severely, with a GDP loss of 3.7%-5.5% (as Fig. 1) (not considering the effect of other non-fossil fuel sanctions). Moreover, such a disruption would lead to ample domestic supplies and lower prices, which in turn could stimulate the domestic fossil energy consumption, especially the energy-intensive sector and other manufacturing, thus leading to a 5.9%-8.5% increase in CO_2 emissions (161-232MtCO_2) (Fig. 1). At the same time, such a shock would ripple through the rest of the world, knocking 0.5%-0.9% off global GDP and decreasing global CO_2 emissions by 1.3%-2.0% (553-881Mt CO_2).

In the long run, if energy disruption between Russia and EU is halved from 2025 in both disruption scenarios, the economic development of EU would rebound to be around from − 0.7% to -1.2% lower than business as usual (BAU) in 2025 and 2030. Because of the energy transition and substitution effect that has taken place within EU, its trade dependence on fossil fuels, and CO_2 emissions would be still significant lower than BAU. The shock of supply suspension is generally beneficial to the EU's Green New Deal that aims to build a climate-neutral industrial economy. Affected by the embargo, Russia's total production of fossil fuel would decline, as exports can only be partially redirected into other world regions. As a result, Russia's GDP losses would remain over the next decade. For example, Russia would still lose 3.4%-5.2% GDP by 2025 compared with BAU and the GDP losses even would increase to 5.4%-8.7% in 2030 owing to the cumulative negative effects.

In addition, based on the embargo simulation method implemented by the model, we can estimate the corresponding importing tariff/fine revenue if the EU imposes sanctions on Russian fossil fuels through economic measures such as by raising importing tariffs or imposing heavy fines. For example, under the moderate disruption scenario, the increasing production costs and living costs caused by increasing

domestic fossil fuel prices, as well as the tariff revenue reduction caused by decreasing imports, would reduce total revenue of EU's government 2.1% in 2022. However, if the embargo is implemented by imposing tariffs, the corresponding revenue would increase $123.2 billion, which would offset the negative shocks and the final total government revenue would fall by only 0.1%. In the case of strong disruption, the original government revenue reduction would be 3.4%, while implementing the partial embargo via tariffs/fines would produce $87 billion revenue increment, resulting in a reduced government revenue loss rate of 2.0%. Hence, if EU's embargoes are not implemented via tariffs, its GDP losses would be magnified due to greater negative impacts on revenues and investments.

Based on the disruption situation, this study also modeled the two response scenarios as the likely complementary measures associated with EU's embargo: (1) Supply-chain Shift: EU will increase the imports of fossil fuels from other main alternative importers outside Russia by improving unimpeded trade, modelled as cutting tariffs on fossil fuel imports in half. The main alternative regions for each product are USA and OBU (for coal); MAF (for oil); MAF, OWE and USA (for natural gas), respectively [4]. (2) Demand-side Response: EU and national government change the demand patterns of the transportation and building sectors in two ways: 1) Modal shift away from privatized motorized transport to reduce oil consumption; 2) Change in consumption patterns of households and tertiary industries to reduce end-use energy demand. We assume that aggressive measures can reduce demand by 10% (cf [6]). In addition, since the model does not subdivide the specific transport modes of residents, the corresponding simulation is realized by adjusting residents' consumption structure, that is, to reduce the share of oil consumption and increase the share of electricity consumption.

We found that if EU reduces energy-related tariffs for other major trading countries, its GDP losses could be eased, but the overall effects would be very weak owing to very low original tariffs (< 1%), as shown in Extended Data Fig. 2. This shows, for EU, the true bottleneck is not trade tariffs but availability of fossil fuels supply. Moreover, this small variation in GDP would make EU's CO_2 emissions higher than the disruption scenarios after 2022, with a rise of around 0.3% in 2025 and 2030.

The demand-side response measure is likely to be a win-win situation for both economy and environment in EU in the long run. The demand-side response could quickly reverse the negative economic tide. Compared with above disruption scenarios, EU's GDP losses would decrease around 0.8 percentage points in 2022 (Extended Data Fig. 3). Moreover, EU' GDP would eventually increase by 0.3% (if moderate disruption happens) or fall slightly by 0.2% (if strong disruption happens) relative to BAU in 2025. In particular, due to the increasing consumption of most non-energy products, the EU economy would be even more prosperous in the long term, going up by 0.9%-1.3% of GDP relative to above disruptions in 2030. Under the demand-side response scenario, CO_2 emissions in the EU are expected to decrease further due to the reduction in final energy demand and the change in residents' transport mode during the current year and in the long term. GHG emissions would be reduced 1.5%-1.6% more compared to above disruption scenarios in 2022.

In addition, we found a combination of demand-side response and embargo could cushion the rise in each region's importing oil prices. Compared with the only embargo situation, the increase of demand-side response would reduce international importing oil price by around 0.2% (Eastern European CIS, EES)-1.0% (Russia). In this case, all countries' GDP losses would decrease and total losses in the world economy would be 0.2 percentage points lower, except that Russia's economy and environment would suffer a little bit more losses than above disruption scenarios (Extended Data Fig. 2 and Fig. 3).

Three types of uncertainty analysis are performed by examining each disruption product separately, assuming different labor markets, and limiting different degrees of trade substitution effects. See Supplementary Material 2 for details. Results show that above findings are generally robust. In addition, economic losses of EU and Russia are mainly from the broke supply of oil and natural gas, and less impacts from coal disruption. On the other hand, the labor market have been assumed to be important for overall economic effects [7,8], and we assume rigid wage and mobile labors among sectors in the basic scenario. Based on this, two additional labor adjustment scenarios are tested here: a more optimistic scenario with flexible wage and a more pessimistic scenario without labor mobility among sectors. We found that, the negative economic effects would be reduced in the former case and the latter case would worsen Russia's and EU's economic losses. Finally, the examination about trade substitution effect shows that the tighter the trade substitution restrictions, the greater the GDP losses of Russia and EU. For example, with moderate disruption in 2022, Russia's GDP losses are 1.3% (no limit)-3.7% (strict limit) and EU's GDP losses are 1.2% (no limit)-1.6% (strict limit), respectively. All indicators of the uncertainty analysis results are available in Supplementary Material 3.

To conclude, EU's embargo to Russian fossil fuels, in particular of oil and natural gas, would hurt both economies. The embargo would increase Russia's CO_2 emissions, while accelerating EU's green deal. Importing tariffs are similar to a partial or full embargo, depending on the height of tariffs. Moreover, such a way of economic sanction could generate extra revenue, which could obviously offset the negative shocks on government deficits, otherwise the negative impact on EU's long-term economic growth would be greater. For the EU, the supply-chain shift measure through simply improving unimpeded trade has little benefits. Demand-side response measure like reducing residents' heating demand, speed limits, and car-free Sundays would however improve overall economic performance in synergy with further decreasing GHG emissions.

Method

The disruption effects in this study are simulated through the Global Energy and Environmental Policy Analysis Model of China's Climate Change Integrated Assessment Model (C^3IAM/GEEPA) we developed [9]. GEEPA is a multi-regional recursive dynamic computable general equilibrium (CGE) model, which is composed of production, income, expenditure, investment and foreign trade these five basic modules. Its basic framework is shown in Extended Data Fig. 4. Greenhouse gases (GHGs) including CO_2, CH_4 and N_2O emissions, and air pollutants have been represented in the model. Detailed introduction of each

module is shown in Supplementary material 4. Countries in this study are aggregated to 12 regions, including USA, China, Japan, Russia, India, OBU (Other Branches of Umbrella Group), EU (European Union), OWE (Other West European Developed Countries), EES (Eastern European CIS excluding Russian Federation), ASIA, MAF (Middle East and Africa), and LAM (Latin America) (see Supplementary material 5 for details). GEEPA is calibrated to Global Trade Analysis Project (GTAP) version 9, which prepared the worldwide input-output tables and trade database [10]. The base year GHGs are derived from the database of Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) [11].

Future normal development is generated following the SSP2 narrative-a Middle of the Road pathway. The world follows a path in which social, economic and technological trends do not shift markedly from historical patterns, with some progress towards achieving development goals, reductions in resource and energy intensity at historical rates, and slowly decreasing fossil fuel dependency [12]. Besides, the energy development is calibrated following the trends projected by EIA (U.S. Energy Information Administration), and the environmental emissions development is calibrated based on the trends in CMIP6 (the Climate Modelling Intercomparison Project 6) emissions [13].

A set of complementary constraints is used to simulate both disruption and non-disruption referring to Jiang et al. [14]and Xue et al. [15], as Eq. (1).

$$\begin{cases} \chi_{i,s,r} \cdot (Ms_{i,s,r}^{disruption} - Ms_{i,s,r}) = 0; \\ Ms_{i,s,r}^{disruption} - Ms_{i,s,r} \geqslant 0; \\ \chi_{i,s,r} \geqslant 0; \end{cases}$$

1

Where, $\chi_{i,s,r}$represents the importing windfall profit tax rate for product *i* from region *r* to region *s*; $Ms_{i,s,r}^{disruption}$and$Ms_{i,s,r}$ represent the importing cap and import volume, respectively. If the second constraint is a strict equality, the windfall profit tax rate$\chi_{i,s,r}$will be the shadow price of this constraint and be zero or strictly positive, when the first and third constraints are satisfied; if the second constraint is strict inequality with no effective disruption restrictions, the third constraint has to hold with strict equality to satisfy the first constraint.

The windfall profit $WP_{i,s,r}$is determined by Eq. (2).

$$WP_{i,s,r} = \chi_{i,s,r} \cdot PMs_{i,s,r} \cdot Ms_{i,s,r}$$

2

Where $WP_{i,s,r}$is the windfall profit and $PMs_{i,s,r}$is the import price.

The import demand function can be modified as shown in Eq. (3).

$$Ms_{i,s,r} = \left[\frac{Am_{i,r}^{\eta_i} \cdot \alpha m_{i,s,r} \cdot PM_{i,r}}{(1 + \chi_{i,s,r} + tm_{i,s,r}) \cdot PMs_{i,s,r}} \right]^{\frac{1}{1\text{-}\eta_i}} \cdot M_{i,r}$$

3

Where $M_{i,r}$ represents aggregate import goods in region ; $PM_{i,r}$ represents aggregate import price in region ; $Am_{i,r}$ represents the scaling coefficient in the Armington commodities function; $\alpha m_{i,s,r}$ is the share parameter in the Armington commodities function; η_i represents the substitution parameter in CES function between imports; $tm_{i,s,r}$ represents import tariff rate *i* in region *r* from region *s*;

The income balance for the government is modified as shown in Eq. (4).

$$G_{Income,r} = TOTITAX_r + TOTTARIFF_r - TOTEXSUB_r + TOTHTAX_r + \sum_{i,s} WP_{i,s,r}$$

4

Where $G_{Income,r}$ is government income in region *r*, $TOTITAX_r$ is total indirect taxes from production in region *r*, $TOTTARIFF_r$ is total import taxes in region *r*, $TOTEXSUB_r$ is total subsidies for exports in region *r*, $TOTHTAX_r$ is total direct taxes from households in region *r*.

Declarations

Data availability

The data that support the plots within this paper and other findings of this study are available from the corresponding authors upon reasonable request.

Code availability

The codes that support the methods of this study are available from the corresponding authors upon reasonable request.

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Figures

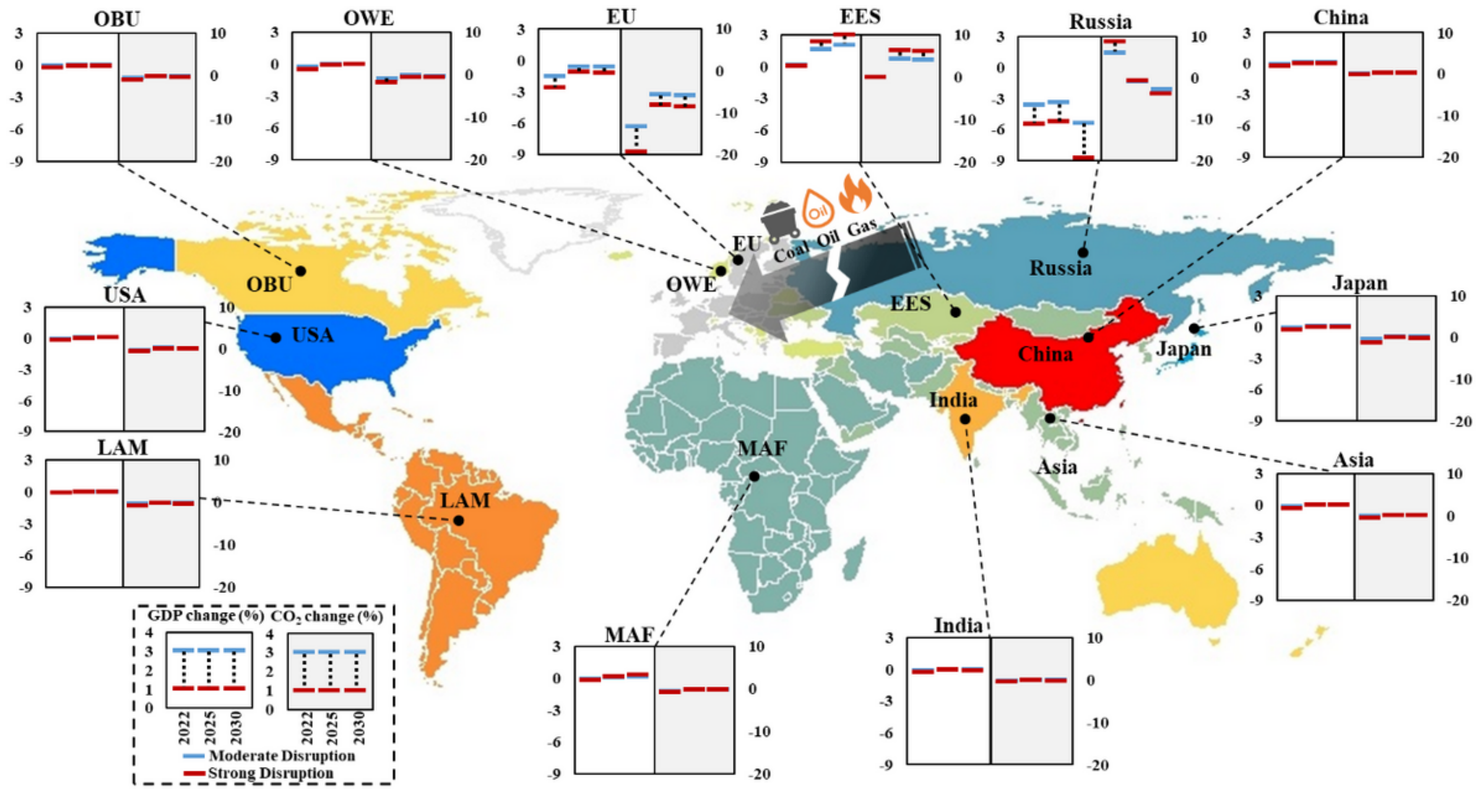

Figure 1

The changes in GDP and CO_2 emissions of each region under the disruption scenarios in 2022.

See Supplementary Material 1 for the numbers and absolute changes in GDP and CO_2 emissions

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial1ChangesofCO2emissionsandGDP.xlsx
- Dataset2.docx
- SupplementaryMaterial3Resultsofuncertaintyanalysis.xlsx
- Dataset4.docx
- Dataset5.docx
- ExtendedFigures.docx