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European Economic impacts of cutting energy imports from Russia: a computable general equilibrium analysis

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Abstract

The recent economic sanctions against Russia can jeopardize the sustainability of the European Union's (EU) energy supply. Despite the EU's strong commitment to stringent abatement targets, fossil fuels still play a significant role in the EU energy policy. Furthermore, high dependency on Russian energy supplies underlines the vulnerability of the EU energy security. Using a global computable general equilibrium model, we prove that the current EU embargo on coal and oil imported from Russia will have adverse supply effects, substantially increasing energy prices and welfare costs for the EU resident. Although it reduces emissions, extending the embargo to include natural gas doubles this welfare cost. The use of coal is likely to increase, especially with respect to EU electricity generation, given the current constraints of additional import capacities from non-Russian producers. The impact on Russia once the EU extends the sanctions to natural gas is less substantial than on the EU. Russian welfare cost will increase less than 50%, indicating that extending the current restriction to boycott Russian gas is a costly policy option.

Keywords: European Union, Russia, computable general equilibrium model, Fit for 55 package, Imports ban
JEL: C68, F51, Q54, Q43
Abbreviations[1]

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[1]bcm: billion cubic meters, b/d: barrels per day, ESR: Effort Sharing Regulation, ETS: Emissi-

Highlights

- We use a CGE model to simulate different configurations of an EU embargo on Russian energy imports within the Fit for 55 climate package.
- We find the current EU embargo on coal and oil leads to an estimated cumulative cost of 1'521 US$ per European resident over the period 2022-2030.
- Extending the embargo to Russian natural gas imports will double the welfare cost for the EU.
- In the full embargo scenario, European gas consumption will have to decrease by around one third.
- The embargo on coal and oil is more detrimental to Russia and switching to the full gas embargo will not substantially increase its welfare cost.

1. Introduction

Russia's aggression toward Ukraine, which began on 24 February 2022, is a global concern and has become a point of great interest among policy makers. Initial studies have been conducted on the recessive impact of the war [63, 25], its impact on food markets [34] and on the environment [62]. However, for the EU, the Russian aggression followed by several economic sanctions highlights the dependence of European countries on Russian fossil energy. While the EU's embargo is already on the table as an immediate response, strengthening sanctions raises questions about European countries' ability to quickly reduce or discontinue cut off their fossil energy imports from Russia. The European Commission has proposed an outline of a plan - *RePowerEU* - to enable Europe's independence from Russian fossil fuels well before 2030 [18].

The economic impacts of a total embargo on fossil energy imports from Russia has become a global concern and is of particular interest among European policy

ons Trading System, EU: European Union, CGE: Computable General Equilibrium Model, GDP: Gross Domestic Product, GHG(s): Green House Gas(es), LNG: Liquified Natural Gas, mcm: million cubic meters, NDC: Nationally Determined Contribution, OECD: Organisation for Economic Co-operation and Development, OPEC: Organization of the Petroleum Exporting Countries, TWh: Terawatt-hour, USA: United States of America makers. Recently published studies such as [4], [7], [5], [16] and [40] analysed the implications of such an embargo, emphasising the cost to European countries due to changes in international trade. The results of these initial works range from relatively low impacts of this embargo to a substantial, but manageable, impact with associated GDP declines.

As the conflict evolves, the EU's position on coal, crude oil and petroleum products is clear. Having issued the 5^{th} package of restrictive measures against Russia [20], the EU has banned Russian coal imports in all forms, starting from August 2022. Assuming Russia can not easily divert its exports to other countries, the ban will affect one quarter of Russia's entire coal exports, representing around 8 billion US$ of revenue loss each year for Russia [20]. Russia accounted for 45% of EU coal imports in 2021 and around 25% of EU oil imports. The 5^{th} package was followed by the recent adoption of the 6^{th} restrictive measures [19], which emphasise the oil import restriction to be completed in 2023. This time-frame allows for a certain transition period for the global market to adapt in order to ensure the Russian oil will be phased out in an orderly fashion.

The EU's position on natural gas import restrictions tends to be less stringent than that for coal and oil. By late July 2022, the EU energy ministers had only reached a political agreement to reduce natural gas demand by 15% [23]. The EU imports 85-90% of its natural gas consumption, with Russia providing around 40% of those imports at varying levels across the member states [77]. While imports from other countries can replace imports of oil and coal from Russia, the situation is much more difficult for natural gas imports [74, 46, 68] due to the capacity constraint of natural gas replacement.

Despite the optimistic view about the future of EU natural gas [52], phasing out Russian gas is likely to present enormous challenges [59]. Shifting could lead to a paradox whereby natural gas is expensive and reliable, emphasising the need for a fundamental transition of the EU energy system to tackle the EU's vulnerability in its energy policy. Yet the role of natural gas is also critical in the EU mitigation agenda as it is considered by many European countries as a transitional fossil energy that allows for a rapid reduction in the use of coal, while waiting for the emergence of alternative energy sources that do not emit CO_2 [38]. There is debate on the EU's classification of natural gas as green energy, reflecting the special status of this fossil fuel in a strategy of strong decarbonisation of our economies.

The restriction of energy import from Russia will likely have strong implications for the implementation of the EU's strategy to reduce greenhouse gas emissions. The current trade restriction and energy security dilemma certainly affects

EU climate mitigation. Thus, to be relevant, the analysis of this EU import restriction should take into account the latest EU climate commitment, the “Fit For 55 Package” [32]. This paper aims to add to the growing literature on the economic impacts of the EU’s cutting energy imports. Our analysis complements the previously published works on the analysis of EU import restrictions on Russian energy by Cheveliev et al. [16], Baqee et al. [5], and the European Commission [33], by taking into account the latest restriction on coal and oil imports and developing additional scenarios for restrictions on natural gas based on the latest progress in 2022. Compared to the initial analysis conducted by Organisation for Economic Cooperation and Development (OECD) [58], we extend this to different restrictions on natural gas that the EU may implement, and evaluate from the perspective of the EU’s latest commitment to Fit for 55.

We use GEMINI-E3, a model of the European and World economy, we construct different simulations to estimate the implications for energy prices of such an embargo, the economic cost to European citizens and whether the impact on the Russian economy would be significant. GEMINI-E3 is a dynamic model in the framework of a computable general equilibrium (CGE), which is a framework that is frequently used to assess the impact of economic sanctions [48],[16]. This general equilibrium approach captures supply and demand by a consistent representation of different sectors, households, markets, and interdependencies; so adjustments in quantities and prices following the implementation of the energy an embargo could be adequately measured. Particularly for GEMINI-E3, GHG emissions are adequately calibrated from the most up-to-date policy databases. These features adapt the model to be applied, including for the analysis of embargo under the EU’s latest climate targets. The decision on the scale of restriction of natural gas (with relatively lower emission contents) can affect the EU abatement target, while the EU’s boycott of Russian energy supplies can affect EU energy prices and demand, resulting in higher abatement and higher costs for the EU.

Our paper is organised as follows. Section 2 presents a review of the literature on energy and the economic implications of import restrictions, followed by an overview of the EU’s energy dependence on Russia. In section 3, we introduce the analysis tool used for this study and the details of our reference scenario, including the implementation of Fit for 55 measures. The scenario is followed by a further scenario depicting the halting of oil, coal and natural gas imports and their impacts. The results are discussed in section 4, followed by a discussion of limitations of this study in section 5. Section 6 concludes the conducted analysis and findings.

2. Economic implications of import restriction and EU energy dependency to Russia

2.1. Trade restrictions on energy imports from Russia: Initial studies

Despite being widely debatable [60, 13, 22], economic sanctions are often politically seen as an effective policy tool [35, 56, 28, 57] to accomplish various policy objectives [43, 24, 30] such as compliance, subversion, and/or international deterrence [50]. The embargo on Russian exports is intended to accomplish these objectives, which will be essential for speeding up an end to this devastating conflict.

The EU has officially banned coal imports from Russia starting in August 2022 [20], followed by oil imports to begin in 2023 [19]. Some countries are also sanctioning Russia by ending gas imports and pipeline oil this year, setting out a plan to reduce use of gas from Russia by at least one-third in 2022 [61]. The European Commission has released its RePowerEU plan [18] targeting a two-thirds cut within a year and Russia has halted gas exports to a few EU member states. There has already been a substantial shift in the composition of European gas imports in the first 21 weeks of 2022. EU imports of Russian gas via pipeline were down by more than 30% compared to the corresponding period in 2021 [58]. The share of Russian gas in total gas imports fell from a weekly average of 35% in the first 21 weeks of 2020 and 2021 to 24% in the same period of 2022. European economies'energy imports from Russia are expected to fall sharply in 2023 [45].

The very initial study by Chepeliev et al. [16] reveals that short-term implications are likely to be non-trivial for the EU – Russia's largest energy export destination. The analysis involves several scenarios, from substantial restriction (80%) to a severe energy embargo from Russia (99%). Households' real income could drop by 0.7-1.7% (relative to the reference case), with energy prices growing by as much as 11%. The cost is expected to be more modest over the longer run, with a 0.04% slowdown in the annual growth rate of real income over the 2022-2030 period. Despite this tendency from Chepeliev et al.'s initial study towards non-trivial impacts, the inflationary impact across the EU will depend more on the extent of reduction of oil and gas imports [51]. An abrupt Europe-wide interruption of energy supplies from Russia will lead to further increases in commodity prices or stronger disruptions to global supply chains [3].

In the latest outlook, OECD also highlights this risk of potential adverse effects from a complete boycott of Russian gas import [58]. The embargo will push up global gas prices and affect energy intensive productions. The increasing demand for energy is expected to spill over into the oil market, raising the oil price.

Assuming 75% of Russian gas exports to EU can not be diverted due to logistical difficulties, growth in most economies is set to be considerably weaker than would typically be expected. The EU growth projected for 2023 is now 1.25 percentage points below the baseline projection. Meanwhile, outside Europe, the repercussions would be smaller, especially in other gas-producing economies [48].

The adverse effects could be much larger [29, 55, 36], for differences across member states in the energy mix and the share of energy inputs that originate in Russia. How it affects different sectors is likely to vary according to their dependency on energy imports from Russia and scope to obtain alternative energy supplies or reduce demand. The worst impact might arise from a sudden stop in imports from Russia at a time when stocks are low and the possibility to switch quickly to alternative supply sources is limited.

A recent study by Bachmann et al. [4] assessed a potential disconnection of the German economy from Russian energy imports as substantial, but manageable. Their state-of-the-art multi-sector open economy model showed that the effects of such a restriction will be a decline in associated GDP from 0.5-3% over the short run. The cost for Germany could reach 1000 € per German resident over a year. Bachman et al.'s study tends to contrast against an earlier estimate using input-output linkages that also pointed to relatively small output costs in Europe if imports of natural gas from Russia ended [11] and supports Gornig et al. [39] regarding the risk of a large and immediate drop in output in the event of a sudden stop in energy imports from Russia. In line with Bachmann et al. [4], Sokolowski et al. [70] found that the effects of an embargo on Russian fuels will also be substantial, but manageable, for Poland. Poland's GDP is expected to fall by 0.2-3.3% by the end of 2022, subject to the magnitude of price increases. The effect on households is regressive, i.e. low-income households would spend 0.3-4.7% more of their incomes on energy in 2022 and 2.6-4.8% more in 2025.

Baqaee et al. [5] reveal significant heterogeneity in the magnitude of the shock across countries. France's national income will decline by around 0.15-0.3%, or 105 € per French citizen. Yet this study finds significant impacts for Germany, confirming Bachman et al.'s findings on Germany of 0.3-3% GDP loss. Lithuania, Bulgaria, Slovakia, Finland and the Czech Republic may each experience national income drops of between 1-5%. However, the study suggests a relatively low impact resulting from an embargo, as companies and the economy as a whole can substitute (even very partially) sources of energy and intermediate or final goods with others.

The availability of substitute for energy sources thus plays a significant role in determining the magnitude of the shock. Further, it underlines how trade restrictions, energy security and climate mitigation are intertwined, and shows that the emergency response to a possible energy crisis has turned out to be a stark scramble for alternative sources of fossil fuels, which consequently affects climate mitigation. While improving external energy security [54] and accelerating development to renewables to solve the EU's potential energy crisis [7, 40] seems to be an ideal solution from the macro and environmental perspectives, moving away from fossils fuels seems to be a longer rather than a short-term solution. Some EU governments have indicated their intention to reopen and extend coal-fired plants to compensate for diminished Russian gas supplies [53].

Moving forward from these studies, the implications of the current economic embargo should be understood without neglecting the EU's commitment to the abatement of emissions. Given the latest acceleration towards the reduction of GHG emission targets in the next decade with Fit for 55, an additional EU embargo on energy imports would lead to substitution with coal, and impose the risks of possible adverse supply-side effects. Despite the relatively modest effect concluded by current literature, the embargo can push up inflation and weaken growth, particularly in Europe, even if alternative supplies can be found on world markets at higher prices and shortages avoided.

Achieving the EU's most stringent climate abatement target in a sluggish period can potentially result in an extra burden that further reduces economic welfare. The Russian invasion and the EU embargo have also altered European perception of Russia's energy security role [47] as important suppliers of a number of commodities. The pandemic and the war exposed many longstanding structural weaknesses with effects on countries that differed, based on their import dependency on Russia.

Despite the similarities between the current situation and the negative supply shock of oil in the mid-1970s, implications may differ as economic policy frameworks are very different, and structural changes may alter the impact on price and economic activity. The stagflationary impact may be less than in the mid-1970s, but persistent uncertainty will probably be a drag on consumption and investment and will impede growth [72]. Reviewing EU dependency on Russian energy export is critical to project the extent to which the change in demand will impede EU growth, given the current dependency on imported energy from Russia, capacity to replace energy imports outside Russia and current climate mitigation targets.

2.2. Dependency of the European Union on Russian fossil energy

Coal: There's relatively low dependence on Russian imports. The use of coal has been declining in Europe for 30 years and is expected to eventually reach zero under the new EU energy and climate policy. However, with 20% of coal imports, Russia remains a major supplier to Europe, particularly for anthracite (hard coal). This dependence can be offset by the existence of domestic lignite resources for electricity and imports from the USA or Australia, albeit at a higher cost. In the event of an abrupt change in gas supply and despite the climatic cost in carbon emissions, coal is a last resort option to replace gas-fired power generation units.

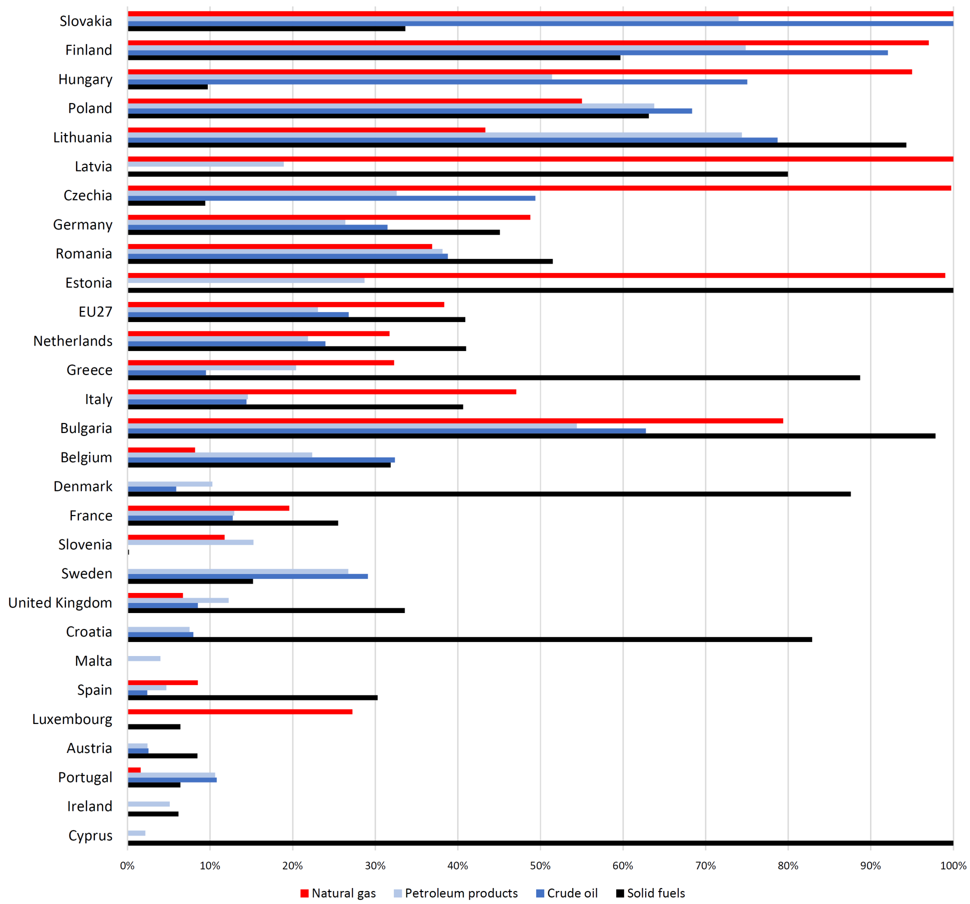

Figure 1: Share of Russian imports in fossil energy imports by country (%) year 2020 (sorted according to total share of Russian energy imports. Source: Eurostat Database)

Oil: There's a manageable dependency. Oil is Russia's main source of export revenue. Russia is the main supplier of crude oil and oil products to Europe, and this dependence has increased since the 1990s. The high-quality Russian crude oil, called Ural, was underpriced by about 30-40%, but the geopolitical situation of the current Russian invasion has increased the price of premium oil. A total replacement of Russian crude oil imports remains feasible as the world market is relatively flexible, and the logistics for the rearrangement of supply routes between Asia, Africa, the Middle East and Europe have already been implemented. OPEC's production capacities, the return of US production growth and a significant storage capacity (more than one year) of Russian exports are expected to fulfil the demand.

European refineries are optimised to use Russian oil and will be less efficient if producing with a different quality of crude. Ural quality can be replaced to some extent by Iraqi, Angolan and Iranian crude, which come closest to Russian crude. A similar problem occured in 2019 (contamination issues by organochloride [17]) and refineries were able to adapt and to re-route deliveries over several months. However, a certain number of Eastern European countries remain highly dependent on pipelines for their supplies, which has led to heated discussions on the European embargo policy. Particularly vulnerable are six large refineries along the Druzhba pipeline (in Poland, Germany, Czechia, Austria, Hungary and Slovakia).

The EU's crude oil production (3.4 million b/d) is only one quarter of its oil demand (13.5 million b/d). Norway and UK productions are also declining. Therefore, the EU imports significantly more oil product than it exports. Russia has a significant market share but only close to 30% of EU imports.

Natural gas: Dependency on Russia. The total consumption of natural gas in Europe (EU27+UK) is about 480 billion cubic meters (bcm) in 2021, with domestic production representing 18% of this total.

Europe produced 192 bcm in which 59% or 114 bcm was produced in Norway, 32 bcm or 26% was from the UK, and Netherlands contributed 18 bcm. These natural gas fields are mature and a less significant increase could be expected. The rest is imported by pipeline and by sea in the form of liquefied natural gas (LNG). A large proportion of this gas is used for heating homes and buildings, so the demand for gas is highly seasonal. Gas is put into storage during the summer and used during the winter months. Imports from Russia account for about 155 bcm (32.4%) through the Nord Stream 1, Yamal-Europe and Ukrainian transit routes, including 18 bcm (3.8%) in the form of LNG. This dependence gives Russia a great deal of influence on Europe [10]. Russia also remains dependent as European countries make up 40% of its gas exports [6]. Additionally, damage caused by the September 26 sabotage from explosions at the Nord Stream 1 and Nord Stream 2 pipelines in the Baltic Sea will be difficult to repair as pipeline repairs are not expected to be necessary during their operational lifespan of at least 50 years. The two pipes were each designed to trasnport 55 bcm per year of natural gas from Russia to Germany, but nothing was delivered as Gazprom had suspended flows through Nord Stream 1 and the Ukraine crisis prevented the start of Nord Stream 2.

The Czech Republic, Latvia and Hungary are totally dependent on Russian gas. Germany, Italy, Poland, Bulgaria and Finland rely on more than 40% of gas imported from Russia. In the short term, where demand is not very elastic, these economies will be severely affected by the slowdown of energy-intensive industries. Rationing over winter and even, at the extreme, the possibility of more or less extensive power cuts are envisaged by the major energy players, particularly if Russian gas flows were to come to a sudden halt. In contrast, France, Spain, Sweden and Austria are less dependent on Russian gas. Since December 2021, gas supplies from Russia have decreased by around 30%, but have remained within pre-established contractual boundaries. The contractual minimum for Russia to deliver to Europe is 94 bcm/year.

2.3. Energy import restriction and the EU's transition to Fit for 55

A quick analysis of Europe and Russia's trade clearly points to the possibility of a shortage situation in the short term and the desire in the medium term to ensure better security of energy supplies for European economies. Optimal decision-making on this issue requires a clear understanding of the economic cost to Europe of diversifying away from Russian gas imports in a context constrained by the energy transition objectives of the Fit for 55 program. Due to the complexity of the European energy system and its interactions with the rest of the world, potential solutions must be assessed within a global economic model. This is the main issue the paper will address by reviewing the newest EU climate target under various scenarios of restriction of energy imports from Russia.

Further, the specific role of natural gas in the EU substantiates the importance of evaluating the impact of the restriction of imports of each fossil fuel. Since coal and oil are easily substituted, restricting their import may have a different impact than for Russian natural gas, on which the EU is highly dependent. Given the logistical and infrastructure difficulties of pipeline gas import, switching to LNG is feasible as a short-term solution. However, this faces constraints on both production and market for the longer term to fulfil the EU demands. Understanding and incorporating these additional constraints will allow for a better projection of price adjustments that affect demand and make it possible to evaluate which energy types affect the EU the most. This information is critical given ongoing efforts to diversify sources of energy supply in Europe.

3. Model and scenarios design

3.1. The GEMINI-E3 model

We use the latest modification of GEMINI-E3 based on the study by Bernard and Vielle [8]. GEMINI-E3 is a multi-country, multi-sector, recursive dynamic, general equilibrium model with backward-looking (adaptive) expectations and total flexibility in macroeconomic and microeconomic markets. International trade is represented by the Armington assumption [2], which assumes that goods from different regions are imperfect substitutes. For fossil energy imports, we use an elasticity higher than 1, meaning that fossil energy goods are highly substitutable. The current version is built on the GTAP-Power database version 10 with the year 2014 as a reference [15], and with countries aggregated into eleven regions. In this version of GEMINI-E3, *European Union* refers to EU28, including the United Kingdom. Sectors are limited to eleven for a tractable and acceptable computation time. All monetary values reported in the simulation section refer to prices in the year 2014.

GEMINI-E3 has nine types of power plants. Three types of power plants are linked to fossil fuels: coal, fuel oil and natural gas power plants. Electricity generation using renewables is represented by wind, solar photovoltaic, hydro and biomass. Finally, nuclear power is also represented, and the rest of the power plants aggregate geothermal energy, waste incineration, etc. Nested CES functions are used to described the different uses of power plants in a stylised manner. This nested CES structure is described in Appendix A.

3.2. The current policies scenario

Our baseline takes the advantage of the work done in the framework of the Paris-Reinforce project, by integrating the climate and energy policies currently decided by all countries. The methodology, assumptions and implications for GHGs and global warming are described in Giarola et al. [37]. The climate objective adopted for Europe is updated to include the new package of measures known as “Fit for 55”, a 55% reduction in emissions by 2030 compared to 1990 emissions. We do not consider that a European carbon border adjustment mechanism is associated with this new climate target as the details and the date of implementation on this new instrument are not yet completely defined.

This new objective is implemented through two carbon prices: an ETS price within the ETS sectors, and a CO_2 tax (called Effort Sharing Regulation (ESR) price) for the other economic sectors and households. The ETS sector includes the refining sector, the power sector, energy intensive industries and aviation. Allowances for ETS emissions are auctioned, so there is no free allocation. In the ESR sectors, a wide variety of measures has been or will be implemented (eg. fuel efficiency target for passenger cars, energy performance standards for appliances, building refurbishment program, etc.). This wide variety of measures are very difficult to represent in a CGE model. The assumption behind a uniform carbon tax is that all of the economic instruments listed above are defined in order to equalise their marginal abatement costs. Furthermore, several European countries have already implemented a carbon tax, such as Germany, Luxembourg, Sweden, etc. The revenues from the CO_2 tax are redistributed to households through a lump-sum transfer so as to leave the government budget unchanged. The ESR price also applies to all GHG emissions of methane, nitrous oxides and fluorinated gases.[2] The databases used to calibrate these non-CO_2 GHG are described in Appendix A, while marginal abatement curves implemented in the model are derived from the work done by the US Protection Agency [76] following the methodology described in [9].

The abatement targets are 61% for the ETS sector and 40% for non-ETS emissions compared to 2005 emissions [31]. As shown in Table 1, the "Fit For 55 Package" increases the ETS price, reaching 113 US$ in 2030. This is in line with the estimation by Cornago [21] of 100 € per tonne of CO_2 in early February.[3] The price in non-ETS sectors (that is, the sectors included in ESR) increases rapidly after 2025 and reaches 189 US$ in 2030, showing how stringent the new "Fit For 55 Package" is, especially in the transport sector and for non-CO_2 GHGs. We assume that other regions implement a subset of current climate policies as defined in the CD-Links policy database, documented in Roelfsema et al. [65]. The resulting GHG emissions are given and compared with other integrated assessment models in Sognnaes et al. [69]. The current policies scenario differs from a more binding scenario where the nationally determined contributions (NDC) are supposed to be implemented. In 2030, Sognnaes et al. [69] evaluate the difference to 2 Gt CO_2 worldwide.

[2]Except those integrated into the ETS.

[3]The *Independent Commodity Intelligence Service* consulting company expects that the EU-ETS price will reach around 90€ by 2030 [64].

Table 1: European CO_2 prices in the current policies scenario in US$$_{2014}$

	2022	2023	2024	2025	2030
CO_2 ETS price	62	75	94	105	113
CO_2 ESR price	0	0	10	25	189

3.3. The fossil energy import restriction scenarios

Simulations cover the period 2022 to 2030, evaluating the economic impacts over the medium term. The 2030 horizon has the additional advantage that the EU's climate objectives are well staked out. The energies affected by the embargo are coal, crude oil, refined petroleum products and natural gas. Technically, these restrictions are integrated in our model through the implementation of tariffs on Russian imports following the methodology proposed by Chepeliev et al. [16]. However, in contrast to Chepeliev et al. [16] we assume that there is no revenue associated to this tariff that increases the European budget. This tariff represents a shadow price associated with the constraint. Here we take into account the actual possibilities for diversified European gas provisions in the short and medium term suggested by Lambert et al. [49] by introducing additional constraints on additional natural gas imports from the EU's trading partners.[4] These reflect capacity constraints on natural gas transportation by pipeline or by sea as illustrated in Figure 2. In our model, additional exports from these countries will require additional production and therefore increase investment in the natural gas sectors.

The stacked-bar graph indicates the main sources of gas supply diversification available to Europe. We assume that these countries will supply as much capacity as possible to Europe and accelerate current and future projects to support the EU policy action, even if the gas prices are escalating. Similarly, the existing LNG exporters, the USA and Qatar will divert the maximum amount of LNG to Europe by price arbitration of LNG cargoes. Within a few years, projects under development in Senegal and Mozambique will also bring significant volumes to the LNG market.

In developing these import restriction scenarios, we follow the most recent update of the EU import restrictions on fossil fuels from Russia. Russian coal, in all forms, was fully terminated by August 2022, following the adoption of the 5^{th} package of sanctions against Russia, issued on 8 April 2022. The updated EU import data shows that the EU had imported 36.64% of the total 2021 import of

[4] These constraints are also implemented into the model via an import tariff.

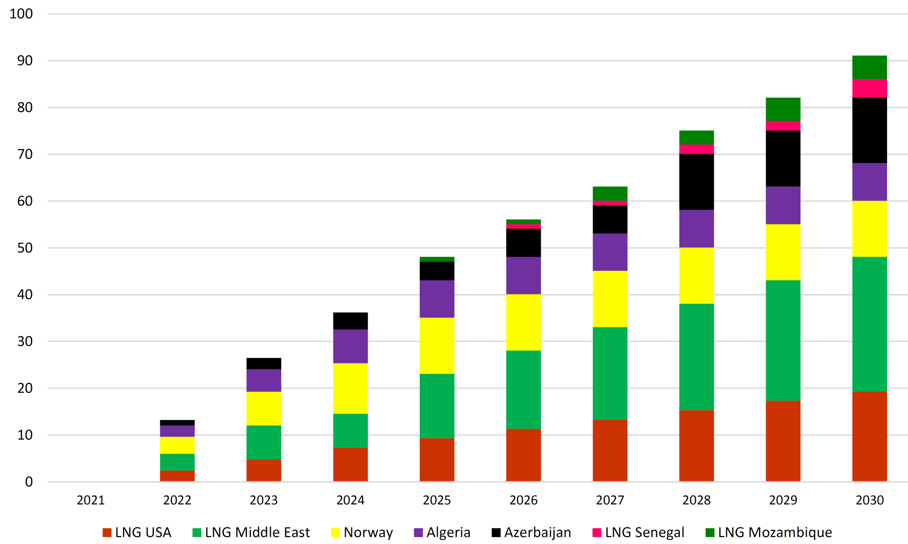

Figure 2: Additional gas import capacities from non-Russian producers in bcm. Source: Authors' estimation from various sources.

coal from Russia by May 2022.[5] The target for complete cessation of Russian oil is the year 2023 following the adoption of the 6^{th} package on 3 June 2022. This time-frame allows a transition period for the global market to adapt and to ensure phase-out is orderly. Oil imports from Russia have been declining since February 2022, and by May 2022 this was reduced to 42.4% of the total imports from Russia in 2021.[6] The embargo scenarios are further developed by projections of gas restriction policies that the EU will implement (Table 2).

The first is the no gas embargo scenario, with the assumption of no restriction of natural gas imported from Russia. The EU monthly import is assumed to be constant from August until the end of 2022. EU imports 943 mcm on the 4^{th} week of July, 2022 [78], thus we assume that Russia will deliver approximately 900 mcm per week or 3.6 bcm per month. Then EU gas imports will return to normal, back to the predicted value of the reference scenario for the year 2023 onward. The results of this scenario will show the impacts of limited import restrictions

[5] Author estimation from Eurostat. Raw data is available at: https://ec.europa.eu/eurostat/databrowser/explore/all

[6] ibid.

only for coal and oil.

The second scenario assumes a full gas embargo scenario, with Russian gas imports fully restricted from 2023, following the same time frame as oil. The monthly imports decline at linear rates until the end of 2022 and the natural gas imports from Russia will be totally banned from 2023 until the end of the forecast period. This scenario estimates the impacts of total restriction of imports for coal, oil and natural gas. Here we assume Russia faces no logistical difficulties and its gas exports could be diverted to beyond the EU. Declines in its natural gas exports, if any, are caused purely by the elasticity of demand outside the EU.

Given the difficulty of fully replacing natural gas imports from Russia due to capacity constraints as previously elaborated, the third scenario (limited gas embargo) limits Russian gas imports to 50% of 2021 levels from 2022 onward. We chose this arbitrary level following the target that EU import of Russian gas will decline by over 45% in 2022, to under 80 bcm [45]. We came up with 78.5 bcm, half of 2021 imports, as the most representative amount. This amount is lower than the 94 bcm contractual minimum of Russian exports to the EU, and this scenario is also consistent with the 55 bcm pipeline delivery capacity that has disappeared after the Nord Stream 1 sabotage.

The last scenario also uses the same limited gas embargo assumption with the additional assumption of the war ending in 2025 and the resumption of energy deliveries, following one of the scenarios developed by Ségur et al. [67]. This scenario assumes that Nord Stream 1 will be repaired. However, repairing such damage to undersea pipelines would be complicated and costly by the incursion of seawater into the line due to the pipeline's corrosion [12]. We do not consider this cost. These last two scenarios are more feasible than the full embargo scenario, given the capacity constraints on redirecting imports from other countries besides Russia.

4. Results of the simulations

4.1. No gas embargo scenario

Table 3 shows the main results of the no gas embargo scenario. In 2022, natural gas consumption is 11.4% lower, following the recent trend of declining demand. Some of this is offset by coal, with a consumption increases of 6.6%. As European gas imports from Russia return to reference levels post 2022, the results indicate the pure impacts of the embargo on coal and oil. The Russian oil is replaced by imports from other trading partners, with no significant impact on

Table 2: European gas imports from Russia in bcm

	Current policies	No gas embargo	Full embargo	Limited gas embargo	Short term embargo
2021	157.0	157.0	157.0	157.0	157.0
2022	155.7	73.9	64.0	78.5	78.5
2023	155.7	155.7	0.0	78.5	78.5
2024	154.5	154.5	0.0	78.5	78.5
2025	153.0	153.0	0.0	78.5	153.0
2026	151.8	151.8	0.0	78.5	151.8
2027	148.9	148.9	0.0	78.5	148.9
2028	146.1	146.1	0.0	78.5	146.1
2029	143.1	143.1	0.0	78.5	143.1
2030	142.8	142.8	0.0	78.5	142.8

the worldwide crude oil price (less than 4% over the entire period). The petroleum products price increases by 12.8% in 2023, reducing European petroleum products consumption by 4.6%. The Russian coal is substituted with additional imports and European coal production. The EU has faced a constant decline in coal production since 1990, yet the current Russian coal embargo needs it to remain at least stagnant to fulfil the domestic demand. In addition to replacement by oil imports from other trading partners, increasing domestic coal production as suggested by Antosiewicz et al. [1] can also be a counter-policy action of declining Russian oil demand. In 2030, in our simulation results, the level of European coal production reaches the same level as in the year 2020.

On the other hand, the impact on energy prices is significant. The price of gas is nearly unchanged after 2022, but the price of coal increases by 29.9% at the end of the simulation. In the current policies scenario, the relative price of Russian coal compared to other producers decreases due to the depreciation of the ruble. The use of other sources of supply (abroad and domestic) increases the price of coal in Europe. This increase in coal production outside Russia also leads to an increase in coal production cost due to capacity constraints. The price of petroleum products also increase, reaching a peak of 12.8% in 2023. Increasing energy prices along with the slowing-down of economic activity results in a decrease of GHG emissions (Figure 3) and induces the lowest CO_2 prices for both ETS and non-ETS sectors. The cumulative welfare cost[7] from 2022 to 2030 in this scenario

[7]GEMINI-E3 assesses the welfare cost of policies by compensating variation in income. This measure is preferable to change in GDP or change in households' final consumption, since both

is approximately 1'521 US$ per European resident. As shown in Figure 4, the greatest decline is reached in 2024 (-0.8% of households' consumption expenditure) before the decline slightly reduces to -0.7% in 2030.

Table 3: No gas embargo scenario - EU28

	2022	2023	2024	2025	2030
GDP*	-0.08%	-0.24%	-0.22%	-0.19%	-0.16%
Welfare†	-0.46%	-0.82%	-0.83%	-0.79%	-0.66%
*Energy consumption**					
Coal	6.6%	-1.6%	0.3%	0.7%	-4.7%
Natural gas	-11.4%	1.9%	2.1%	3.1%	2.3%
Petroleum products	-0.7%	-4.6%	-3.9%	-2.8%	-2.0%
Electricity	-0.7%	0.2%	0.7%	0.7%	1.3%
*Wholesale energy price**					
Coal	10.6%	26.9%	27.8%	28.0%	29.9%
Natural gas	19.4%	1.5%	1.7%	2.2%	1.5%
Petroleum products	2.5%	12.8%	12.2%	11.0%	10.6%
Electricity	2.1%	-0.5%	-1.6%	-1.4%	-2.2%
CO_2 ETS price‡	52	62	79	92	113
CO_2 ESR price‡	0	0	0	0	146

* in percentage relative to the current policies scenario
† in percentage of households' consumption expenditure
‡ in $US\$_{2014}$

4.2. *Full embargo scenario*

The cessation of Russian gas imports has a more significant detrimental impact than the previous scenario, especially in the short term. In the first years, the loss of Russian gas cannot be replaced to equal capacity by other partners, and the gas consumption decreases by 33.2% in 2023.

In 2025, European gas consumption decreases by 134 bcm in the following sectors:

- Electricity generation (-51 bcm),
- Energy intensive industries (-21 bcm),
- Residential (-31 bcm),

are measured at constant prices that follow national accounting methods. Both fail to capture the change in the structure of prices, which is a main effect of an embargo.

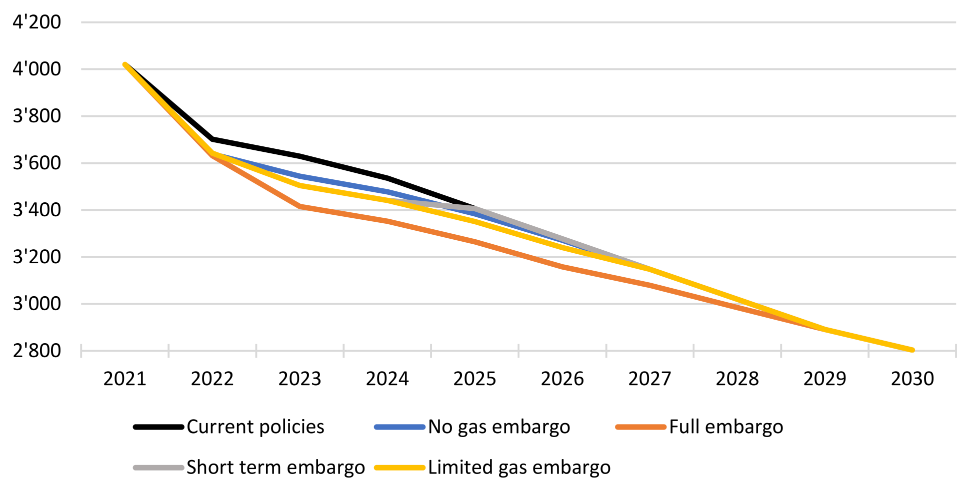

Figure 3: EU28 GHG emissions in million tonnes of CO_2

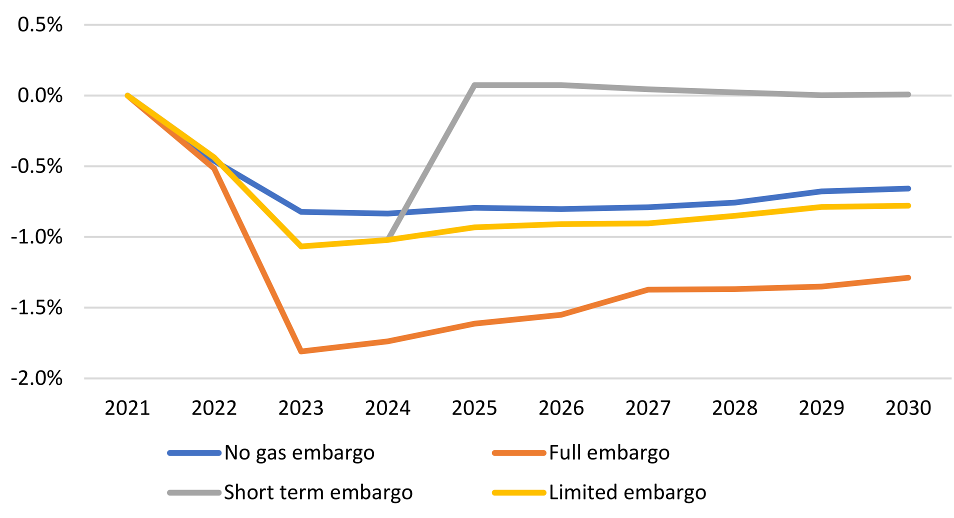

Figure 4: EU28 Welfare change relative to the current policies scenario in % of households' consumption expenditure

- Other sectors (-31 bcm).

These projections are in line with the analysis by Kotec et al. [46], which uses a bottom-up model. The study finds gas consumption will be 5 to 30 bcm lower in residential sectors and 28 bcm lower for industries. The potential natural gas saving for electricity generation is 99 bcm. These substantial differences are likely due to a higher substitutability with coal in electricity generation, as Kotec et al.'s analysis does not consider any constraint on CO_2 emissions. Furthermore, like Chepeliev et al. [16], Deane et al. [26], and Kotec et al. [46], we still find that gas is likely to be replaced with coal power plants in the short term (Figure 5). In 2023, electricity from coal power plants increases by 140 TWh, in line with the IEA assumption [45] that estimates this contribution at 120 TWh.

The new capacities of renewables make it possible to limit the additional contribution of coal power plants in the longer run. In 2030, electricity from renewable sources increases by 178 TWh and that from coal power plants by 68 TWh, whereas electricity from natural gas decreases by 248 TWh. Likewise, in the long term, Russian gas can be replaced by increasing imports from the USA, Qatar, Norway and African producers. The wholesale gas price increases by 63.8% in 2030,[8], and the natural gas consumption decrease reaches 24.3% in 2030.

In the ESR sectors, the rise in wholesale energy prices reduce energy consumption. In 2025, gas consumption decreases by 25%, refined oil by 4.5% and electricity by 2.3%. In contrast, coal consumption increases by 12.3%, however its contribution to the ESR energy mix remains modest (less than 2%). This overall decrease in energy consumption leads to a reduction in GHG emissions in the ESR sectors until 2029 when the GHG emissions reach the level of the current policies scenarios, as shown in Figure 3. Decreasing GHG emissions impacts the ESR price. It is equal to zero until 2028, and reaches 47 US$ in 2030 or 142 US$ less than in the current policies scenarios. However, the ETS price is less impacted as the coal consumption increases significantly in ETS sectors. The ETS price is only 7 US$ lower in 2030, from 113 US$ to 106 US$ with a full gas embargo. The negative welfare impact is exacerbated: 3'205 US$ per EU resident from 2022 to 2030, double the estimated cost in the previous scenario. The welfare cost is evaluated at 1.3% of households' consumption expenditure in 2030, close to the 1.7% income loss assessed by Chepeliev et al. [16] in the "severe" scenario.

[8] Greater than 40% increase in the cost of procuring gas estimated by Tóth et al. [73].

Table 4: Full embargo scenario - EU28

	2022	2023	2024	2025	2030
GDP*	-0.10%	-0.46%	-0.43%	-0.38%	-0.16%
Welfare†	-0.52%	-1.81%	-1.74%	-1.61%	-1.29%
*Energy consumption**					
Coal	7.9%	22.9%	24.0%	26.2%	15.9%
Natural gas	-13.4%	-33.2%	-31.9%	-30.4%	-24.3%
Petroleum products	-0.7%	-4.1%	-3.4%	-2.3%	1.1%
Electricity	-0.9%	-2.2%	-1.7%	-0.3%	1.0%
*Wholesale energy price**					
Coal	11.1%	36.5%	36.6%	36.7%	37.7%
Natural gas	23.1%	76.6%	74.4%	69.3%	63.8%
Petroleum products	2.5%	14.1%	13.3%	11.9%	12.3%
Electricity	2.6%	7.2%	5.4%	2.0%	1.0%
CO_2 ETS price‡	51	43	61	75	106
CO_2 ESR price‡	0	0	0	0	47

* in percentage wrt to the current policies scenario
† in percentage of households' consumption expenditure
‡ in US$$_{2014}$

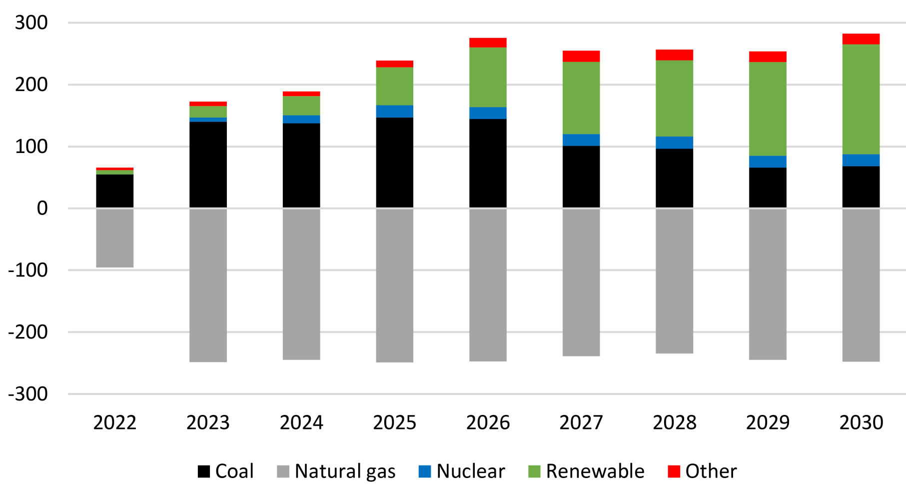

Figure 5: Change in EU28 electricity generation in the full embargo scenario relative to current policies scenario (TWh)

4.3. Other scenarios

As shown in Figure 4, the limited gas embargo scenario would have a rather limited welfare cost compared to the no gas embargo scenario. Half of Russian gas imports can be replaced by additional imports from other gas producers. The cumulative welfare impact of this scenario from 2022 to 2030 is 1'953 US$ per European resident, or 432 US$ higher than the no gas scenario (Table 5).

Table 5: Limited gas embargo scenario - EU28

	2022	2023	2024	2025	2030
GDP*	-0.08%	-0.28%	-0.26%	-0.22%	-0.19%
Welfare†	-0.44%	-1.07%	-1.02%	-0.93%	-0.78%
*Energy consumption**					
Coal	6.0%	5.5%	7.0%	7.4%	-5.3%
Natural gas	-10.5%	-8.7%	-7.4%	-5.8%	-3.7%
Petroleum products	-0.7%	-4.4%	-3.7%	-2.5%	-1.7%
Electricity	-0.7%	-0.5%	0.1%	0.4%	-0.2%
*Wholesale energy price**					
Coal	10.4%	29.7%	30.3%	30.4%	29.8%
Natural gas	17.8%	18.4%	17.3%	16.3%	11.4%
Petroleum products	2.4%	13.1%	12.5%	11.2%	10.9%
Electricity	1.9%	1.3%	0.0%	-0.7%	1.3%
CO_2 ETS price‡	53	55	71	82	122
CO_2 ESR price‡	0	0	0	0	127

* in percentage relative to the current policies scenario
† in percentage of households' consumption expenditure
‡ in $US\$_{2014}$

Finally, the scenario in which the embargo is limited to the period 2022-2025, would have a rather limited economic impact. As shown in Figures 3 and 4, the European economy returns to our current policies scenario in 2025. The cumulative welfare cost is estimated at 562 US$ per European resident (Table 6).

4.4. Impacts on other regions

Figure 6 shows the impact of the scenarios on the welfare of non-EU countries. As expected, Russia is significantly impacted by the embargo. The welfare cost ranges from 1.1% (short term embargo) to 3.9% (full gas embargo). It is interesting to note that switching from a no gas to a full gas embargo increases the Russian cumulative welfare cost by only 44%. This is contradictory to what is projected for the EU. Russian exports of crude oil and petroleum products account

Table 6: Short term embargo scenario - EU28

	2022	2023	2024	2025	2030
GDP*	-0.08%	-0.28%	-0.26%	0.01%	0.01%
Welfare†	-0.44%	-1.07%	-1.02%	0.07%	0.01%
*Energy consumption**					
Coal	6.0%	5.5%	7.0%	-1.0%	-0.5%
Natural gas	-10.5%	-8.7%	-7.4%	-1.2%	-0.3%
Petroleum products	-0.7%	-4.4%	-3.7%	0.6%	0.0%
Electricity	-0.7%	-0.5%	0.1%	0.7%	0.6%
*Wholesale energy price**					
Coal	10.4%	29.7%	30.3%	0.1%	1.0%
Natural gas	17.8%	18.4%	17.3%	-0.5%	-0.1%
Petroleum products	2.4%	13.1%	12.5%	-1.6%	0.0%
Electricity	1.9%	1.3%	0.0%	-1.8%	-1.1%
CO_2 ETS price‡	53	55	71	104	112
CO_2 ESR price‡	0	0	0	32	195

* in percentage wrt to the current policies scenario

† in percentage of households' consumption expenditure

‡ in US$$_{2014}$

for three quarters of energy export earnings from the EU; thus, most of the Russia's cost is caused by the embargo on these energy sources rather than on natural gas.

In the full gas embargo scenario, the additional negative impact on the ruble (which is depreciated) increases oil exports to non-European countries and limits the cost. From an economic point of view, cutting the export of Russian gas is more costly for the EU than for Russia. This finding raises the probability of such a decision, rationalising exports from Russia. Russia has not delivered gas to Europe via the Nord Stream 1 line since August 2022, and Nord Stream 2 was never commissioned and so did not delivered any gas to EU.

The impacts on other regions are rather limited, especially for China and other Asian countries (ASI), because the European embargo has limited impact on the worldwide energy prices and the global GDP. Welfare is improved in energy exporting-countries that increase their energy deliveries to the EU, such as Africa, Middle East, the rest of the word (including Norway and Canada) and the USA.

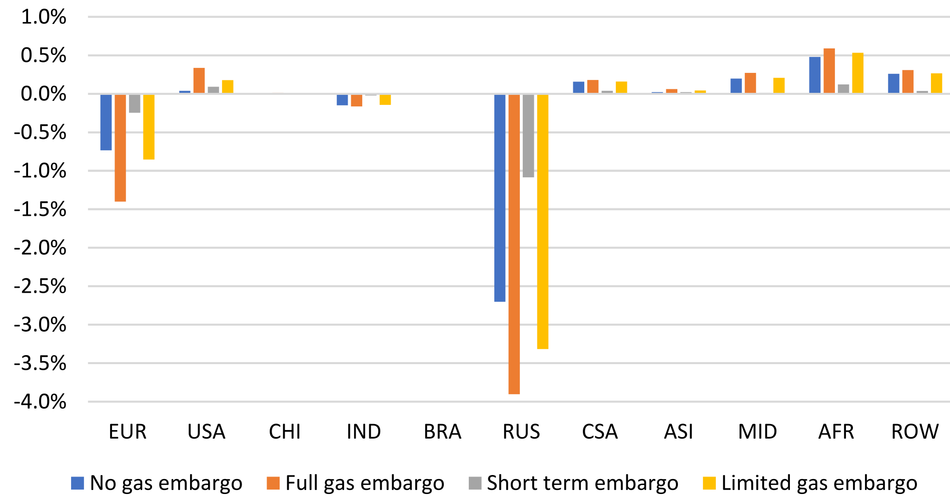

Figure 6: Cumulative welfare in % of households' consumption expenditure over 2022-2030 period

5. Caveats and limitations of this analysis

Initial studies on the impacts of reducing the energy imports from Russia report output losses to different extents ranging from near zero to over 2.8% [27]. Economic models equipped with rigid economic structures and fully modeled demand effects, such as the European Commission's with a dynamic stochastic general equilibrium model [33] or Schnittker et al. [66] using the partial equilibrium, estimate higher output losses. On the other hand, the estimated impacts with general equilibrium models, such as those by Baqaee et al. [5], Chepeliev et al. [16], and this paper, tend to be lower.

Despite an approximation to a general equilibrium fit for a perfect price adjustments system and the design being well suited to perform international trade analysis [71], it is not particularly suited to represent precise deviations in longer-term impacts. As the model does not inherit a comprehensive production-based approach, technical constraints such as infrastructure bottlenecks or fragments in gas markets are not represented. This absence results in underestimating the estimated output and welfare cost. In addition, most CGE models, including GEMINI-E3, do not adequately represent wholesale liberalised electricity markets (such as the European one). Again, this misrepresentation affects estimated electricity supply, demand, and price precision.

Particular to the general equilibrium approach applied in this paper, some caveats are related to common assumptions such as a constant return to scale and full employment [14]. These assumptions tend to be less flexible and affect the predictive precision of our results. It also includes trade substitutability assumptions that relate to elasticity used with the Armington hypothesis [2], which is commonly used for trade, assuming that goods from different regions are imperfect substitutes. Different elasticity values conducted by Chepeliev et al. [16] explore short-term implications of a Russian embargo by lowering the trade elasticities by 50%. Yet a more systematic analysis about assumptions should be further investigated in future research.

Another critical dimension lies on the aggregated EU level, which cannot capture heterogeneity across EU countries and infrastructure bottlenecks, especially on the European gas market [27], and therefore our analysis probably underestimates the cost of the embargo. Finally, a single representative household represented in the current model does not sufficiently represent or incorporate current policies aiming at limiting the burden on households and potential adverse effects. This is certainly an important issue to be considered in future works.

6. Conclusion

Russia's current invasion of Ukraine affects the world in countless ways and raises global concerns. Many countries have imposed economic sanctions on Russia to hasten the end of this devastating conflict. Sanctions unquestionably come with consequences that are likely detrimental to Russia and to countries that impose them. This paper aims to analyse those consequences for the EU given its current position of restricting its import from Russia, the sanctioning policies chosen, and its dependency on Russian exports.

Instead of evaluating the recessive impact of the war or its impact on the food market, which has been widely discussed in the literature, here we focus on the EU energy embargo on Russia and its cost. Following the adoption of the 5^{th} package of restrictive measures to ban coal import in all forms from August 2022 and the 6^{th} package to restrict oil import, to be completed in 2023, this paper analyses the implications for energy prices of such an embargo, the economic cost to European residents and the impact on the Russian economy.

The analysis is conducted from the perspective of the latest EU climate commitment, the Fit For 55 Package. Strengthening sanctions raises questions about European countries' ability to reach full independence from Russia's fossil energy imports. However, it also underlines how trade restriction, energy security, and climate mitigation are intertwined and shows that emergency response to a possible energy crisis has become a stark scramble for alternative sources of fossil fuels that affect climate mitigation.

We used GEMINI-E3's model of the European and World economy, to construct simulations with different Russian energy import embargo configurations. The results emerge from the following critical findings. First, the impact of the current embargo on oil and coal is quite substantial. The embargo imposes an adverse supply effect as the price of coal and oil increases. It costs 1'521 US$ per resident or 0.67% of households' consumption expenditure cumulative over the period 2022 to 2030. As seen in the current market, EU coal and oil prices jumped after the ban on Russian imports. Coal price hit US$-303 per tonne right after the announcement of the 5^{th} restriction package and continues to rise, reaching more than US$ 400 in mid-October 2022. Likewise, oil prices jumped after the EU leaders reached an agreement to ban 90% of Russian crude oil by the end of the year. This puts EU energy security in dire straits for the winter season.

Second, extending the embargo to natural gas doubles this cost, thus confirming previous studies pointing out the challenge of reducing EU gas imports from Russia. Given the current constraints on additional import capacities from non-Russian producers and assuming restriction of natural gas import will be implemented within the same time frame as oil, discontinuing Russian gas imports has a more significant detrimental impact than solely an embargo on coal and oil. However, a stronger rise in energy prices moderates carbon prices in non-ETS sectors and decreases energy consumption, resulting in lower emissions.

Third, coal will play a central role in energy replacement in the short term, especially in electricity generation. Within the current embargo scheme, coal consumption increases to offset the recent declining trend in gas demand. This pattern persists when the embargo is extended to include natural gas. With the current capacity constraint of gas exports from non-Russian partners and limited additional contributions of renewables, the likelihood of replacing gas with coal power plants is still high in the short term, even with a more stringent abatement target. The invasion already leads to gas price hikes, driving up whole sale electricity prices in the EU area. With the current shortage of demand and the commitment to rely less on Russian gas with RePower EU [18], boosting coal and recalibrating of gas storage is likely the most feasible solution. Germany, for instance, despite its commitment to phase out coal by 2030 and to have a rapid expansion of renewable capacity, will restart coal-fired power plants, as a short-term response to tackle the supply shortage after Russia cuts gas deliveries.

In contrast with findings for the EU, the oil and coal embargo had a more detrimental impact on Russia than the gas embargo. Extending from coal and oil to natural gas increases the Russian welfare cost by only 44%. The additional negative impacts of including natural gas in the EU embargo depreciate the Russian ruble even more. This leads to an increase in Russian oil exports to non EU countries, thus limiting its welfare cost. From this economic point of view, cutting Russian gas exports is costlier for the EU than for Russia. This finding raises the probability of such a decision from Russia, and might justify the recent accusation of using gas supplies as a weapon against the West.

Overall, all complexities of the current challenge suggest that EU policy should be optimising across the system. In practical terms, the policy taken should be based on flexibility potentials to deal with the energy scarcity. Activating coal power plant capacity and gas storage optimization will be an unavoidable short-term solution. While the acceleration of developing renewables to support deep electrification and control the demand through energy saving becomes a long-term measure to achieve EU dependency on Russian Energy in line with REPower EU. Finally, further studies should investigate the fiscal policies currently implemented by many European governments to try and curb the impact of rising energy prices on households and businesses.

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Appendix A. Key features of the model - GEMINI-E3

This section describes the key features of the GEMINI-E3 model, more information can be found on the web-page of the H2020 Paris-Reinforce project. See `https://paris-reinforce.eu/i2am-paris/models`.

Sectoral disaggregation distinguishes sectors participating in the ETS market from others, such as petroleum products, electricity generation, and energy-intensive industries. Energy-intensive industries comprise of the iron and steel industries, the chemical industry, the non-ferrous metals industry, the non-metallic mineral products, and the paper and paper products. Three other energy goods are described by the model; coal, crude oil, and natural gas. The remaining five sectors consist of agriculture, land transport, sea transport, air transport, and other goods and services that aggregates all other sectors. For each sector, the model computes the demand of its production based on household consumption, government consumption, exports, investment and intermediate uses. Total demand is then divided between domestic production and imports using the Armington assumption [2], which assumes that domestic and imported goods are not perfectly homogenous.

Domestic production

Domestic production technologies are described through nested CES functions, which differ according to the sector. Figure A.7 shows the nested CES production structure of the non-fossil energy sector. Production is carried out using four aggregates; capital, labor, material and energy. In a second step (nest), material and energy are decomposed in individual goods again using CES functions.

Electricity generation

For electricity we used a specific nested CES production structure that is represented in Figure A.8.

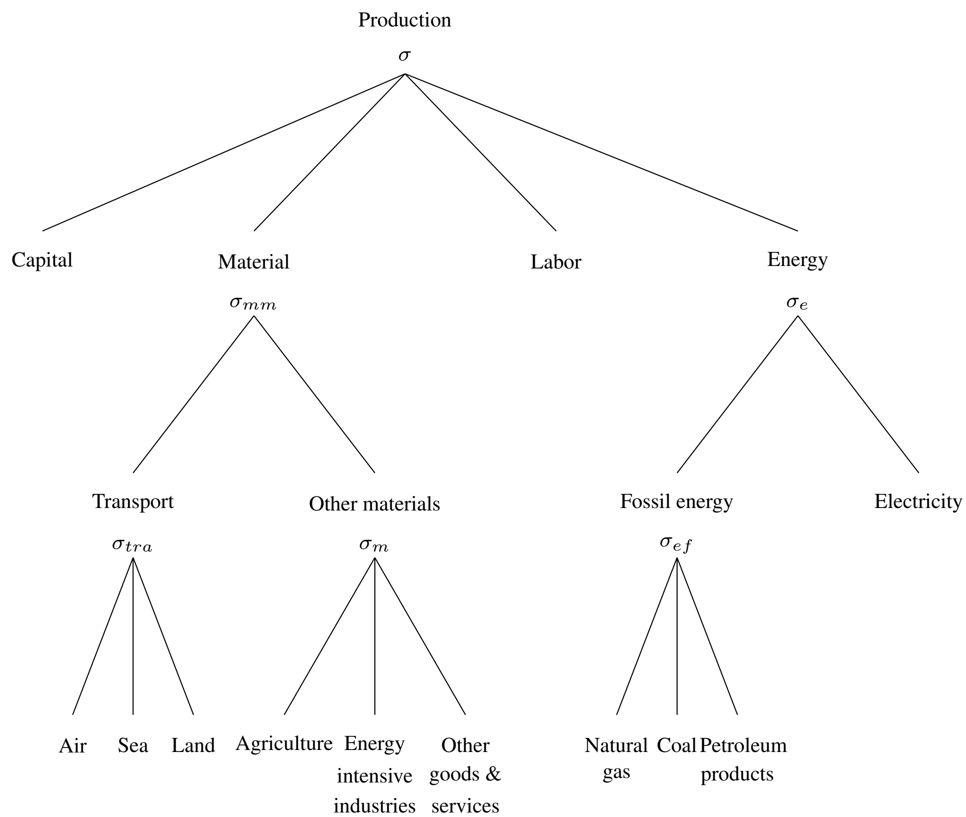

Figure A.7: Nested CES production structure of the industrial sector

Household consumption

Household behaviour consists of three interdependent decisions; 1) labor supply, 2) savings, and 3) consumption of the various goods and services. Labor supply and the rate of savings are exogenously driven, while the demand on different commodities drives of consumption and income price(more precisely “spent” income, income after savings) as arguments, and is derived from a nested CES utility function. The government collects taxes and distributes the resulting revenues to households and firms through transfers and subsidies. Wage is chosen as a numeraire in each region.

Regional and sectoral classifications

Tables A.9 and A.10 provide the regional and sectoral classifications of the version of the GEMINI-E3 model used in this paper.

Table A.7: Elasticities Nested CES production structure

	Armington	σ_{ff}	σ_{pp}	σ	σ_e	σ_{ef}	σ_{tra}	σ_m	σ_{mm}
Sector									
1	2	0.2		0.6	0.1	0.1	0.6	0.2	0.2
2	3	0.2		0.6	0.1	0.1	0.6	0.2	0.2
3	2	0.2		0.6	0.1	0.1	0.6	0.2	0.2
4	3		0.1	0.6	0.1	0.1	0.6	0.2	0.2
6	2			0.6	0.6	0.9	0.6	0.2	0.2
7	2			0.6	0.6	0.9	0.6	0.2	0.2
8	1.5			0.6	0.6	0.9	0.6	0.2	0.2
9	0.7			0.6	0.8	0.9	0.6	0.2	0.2
10	0.7			0.6	0.8	0.9	0.6	0.2	0.2
11	0.7			0.6	0.8	0.9	0.6	0.2	0.2

Table A.8: Elasticities Nested CES structure of electricity production

Armington	0.5
σ	0.1
σ_{gen}	2
σ_{nogen}	0.1
σ_{foss}	3
$\sigma_{gas}, \sigma_{oil}, \sigma_{coa}, \sigma_{nuc} \ldots \sigma_{hyd}$	0.3

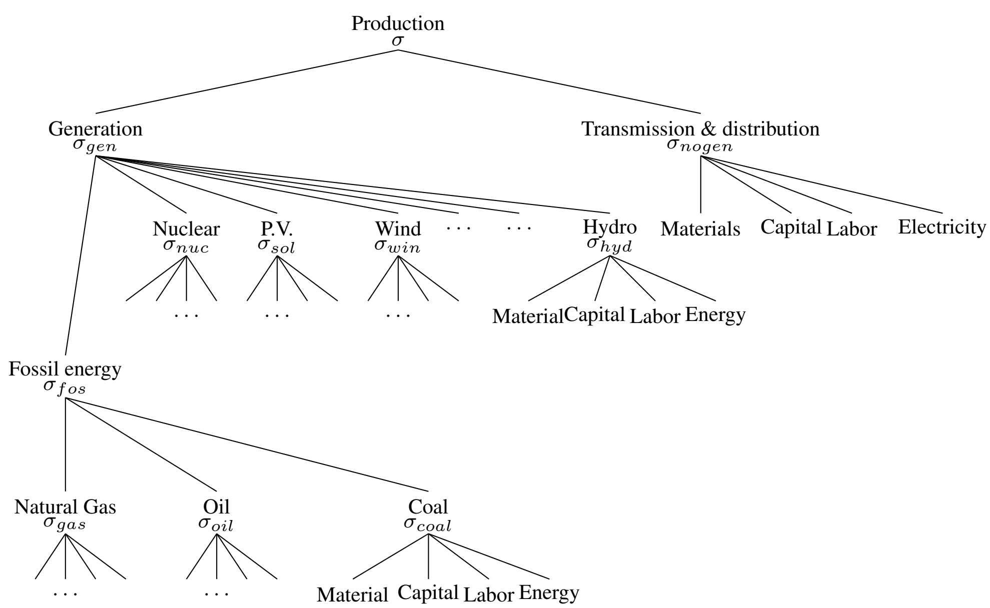

Figure A.8: Nested CES structure of electricity production

Table A.9: Regional classification and corresponding GTAP region

Abbreviation	Name	Countries	GTAP regions
USA	United States of America	United States of America	usa
EUR	European Union (28)	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom	aut, bel, bgr hrv, cyp,cze dnk, est, fin fra, deu, grc hun, irl, ita lva, ltu, lux mlt, nld, pol prt, rou, svk svn, esp, swe gbr
CHI	China	China, Hong Kong	chn, hkg
IND	India	India	ind
BRA	Brazil	Brazil	bra
RUS	Russia	Russia	rus
CSA	Central and South America countries	Mexico, Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean, Rest of North America, Rest of South America, Rest of Central America	mex, arg, bol chl, col, ecu pry, per, ury ven, cri gtm, hnd, nic pan, slv, dom jam, pri, tto xcb, xna xsm, xca
ASI	Other Asian countries	Japan, South Korea, Mongolia, Taiwan, Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Bangladesh, Nepal, Pakistan, Sri Lanka, Rest of East Asia, Rest of South Asia	jpn, kor, mng twn, brn, khm idn, lao, mys phl, sgp, tha vnm, bgd, npl pak, lka, xea xse
MID	Middle East	Bahrain, Iran, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of Western Asia	bhr, irn, jor kwt, omn, qat sau, tur, are xws
AFR	Africa	Egypt, Morocco, Tunisia, Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Central Africa, South Central Africa, Ghana, Guinea, Nigeria, Senegal, Togo, Ethiopia Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda Tanzania, Uganda, Zambia, Zimbabwe, Botswana, Namibia, South Africa, Rest of Western Africa, Rest of South African Customs	egy, mar, tun, ben bfa, cmr civ, xcf, xac gha, gin, nig sen , tgo, eth ken, mdg, mwi mus, moz, rwa tza, uga, zmb zwe, bwa, nam zaf, xec xsc
ROW	Rest of the World	Australia, New Zealand, Canada, Switzerland, Norway, Albania, Belarus, Ukraine, Kazakhstan, Kyrgyzstan, Tajikistan, Armenia, Azerbaijan, Georgia, Israel, Rest of Oceania, Rest of Former Soviet Union, Rest of the World	aus, nzl che, nor, alb blr, ukr, kaz kgz, tjk, arm aze, geo, isr xoc, xsu xtw

Table A.10: Sectoral classification

Sector Id	Sector	GTAP sectors
1	Coal	coa
2	Crude oil	oil
3	Natural gas	gas, gdt
4	Refined petroleum products	p_c
5	Electricity	TnD, NuclearBL, CoalBL, GasBL, WindBL, HydroBL OilBL, OtherBL, GasP, HydroP, OilP, SolarP
6	Agriculture	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol frs, fsh
7	Energy intensive industries	oxt, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp
8	Other goods and services	cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum wtr, cns, trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg edu, hht, dwe
9	Land sector	otp
10	Sea transport	wtp
11	Air transport	atp

Green House Gas (GHG) emissions covered

GHG emissions in GEMINI-E3 are calibrated from the most up-to-date policy databases that cover country to the sectoral level of disaggregation. Historical inventories for CO_2 and methane, are based on the Community Emissions Data System (CEDS) detailed in Hoesly et al. [42]. Nitrous oxide is aligned with the PRIMAP Dataset [41], and F gases are calibrated from the U.S. Environmental Protection Agency [76]. The non-CO_2 gases come from diverse sources such as agriculture, industries, transport, etc., and where emissions and mitigation options must be represented at the bottom-up level. These non-CO_2 gases represent 19% of EU28 GHG emissions in 2016 [75]. The agriculture sector contributes the most (52%), followed by the waste and waste-water sector (18%) and the energy sector (15%) [44]. Non-CO_2 GHG emissions included in the EU-ETS are nitrous oxide emissions from adipic and nitric acid production, and perfluorocarbons emissions from the aluminium industry. In constructing both reference and climate scenarios, abatement for non-CO_2 gases are calculated based on the marginal abatement cost.

Appendix B. Change in worldwide energy trading

Table B.11: Change in international trade of coal in % wrt current policies scenario - year 2030 - Full embargo scenario

		Importers											
		USA	EUR	CHI	IND	BRA	RUS	CSA	ASI	MID	AFR	ROW	Total
Exporters	USA		105%	-4%	-4%	-2%	-21%	13%	-5%	-3%	1%	-3%	16%
	EUR	-42%		-46%	-45%	-45%	-56%	-36%	-46%	-43%	-41%	-43%	-42%
	CHI	8%	114%		1%	2%	-18%	18%	0%	2%	5%	2%	1%
	IND	7%	113%	0%		2%	-18%	18%	0%	2%	5%	2%	0%
	BRA	4%	108%	-2%	-1%		-20%	15%	-3%	-1%	3%	0%	3%
	RUS	24%	-99%	15%	16%	18%		36%	15%	17%	21%	17%	-3%
	CSA	-2%	96%	-8%	-8%	-6%	-25%		-9%	-7%	-4%	-7%	29%
	ASI	8%	115%	1%	1%	3%	-17%	19%		3%	6%	3%	2%
	MID	6%	110%	-1%	-1%	1%	-19%	16%	-2%		4%	1%	13%
	AFR	4%	106%	-3%	-3%	-1%	-21%	14%	-4%	-2%		-2%	2%
	ROW	6%	111%	-1%	-1%	1%	-19%	17%	-2%	1%	4%		1%
	Total	0%	1%	3%	0%	0%	-19%	15%	2%	1%	9%	9%	

Table B.12: Change in international trade of crude oil in % wrt current policies scenario - year 2030 - Full embargo scenario

		Importers											
		USA	EUR	CHI	IND	BRA	RUS	CSA	ASI	MID	AFR	ROW	Total
Exporters	USA		77%	-8%	1%	6%	-22%	-3%	-10%	-13%	5%	-15%	-11%
	EUR	-34%		-40%	-34%	-31%	-50%	-37%	-41%	-43%	-31%	-44%	-40%
	CHI	11%	93%		10%	16%	-15%	6%	-2%	-5%	15%	-7%	10%
	IND	1%	76%	-9%		6%	-23%	-4%	-10%	-13%	5%	-15%	-13%
	BRA	3%	80%	-7%	2%		-21%	-2%	-9%	-11%	6%	-13%	2%
	RUS	130%	-99%	107%	132%	144%		120%	105%	98%	138%	94%	0%
	CSA	0%	74%	-10%	-1%	4%	-24%		-11%	-14%	3%	-16%	6%
	ASI	13%	96%	1%	12%	18%	-13%	7%		-3%	16%	-5%	5%
	MID	3%	80%	-7%	3%	8%	-21%	-2%	-8%		7%	-13%	1%
	AFR	-11%	55%	-20%	-12%	-7%	-32%	-15%	-21%	-23%		-25%	6%
	ROW	-7%	63%	-16%	-7%	-2%	-28%	-11%	-17%	-20%	-4%		23%
	Total	-1%	16%	1%	-1%	-3%	-28%	7%	1%	7%	11%	31%	

Table B.13: Change in international trade of natural gas in % wrt current policies scenario - year 2030 - Full embargo scenario

		Importers											
		USA	EUR	CHI	IND	BRA	RUS	CSA	ASI	MID	AFR	ROW	Total
Exporters	USA		93%	-1%	0%	0%	-27%	0%	-2%	3%	6%	3%	11%
	EUR	-61%		-62%	-62%	-61%	-72%	-61%	-62%	-60%	-59%	-58%	-61%
	CHI	3%	10%		1%	1%	-26%	2%	-1%	5%	7%	4%	2%
	IND	1%	10%	-1%		0%	-27%	0%	-3%	3%	6%	2%	2%
	BRA	1%	10%	-2%	-1%		-27%	0%	-3%	3%	6%	2%	2%
	RUS	30%	-99%	26%	27%	28%		29%	24%	32%	36%	30%	-24%
	CSA	2%	10%	-1%	-1%	0%	-27%		-2%	3%	6%	2%	2%
	ASI	5%	10%	2%	3%	3%	-25%	4%		7%	10%	6%	5%
	MID	-1%	47%	-3%	-3%	-2%	-29%	-2%	-5%		4%	0%	6%
	AFR	-3%	17%	-6%	-5%	-4%	-31%	-4%	-7%	-1%		-2%	4%
	ROW	3%	21%	0%	1%	1%	-26%	2%	-1%	5%	7%		7%
	Total	2%	-12%	0%	-3%	-1%	-32%	0%	3%	0%	2%	18%	

Table B.14: Change in international trade of petroleum products in % wrt current policies scenario - year 2030 - Full embargo scenario

		Importers											
		USA	EUR	CHI	IND	BRA	RUS	CSA	ASI	MID	AFR	ROW	Total
Exporters	EUR	-18%		-19%	-18%	-18%	-44%	-17%	-19%	-19%	-16%	-18%	-18%
	CHI	1%	-11%		1%	1%	-31%	1%	0%	0%	3%	1%	0%
	IND	-1%	-13%	-2%		-1%	-32%	0%	-2%	-2%	2%	0%	-1%
	BRA	-1%	-13%	-2%	-1%		-32%	0%	-2%	-2%	2%	0%	-1%
	RUS	16%	-99%	15%	16%	16%		17%	15%	15%	19%	17%	-37%
	CSA	-1%	-13%	-2%	-1%	-1%	-33%		-2%	-2%	1%	-1%	-2%
	ASI	1%	-11%	0%	1%	1%	-31%	2%		0%	3%	1%	0%
	MID	-1%	-13%	-2%	-1%	-1%	-32%	0%	-2%		1%	-1%	-3%
	AFR	-4%	-16%	-5%	-4%	-4%	-35%	-4%	-5%	-5%		-4%	-8%
	ROW	-2%	-14%	-3%	-2%	-2%	-33%	-2%	-3%	-3%	0%		-8%
	Total	-2%	-45%	-1%	-1%	-1%	-36%	-1%	-1%	-5%	-3%	-3%	

Figure Captions

Figure 1	Share of Russian imports in fossil energy imports by country (%) year 2020.
Figure 2	Additional gas import capacities from non-Russian producers in bcm.
Figure 3	EU28 GHG emissions in millions tonnes of CO_2.
Figure 4	EU28 Welfare change relative to the current policies scenario in % of households' consumption expenditure.
Figure 5	Change in EU28 electricity generation in the full embargo scenario relative to current policies scenario (TWh).
Figure 6	Cumulative welfare in % of households' consumption expenditure over 2022-2030 period.

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