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Medium-term Macroeconomic Effects of Russia's War in Ukraine and How it Affects Energy Security and Global Emission Targets

Hugo Rojas-Romagosa

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Prepared by Hugo Rojas-Romagosa*

Authorized for distribution by Florence Jaumotte
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ABSTRACT: Russia's war in Ukraine has disrupted the supply of natural gas for many European countries, triggering an energy crisis and affecting energy security. We simulate the medium-term effects of these trade disruptions and find that most European countries have limited GDP losses but those more dependent on Russian natural gas face moderate losses. European fossil fuel consumption and emissions are reduced and after accounting for the war impacts, achieving Europe's emission targets becomes slightly less costly. In terms of energy security, the war eliminates European energy dependency from Russian imports, but most of the natural gas and oil imports will be substituted by other suppliers. We also find that constructing a new Russian pipeline to China does not provide significant macroeconomic benefits to either country.

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Author's E-Mail Address:	HRojas-Romagosa@imf.org

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WORKING PAPERS

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Prepared by Hugo Rojas-Romagosa[1]

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1 Introduction

The Russian invasion and current war in Ukraine was met by trade restrictions from several countries and countermeasures by the Russian authorities. As a result of the war, Russian trade flows to Europe have been severely disrupted, in particular Russian natural gas and oil exports. This presents both a risk and an opportunity for EU countries. On the one hand, the EU faced a short-term gas shortage that resulted in an energy crisis with large price increases that has required several countermeasures in Europe. On the other hand, unwinding itself from the heavy reliance on Russian energy imports, the EU has the opportunity to increase its energy security and accelerate its transformation into a green economy reliant mostly on renewable energy.

The short term implications of the Russian gas shutoff have been extensively analyzed (see for example, Albrizio et al., 2022; Di Bella et al., 2022; Bachmann et al., 2022; Baqaee et al., 2022; Lan et al., 2022). As a complement to these papers, in this study we focus on the medium- and long-term impacts of Russia's war in Ukraine on EU energy markets and its economic implications for the EU and Russia. We assume that by 2027 natural gas and oil trade between Russia and the EU is shut-off as result of strategic decisions by both the EU and Russia to decouple their energy trade. In this context, we analyze the macroeconomic and global emission changes that would result from a reshaping of the international oil and natural gas markets through the redirection of Russian energy to other non-European markets and the expected expansion in liquefied natural gas (LNG) trade. This will have implications for how energy security in Europe is changed after the war. These concerns are mostly related to the disruption of natural gas trade, and less about oil trade. The non-fungibility of natural gas trade, which requires specific infrastructures (pipelines or LNG facilities), makes it more difficult to substitute than oil, where trade is fungible, and suppliers are much easier to replace. Finally, we analyze how Russia's war in Ukraine will affect the economic costs of countries implementing the emission reductions agreed in their national determined contributions (NDCs). It is important to note that the scope of the paper is limited to analyze only the trade-related medium-term disruptions associated with the war and abstracts from other potential effects that can also have substantial regional and global effects.[2]

For this quantitative analysis we employ the IMF-ENV model, which is a global recursive dynamic computable general equilibrium (CGE) model that provides rich sectoral detail and includes modeling features for energy and climate issues. The model is well suited to analyze the medium- and long-term macroeconomic effects and structural change that result from energy shocks and climate policy changes. It allows simulating impacts on energy demand and supply, changes in the electricity generation mix, greenhouse gas (GHG) emissions, macroeconomic variables, sectoral outcomes and trade.[3] For this study, we focus our analysis on how the trade disruptions from Russia's war in Ukraine affect the electricity generation mix and energy security in the three major EU economies (Germany, Italy, France), the rest of the EU, the UK, as well as China and India, and how this will affect national and global emission levels as well as real GDP.

[2] Such as the effects of sanctions imposed at the beginning of the war, reductions in investments and technological transfers to Russia, the loss of infrastructure and human capital in Ukraine, global increases in food prices, and the increase in military spending in Europe, among others.

[3] The current version of the model includes all G20 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States) and regional aggregations (Africa, East Asia, Eurasia, EU, Latin America and oil-producers) that include all other countries to make the model global.

We run four main scenarios. First, we implement the initial trade bans imposed by the EU, the UK and selected OECD countries (Australia, Canada, Japan, South Korea and the US).[4] We also include the shutoff of natural gas applied by the Russian government. In addition, we assume that by 2027 there is a total shut-off of energy trade between Europe and Russia. This provides a medium-term outlook on the consequences of an energy trade decoupling between Russia and Europe. In a t second scenario, we allow the possibility of Russia diverting gas exports to China –through an additional pipeline that is assumed to be completed by 2030. There is, moreover, increased Russian LNG exports to non-EU countries, while US and other countries increase their LNG exports to the EU.[5] These new trade flows reshape the international natural gas markets to mostly compensate for the shutdown of the gas pipelines connecting Russia and the EU.

In the third scenario we analyze the macroeconomic, energy and climate effects when countries implement their current NDC emission targets, but we do not account for Russia's war in Ukraine and its related trade disruptions. In our fourth and final scenario, we include the trade disruptions and reshaping of the natural gas markets triggered by Russia's war in Ukraine, and also assume that countries achieve their NDCs using a generalized carbon tax on all GHG emissions. Comparing these last two scenarios allows us to estimate how the costs of implementing these NDCs change with Russia's war in Ukraine.

We find that the trade disruptions resulting from Russia's war in Ukraine result in only moderate losses for the EU and UK. The losses we simulate for Russia are larger, but the magnitude is uncertain given that several policies currently being implemented are not modeled.[6] EU GDP losses by 2030 are below 1%, and higher for the countries that are more dependent on Russian gas –i.e., Italy, Germany, and the Rest EU region. As a reaction to the natural gas shutoff, most EU countries increase their natural gas imports from other suppliers (mainly Norway, US, and Algeria), but they also reshuffle their electricity generation mix to rely more on renewable generation. These shifts reduce overall GHG emissions in the EU by around 5% in 2030 when compared with the baseline values. In addition, the ratio of energy imports to domestic energy consumption is also declining in most EU countries and international natural gas prices are expected to be only 1% higher by 2030. These indicators point to an increase in energy security in Europe, although they would be more dependent on other natural gas suppliers.[7]

Given that around 95% of Russian natural gas exports go through pipelines, the shutoff of trade with the EU drastically decreases these exports. Even if Russia increases LNG exports and constructs a new pipeline to link its Western Siberian gas fields to China, exports will still decrease by 75% compared to the baseline pre-war volumes. Moreover, the economic benefits to China of getting access to relatively cheaper Russian natural gas are also expected to be relatively muted, as China relies heavily on coal and renewable electricity generation and the new import volumes of Russian natural gas are relatively low compared to China's overall energy

[4] Note that we do not model other sanctions that have been imposed by the EU and other OECD countries, such as freezes of Russian foreign assets, individual restrictive measures, sanctions targeted at the financial sector and the closure of EU airspace and ports to Russian vessels. See for example: https://www.consilium.europa.eu/en/policies/sanctions/ restrictive-measures-against-russia-over-ukraine/.

[5] The increases in LNG trade are modelled as a 5% decrease in natural gas trade costs to the European regions. The model then endogenously determined how exports from different suppliers is changed and its consequent trade diversion effects to other regions.

[6] For our simulations we assume medium-term macroeconomic closure rules that keep both the current account balance and the government budget fixed as a share of GDP at the baseline (pre-war) levels. Hence, the simulations do not account for any short-term or transitional policies currently implemented by the Russian authorities. Ultimately, the duration and depth of these policies and their effect on TFP growth, will determine the medium-term macroeconomic implications for Russia.

[7] Dolphin *et al.* (2024) explore the energy security implications of the war in more detail, using other energy security indicators.

imports.[8] However, China will increase its overall emissions by around 1.5% as the cheaper Russian natural gas imports would reduce electricity prices and increase energy consumption.

Finally, we interact the trade disruptions and rerouting of natural gas exports resulting from Russia's war in Ukraine with NDC emission mitigation policies. We find that once the economic costs of the trade shock from Russia's war in Ukraine are accounted for, the costs for European countries of reaching their NDCs emission targets are slightly lower. This implies some positive indirect effects of the war trade shock, which are associated with increased renewable generation triggered by the disruption of natural gas and oil imports from Russia.

2. Review of Studies Analyzing the Short-term Effects of a Russian Natural Gas Shutoff

Several recent papers analyze the short-term (2022–23) effects of the disruption of Russian natural gas imports to Germany (Bachmann et al., 2022; Lan et al., 2022) and Europe (Albrizio et al., 2022; Baqaee et al., 2022; Di Bella et al., 2022). They analyze the differential impact of gas shortages for Euro- pean countries and the potential GDP effects.[9] All papers use several (technical) assumptions to estimate the gas shortages for 2022 and 2023 (i.e., LNG imports, gas consumption, inventory changes, infrastructure expansion, gas to coal switching, renewable and nuclear power expansion). For the GDP effects they use different IO and production function models, which require an additional set of assumptions regarding different elasticities of substitution (mainly between gas another energy sources) and how the shortages are dealt with (price adjustments or rationing). Some studies also add demand side effects (through changes in trade) and uncertainty effects.

Albrizio et al. (2022), Bachmann et al. (2022) and Baqaee et al. (2022) use the trade model from Baqaee and Farhi (2019) to estimate the GDP effects of the gas shortages.[10] However, it is important to remark that these papers are running a partial-equilibrium version of the Baqaee and Farhi (2019) model using a "sufficient statistic" approach. This, however, is an inadequate numerical instrument for the exercise, as it is based on a second-order approximation that in general only holds for marginal shocks to the model, and by keeping other variables fixed. For instance, this approximation assumes that total exports are unchanged by the gas supply shock, which fails to account for the trade-related general equilibrium effects of lower aggregate demand in a highly integrated region as the EU.

[8] Natural gas markets are fragmented with concentrated market power for its main suppliers. Hence, there are significant price differences between regions, which makes it harder to assess the price differences between Russian pipeline and alternative LNG imports. However, using the data from the IMF's Primary Commodity Prices database, available at https://www.imf.org/en/Research/commodity-prices, we compare two different price references: the Netherlands TTF index, which includes mainly pipeline gas but also LNG, and the Indonesian LNG price in Japan. From 1992 to 2021 the TTF has been on average 27% cheaper. This indicates a significant price difference between pipeline gas and LNG. Moreover, given that the TTF price also includes LNG, the price difference between pipeline gas and LNG is likely to be larger.

[9] Lan et al. (2022) also summarizes other papers that have done short-term assessments for Germany, including Bachmann et al. (2022).

[10] The model is part of the new quantitative trade (NQT) framework, which are highly stylized general equilibrium models (static, one factor, few sectors, simple production and demand functions, no government) used mainly in academia. These models are more parsimonious and rely on fewer elasticities (or assume CD functions) and are easier to describe and analyze than CGE models. On the other hand, they lack most of the sectoral, factor and public finance details that policy research requires.

Di Bella et al. (2022) has the advantage that it deals with most European countries, and it presents a very detailed analysis on the country-specific Russian gas dependence and substitution possibilities. They identify two main groups of countries that will experience the largest short-term disruptions: i. Germany and Austria (with a gas shortage in winter of 18%); ii. Czechia, Slovakia, and Hungary (with a shortage in winter of 91%). Importantly, all other countries are expected to be able to substitute to alternative gas supply sources (mainly LNG) and are not expected to have gas shortages but will be indirectly affected by gas price increases. To estimate the short-term macroeconomic effects of these shortages they use a combination of two models: the estimations from Albrizio et al. (2022) (using the second-order approximation from the model by Baqaee and Farhi, 2019) and a multi-sector model with demand spillovers. They calibrate the second model to the regional gas shortage that they have previously estimated. Their results show that losses are conditional on the country-specific reliance on Russian gas and the overall gas-intensity of each economy, while gas-intensive sectors (electricity, chemicals) are the most affected. They also estimate a "solidarity" scenario where gas is re-exported to the hardest hit countries, which spreads the GDP losses to reduce the large negative impacts for the most affected countries. Finally, they also estimate a scenario where households are protected from the shock—by keeping their gas consumption fixed—and find that GDP losses are increased by around 50% on average, with GDP losses reaching up to 6% in the most affected countries.[11]

For Germany, the studies have a wide range of GDP effects (from 0.2 to 5% of GDP for 2022/23). But when using more realistic short-term elasticities and gas substitution constraints, the effects are between (2 and 5%). For other EU countries, the results are country-specific depending on the extent that each country is expected to have a gas shortage. For those countries that will, the results can be substantial.

As highlighted by Albrizio et al. (2022), there is an important indirect effect of Russia's war in Ukraine: the higher demand of LNG by Europe will increase international LNG prices, and Korea and Japan will also be negatively affected by higher international LNG prices. In addition, this paper also mentions that redirecting Russian natural gas exports from Europe to China will only become viable at least until 2030. The pipeline that currently connects Russia to China sources its gas from fields in Far East Russia and the volumes are relatively small (around 5% of total Russian gas exports). China and Russia have agreed to build a second pipeline that would connect the natural gas fields in Western Siberia, but the timeline for full construction is 2030 and its capacity will only cover one-third of the current Russian exports to Europe.

Al-Karablieh (2022), on the other hand, analyses the short-term impacts of a European ban on imports of crude and refined oil from Russia as a result of Russia's war in Ukraine. This study finds that the effects can also be significant for some specific European countries but given the easier substitution possibilities to alternative oil suppliers, the effects are smaller than the natural gas disruption from the war.

A related IMF study by Ari et al. (2022) emphasizes the trade-offs between short term energy price and security issues with the medium-term EU climate goals. The main policy recommendation balances these trade-offs by proposing short-term income support for low-income households (with limited and targeted support to vulnerable firms), while not distorting prices to keep the incentives for both firms and households to reduce energy consumption, increase energy efficiency investments and switch to renewable sources. The paper also highlights

[11] Di Bella et al. (2022) compare their results to other studies at the EU-level: ECB (using DSGE and NiGEM models), ECFIN (DSGE), and OECD (using NiGEM and a partial equilibrium IO model). Their results are on the lower end of the output losses when compared to the other papers in the literature.

that substituting away from gas could have positive climate implications, but there are also dangers: short-term gas-to-oil and gas-to-coal substitution, and the global effects of larger EU LNG demand on prices for countries that currently rely on it (Bangladesh, Pakistan, India, and Indonesia), moving to coal.

Finally, our study is closest to Chepeliev et al. (2022) who also employ a CGE model, but assess both the short and medium-run effects of trade disruptions to Russian fossil fuel exports. They employ the ENVISAGE model calibrated until 2030 and apply a gradual tariff increase by mostly OECD countries to Russian exports of natural gas, crude oil, coal, and petroleum products. This generates a gradual reduction in Russian exports to the EU (50% in 2022 and 80% in 2030). They find moderate medium term GDP effects for the EU (real income drops by 0.4% in 2030), but substantial environmental co-benefits: CO2 emissions drop by 3.1% in 2022 and the reduction reaches 7% in 2030 compared to the baseline. According to this study, such emission reductions can ease the EU mitigation targets outlined in the Green Deal[12] and it will also reduce the implicit carbon price to achieve their emission targets by around 40 EUR per ton of CO2. By contrast the Russian economic impacts will be substantial. They estimated that Russian real income is reduced by 6% (relative to baseline values) already in 2022 and reaches 8% losses by 2030. They also present short-term effects for EU countries, which are in the lower bound of other related studies (-0.7 to -1.7%). This study, however, was designed before the EU trade restrictions were defined, and Russia decided to partially shut-off natural gas exports to Europe. Moreover, they do not update the global natural gas trade shares nor account for the non-fungibility of natural gas trade: Russian imports to the EU are mainly done through existing pipelines, with a very low share imported as LNG. This severely restricts the capacity of Russia to redirect natural gas exports to other countries, but also the import capacity of the EU to substitute Russian natural gas from other suppliers.

3. Methodology and Data

In this section we provide an overview of the IMF-ENV model that we employ and of the main characteristics of the baseline, where we update both the overall Russian trade to Europe and European energy imports from different sources.

3.1 Model

IMF-ENV is a global recursive dynamic computable general equilibrium (CGE) model developed by the IMF research department.[13] Dynamic CGE models are well suited for the analysis of structural change and sectoral impacts that result from energy and climate shocks and policies. The model allows simulating impacts on energy demand and supply, greenhouse gas (GHG), macroeconomic variables, sectoral outcomes, and trade. The model is based on a neo-classical framework, which optimizes consumption and production decisions by house- holds and firms but deals mainly with real values and with almost perfect markets for commodities and production factors (labor, capital, land).

The model is based on the activities of the key actors: firms, households, and markets. Firms purchase inputs and primary factors to produce goods and services. Households receive the factor incomes and in turn

[12] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

[13] The technical details of the model are explained in Chateau et al. 2023.

demand the goods and services produced by firms. Markets determine equilibrium prices for factors, goods, and services. Finally, countries exchange goods on international markets. Factors of production are almost perfectly mobile across sectors (real rigidities means that adjustments are sluggish in the short run) but not across countries. However, an important feature of IMF-ENV is that capital stocks have vintages such that firms' production and behavior are different in the short and long run. This allows a more realistic adjustment of the capital stock in the short- and medium-run, as it increases the capital costs for expanding activities and reduces the productivity of capital that is tied to declining economic activities.

The model is recursive dynamic: it is solved as a sequence of comparative static equilibria. The factors of production are taken exogenously at each point in time and linked between time periods with accumulation expressions, like the dynamics of a Solow growth model. Production follows a series of nested constant-elasticity-of-substitution (CES) functions to capture the different substitutability across all inputs. International trade is modeled using the so-called Armington specification that posits that demand for goods is differentiated by region of origin. This specification uses a full set of bilateral flows and prices by traded commodity. The model also links economic activity to environmental outcomes, specifically to the emission of greenhouses gases and other pollutants. The model describes how economic activities and agents are inter-linked across economic sectors and world countries or regions.

The model can be used for scenario analysis and quantitative policy assessments. For scenario analysis, the model projects up to 2050 and contains an internally consistent set of trends of all economic, sectoral, trade-related, and environmental variables. In this context, the model can be used to analyze economic impacts of various drivers of structural changes like technical progress, increases in living standards, changes in preferences and in production. A second use for the model is quantitative economic and environmental policy assessment for the coming decades, including scenarios of a transition to a low carbon economy. In this case the model assesses the costs and benefits of different sets of policy instruments for reaching given targets like GHGs emission reduction. However, the model's projections for the very long-run are especially uncertain since disruptive technology innovations could materialize at longer horizons.

3.2 Data and baseline values

The model is built primarily on a database of input-output tables, combined with national accounts and bilateral trade flows. The central input of the model is the GTAP 10 Power database (Aguiar et al., 2019; Chepeliev, 2020b). The database contains country-specific input-output tables for 141 countries and 65 commodities and real macro flows.[14] The database also represents world trade flows comprehensively for a given starting year. To allow a detailed modeling of energy supply, the database includes eight electricity generation technologies, as well as an electricity transmission and distribution activity. Finally, the database also includes all main greenhouse gases: carbon dioxide ($CO2$), methane ($CH4$), nitrous oxide ($N2O$) and fluorinated gases—hydrofluorocarbons (HFCs), Per-fluorocarbons (PFCs) and Sulphur hexafluoride ($SF6$)15 In our baseline we calibrate electricity generation and total GHG emission values using the projections from the Climate Policy Assessment Tool (CPAT) from the IMF's Fiscal Affairs Department (FAD). The electricity generation projections incorporate the expected increase in renewable generation, and we assume an annual overall energy efficiency

[14] This version of the model employs 36 activities, 28 commodities sectors and 25 country/regions, which are detailed in Tables 1-3 in the Appendix.

[15] Cf. Chepeliev (2020a).

growth of 1.5%. Emission projections include technological advances that reduce the emission intensity of economic activities, but it does not include emission reductions associated with new mitigation policies. The baseline only includes already implemented carbon pricing policies, such as the EU's emissions trading system (ETS).

For this study, we include two major adjustments to the GTAP database. First, we updated the natural gas bilateral Russian exports data; and second, we updated the EU and the United Kingdom (UK) bilateral natural gas imports to reflect the latest data for 2021. Natural gas import data are taken from the OECD/ IEA Natural Gas Information Statistics for 2021.[16] The first adjustment is reflected in the updated Russian natural gas export values in Figures 1 and 2. This also implies that total Russian energy exports are also updated (see Figures 3 and 4).

Figure 1. Russian Exports by Product in 2021 (baseline shares)

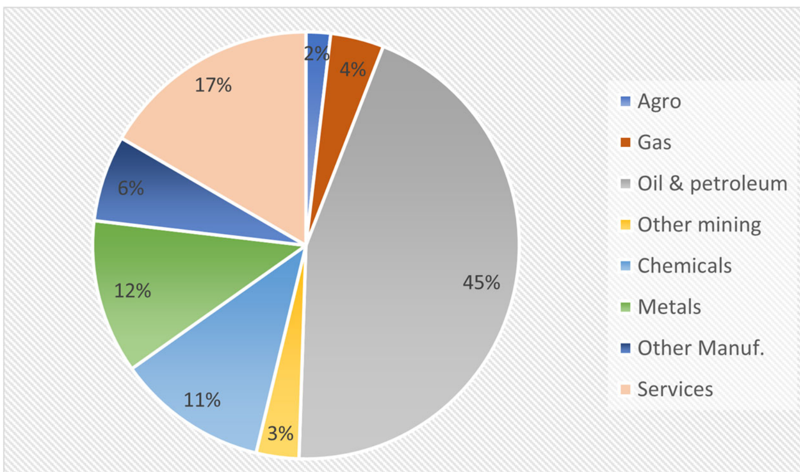


Figure 2: Russian exports by destination in 2021 (baseline shares)

[16] https://doi-org.libproxy-imf.imf.org/10.1787/naturgas-data-en

Figure 3: Russian Natural Gas Exports by Destination in 2021 (baseline shares)

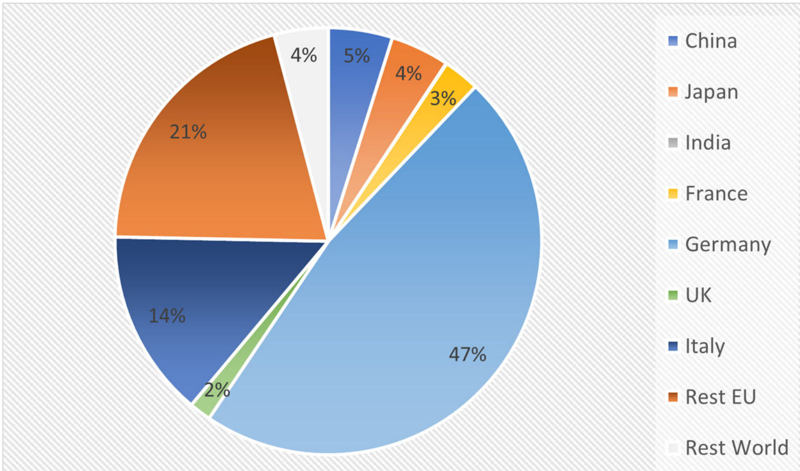
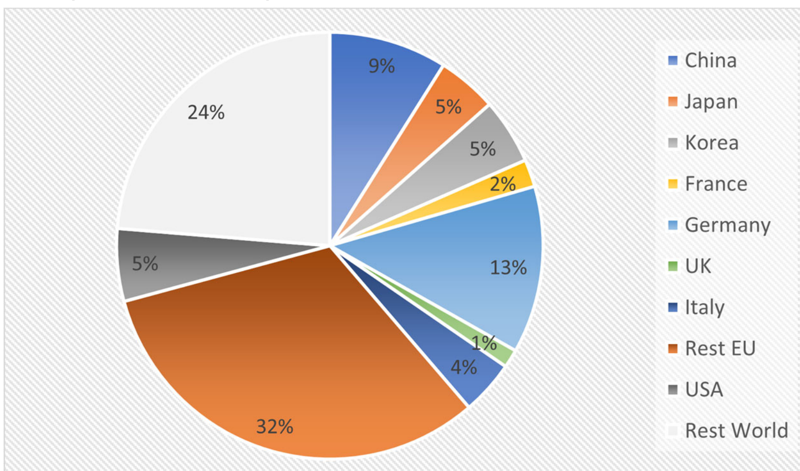


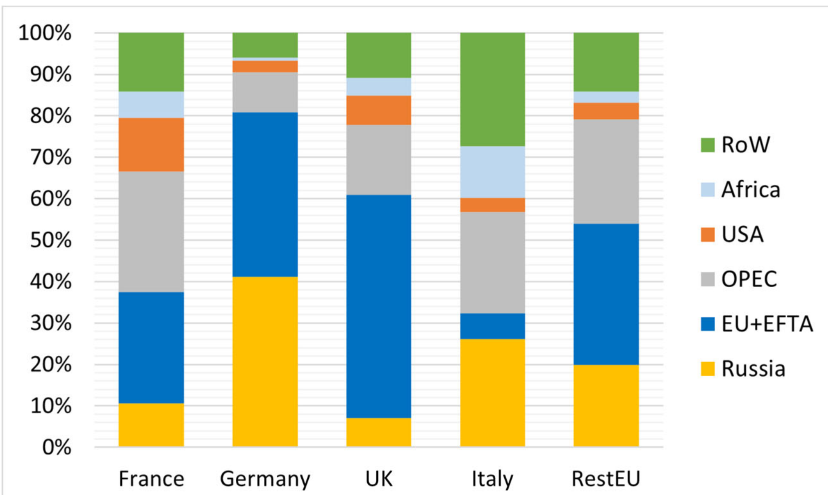
Figure 4: Russian Crude and Refined Oil Exports by Destination in 2021 (baseline shares)



We observe that Russian crude and refined oil is the main Russian export, while gas only represents 4% of total exports. But almost half of all Russian exports, including energy, go to other European countries. Russian gas exports by large go to EU countries (around 80%), but more importantly they represent the bulk of gas imports for some central European countries. For instance, it accounts for around 60% of German natural gas imports, but more than 90% for other countries like Bulgaria, Hungary, Czechia and Slovakia (cf. Di Bella et al., 2022). Given that these natural gas exports are done mainly through pipelines, this makes natural gas trade non-fungible and very difficult to substitute, both for importers and exporters. Conversely, even though Russian oil exports are also going mainly to the EU, they can be more easily redirected to other markets. Oil trade data is taken from the latest available year in Eurostat (usually 2022). These data show that all large EU countries (Germany, Italy, France; as well as the UK) have already stopped oil imports from Russia. Of the rest of EU countries, only Hungary, Greece, Czechia, and Latvia are still importing, and these flows represent around one quarter of the pre-war Russian oil imports for our RestEU region. However, the EU has stated that it intends to stop gas and oil imports from Russia as soon as possible.[17] Thus, we assume in our policy scenarios that there are no more imports of Russian natural gas and oil by European countries in the medium term.

The second major trade data adjustment provides updated values on natural gas import sources for the EU and UK. For this adjustment we used a combination of IEA Natural Gas Information Statistics[18] and Eurostat natural gas consumption and supply statistics.[19] Figure 5 shows the initial (2021) energy import dependence of EU countries. We observe that Germany, Italy, and the Rest EU region rely heavily on Russian energy imports, while France and the UK do not. When focusing only on natural gas, Figure 6 shows that the import dependence ratios are the highest for Germany, and above 40% for Italy and the Rest EU region. The RestEU region which includes different countries is hiding large natural gas import dependency for Central European countries (e.g., Austria, Czechia, Slovakia and Hungary) and very low dependencies of Western Europe (i.e., Spain and Portugal).

Figure 5: Energy Import Shares for European Countries by Supplier in 2021 (baseline shares)



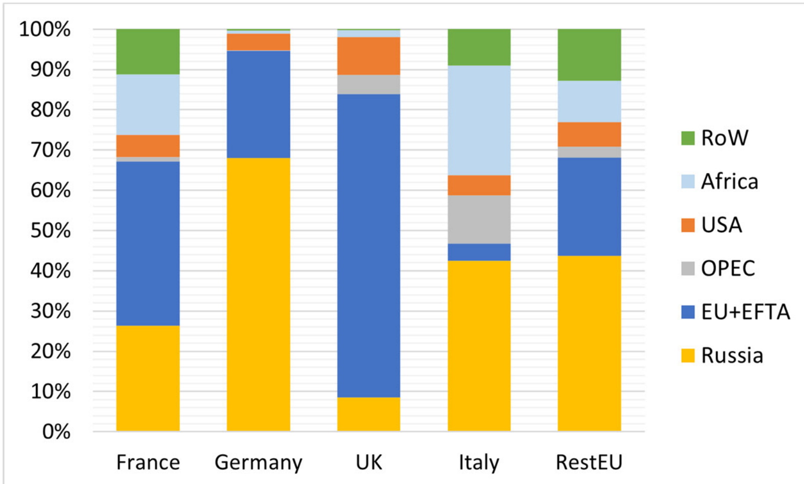
Note: Energy commodities are coal, crude and refined oil, and natural gas.
The OPEC region includes Saudi Arabia and other oil-exporting countries (see Table 1).

[17] See the Versailles declaration (https://www.consilium.europa.eu/media/54773/20220311-versailles-declaration-en.pdf), the European Council conclusions of 24/25 March 2022 (https://data.consilium.europa.eu/doc/document/ST-1-2022-INIT/en/pdf), and the REPowerEU annex (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653034026255).

[18] IEA data are provided by OECD (https://www.oecd-ilibrary.org/energy/data/ iea-natural-gas-information-statistics_naturgas-data-en.

[19] https://ec.europa.eu/eurostat/web/energy/data

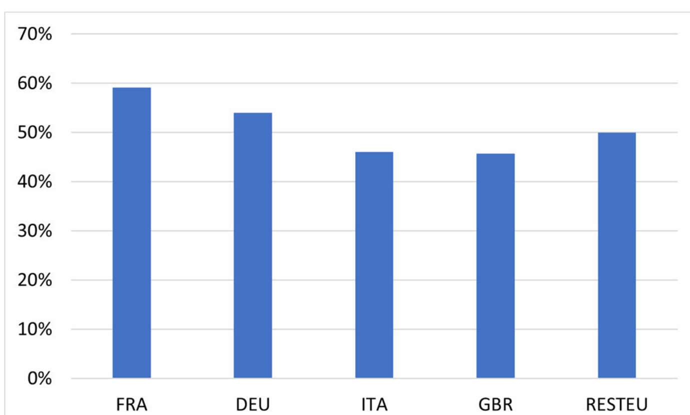
Figure 6: Natural gas import shares by supplier in 2021 (baseline shares)



Note: The OPEC region includes Saudi Arabia and other oil-exporting countries (see Table 1).

Finally, Figure 7 presents the share of total energy imports relative to domestic energy consumption. Here we find that most European countries have dependency ratios of around 50%, with Italy and the UK having a lower share. This means that more than half of energy demand is linked to imports. This measure is directly linked to energy security, as high energy import dependency ratios indicate larger risks.[20] This indicator is inversely correlated with the share of renewable energy in total electricity generation and domestic fossil fuel pro- duction. Larger renewable generation shares implies that less fossil fuels are needed in total energy consumption, while higher domestic fossil fuel production also reduces the need for energy imports.

Figure 7: Energy imports as a share of total energy domestic consumption in 2021 (baseline shares)



[20] On the other hand, trade can also be a source of resilience. Although high import dependence implies greater exposure to foreign risks, it also means that there is lower exposure to domestic risks, which can also be relevant in the energy context—for example, domestic supply issues in 2021 caused France to import electricity, and the country would have been worse off without the ability to import.

Finally, it is important to note that the baseline or business-as-usual (BaU) is a reference scenario that excludes future policies, even if they have been committed. Hence, it only includes the latest carbon pricing policies and not future commitments. As such, the baseline cannot be taken as a prediction of a likely outcome, but a reference where future policy changes are compared to the case where these policies are not implemented. This is reflected, for instance, in the baseline having an electricity generation mix that remains close to the current mix, even if this is expected to change as countries begin to implement policies to achieve their NDC targets.

4. Scenario Construction

In this section we explain in detail how we construct each of our scenarios, which are divided into two main groups: trade disruptions and interactions with countries' mitigation policies as stated in their NDCs.

4.1 Trade disruptions from Russia's war in Ukraine

In the first scenario, we implement the trade disruptions based on the initial EU bans imposed by the European Council.[21] Hence, we assume a full import ban for all products, with the exception of agricultural products and food, fertilizers, pharmaceutical and medical products. On the other hand, the EU did not ban Russian natural gas imports, but Russia stopped a large share of its gas exports to European countries. By the summer of 2023, European imports of natural gas from Russia represented around 25% of the pre-war levels.[22] Based on this information and EU commitments, as explained above, we assume that all European energy imports from Russia are shutoff by 2027 in our policy scenarios. This assumes that there is a strategic decision by both the EU and Russia to decouple their energy trade in the medium run. There are no explicit bans on electricity imports from Russia, so we assume that electricity trade continues (i.e., Baltic countries continue to import electricity from Russia). The EU also imposed export bans for EU firms to export to Russia iron and steel, cement, wood, and seafood.

An important consideration in our scenarios, is that natural gas exported through pipelines cannot be redirected to other countries not connected to the pipeline. The non-fungibility of natural gas trade is crucial to understand the energy security and economic implications of Russia's war in Ukraine. For instance, Gustafson (2020) explains in detail the economic, legal, and geopolitical conditions required to build these pipelines, which take many years to negotiate and build. LNG, on the other hand, while making natural gas more tradable, still requires large investments for both exporting and importing countries.[23] Hence, it can take several years to fully be able to substitute for natural gas that was previously traded through existing pipelines. Therefore, we assume in both Scenarios 1 and 2 that Russian natural gas that was exported to Europe before the trade shock

[21] These include all the trade restrictions imposed until the summer of 2023. For simplicity, we also assume that the other OECD countries imposing trade bans follow the EU-specific bans.

[22] While the Nord Stream and Yamal pipelines are no longer operational or used, the Turkstream and Ukraine transit pipelines are still active (see https://www.bruegel.org/dataset/european-natural-gas-imports).

[23] Conventional land-based LNG terminals take between seven to ten years to plan and build. However, floating terminals only take up to two years. Since Russia's invasion, Germany has already put three floating terminals into operation, with two more expected to start operating by end-2023. Italy has one new floating terminal. Here is a list of floating terminals announced in Europe since the invasion: https://ieefa.org/european-lng-tracker

cannot be redirected to other countries. In addition, to reflect the limitations of expanding natural gas exports in the short-term, we also constrain the natural gas exports of other (non-Russian) suppliers to Europe to be the same as in the baseline projections.

In Scenario 3, we relax these natural gas constraints to allow for an expansion of Russian LNG and pipeline exports. There are currently two major LNG projects in Russia (Sakhalin II and Yamal LNG). However, given limits to how fast a country can scale up its LNG capacity, we assume that future expansion of LNG exports will increase total Russian natural gas exports by 5% annually. Regarding new pipelines to redirect Russian natural gas exports to Europe, a key alternative is a new pipeline to China. The current pipeline connecting Russia to China (Power of Siberia I) is running close to full capacity and it is constrained by the size of the natural gas fields in East Siberia. Therefore, a new pipeline (Power of Siberia II) needs to connect the fields in West Siberia to China. We assume that Russia constructs a new pipeline to China by 2030, which increases current exports to this country by 300%.

Moreover, in Scenario 3 we allow for increased pipeline gas exports from Norway and we also expand the LNG exports of the US, Qatar and Algeria to Europe in response to higher prices and the supply vacuum after the shutoff of Russian natural gas imports.[24] The US started exporting LNG to the EU in 2018 and volumes have been increasing rapidly, from 14.2 billion cubic meters (bcm) in 2019 to 34 bcm in 2021, and 2022 has seen an even larger increase with an expected 79 bcm by years end.[25] This represents an average yearly increase of around 80%. In Scenario 3 we simulate additional growth of LNG exports from these non-Russian suppliers, while in previous scenarios these exports were fixed at the baseline values.

Technically, these trade disruptions are modeled using the so-called iceberg trade costs, which create a price wedge between exporting producers and im- porting consumers. To ban certain trade flows, we arbitrarily increase these trade costs to effectively make the trade flows zero. This methodology has the advantage that it does not require import tariffs to reduce the trade flows, which would create tariff revenues that in reality are not being received by the countries imposing the import bans.

4.2 Interaction with climate policies

First, in Scenario 4 we only assume that the climate policies consistent with the NDCs are implemented. This scenario, therefore, will be used as a reference for the economic costs of achieving the NDCs without the direct and indirect effects of Russia's war in Ukraine on trade. Hence, Scenario 5 includes the trade disruptions resulting from Russia's war in Ukraine (from Scenario 2) and the reshaping of the international natural gas markets (from Scenario 3), but we now add climate policies that are consistent with national determined contributions (NDCs). In this case, we estimate the carbon price that will be consistent with the emission reductions required for the EU and other countries to reach their NDCs by 2030.

[24] Qatar and Algeria are not separate regions in our model and are included in the Rest OPEC and the Other African (OAF) regions, respectively. However, natural gas exports from these aggregate regions to the EU represent the exports of these two countries only.

[25] According to the European Commission (EU-US LNG Trade bulletin) and Reuters.

These NDC scenarios, which are based solely on carbon taxation, do not reflect the most recently announced climate policies.26 In general, all countries will likely employ a combination of different climate policy instruments. For example, many countries, including the US, are not planning to use carbon pricing as their main climate policy to decrease GHG emissions. In the case of the EU and as a reaction to Russia cutting their gas exports to the EU, the European Commission has proposed the REPowerEU package,27 which aims to achieve full independence from Russian energy imports well before 2030. This is planned to be achieved through four inter-related dimensions: (i) reducing energy consumption; (ii) diversifying supplies; (iii) accelerating the green transition; and (iv) improving connectivity within Europe. On the other hand, this proposal does not include the temporary use of coal plants to avoid gas short- ages in 2022/23. While Europe is initially replacing Russian gas with cargoes of seaborne LNG from countries including the US and Qatar, the longer-term part of the project focuses on cutting reliance on imported fossil fuels. Under the plan, the EU wants to have 17.5 gigawatts of hydrogen capacity within three years and has increased the renewable generation target from 40 to 45% of total electricity generation by 2030.28 Analyzing these more detailed climate policies are beyond the scope of this study, but the policies in the REPowerEU package and the EU Green Deal (Fit for 55), will be analyzed in an upcoming joint paper with the IMF's European Department (EUR).

4.3 Scenario summary

Based on the considerations and assumptions explained above, we construct the following scenarios, which are divided into two main groups:

1. Russian trade disruptions:

- Scenario 1 (Sce1): Most Russian exports to the EU, UK, Australia, Canada, Japan, Korea, and the US are banned, but we exclude sectors with no bans in the EU: agriculture, food, and electricity. We include the reduction of Russian exports of natural gas to the EU. In addition, we assume that Russia cannot divert its pipeline natural gas exports that currently go to the EU to other regions, while the EU cannot increase (for 2022 and 2023) their natural gas imports from other non-EU regions. Moreover, we assume that there is a total shut-off of energy trade between Russia, the EU and other OECD countries by 2027. The EU also imposes bans on exports to Russia of iron, steel, wood, cement, and seafood.
- Scenario 2 (Sce2): Same as Scenario1, but we adjust the international market for natural gas. Russia increases its natural gas exports by 5% annually (through expanding LNG exports) to all countries, except those who imposed trade restrictions. Russia constructs a new pipeline to China (with an increase of 300% on current exports there). In addition, European countries increase natural gas imports from alternative suppliers: the US, Qatar, Algeria, and other countries.

2. Interaction with climate commitments:

- Scenario 3 (Sce3): All countries achieve their NDC emission targets, but we do not assume the international trade shock from Russia's war in Ukraine (as a way to compare the NDC costs with and without the war).

[26] Moreover, we assume that the carbon tax revenue is recycled towards a decrease in labor taxes. These revenues can be recycled in many ways, but using labor taxes provides one of the most efficient options. Other recycling options, for example, direct transfers to household will be less efficient and likely increase the GDP costs of the carbon taxation. We choose one recycling option for all countries to make the results comparable.

[27] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

[28] Financial Times, Special Report on Energy Transition, September 2022.

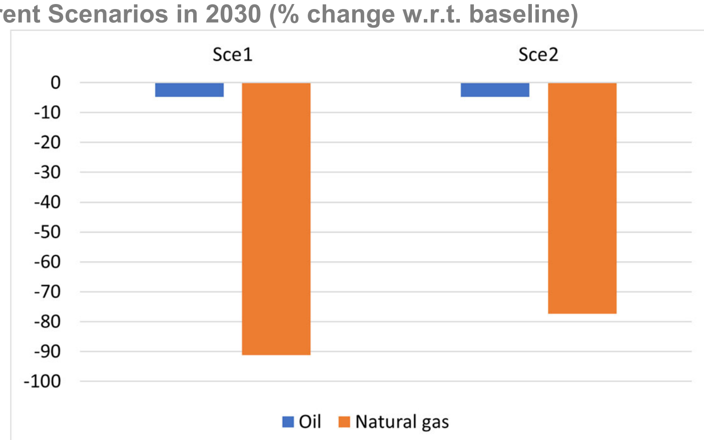
- Scenario 4 (Sce4): Same as Scenario 2 but now all countries achieve their NDC emission targets through an increase in the overall carbon tax rate.

5. Main results

5.1 Trade disruptions from the war

First, we analyze the effects of the trade shocks triggered by the war on Russian trade flows. The initial impact of the partial import bans from the EU and other OECD countries (Scenario 1) is a substantial reduction of Russian natural gas exports by around 90%, while crude and refined oil exports only decrease by around 5% (see Figure8[29] The large decrease of Russian natural gas exports reflects the shutdown of the pipelines to Europe. Russia's oil exports to non-European destinations mostly compensate for the closure of the European markets. In this way the lost foreign income from previous exports to Europe is less critical as Russia increases foreign revenue from oil.[30] Conversely, allowing Russia to increase LNG exports and including additional natural gas exports through a new pipeline to China improve natural gas exports, and these are now declining by around 75% in Scenario 2. Note that we assume that by 2030 the new pipeline from Russia to China is fully operational and the full effects are therefore accounted for in Scenario 2. However, for Russian natural gas exports to regain pre-war levels will require much larger volumes of exports to China and/or exporting to India or other large markets.

Figure 8: Russian Exports of Crude and Refined Oil and Natural Gas for Different Scenarios in 2030 (% change w.r.t. baseline)



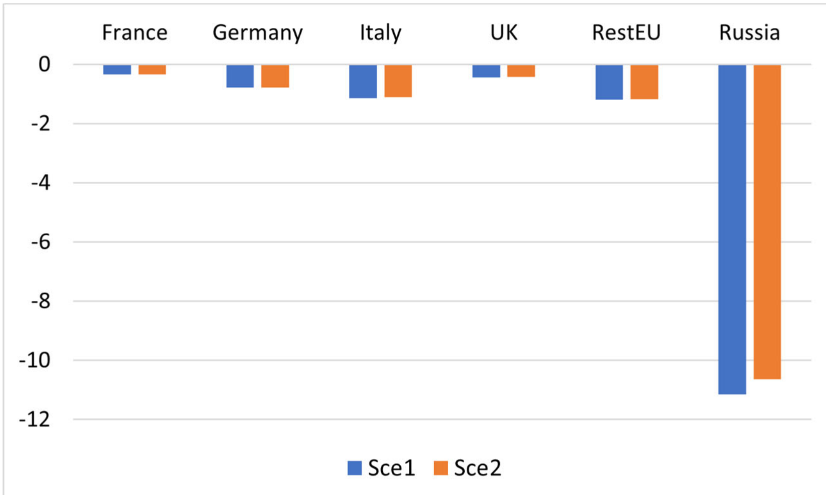
When we simulate the partial trade disruptions, overall Russian exports decrease by around 11% (see Figure 9). Allowing a part of Russian natural gas to be redirected to China, together with larger LNG trade, mitigates the decline of Russian exports. Recall that crude and refined oil represent almost half of total Russian exports, and

[29] Note that the IMF-ENV model assumes that the current account balance (CAB) is kept constant as a share of real GDP. Therefore, part of these export effects are driven by this CAB constraint.

[30] Up to now, trade bans have not created a significant reduction in Russian crude oil exports, as these have been redirected from Europe to China and India as reported by The Economist (2023).

total exports are mainly driven by the changes in oil exports. Hence, redirecting Russian natural gas exports has a limited effect on total Russian exports, much less so than redirecting oil exports.

Figure 9: Total Exports for Different Scenarios in 2030 (% change w.r.t. baseline)



In our simulations, these reductions in trade result in substantial macroeconomic implications for Russia. Figure 10 shows the simulated real GDP changes in 2030 when compared to baseline 2030 values (not to pre-war GDP). Russia has the highest GDP losses when there are partial trade disruptions (Scenario 1) and less pronounced when Russia can redirect its natural gas exports to China and increase its LNG exports to other regions (Scenario 2). These simulations should not be seen as medium-term projections of output losses in Russia. In particular, the magnitude of any medium-term GDP losses is uncertain given that many factors at are at play which have not been modeled, including policies currently being implemented in Russia.[31] On the other hand, we do not include potential productivity losses associated with lower trade levels, such as technological transfers imbedded in imports and other dynamic benefits associated with closer integration to international markets.[32]

For EU countries the GDP costs are less than 1% and do not vary much between scenarios. China and the US have very small negative effects (not shown), which are driven by the indirect effect on their exports as European demand decreases. For China, the option to import cheaper Russian natural gas does not have a substantial overall economic effect.

[31] As explained above, the model assumes standard medium-term macroeconomic closure rules where both the government budget and the current account balance are assumed to remain fixed as a share of GDP during the simulations. These standard medium-term behavioral equations, however, are not well suited to simulate the short-term policies currently being implemented in Russia. Therefore, the medium-term GDP effects in Russia will be conditional on the length and depth of these policies, the transition to pre-war policies and how these affect TFP growth.

[32] The model does not directly include losses to human capital associated with the war. However, the model has a reduced form endogenous labor supply mechanism linked to changes in real wages (i.e., a labor supply curve) and overall employment is decreasing as a result of the trade disruptions.

Figure 10: Real GDP for Different Scenarios in 2030 (% change w.r.t. baseline)

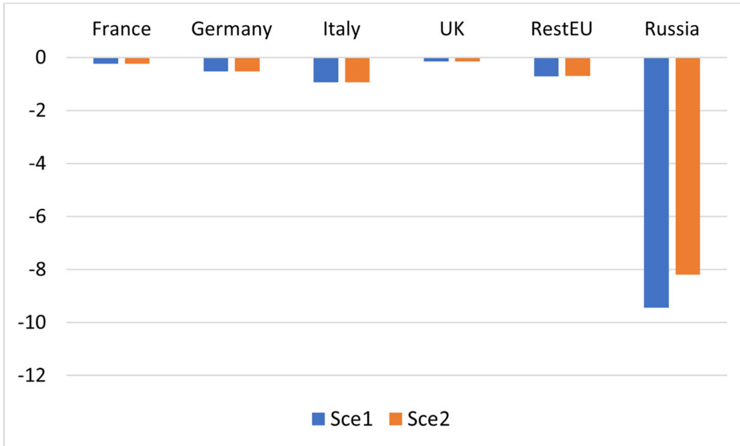
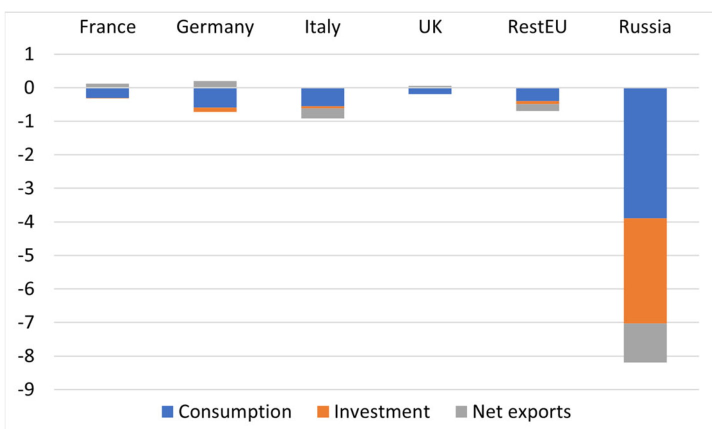


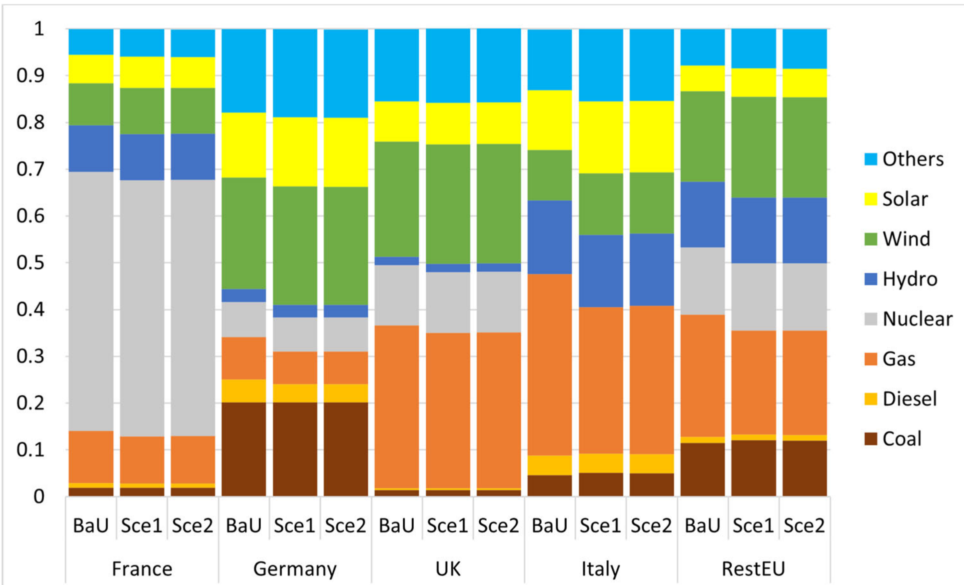
Figure 11 breaks down the simulated real GDP changes by components. For most European countries private consumption is the main declining component. In the case of Germany, the net export increase compensates for losses in consumption and investment. This is not the case for Italy and the Rest of EU region, where net exports are also decreasing and hence the overall GDP changes are larger than for Germany. Note that overall reductions in private consumption are correlated with consumer welfare losses.

Figure 11: Decomposition of Real GDP Effects in Scenario 2 in 2030 (% change w.r.t. baseline)



From Figure 12 we observe that the Russian shutoff of natural gas exports triggers changes in the electricity generation mix in all EU regions. As expected, there is a substantial reduction in gas generation. Italy has the highest decrease in gas, but this is also significant for Germany and the other EU countries (Rest EU). The reduction in gas generation is substituted mostly by renewable sources, as coal and oil generation remain very close to their baseline (BaU) values. Recall that these are medium-term effects and in the short-term European countries might need to revert to coal and nuclear-powered electricity. The reduction in gas generation, moreover, is not so pronounced because Russian gas imports into Europe are almost completely substituted by imports from other natural gas suppliers.

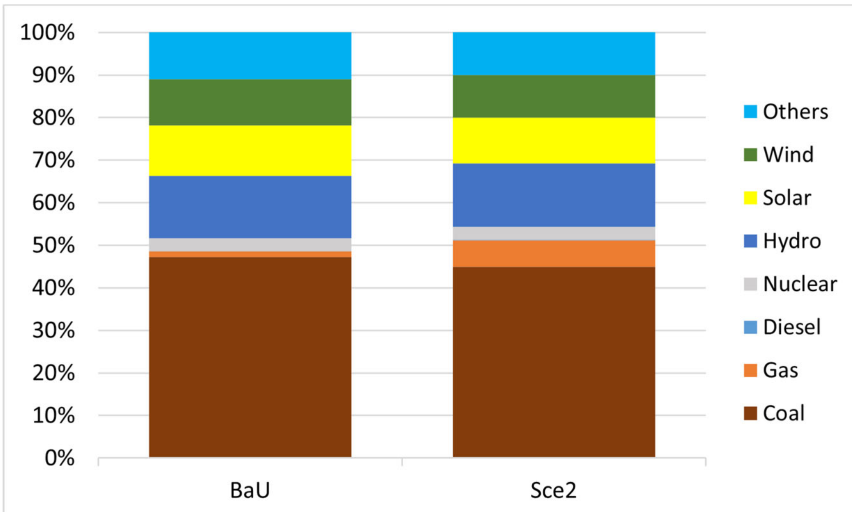
Figure 12: Electricity Generation Mix for EU Countries for Different Scenarios in 2030 (shares)



Note: BaU denotes the business as usual (baseline) values. Other generation sources include biomass and geothermal generation.

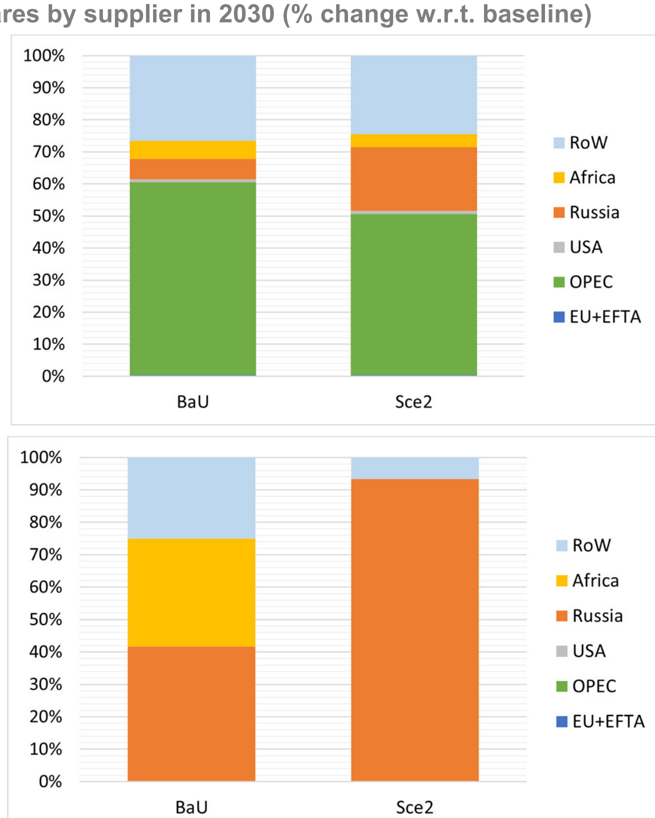
Figure 13 shows the electricity generation mix for China under the baseline and Scenario 1. Electricity generation is dominated by coal and renewable generation, with natural gas being one of the least important power sources. Hence, the new Russia-China pipeline, which is expected to generate a 300% expansion in current Russian natural gas exports to China, only has a moderate effect on electricity generation and the resulting export volumes are still relatively small compared to overall Chinese energy demand. Figure 14 shows the energy import shares of China by main supplier. The bottom graphs shows that Russia was already the largest supplier of natural gas to China, and with the new pipeline it is expected to provide more than 90% of total imports. Nonetheless, the upper graph in Figure 14 shows that Russia provides less than 10% of total energy imports from China, which also include oil and coal imports. Russia's war in Ukraine increases this share to 20%, but this also includes a sharp increase in crude and refined oil imports from Russia, and not only the additional natural gas. Hence the new gas pipeline will represent only a fraction of increased energy imports to China. This explains why China does not benefit much in term of GDP changes or electricity generation changes from the new pipeline, even though this will reduce the price it pays for natural gas imports.

Figure 13: Electricity Generation Mix for China for Different Scenarios in 2030 (shares)



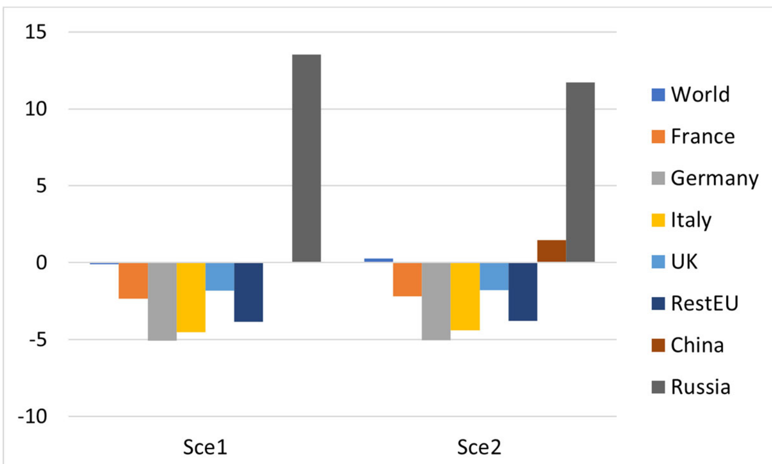
Note: BaU denotes the business as usual (baseline) values. Other generation sources include biomass and geothermal generation.

Figure 14: China: Total energy (top graph) and natural gas (bottom graph) import shares by supplier in 2030 (% change w.r.t. baseline)



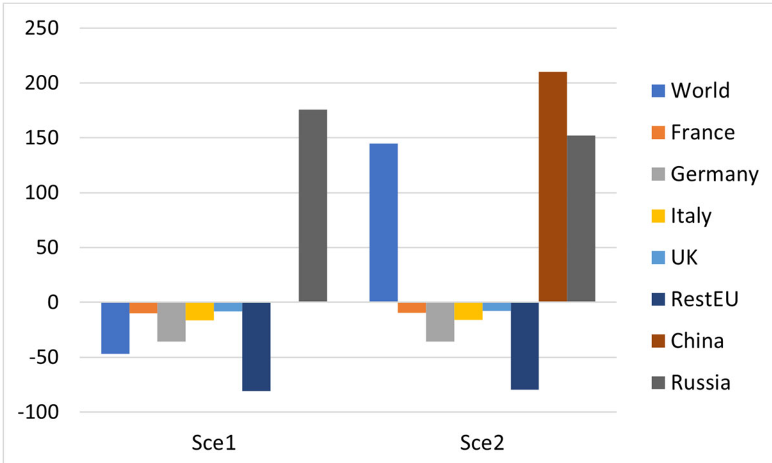
In our simulations, the shutoff of Russian natural gas exports to the EU has a positive impact in terms of reducing GHG emissions in European countries through a substitution away from gas to renewable generation. Figure 15 shows the percentage changes in total emissions with respect to the baseline and here we observe that Italy, Germany, and the Rest EU region have the largest decreases. This is explained by the substitution from gas to renewable electricity generation. However, these emission reductions are less than 5% of total European emissions. On the other hand, Russia has a relatively large rise in emissions in the simulations as the country increases domestic consumption of natural gas, which reduces electricity prices. Chinese emissions increase with the inflow of cheaper Russian natural gas (Scenario 2). This initially decreases the share of coal generation in China, but electricity prices decline due to the cheaper Russian natural gas (see Figure 22 below), and overall energy consumption increases, which accounts for the rise in emissions in China by about 1.5% with respect to its baseline levels.

Figure 15: Overall GHG Emissions for Different Scenarios in 2030 (% change w.r.t. baseline)



This relatively small percentage increase in emissions in China however translates into relatively large absolute emission reductions when compared with other countries. Figure 16 shows how these relative increases are translated into absolute emission reductions in MTCO2eq levels. In the first scenario, global emissions are being reduced and the largest contributor is the Rest of EU region and to a lesser extent the other European countries, but in Scenario 2 global emissions increase due to larger Chinese emissions.

Figure 16: Overall GHG Emissions for Different Scenarios in 2030 (changes in MTCO2eq levels w.r.t baseline)



To assess how Russia's war in Ukraine can potentially change energy security in Europe, we employ two main indicators.[33] The first is the concentration of imported energy from different suppliers. Figure 17 shows the supplier shares for overall energy imports (coal, crude and refined oil and natural gas), while Figure 18 shows the imports shares only for natural gas. As expected from the shutoff of natural gas and oil imports from Russia, we project that the EU is not dependent any longer on Russian energy imports by 2030.

These sharp reductions are compensated mainly by more energy (and natural gas) imports from Norway (included in the EU+EFTA region). However, there are also substantial increases of LNG imports from Qatar (OPEC), Algeria (Africa) and the US.[34] This includes the large investments in LNG terminals undertaken in Europe, in particular in Germany, which accounts for the increased shares of LNG imports into Europe from the US and Qatar.

The increased dependency on non-Russian exports, however, can create future security issues if these countries become less reliable energy sources. It is also important to note that Norway will need to expand their current natural gas production and exports in this scenario, as they have lower trade costs (through existing pipelines) to supply European markets. Nevertheless, this will require that Norway invests heavily in new gas fields and possibly in new pipelines to Europe.

[33] In a related paper, Dolphin *et al.* (2024) use a larger sample of European countries to look at the specific energy security effects of the war on these countries.

[34] These results are consistent with the recent study by EWI (2022), which finds that the current shutoff of Russian gas export to the EU can be substituted in the medium term by LNG imports, in particular from the US. They also estimate that under most of their scenarios, international gas prices go to their pre-crisis values.

Figure 17: Imported Energy Shares by Source for Different Scenarios in 2030

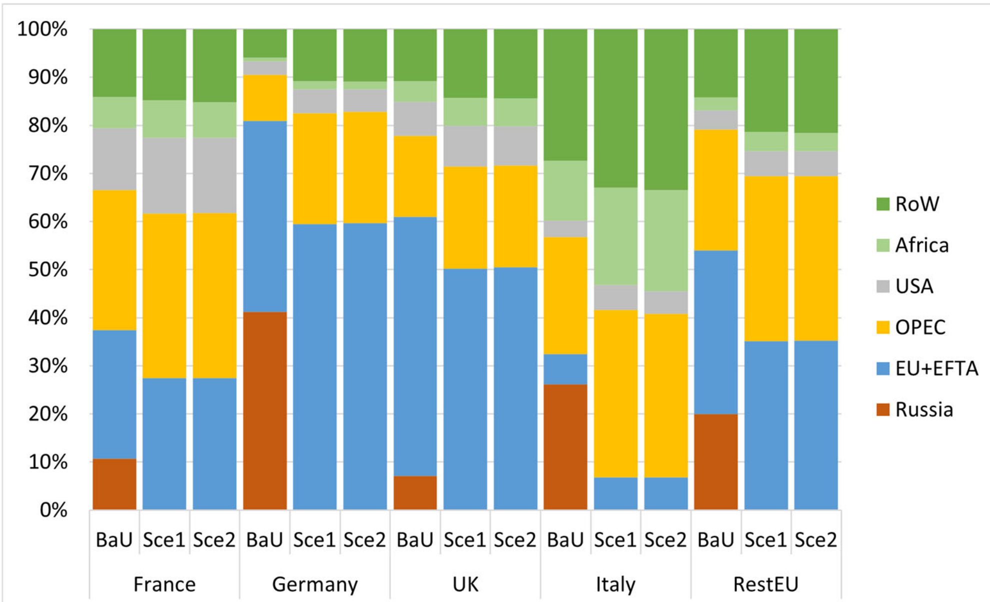
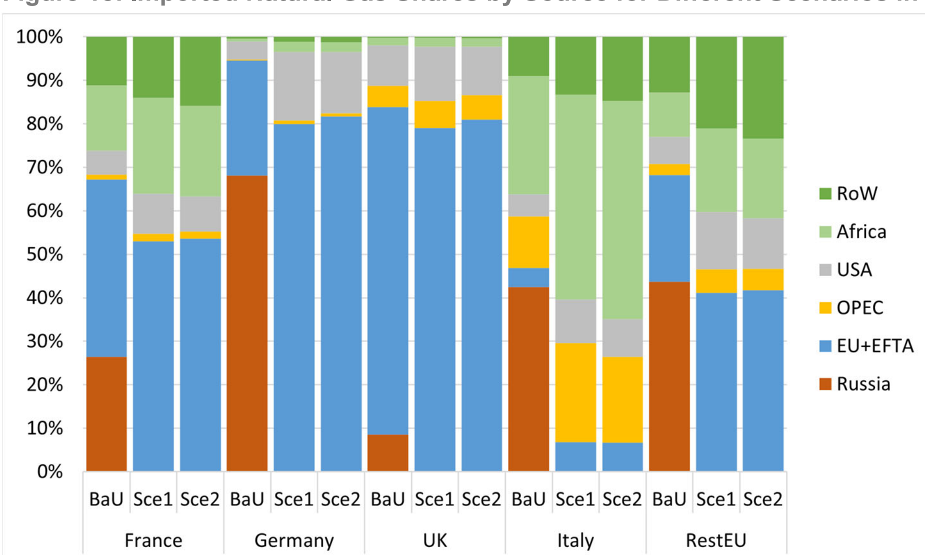
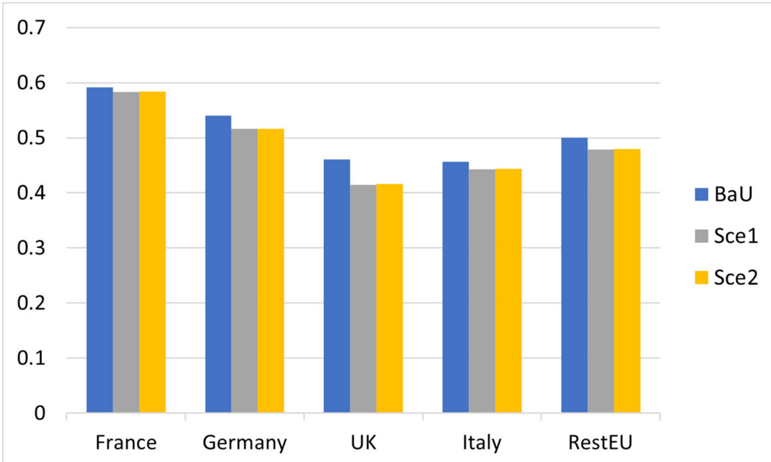


Figure 18: Imported Natural Gas Shares by Source for Different Scenarios in 2030



The second indicator is the share of energy (and natural gas) imports to domestic energy consumption. Figure 19 shows that all European countries experience a decline in the share of imported energy relative to their energy demand, but the reduction is not substantial. This is explained by the fact that Russian natural gas consumption is being substituted by imports from other sources.

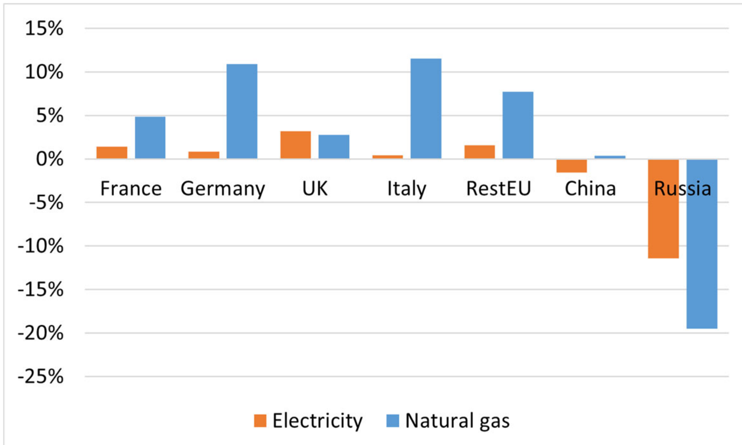
Figure 19: Share of Imported Energy Relative to Domestic Energy Demand for Different Scenarios in 2030



The fact that Russian imports are mainly being substituted by energy imports from other non-European countries (i.e., USA, Qatar, and Algeria) will continue the European reliance on external energy suppliers. Another measure of energy security are energy prices, and we find that in the medium-term simulations, natural gas domestic prices in Europe are increasing. This increase is largest (around 10 percent) for the countries with larger initial imports from Russia: Germany, Italy and RestEU. On the other hand, the international price of natural gas only increases by 1 percent relative to baseline prices. These relatively small price increases reflect the substitution of Russian natural gas by other suppliers in Europe, and the increase in LNG supply in international markets. Hence, despite the relatively high initial international gas prices, it is expected that in the medium-term the increase in natural gas exports from non-Russian countries will fill the supply gap left by Russian pipeline gas.

Lastly, larger international prices are translated into higher domestic consumer prices for natural gas (see Figure 20). Electricity prices are also increasing in the simulations, but less than natural gas prices. This reflects the dual use of natural gas for electricity generation, but also for heating and industrial activities. In addition, electricity prices reflect changes in the costs of the different generation sources and their relative importance in the electricity mix. Note that electricity prices in China are decreasing and this helps explain their increase in energy consumption and emissions in Scenario 2.

Figure 20: Consumer Price for Natural Gas and Electricity in Scenario 2 in 2030 (% change w.r.t. baseline prices)



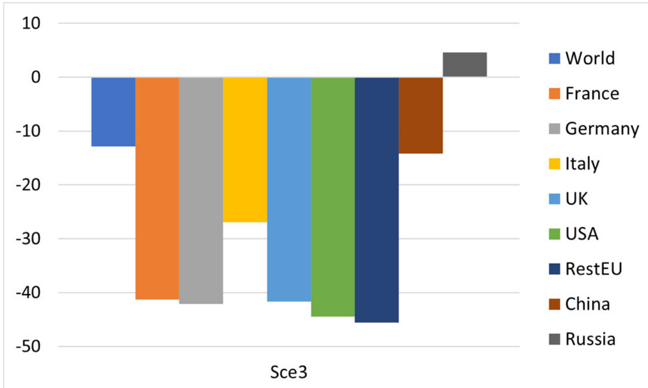
5.2 Interaction of the war with climate commitments

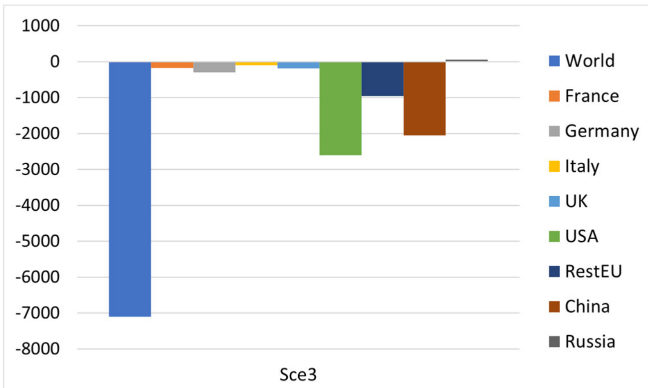
In this section we model a global commitment to reducing emissions through the implementation of the NDCs in G20 countries (Scenario 3). We then interact this global NDC scenario with the trade shocks resulting from Russia's war in Ukraine (Scenario 4) to assess how the war affects the implementation of the NDCs.

Achieving the NDC commitments requires drastic GHG emission reductions by 2030. For example, the EU's Green Deal envisages a reduction of 55% with respect to 2005 emission values for all sources of GHG.[35] Figure 21 shows the percentage reduction with respect to baseline values and the level decrease in total GHG emissions. The NDC commitments, which are relative to a historical emission value (2005 for the EU), result in emission changes with respect to our emission projections of around 40% for most European countries, except for Italy that requires a lower emission reduction. The implementation of these NDC targets results in global emissions reductions of around 12% or 7000 MTCO2eq with respect to baseline projections in 2030. Most emissions reductions by volume are in China and the US, even though EU countries have similar percentage reductions as the US.

[35] Including CO_2 emissions from land use and land-use change and forestry (LULUCF). The NDC 2030 emission levels were taken from the IMF's Climate Policy Assessment Tool (CPAT).

Figure 21: Overall GHG Emissions for NDC Scenario (Sce3) in 2030, as % Change w.r.t. Baseline Values (top graph) and Changes in MTCO2eq w.r.t Baseline Levels (bottom graph)





For simplicity, we model the NDC emission reductions through a general carbon tax levied on all GHGs and polluting activities.[36] Figure 22 shows that to achieve their NDCs countries require substantial increases in carbon tax rates. The level of these tax rates is related to the carbon-intensity of each country, including the effects of the trade disruptions triggered by Russia's war in Ukraine (Scenario 4), which shifts the electricity mix towards a larger share of renewable generation and reduces the domestic consumption of imported fossil fuels, means that the carbon tax rate is lower on average by around US$18 per ton of CO_2eq for EU countries, with the largest decreases in Germany, Italy and the Rest of EU region.

[36] In reality, most countries are planning to reduce emissions through a combination of different mitigation policies, many of which include some type of carbon pricing

Figure 22: Carbon Tax Rates for Scenarios Including NDCs in 2030 (US$ by ton of $CO2$eq)

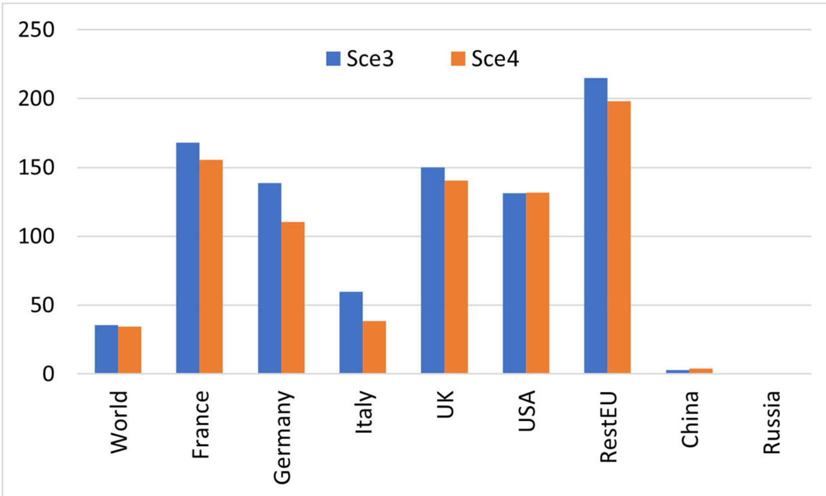
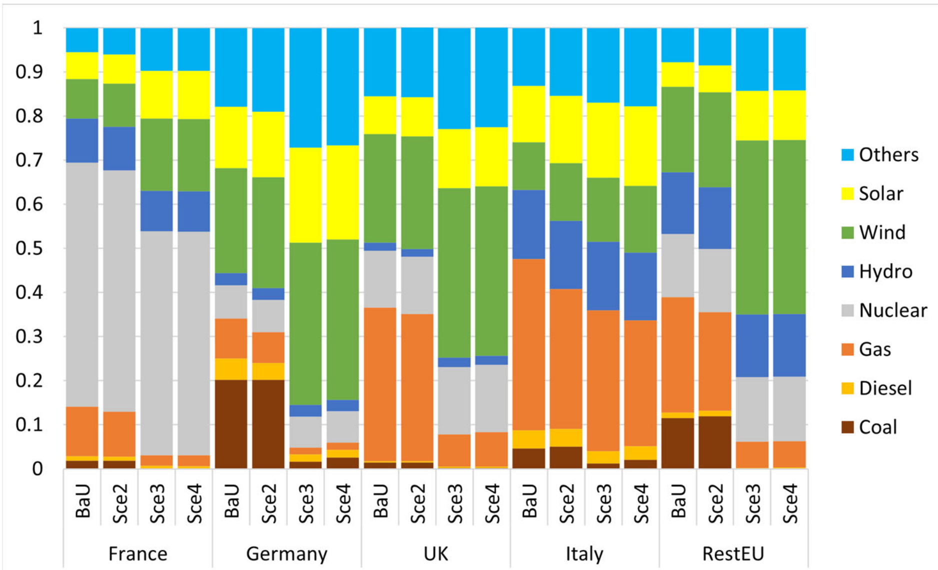


Figure 23 presents the changes in the electricity generation mix in all EU regions and the UK. The electricity mix for 2030 under the NDC is calibrated to match the values from the PRIMES energy model from the European Commission's Joint Research Center (JRC-Seville).[37] The calibration to the PRIMES values match the shares of fossil fuel and renewable generation, while the shares of different fossil fuels (coal, gas and oil) and different renewables (solar, hydro, wind and others) can be different than in PRIMES.[38] Therefore, by construction the NDC values for both Scenario 3 and 4 are similar. However, the figure shows that for all European countries, Russia's war in Ukraine (Scenario 2) produces an intermediate step between the baseline values and the NDC targets. In Italy the changes associated with the trade disruptions brought about by the war bring them already closer to the electricity generation mix that is compatible with their NDC targets. For other European countries –mainly Germany, the UK, and the Rest EU region—the electricity generation mix requires much larger adjustments with large reductions of coal and natural gas generation.

[37] Energy models provide richer technical details than CGE models regarding the interaction of different generation technologies, the specification of the country grid and the potential (and costs) of increasing each power source in each country.

[38] We keep the volumes of nuclear generation fixed to the baseline values.

Figure 23: Electricity Generation Mix for EU Countries for Scenarios Including NDCs in 2030 (shares)

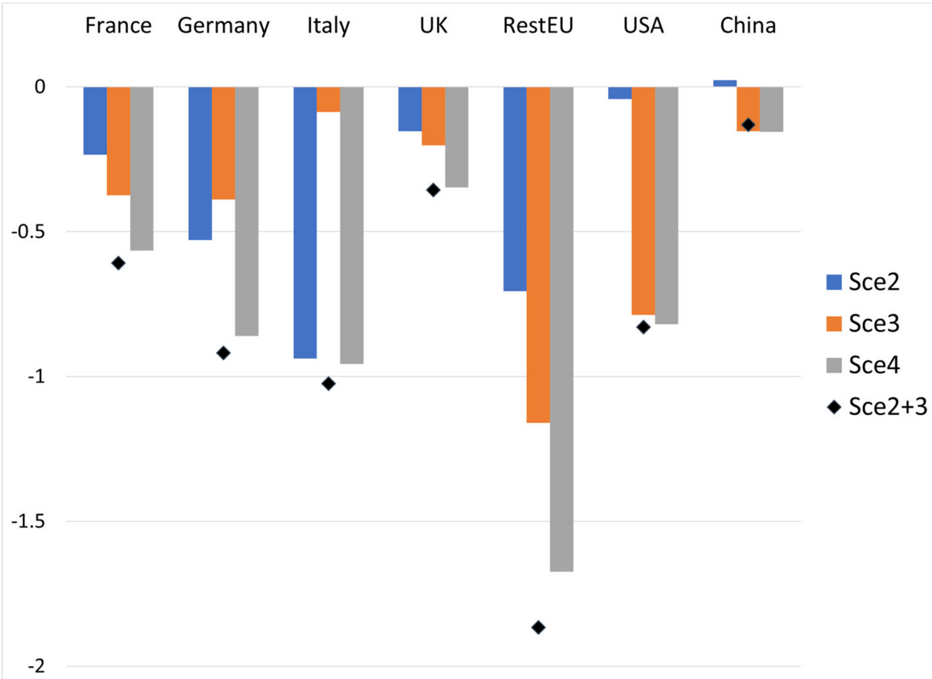


Note: Other generation sources include biomass and geothermal generation

In our simulations, the shock from Russia's war in Ukraine, nevertheless, slightly reduces the overall economic costs (reflected in the reductions in real GDP) of reaching the NDCs. From Figure 24 we observe that real GDP losses are larger in the scenario with the shock of Russia's war in Ukraine (Scenario 4) than in the scenario without (Scenario 3) in all European countries. However, these costs are lower than when the war trade shock (Scenario 2) and the NDC costs (Scenario 3) are summed together (the black marker in Figure 24). In other words, when the trade shocks and the NDC policies are simulated jointly, the GDP effects are lower than the GDP effects of each scenario (2 and 3) run separately. This points to positive general equilibrium effects of running both scenarios simultaneously. Italy, Germany, and the Rest of EU region have the largest differences. On the other hand, China and the US experience very limited GDP changes from the trade shocks associated with Russia's war in Ukraine.

Interestingly, the NDC costs for China are almost identical than with trade disruptions associated with of Russia's war in Ukraine , even though they initially benefit from access to cheaper Russian natural gas imports that are less polluting than their coal generation. As explained above, gas generation represents a very small fraction of electricity generation in China and the larger imports of natural gas from Russia are relatively small when compared to their overall energy imports. In addition, the reduction in electricity price generated by the cheaper Russian natural gas also requires a higher implicit carbon tax to reduce emissions.

Figure 24: Real GDP for Scenarios Including NDCs in 2030 (% change w.r.t. baseline)



Finally, we look at our energy security indicators. First, the concentration of total energy imports by suppliers (Figure 25) does not change much between the war trade shocks (Scenario 2) and when those are combined with the NDC (Scenario 4). In the case of natural gas imports (Figure 26), although the shares shifts are larger between Scenarios 2 and 4, they are still relatively close. This implies that implementing the NDC targets after the war does not affect the supplier-composition of energy and natural gas imports.

Figure 25: Imported Energy Shares by Source for Different Scenarios in 2030

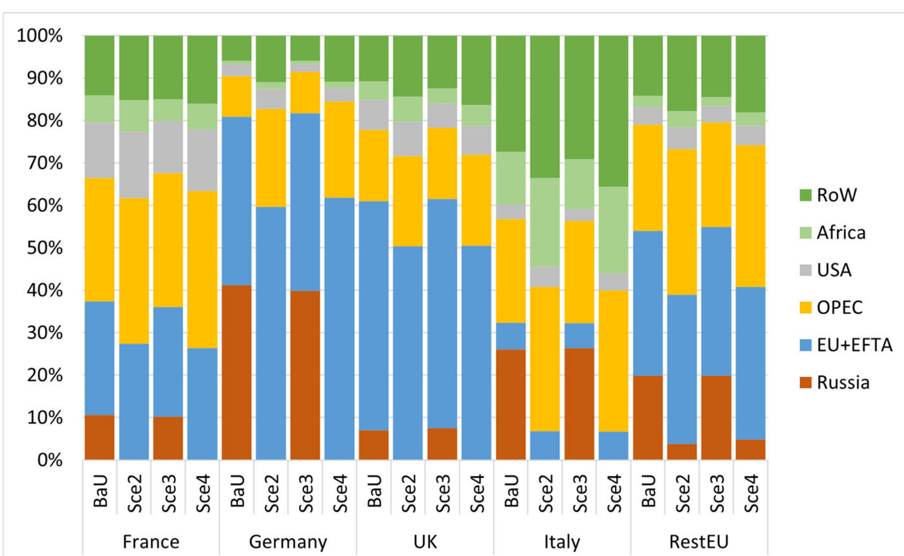
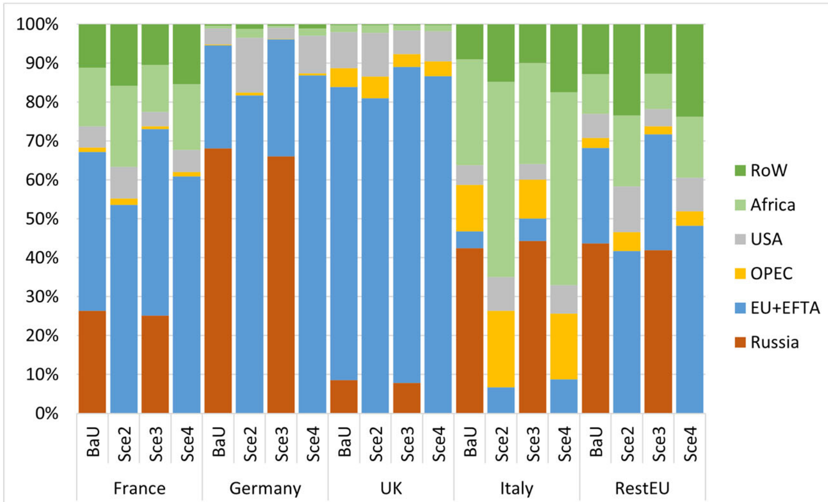
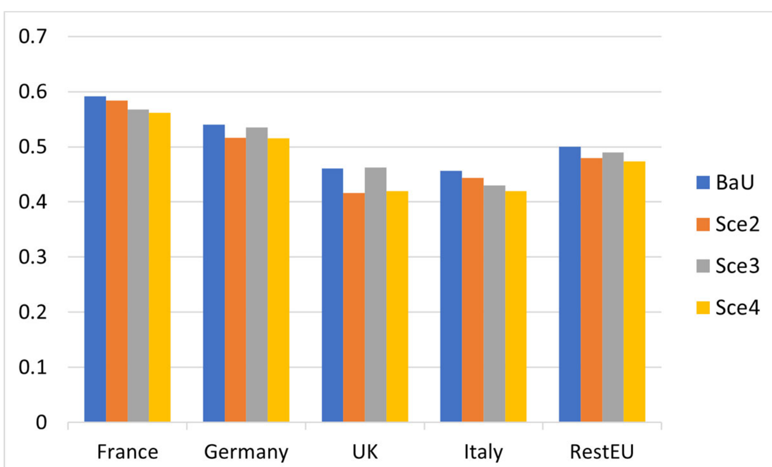


Figure 26: Imported Natural Gas Shares by Source for Different Scenarios in 2030



Second, Figure 27 shows that total energy imports relative to total energy domestic demand is lower when the NDC targets are combined with the war trade shocks for all European regions. This implies that energy security, using this indicator, is improved by the war trade shocks, the NDC scenario and also the combination of both.

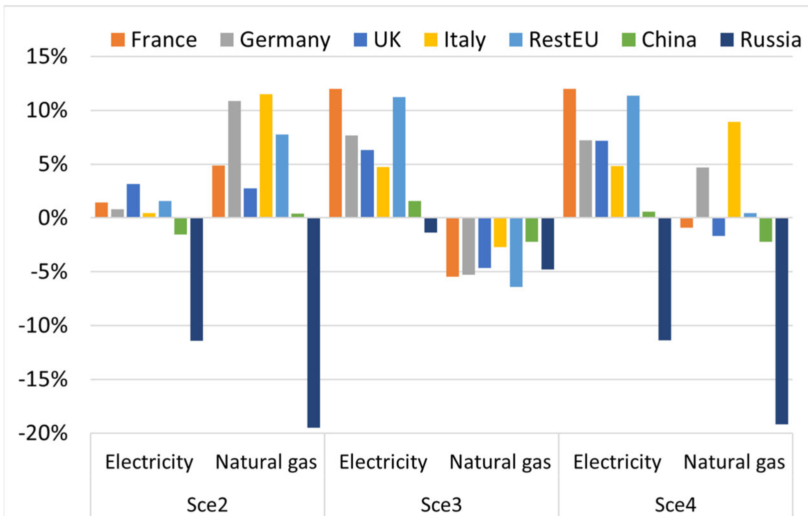
Figure 27: Share of Imported Energy Relative to Domestic Energy Demand for Different Scenarios in 2030



Third, Figure 28 shows that electricity prices in the NDC scenario (Scenario 3) are increasing with carbon taxation, even though the price of natural gas is declining. This reflects that carbon taxation makes fossil fuel generation more expensive, which yields higher electricity prices, while at the same time it reduces the demand for fossil fuels and their prices. In our simulations, the interaction of the NDC policies with the trade shock of

Russia's war in Ukraine (Scenario 4) make natural gas prices lower than in Scenario 2, as the shutoff of Russian natural gas imports forces countries to move more aggressively towards renewable generation. The electricity prices in Scenario 4 are not changing much when compared to the NDC scenario. To sum up, we find that the war trade shocks, the implementation of the NDC targets and the combination of both, provide more energy security when measured as the share of imported energy to domestic consumption or energy price changes.

Figure 28: Consumer price for electricity and natural gas in different scenarios in 2030 (% Change w.r.t. baseline prices)



6. Summary

The trade disruptions triggered by the Russian invasion of Ukraine are expected to generate modest economic losses for European countries in the medium term. In particular, the Russian shutoff of gas exports to the EU resulted in very high energy prices during 2022 and 2023, and significant economic losses for the European countries that are most dependent on Russian natural gas imports. In the medium term, our simulations show that the real GDP losses associated with the trade disruptions triggered by the war are expected to be higher for Russia but moderate for other European countries (less than 1%) and negligible for other G20 countries. These simulation results are conditional on model assumptions however, which in our case do not include the effects of policies currently being implemented and which may affect actual medium-term losses. On the other hand, switching away from the energy imports from Russia is expected to create a greener electricity generation mix in Europe and reduce EU overall emissions between 2% to 5% as a consequence of the trade disruptions associated with the war.

In general, from the countries in our model, Italy, Germany, and the Rest EU region are the most affected by Russia's war in Ukraine, with the largest GDP losses and higher natural gas consumer prices changes. This is a result of their initial high dependency on Russian natural gas imports and their relatively large share of electricity generation using natural gas. However, other European countries can be more severely affected by the war, in particular Central and Eastern European countries that also depend heavily on Russian energy imports, such as Austria, Czechia, Slovakia, Hungary and Bulgaria. In our model these countries are aggregated in the Rest of EU region, which also includes countries that are not expected to be as affected by the war, and hence, the average effect for the region is not as large as it will be for these specific countries.

The switch of EU countries from less gas to more renewable generation could also increase energy security for these countries, at least if measured by the share of total energy imports relative to domestic energy consumption. Natural gas prices are not expected to increase substantially in the medium-term, as the EU countries will still import substantial amounts of natural gas, but the main suppliers will be Norway, the US, Qatar, and Algeria, instead of Russia. We also find that if a new pipeline between Russia and China is constructed, it will have relatively small GDP effects for both countries. We assume that natural gas exports of Russia will still decrease by almost 75% of pre-war levels and the increased trade volumes are not substantial enough for China to have macroeconomic impacts. Nevertheless, the new pipeline between both countries would increase natural gas electricity generation in China and decrease electricity prices, which generates a relatively small increase in energy consumption and GHG emissions.

When countries implement their NDCs, the overall costs of implementing the NDCs are slightly reduced for European countries as the trade shocks associated with Russia's war in Ukraine already have a positive impact on renewable generation and lead to a reduction in natural gas demand. Even after losing access to Russian natural gas, Europe has been able to substitute its imports from alternative suppliers, such as Norway, the US, Algeria, and Qatar. Moreover, the required shadow price of carbon to reach the NDCs is slightly lower after Russia's war in Ukraine, as countries move faster toward renewable generation and rely less on imported fossil fuel energy.

A Aggregation tables

Table 1: Regional concordance between IMF-ENV and the GTAP database

1	Australia (AUS)	Australia (AUS)
2	China (CHN)	China (CHN)
3	Japan (JPN)	Japan (JPN)
4	India (IND)	India (IND)
5	United States (USA)	United States of America (USA)
6	Russia (RUS)	Russian Federation (RUS)
7	Argentina (Argentina)	Argentina (ARG)
8	Brazil (Brazil)	Brazil (BRA)
9	Canada (Canada)	Canada (CAN)
10	Indonesia (Indonesia)	Indonesia (IDN)
11	Korea (Korea)	Korea, Republic of (KOR)
12	Mexico (Mexico)	Mexico (MEX)
13	Saudi Arabia (Saudi)	Saudi Arabia (SAU)
14	South Africa (SouthAfrica)	South Africa (ZAF)
15	Turkey (Turkey)	Turkey (TUR)
16	France (France)	France (FRA)
17	Germany (Germany)	Germany (DEU)
18	United Kingdom (UK)	United Kingdom (GBR)
19	Italy (Italy)	Italy (ITA)
20	Rest of EU & EFTA (RES-TEU)	Austria (AUT), Belgium (BEL), Cyprus (CYP), Czech Republic (CZE), Denmark (DNK), Estonia (EST), Finland (FIN), Greece (GRC), Hungary (HUN), Ireland (IRL), Latvia (LVA), Lithuania (LTU), Luxembourg (LUX), Malta (MLT), Netherlands (NLD), Poland (POL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Spain (ESP), Sweden (SWE), Switzerland (CHE), Norway (NOR), Rest of EFTA (XEF), Bulgaria (BGR), Croatia (HRV), Romania (ROU)
21	Other Oil-Exporting coun- tries (RESTOPEC)	Ecuador (ECU), Venezuela (VEN), Bahrain (BHR), Islamic Republic of Iran (IRN), Israel (ISR), Kuwait (KWT), Oman (OMN), Qatar (QAT), United Arab Emirates (ARE), Rest of Western Asia (XWS), Jordan (JOR), Rest of North Africa (XNF), Nigeria (NGA), South Central Africa (XAC)
22	Other developing and emerging East Asia & New Zealand (ODA)	New Zealand (NZL), Rest of Oceania (XOC), Hong Kong (HKG), Mon- golia (MNG), Chinese Taipei (TWN), Rest of East Asia (XEA), Cam- bodia (KHM), Lao People s Democratic Republic (LAO), Malaysia (MYS), Philippines (PHL), Singapore (SGP), Thailand (THA), Viet Nam (VNM), Rest of Southeast Asia (XSE), Brunei Darussalam (BRN), Bangladesh (BGD), Nepal (NPL), Pakistan (PAK), Sri Lanka (LKA), Rest of South Asia (XSA), Rest of South African Customs Union (XSC)
23	Other developing and emerging Africa (OAF)	Egypt (EGY), Morocco (MAR), Tunisia (TUN), Cameroon (CMR), Cote d Ivoire (CIV), Ghana (GHA), Senegal (SEN), Benin (BEN), Burkina Faso (BFA), Guinea (GIN), Togo (TGO), Rest of Western Africa (XWF), Central Africa (XCF), Ethiopia (ETH), Kenya (KEN), Madagascar (MDG), Malawi (MWI), Mauritius (MUS), Mozambique (MOZ), United Republic of Tanzania (TZA), Uganda (UGA), Zam- bia (ZMB), Zimbabwe (ZWE), Rwanda (RWA), Rest of Eastern Africa (XEC), Botswana (BWA), Namibia (NAM)
24	Other developing and emerging Eurasia (OEURA- SIA)	Albania (ALB), Belarus (BLR), Ukraine (UKR), Rest of Eastern Eu- rope (XEE), Rest of Europe (XER), Kazakhstan (KAZ), Kyrgyzstan (KGZ), Rest of Former Soviet Union (XSU), Tajikistan (TJK), Arme- nia (ARM), Azerbaijan (AZE), Georgia (GEO)
25	Other developing and emerging Latin America (OLA)	Rest of North America (XNA), Plurinational Republic of Bolivia (BOL), Chile (CHL), Colombia (COL), Paraguay (PRY), Peru (PER), Uruguay (URY), Rest of South America (XSM), Costa Rica (CRI), Guatemala (GTM), Honduras (HND), Nicaragua (NIC), Panama (PAN), El Salvador (SLV), Rest of Central America (XCA), Caribbean (XCB), Dominican Republic (DOM), Jamaica (JAM), Puerto Rico (PRI), Trinidad and Tobago (TTO), Rest of the World (XTW)

Table 2: Concordance for activities between IMF-ENV and the GTAP database

1	All Crops (cro)	Paddy Rice (pdr), Wheat (wht), Other Grains (maize, barley, rye, oats, other cereals) (gro), Vegetables and fruits (v_f), Oil Seeds (osd), Sugar cane and sugar beet (c_b), Plant Fibres (cotton, flax, hemp, sisal and other raw vegetable materials used in textiles) (pfb), Other Crops (ocr)
2	Livestock (lvs)	Bovine cattle, sheep and goats, horses (ctl), Animal products n.e.s. (oap), Raw milk (rmk), Wool, silk-worm cocoons (wol)
3	Forestry (frs)	Forestry (frs)
4	Fisheries (fsh)	Fishing (fsh)
5	Construction (cns)	Construction (cns)
6	Minerals n.e.s. (OMN)	Minerals n.e.s. (oxt)
7	Water services (wts)	Water supply; sewerage, waste management and remediation activities (wtr)
8	Coal extraction (coa)	Coal (coa)
9	Crude Oil extraction (oil)	Oil (oil)
10	Petroleum and coal products (p_c)	Manufacture of coke and refined petroleum products (p_c)
11	Natural gas: extraction, manufac- ture & distribution (gas)	Gas (gas), Gas manufacture, distribution (gdt)
12	Coal powered electricity (clp)	Coal power baseload (CoalBL), Coal-based CCS (colccs)
13	Oil powered electricity (olp)	Oil power baseload (OilBL), Oil power peakload (OilP)
14	Gas Powered electricity (gsp)	Gas power baseload (GasBL), Gas power peakload (GasP), Gas-based CCS (gasccs)
15	Nuclear power (nuc)	Nuclear power (NuclearBL), Advanced nuclear (advnuc)
16	Hydro power (hyd)	Hydro power baseload (HydroBL), Hydro power peakload (HydroP)
17	Wind power (wnd)	Wind power (WindBL)
18	Solar power (sol)	Solar power (SolarP)
19	Other power (xel)	Other baseload includes biofuels, waste, geothermal, and tidal tech- nologies (OtherBL)
20	Electricity transmission and distri- bution (etd)	Electricity transmission and distribution (TnD)
21	Paper & Paper Products (ppp)	Paper products, publishing (ppp)
22	Non-metallic minerals (nmm)	Mineral products n.e.s. (nmm)
23	Iron and Steel (i_s)	Iron and steel (i_s)
24	Chemical products (crp)	Chemical products (chm)
25	Non-ferrous metals (nfm)	Non-ferrous Metals (nfm)
26	Electronics (ele)	Electronic equipment (ele)
27	Food Products (fdp)	Bovine cattle, sheep and goat, horse meat products (cmt), Meat prod- ucts n.e.s. (omt), Vegetable oils and fats (vol), Dairy products (mil), Processed rice (pcr), Sugar (sgr), Food products n.e.s. (ofd), Beverages and tobacco products (b_t)
28	Textiles (txt)	Textiles (tex), Wearing apparel (wap), Leather products (lea)
29	Transport Equipment (mvh)	Motor vehicles and parts (mvh), Transport equipment n.e.s. (otn)
30	Fabricated metal products (fmp)	Metal products (fmp)
31	Other manufacturing (includes re- cycling) (oma)	Wood products (lum), Machinery and equipment n.e.s. (ome), Electri- cal equipment (eeq), Basic pharmaceuticals (bph), Rubber and plastic products (rpp), Manufactures n.e.s. (omf)
32	Water Transport (wtp)	Sea transport (wtp)
33	Air Transport (atp)	Air transport (atp)
34	Land transport (otp)	Transport n.e.s.: Land transport and transport via pipelines (otp)
35	Other collective services (osg)	Public administration and defense (osg), Education (edu), Human health and social work (hht)
36	Other Business services (osc)	Communication (cmn), Financial services n.e.s. (ofi), Insurance (ins), Recreation and other services (ros), Dwellings (dwe), Trade (trd), Ac- commodation and food service activities (afs), Warehousing and sup- port activities (whs), Business services n.e.s. (obs), Real estate activi- ties (rsa)

Table 3: Concordance for commodities between IMF-ENV and the GTAP database

1	All Crops (cro)	Paddy Rice (pdr), Wheat (wht), Other Grains (maize, barley, rye, oats, other cereals) (gro), Vegetables and fruits (v_f), Oil Seeds (osd), Sugar cane and sugar beet (c_b), Plant Fibres (cotton, flax, hemp, sisal and other raw vegetable materials used in textiles) (pfb), Other Crops (ocr)
2	Livestock (lvs)	Bovine cattle, sheep and goats, horses (ctl), Animal products n.e.s. (oap), Raw milk (rmk), Wool, silk-worm cocoons (wol)
3	Forestry (frs)	Forestry (frs)
4	Fisheries (fsh)	Fishing (fsh)
5	Construction (cns)	Construction (cns)
6	Minerals n.e.s. (OMN)	Minerals n.e.s. (oxt)
7	Water services (wts)	Water supply; sewerage, waste management and remediation activities (wtr)
8	Coal extraction (coa)	Coal (coa)
9	Crude Oil extraction (oil)	Oil (oil)
10	Petroleum and coal products (p_c)	Manufacture of coke and refined petroleum products (p_c)
11	Natural gas (gas)	Natural gas extraction (gas), Gas manufacture and distribution (gdt)
12	Electricity (ELY)	Coal power baseload (CoalBL), Coal-based CCS (colccs), Oil power baseload (OilBL), Oil power peakload (OilP), Gas power baseload (GasBL), Gas power peakload (GasP), Gas-based CCS (gasccs), Nuclear power (NuclearBL), Advanced nuclear (advnuc), Hydro power baseload (HydroBL), Hydro power peakload (HydroP), Wind power (WindBL), Solar power (SolarP), Other baseload includes biofuels, waste, geothermal, and tidal technologies (OtherBL), Electricity transmission and distribution (TnD)
13	Paper & Paper Products (ppp)	Paper products, publishing (ppp)
14	Non-metallic minerals (nmm)	Mineral products n.e.s. (nmm)
15	Iron and Steel (i_s)	Iron and steel (i_s)
16	Chemical products (crp)	Chemical products (chm)
17	Non-ferrous metals (nfm)	Non-ferrous Metals (nfm)
18	Electronics (ele)	Electronic equipment (ele)
19	Food Products (fdp)	Bovine cattle, sheep and goat, horse meat products (cmt), Meat products n.e.s. (omt), Vegetable oils and fats (vol), Dairy products (mil), Processed rice (pcr), Sugar (sgr), Food products n.e.s. (ofd), Beverages and tobacco products (b_t)
20	Textiles (txt)	Textiles (tex), Wearing apparel (wap), Leather products (lea)
21	Transport Equipment (mvh)	Motor vehicles and parts (mvh), Transport equipment n.e.s. (otn)
22	Fabricated metal products (fmp)	Metal products (fmp)Other manufacturing (includes re- cycling) (oma) Wood products (lum), Machinery and equipment n.e.s. (ome), Electrical equipment (eeq), Basic pharmaceuticals (bph), Rubber and plastic products (rpp), Manufactures n.e.s. (omf)Water Transport (wtp) Sea transport (wtp)
23	Air Transport (atp)	Air transport (atp)
24	Land transport (otp)	Transport n.e.s.: Land transport and transport via pipelines (otp)
25	Other collective services (osg)	Public administration and defense (osg), Education (edu), Human health and social work (hht)
26	Other Business services (osc)	Communication (cmn), Financial services n.e.s. (ofi), Insurance (ins), Recreation and other services (ros), Dwellings (dwe), Trade (trd), Accommodation and food service activities (afs), Warehousing and sup- port activities (whs), Business services n.e.s. (obs), Real estate activities (rsa)

References

Aguiar, A., Chepeliev, M., Corong, E., McDougall, R., and van der Mensbrugghe, D. (2019). The GTAP data base: Version 10. *Journal of Global Economic Analysis*, 4(1):1–27.

Al-Karablieh, Y. (2022). Oil supply shock: The output impact of a European ban on Russian oil. Technical note, International Monetary Fund, European Department.

Albrizio, S., Bluedorn, J. C., Koch, C., Pescatori, A., and Stuermer, M. (2022). Market size and supply disruptions: Sharing the pain of a potential Russian gas shut-off to the European Union. IMF Working Paper WP/22/143, International Monetary Fund, Washington, D.C.

Ari, A., Arregui, N., Black, S., Celasun, O., Iakova, D. M., Mineshima, A., Mylonasan, V., Parry, I. W., Teodoru, I., and Zhunussova, K. (2022). Surging energy prices in Europe in the aftermath of the war: How to support the vulnerable and speed up the transition away from fossil fuels. IMF Working Paper WP/22/152, International Monetary Fund, Washington, D.C.

Bachmann, R., Baqaee, D., Bayer, C., Kuhn, M., Löschel, A., Moll, B., Peichl, A., Pittel, K., and Schularick, M. (2022). Wat if? The economic effects for Germany of a stop of energy imports from Russia. EconPol Policy Re- search 36, iFo Institute, Munich.

Baker, S. R., Bloom, N., and Davis, S. J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, 131(4):1593–1636.

Baqaee, D. and Farhi, E. (2019). Networks, barriers, and trade. NBER Working Paper 26108, National Bureau of Economic Research, Cambridge, MA.

Baqaee, D., Moll, B., Landais, C., and Martin, P. (2022). The economic con- sequences of a stop of energy imports from Russia. Focus 084-2022, Conseil d'Analyse Économique.

Château, J., Rojas-Romagosa H, and Thube, S., van den Mensbrugghe, D. (2023). "The IMF-ENV model: A technical overview," Version 1.01. Research Department, International Monetary Fund. *Forthcoming*.

Chepeliev, M. (2020a). Development of the non-CO2 GHG emissions database for the GTAP 10a database. GTAP Research Memorandum 30.

Chepeliev, M. (2020b). GTAP-Power data base: Version 10. *Journal of Global Economic Analysis*, 5(2):110–137.

Chepeliev, M., Hertel, T., and van der Mensbrugghe, D. (2022). Cutting Russia's fossil fuel exports: Short-term economic pain for long-term environmental gain. *World Economy*, Forthcoming.

Di Bella, G., Flanagan, M. J., Foda, K., Maslova, S., Pienkowski, A., Stuermer, M., and Toscani, F. G. (2022). Natural gas in Europe: The potential impact of disruptions to supply. IMF Working Paper WP/22/145, International Monetary Fund, Washington, D.C.

Dolphin, G., Duval, R., Rojas-Romagosa, H., and Sher, G. (2024). Secure Energy in Europe's Green Transition. European and Research Departments. Departmental paper. International Monetary Fund. *Forthcoming.*

EWI (2022). Developments in the global gas markets up to 2030. Final Report, Energy Economics Institute at the University of Cologne (EWI).

Gustafson, T. (2020). *The bridge: Natural gas in a redivided Europe*. Harvard University Press, Cambridge, MA.

Lan, T., Sher, G., and Zhou, J. (2022). The economic impacts on Germany of a potential Russian gas shutoff. IMF Working Paper WP/22/144, International Monetary Fund, Washington, D.C.

The Economist (2023). Why the West's oil sanctions on Russia are proving to be underwhelming. Article, February 1st.

PUBLICATIONS

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