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The economic and energy security implications of the Russian energy weapon

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ABSTRACT

The Russian–Ukrainian war of 2022 sent shockwaves through the global economy and disrupted energy markets on an unprecedented scale. The conflict not only caused extensive devastation in Ukraine but also triggered a commodity supply shock in various international markets. In this paper, we look at the impacts of this energy weapon and the global consequences of its use. We investigate the interplay between gas market fluctuations, energy price shocks, and trade dependencies, while offering insights into building resilient global systems for a sustainable and secure energy futures. Using a novel approach we combine energy trade modelling and integrated assessment modelling to compare a hypothetical counterfactual scenario, with no price and supply shock, to a scenario of disrupted trade and regionalized gas prices. We conclude that the Russian energy weapon had only had short-term economic consequences, but influences energy-system transformation in the EU, accelerating diversification and renewable deployment.

1. Introduction

"Gazprom has completely suspended gas supplies to Bulgargaz (Bulgaria) and PGNiG (Poland) due to non-payment in roubles" [1] reads a Gazprom communiqué from April 2022, two months after the beginning of the war between Ukraine and Russia. Exports to Finland, the Netherlands, Denmark and Germany were also ceased shortly after [2,3]. These moves came following a decree signed by Vladimir Putin, President of Russia, forcing new conditions on "unfriendly" countries that had imposed sanctions on Russia for its aggression against Ukraine [4].

While EU officials decried *blackmail* [5], this kind of behaviour was not completely unexpected from Russia. Since 2006 there have been continued concerns about EU member states' dependency on Russian gas. Mentions of Russia's *energy weapon* and the EU's *energy security* have started to gain traction on multiple occasions [6,7]. Most recently in 2021, when Russia was putting pressure on the German regulator by limiting flows on Yamal with the intention to speed up licensing on Nord Stream 2.

In 2022 Russia was clearly using its *energy weapon* to make a point and pressure European states who sided with Ukraine in the conflict. Based on Van de Graaf and Colgan [8] we use the term *energy weapon* to describe the action when one state uses or threatens to use its energy resources to compel or deter another state. While the potency of this *energy weapon* has long been debated [7–10] it is generally understood that it could be a source of *"significant political leverage"* [7, p. 461]. In fact, it was seen as a geopolitical weapon both by Russia and by EU officials too: President Putin reportedly threatened to shut down gas supply due to conflicts with Ukraine as early as 2014 [7], and used gas trade as a geopolitical bargaining chip in 2022. Meanwhile, EU and member state officials have been talking about the need to *"disarm Russia's energy weapon"* since 2014 [8].

Russia had restricted supplies towards Europe *already* at the end of 2021, by delivering the minimum of pledged volumes of existing contracts. After the start of the armed conflict, throughout 2022, Gazprom stopped shipping gas to its European counterparts claiming failures to pay in Rubles and other failures in contract terms. The tactics of cutting European supply and creating scarcity proved to be a failure in September 2022, when European prices continued to fall and the trend did not reverse after the Nord Stream pipelines exploded. Eventually, these events lead Europe to a rapid shift away from its dependence on Russian energy imports (see Fig. 1). Phasing out Russian gas in Europe required a combination of enhanced liquefied natural gas (LNG) imports, accelerated renewable energy capacity deployment, and a reduction of demand [12].

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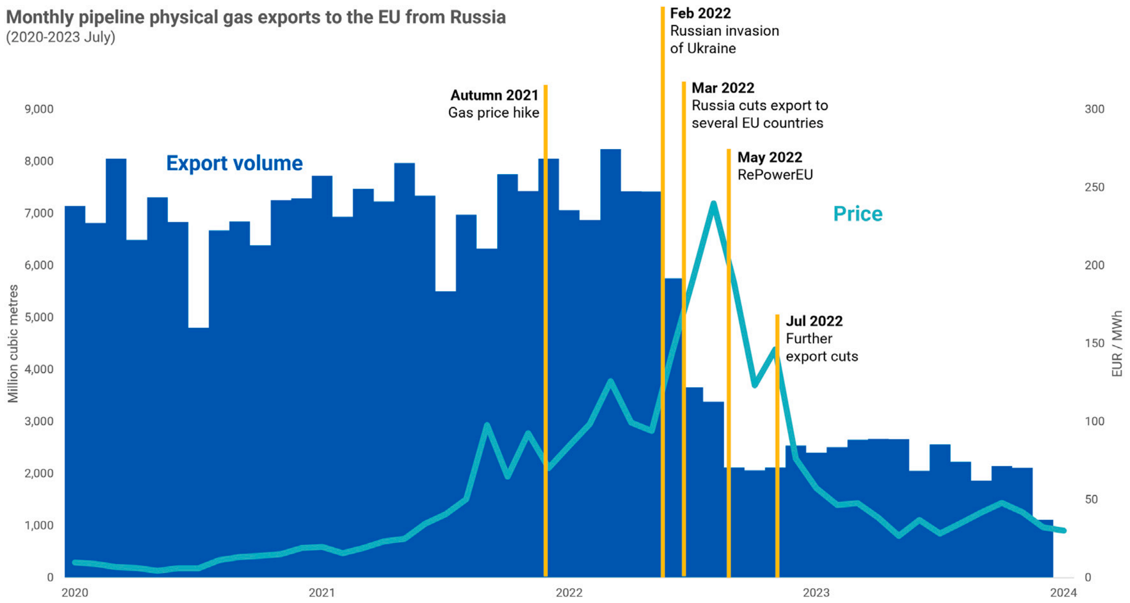

Fig. 1. Monthly pipeline exports from Russia has declined heavily, source: own work, based on [11] and Eurostat data on pipeline exports, price displayed is Dutch TTF contract price.

In this paper we look at the potency of the *energy weapon* as well as reactions to it. While it is nearly impossible to fully capture and single out the effects of gas supply and pricing from other economic effects connected to the conflict (e.g., supply-chain disruptions, economic sanctions against Russia, etc.) we can use energy trade and macroeconomic modelling to compare a hypothetical counterfactual scenario to a scenario where the adverse energy market developments do happen, i.e., where Russia deploys its *energy weapon*. Our analysis seeks to make a contribution based on this approach to the existing literature. First, we undertake a comprehensive multi-model analysis, combining the REKK World Gas Model (WGMM) and Cambridge Econometrics' E3ME macroeconometric model. This novel approach allows us to assess the impacts of withheld supplies on global energy prices, trade flows and to use these results to simulate energy-system and economic outcomes. Second, we discuss how these shifts, induced by the conflict have impacted European energy security, long-term energy use and system development.

While several papers in the literature have already appeared analysing different energy aspects of the war in Ukraine (e.g., gas savings [13,14], high gas prices in Europe [15], the role of the US in gas supplies [12] or Russian nuclear energy diplomacy [16]) we believe that our approach to the question is a novel one as we assess the global impacts of the gas supply shock from an economic, environmental and energy security perspective as well.

The remainder of this paper is organized as follows. Section 2 provides a short description of the REKK World Gas Model (WGMM) and Cambridge Econometrics' E3ME macroeconometric model, while Section 3 outlines scenario designs. This leads into Sections 4–7, where we discuss the gas market, energy system, economic and energy security outcomes of the modelling exercise. Finally, Section 8 summarizes our conclusions and policy implications.

2. Methods

As we are aiming to understand not just the direct energy market effects of the restricted Russian gas supply we combine two models with different advantages and characteristics. To integrate approaches of the models we iterate between them, i.e., results produced by one of the models are run through the other model and then the process is repeated. Main energy market impacts are modelled with REKK's WGMM based on expected supply restrictions, this yields prices and bilateral traded amounts. Cambridge Econometrics' E3ME-FTT is then used to estimate the short- to medium-term impacts of these trade and price changes on demand (including fuel and technology substitution), industry, energy structure and global non-energy trade. Calculated demand responses are then fed back to the WGMM, which produces a new set of prices and trade figures, which are used in another step in the E3ME-FTT calculations.

We believe that the application of WGMM, a partial equilibrium model, is well suited to global commodity trade, while the bounded rationality treatment of E3ME is best suited to assessing the economic implications. A high-level schematic of model linkage is presented in Fig. 2. We provide a brief description of both models used in this section.

WGMM

WGMM is a competitive, dynamic, multi-market partial equilibrium model that simulates the operation of the wholesale natural gas market across the world. It includes a supply–demand representation for 90 countries of the world, accounting for over 95% of global gas demand and supply. The spatial granularity of the model is country-level, while the time-granularity is monthly. The model explicitly includes gas storage, pipeline and LNG infrastructure as technical constraints. The timeframe of the model covers 12 consecutive months and market participants have perfect information over this period. Dynamic connections between months are introduced by the operation of gas storage.

Main building blocks of the model include (1) supply, (2) demand, (3) pipelines, (4) LNG liquefaction and regasification, and (5) storage:

1. Supply considers country-specific production costs for natural gas. Monthly minimum and maximum volume of production as well as the cost of gas production is set using historical data. Volume of production on a monthly basis was based on the Jodigas database. Costs were estimated based on the World Bank data publication Natural gas rents.
2. Demand is represented by downward sloping linear demand function for each national market. The linearity and price responsiveness of local demand ensures that market clearing prices will always exist in the model. Regardless of how little supply there is in a local market, there will be a high enough price

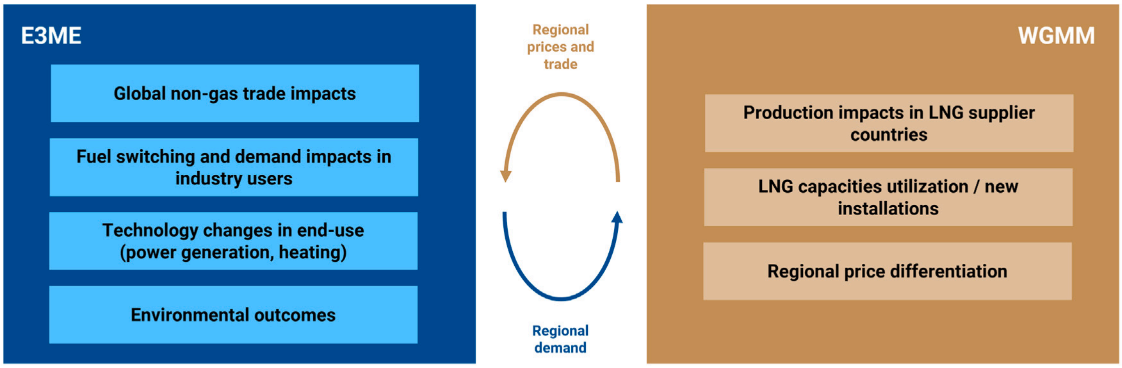

Fig. 2. Main topics covered by the models and linkage between them.

so that the quantity demanded will fall back to the level of quantity supplied, achieving market equilibrium. Demand data were based on Jodigas statistics, for future years the demand development patterns of IEA WEO 2022 were used.

3. Cross-border pipeline connect the national markets. The cost of using the pipeline reflects short-term marginal costs of operation, and is based on applicable tariffs within the EU, while is mainly distance-based elsewhere in the world. Pipeline infrastructure capacities were based on Global Energy Monitor Gas Pipeline database. Different scenarios modelled assumed different pipeline infrastructure settings.
4. LNG infrastructure allows to connect far-away markets via shipping. Cost of LNG shipping is distance-based, also accounting for liquefaction and regasification costs. LNG infrastructure data was based on GIIGNL annual statistics, for future capacities the expansion rate of the last 5 years in liquefaction terminals was assumed.
5. Gas storages are capable of storing natural gas from one period to another, arbitraging away large market price differences across periods. Storage units have a constant marginal cost of injection and (separately) of withdrawal. In each month, there are upper limits on total injections and total withdrawals. There are three additional constraints on storage operation: (1) working gas capacity; (2) starting inventory level; and (3) year-end inventory level. Injections and withdrawals must be such during the year that working gas capacity is never exceeded, intra-year inventory levels never drop below zero, and year-end inventory levels are met. This allows for setting intra-year targets as prescribed by EU regulation for storages.

Demand and supply of natural gas are the most important drivers of gas markets; however, a proper representation of the physical infrastructure is needed to consider the constraints to physical trade. The different infrastructure setup between scenarios allows for different trading opportunities.

The optimization algorithm reads the input data and searches for the simultaneous supply–demand equilibrium (including storage stock changes and net imports) of all local markets in all months, respecting all the constraints detailed above.

In short, the equilibrium state (the ‘‘result’’) of the model can be described by a simple no-arbitrage condition across space and time. Modelling results provide a welfare-maximizing outcome from the perspective of gas producers, gas consumers and traders. Results are driven by production costs, regional demand and transportation cost between the markets. However, it is instructive to spell out this condition results in optimal welfare in terms of the behaviour of market participants: consumers, producers and traders. Infrastructure operators (TSO, storage and LNG operator) observe gas flows and their welfare is not factored in the equilibrium.

E3ME-FTT

While the WGMM model provides detailed insights into the workings of global gas markets under the input conditions a global macroeconomic model is needed to analyse economy-wide effects, changes in the energy-mix (due to supply and price effects) as well as non-gas global trade effects. These are the parts that the E3ME-FTT macroeconomic modelling framework adequately covers.

The E3ME-FTT is an integrated solution comprising of the core E3ME model [17–20] and the FTT (Future Technology Transformation) suite of models [21–23]. The core E3ME model covers primary interactions between economics-energy and environment, while the FTT models provide detailed bottom-up modelling for some sectors that are key from an energy use perspective. In this section we briefly discuss main characteristics of the framework. The full model, including the set of equations and data sources is described in Mercure et al. [17] and in the E3ME manual [19].

E3ME is an E3 (economy-energy-environment) type of model, closely resembling the capabilities of integrated assessments (IAM) models. Nevertheless, contrasting economic modules of common IAMs E3ME is built on post-Keynesian economic theory, the ideas of complexity economics and an econometric approach [17–20,24].

The model is structured around an input–output model of each of the represented economies, while individual economies are linked together through bilateral trade linkages. The model is very granular in its nature, distinguishing 70 world regions (often single countries), 43 industrial sectors for each of the regions, several consumption categories (following COICOP classifications) and 23 fuel users with the possibility of using 12 different fuel types. The model is demand-led, meaning effective aggregate consumption drives output, as well as trade and the demand for intermediate output and other inputs (e.g., labour, energy). The use of these inputs have their own impacts: energy demand is modelled separately by fuel type and by sector, which then translates energy use into physical units. Unit costs (which are impacted by labour availability and input prices) as well as prior investments determine prices [18,19,24,25].

Connected to the core economic module, energy use is calculated with its own sector/region specific parameters (allowing for endogenous fuel switching and fuel specific demand responses) and is represented both in monetary and physical terms. Meanwhile greenhouse gas (GHG) emissions are calculated based on fuel usage, therefore linking emissions to fuel use (with process emission separately linked to output) [19,25].

Most of the parameters used to represent these relationships are econometrically estimated from time-series data. The error-correction method, with a two-stage process as prescribed by Hendry et al. [26] and Engle and Granger [27], with testing for cointegration, is used to estimate sector/region specific parameters, capturing both short- and long-term effects. As the model uses parameters that are estimated on historical data it is inherently vulnerable to the ‘*Lucas Critique*’ [24,25].

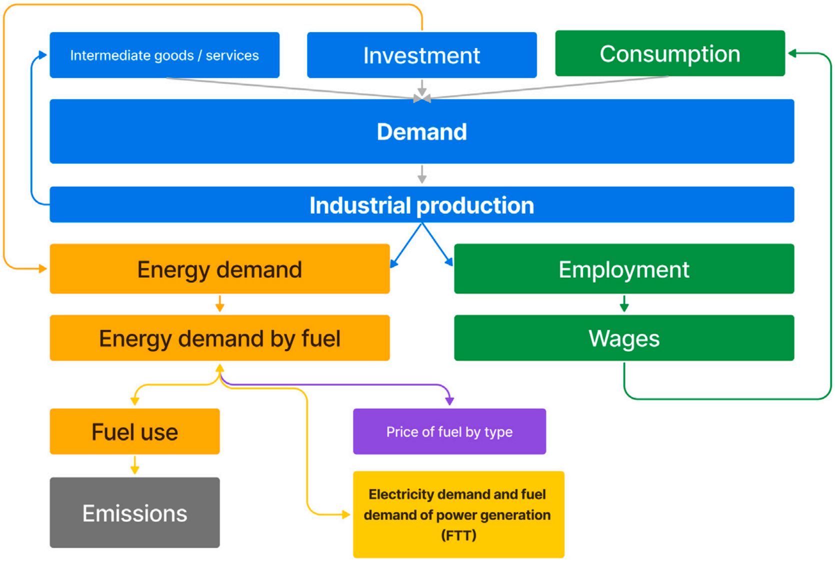

Fig. 3. Simplified overview of linkages in the E3ME-FTT model. *Source:* Reproduced from Kiss-Dobronyi et al. [25] with permission.

To address this issue and to specifically model innovation in high impact sectors the FTT suite of models has been introduced to the modelling framework [17,19].

The FTT models simulate technology diffusion in selected sectors, including transport [23,28], power generation [29] and heating [22, 23]. They employ ideas that are in line with the overall philosophy of E3ME, namely bounded rationality and the Keynesian interpretation of decision making under uncertainty. The models use a differential equation structure to represent technology choice between different options from the investors' perspective. Investors make their choices based on levelized costs, but levelized costs are defined as cost distributions rather than single points, therefore allowing for local, unobserved conditions to influence the investment decisions [29]. Adaptation of the technology, based on ideas of Rogers [30] and similarly to the Bass diffusion model [31] are then dependent on technology shares, i.e. technology choices are path-dependent on the level of the overall system. This is further reinforced by effects of learning-by-doing and decreasing costs due to increasing competition, higher adoption of a technology in period t can not only lead to higher adaptation in period t+1, but also because cumulative adaptation can decrease price of the technology [19,25,29]. Fig. 3 provides a high level visual overview of the main model linkages.

3. Estimating the consequences of the gas supply shock

In the analysis we compare two different scenarios. Our **Reference scenario** serves as a counterfactual. Here the Russian invasion of Ukraine has not happened, and Europe continues to consume Russian pipeline gas. Natural gas demand in the EU and Ukraine is defined by the Stated Policies Scenario of IEA WEO 2022 [32]. The Power of Siberia 2 pipeline connecting Russia to China is not commissioned. Regasification capacities in Europe are not expanded. A natural gas price hike is not observed.

The **Conflict scenario** describes an outcome similar to what has happened in 2022–2023: Russian gas flows to the EU are halted on the Nord Stream pipeline, on the Yamal pipeline and to the Baltics, as well as via Ukraine. Russian flows are still allowed on the Turkstream system. As a response, European LNG regasification capacities are nearly doubled by 2030. The Power of Siberia 2 pipeline is commissioned by 2030 adding 80 bcm/year pipeline capacity from Russia to China. Additionally, LNG liquefaction capacities in Russia increase to around 200 bcm/year by 2040.

Notably, the turbulence experienced in the gas markets had an impact on other commodity markets, particularly coal. Therefore, coal prices in the Conflict scenario are based on KPMG's Coal Price and FX Market forecasts series [33].[2]

4. The Russian gas supply shock and reorganization of natural gas trade

Struggling with rising commodity prices and increasing supply disruptions and following calls to reduce the EU's energy dependence on Russia [8], the EU has committed to becoming independent of Russian fossil fuels by 2027 [34].

European countries are affected by the restricted gas supply to differing extents. A primary factor is their use of Russian pipeline gas: continental Central Eastern European countries east of Germany have used Russian pipeline gas [9,10] and had limited alternatives compared to Western European countries. Consequently, the price effect in countries with higher shares of Russian pipeline gas and limited alternatives is more severe: in the Netherlands, for example, modelling suggests that prices *only* doubles while German prices are seven times higher then in the Reference scenario (see Fig. 4). However, these affects are only short-term: to 2030, increased LNG import capacity coupled with demand reduction in Europe results in more limited price responses to the constrained Russian deliveries.

The impact of the gas supply shock is less severe outside Europe. In most regions (Africa, South Asia, East Asia and Pacific and Rest of the World), gas prices in 2022 are about 30% higher in the Conflict scenario than in the Reference scenario, while in the other regions the shock is less pronounced.

Overall Russian gas exports are substantially decreased in the short run. The volumes historically transported to Europe cannot be effectively shifted to other markets without sufficient pipeline export capacity. However, by 2030, the commissioning of additional pipeline infras-

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[2] Relative difference between the price forecasts for hard coking coal in the December 2021/January 2022 edition and the June/July 2022 edition were calculated. Forecast only covers period until 2026, after this a gradual alignment with Reference prices were assumed.

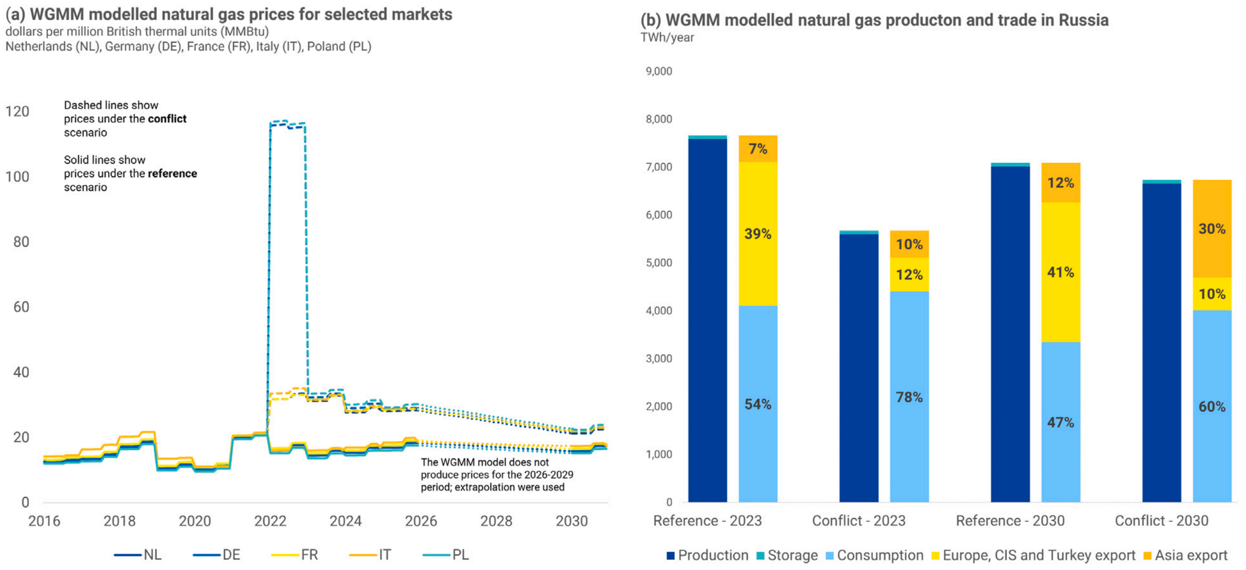

Fig. 4. (**a**) Gas prices in the Conflict scenario and in the Reference case in selected European markets (%) and (**b**) the structure of Russian gas production, consumption and exports (TWh/year).
Source: Own work, based on WGMM results.

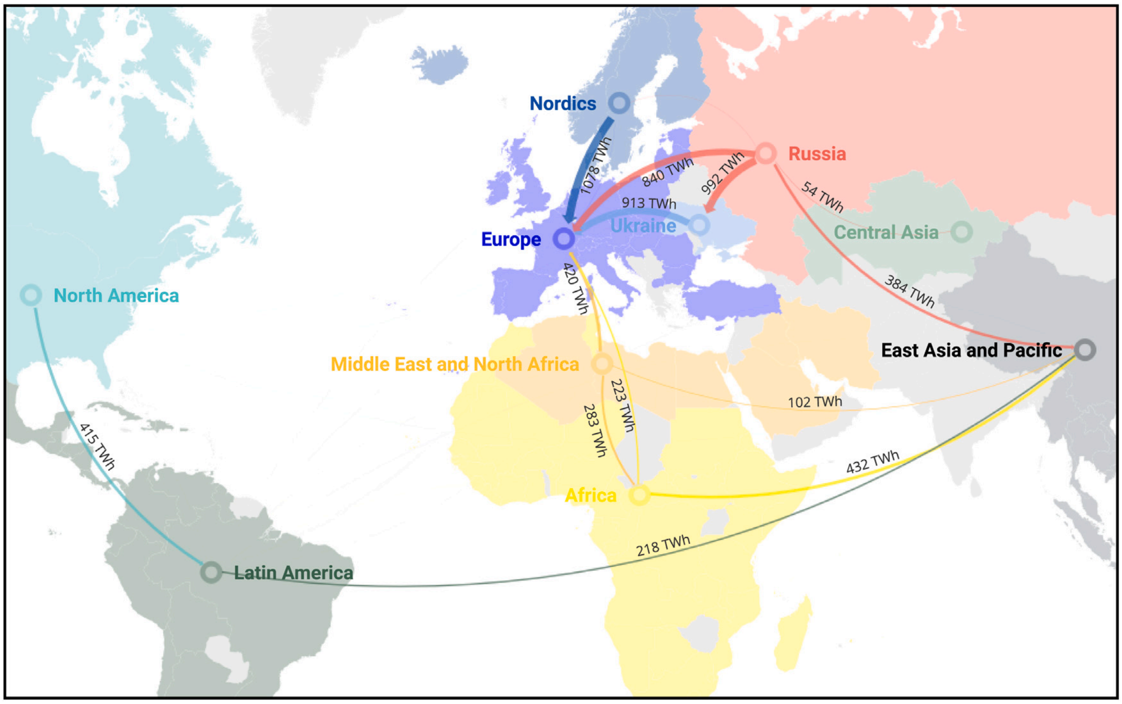

Fig. 5. Natural gas trade flows between partners connected with Russia/EU, 2019.
Source: Own work, based on WGMM results.

tructure to China allows for redirecting 780 TWh/year (80 bcm/year) flows to Asian markets [35]. But even with this investment, the total net export volumes in 2030 are 13% below the Reference case of 2023.

Flows show an increased role for LNG trade in the Conflict scenario. Russian gas is replaced by LNG in the European supply structure, as no additional free pipeline capacities are available. In 2023, the modelled US LNG accounts for 53% of EU LNG imports, which is very close to the actual data reported by EIA [36]. This dominance increases to 73% in 2030. This implies an exposure of EU gas markets to US LNG supply that should be closely monitored by EU institutions. US LNG does not pose a security of supply threat to the EU in the way that Russian pipeline exports to Eastern Europe did, for two reasons. First, the LNG infrastructure allows for easy market access and source substitution. Second, the price of US LNG must remain competitive, otherwise alternative suppliers can easily enter the market.

Natural gas trade implications calculated by combining trade impacts from the WGMM and demand impacts from the E3ME are shown in Figs. 5–7. Fig. 5 presents natural gas flows in 2019, while Fig. 6 presents the realigned trade structure by 2030 given war impacts, while Fig. 7 shows trade flows in the counterfactual case.

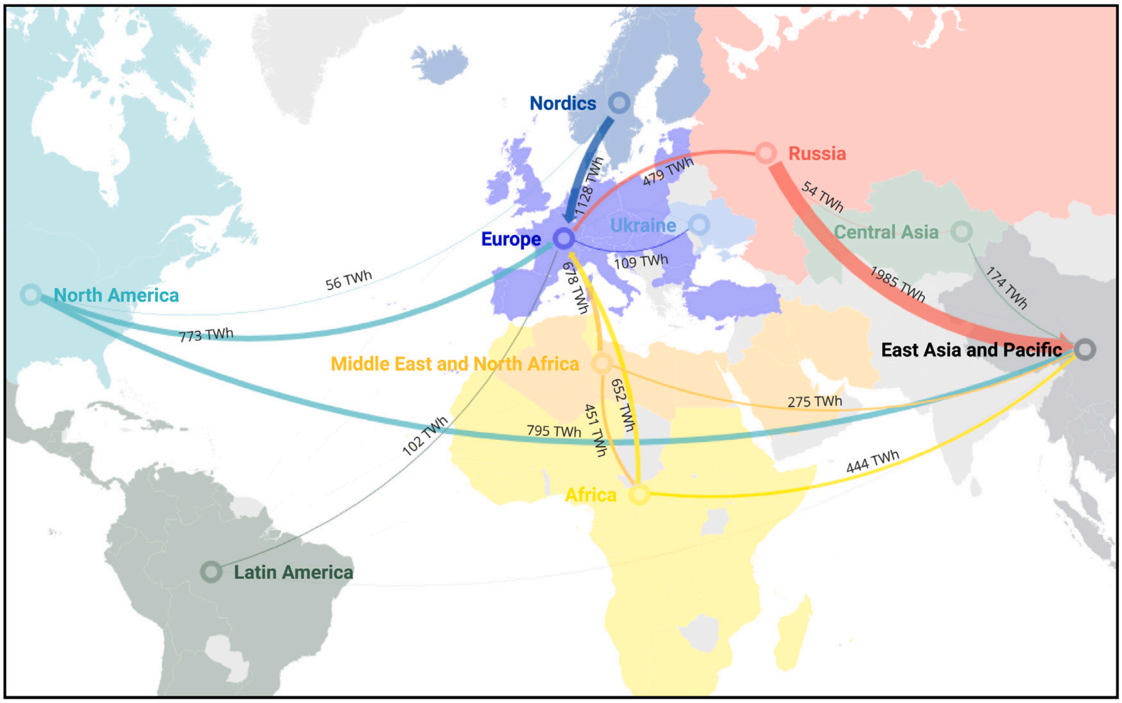

Fig. 6. Natural gas trade flows between partners connected with Russia/EU, 2030.
Source: Own work, based on WGMM results, **Conflict** scenario.

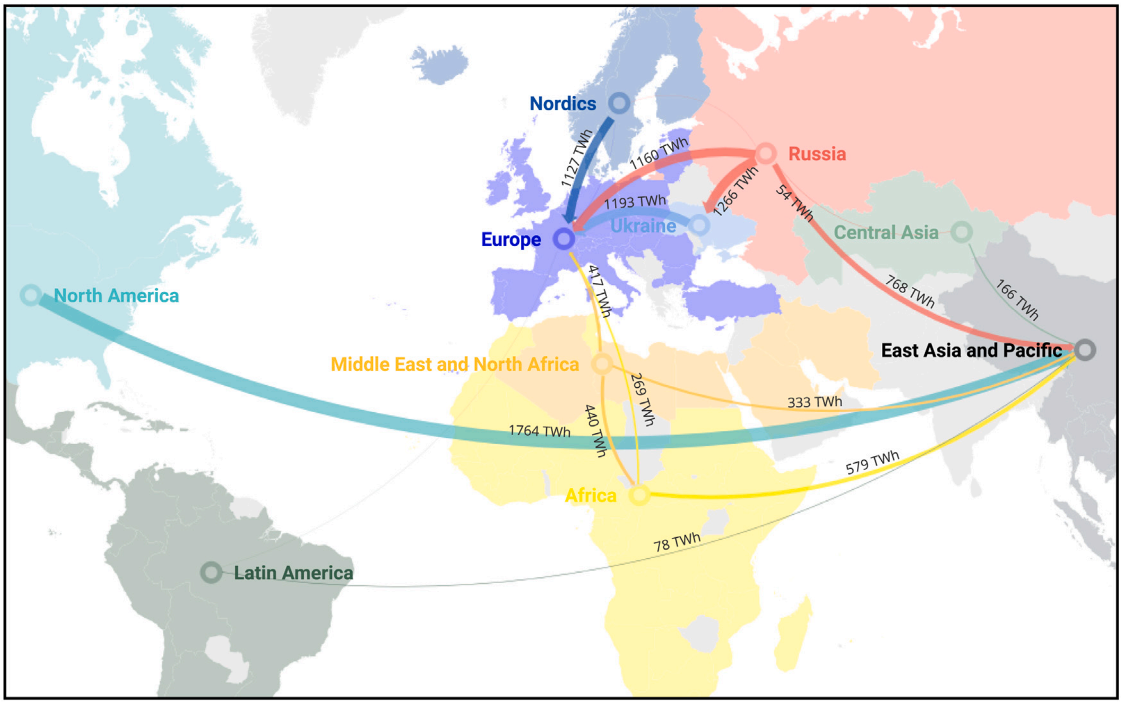

Fig. 7. Natural gas trade flows between partners connected with Russia/EU, 2030.
Source: Own work, based on WGMM results, **Reference** scenario.

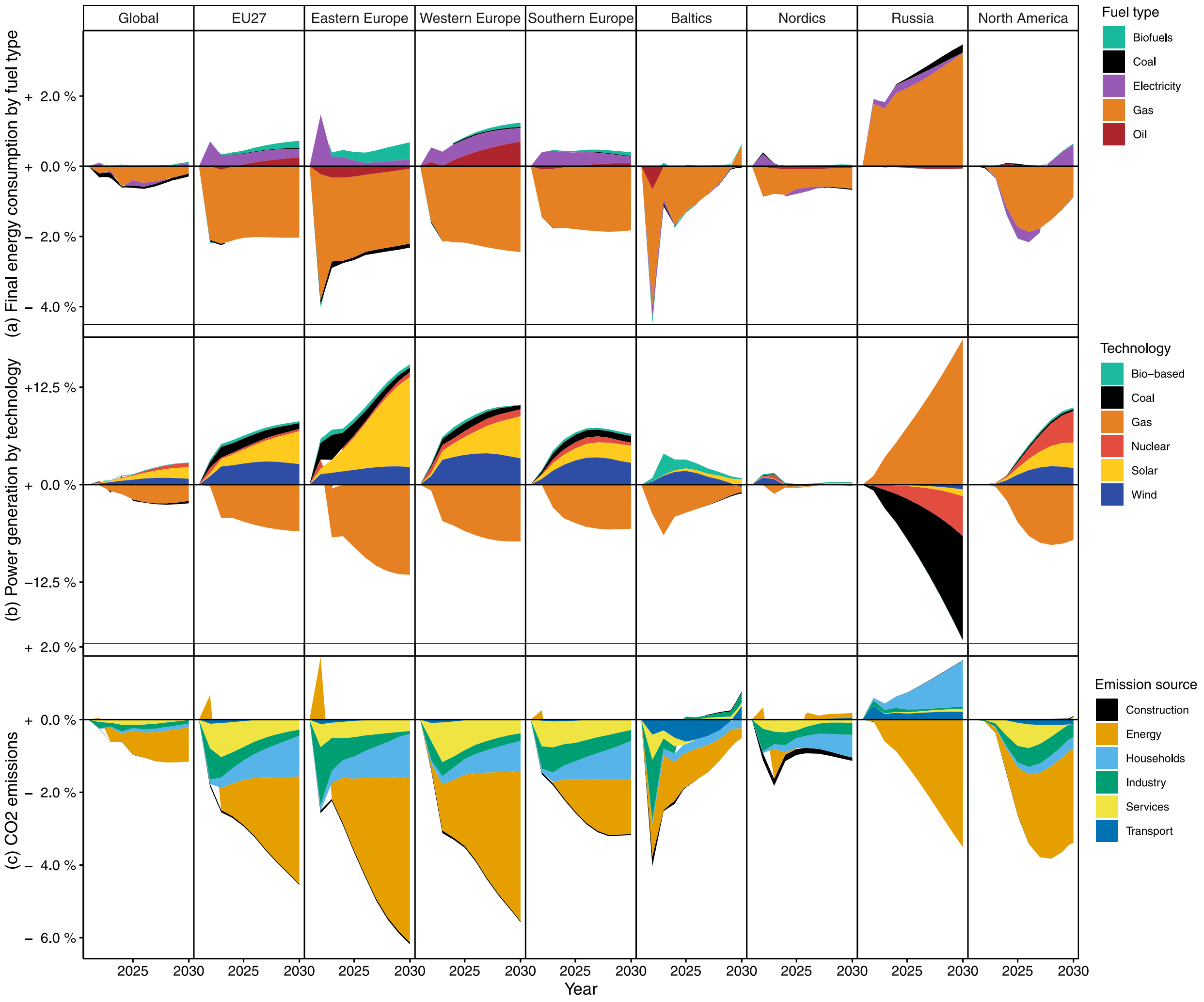

Fig. 8. Main energy and emission results by region in the Conflict scenario relative to the Reference scenario.
Source: Own work, based on E3ME results.

5. Medium-term energy implications of the shock

Rising gas prices have a direct effect not only on demand for natural gas, but also on electricity prices and the prices of goods and services where gas and electricity are inputs to the production process. Furthermore, rising gas costs might induce fuel and technology switching (i.e., switching from gas-based heating to another technology). At the same time, exporters might see increasing export revenues [37], and real economic impacts from that, due to the price hike. These impacts and the energy-system consequences are all represented in the E3ME-FTT framework.

First, a combination of gas, coal and induced electricity price increases, coupled with economic feedbacks (i.e., decreased consumption) lead to a decreasing demand for energy. Global demand for energy decreases by about 860 PJ (−0.2%) in 2022, but the magnitude of the reduction decreases over time. Nevertheless, the total energy demand is still about 740 PJ (−0.2%) lower than in the Reference case by the end of the decade (see Fig. 8). Most of the reduction, as expected, comes from Europe: in EU27 countries an initial demand reduction of about 570 PJ (−1.5%) can be observed in 2022, decreasing to about 480 PJ (−1.3%) by 2030.

In most cases the reduction of gas demand in itself is stronger than the reduction in overall energy demand: there is a substitution effect, demand switching from gas to electricity, oil and biofuels (see Panel A of Fig. 8). The substitution is dominated by switching to electricity. Electricity demand increases initially by 3% in EU27 (2022), and although the magnitude later decreases to 0.9–1.1%, there is a permanent switch from gas to electricity.

Outside of Europe in North America energy demand decreases in the medium-term, explained by the strong embeddedness of the US in gas and especially LNG trade. As US producers have the opportunity to sell gas internationally at higher prices, domestic prices are expected to increase too. Gas consumption therefore decreases by up to 3% by 2030, with demanded electricity growing by the end of the decade by 3%. Meanwhile, Russian trade options are severely limited as transport capacities towards new markets are not yet available. In Russia, therefore, the domestic price is plummeting, leading to increased domestic gas consumption (+4.1–8.3%, 300–580 PJ) and an overall increased demand for energy (+2-3.4%, 300–600 PJ).

Decreasing gas use leads to decreased CO_2 emissions (see Panel C of Fig. 8). Emission reduction in 2022 is about net 78 $MtCO_2$ (−0.21%) globally, growing to 450 $MtCO_2$ (−1.16%) by the end of the decade. About 44% of the initial reduction and 24% of the final reduction comes from EU27. Emission reductions are driven by changes in the energy sector (i.e., switching from gas-based power generation to other technologies, see Panel B of Fig. 8), but there is also an increasing contribution from technology switching in heating (households). Meanwhile demand reduction in industry and services is

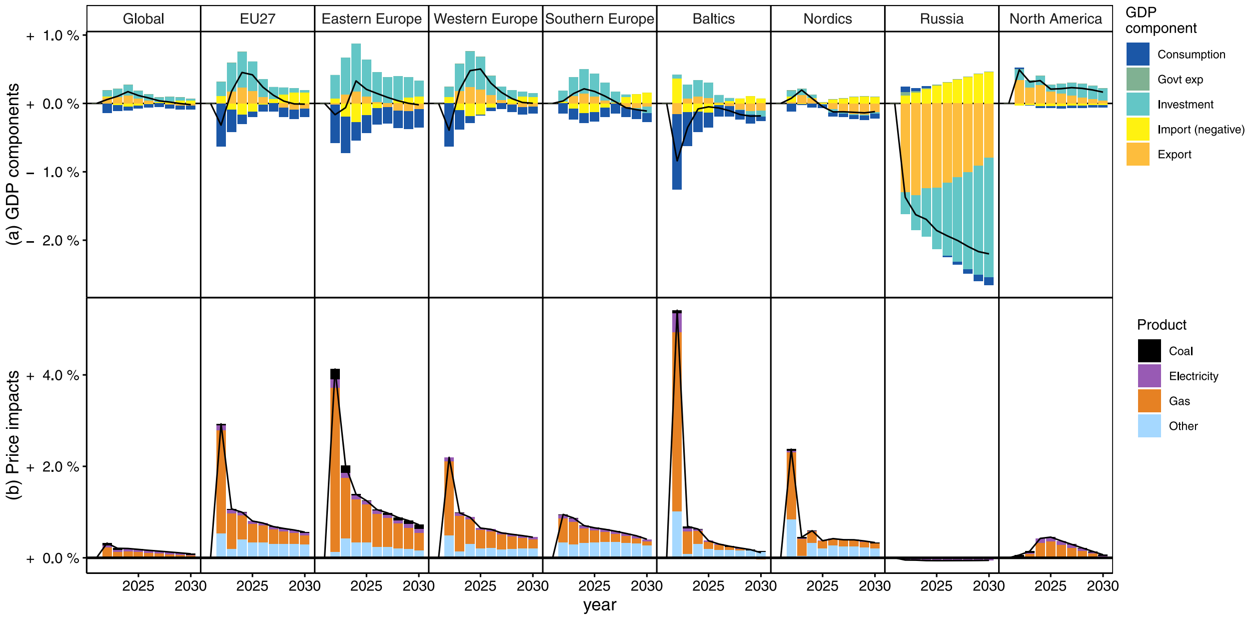

Fig. 9. Regional GDP and price impacts in the Conflict scenario relative to the Reference scenario.
Source: Own work, based on E3ME results.

only temporary.[3] The impact in the power sector is strong and steady until 2030 in European regions, i.e., even if gas becomes cheaper there is no switching back in the sector. Emissions in the household sector, driven by heating, show another pattern: turnover rate is slower in household heating technology and the model captures the relatively strong investment lock-ins in consumer heating. Consequently, we see a steadily decreasing emission profile with limited impacts in the beginning. Results also show an initial emission spike, especially in Eastern Europe. A strange dynamic can be observed here: demand in final energy shifts away from natural gas towards electricity, but the increasing electricity demand means that whatever capacity is available will be used. Therefore, coal-based power generation is temporarily brought back, causing emissions to spike in the short-term.

Surprisingly in the case of Russia we too observe net emission reductions. While in most sectors CO_2 emissions increase due to the use of cheap gas, in the case of the power sector cheap gas actually crowds-out another energy carrier with even higher carbon content: coal. In other words, even though Russia uses more of its domestically produced gas its overall carbon footprint might decrease because of how coal-based generation might be substituted with natural gas-based.

The accelerated transition towards renewable energy can be considered the positive side of the shock, as in total it means that Europe got about 110 $GtCO_2$ closer to a Net-zero goal, which entails a 2,012–2,145 $GtCO_2$[4] reduction by 2050, putting the shocks contribution at around 5% of the goal. However the shock brings severe economic effects as well.

6. Economic impacts of the gas shock

Natural gas is widely used both in production processes and as a heating fuel, but is frequently used in power generation as well. Although its increasing prices cause demand responses and potential substitution effects, the inflexibility of the system still creates inflationary pressures. These, combined with the crowding-out effect of increased energy costs,[5] are the main economic forces driving real economic outcomes.

These impacts appear in our GDP results (see Fig. 9). Price effects are the strongest in Eastern Europe and the Baltic states with gas prices driving price increases, but electricity prices also contributing. This increase of electricity prices is explained by relatively high gas-based power generation in these regions. Due to high gas prices, investors in the power sector choose to replace gas-based generation with new capacities, e.g., renewables. While the switch decreases prices in the medium-term, this requires immense investment in the short-term. The cost of this is generally passed through to consumers, temporarily increasing electricity prices. Overall combined price increase in EU27 is 2.9% in 2022. These increased energy prices reduce real consumption through the crowding-out effects, on EU27 level this results in about −1.2% reduction of real consumption in 2022.

Investment impacts, after the first years, compensate for consumption effects in economic activity, bringing overall GDP effect in most European regions into positive. Investment is linked to power sector, heating transition, energy efficiency and fuel substitution triggered by the high gas prices. At the EU27 level, investment increases by 2% (2024, peak, about €78 billion) or about €340 billion[6] through 2022–2030. This amount coincides with the budget of the REPowerEU package launched in 2022 May [34].

In Russia, negative GDP effects appear due to the loss of exports, however we observe initial positive consumption and government spending impacts due to heightened revenues from gas exports. Nevertheless, as exports contract, investment starts to shrink increasingly as well. Altogether, in the simulation Russia is in economic recession for

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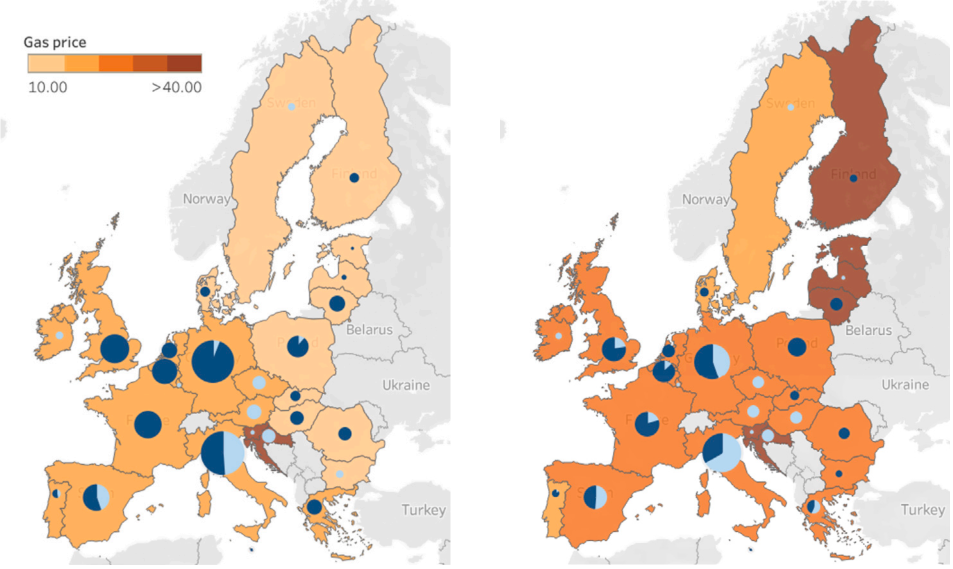
[3] Noting that the modelling framework does not model technology switching explicitly in these sectors, therefore impacts might be underestimated.

[4] Based on 2019 EEA data: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer and EU Net-zero target reported by the CAT: https://climateactiontracker.org/countries/eu/targets/.

[5] By crowding-out effect of increased energy costs we mean the situation where energy products with generally low elasticities see increasing prices, therefore, eventually decreasing incomes available for spending on other goods and services.

[6] 2020 prices.



(a) Reference - 2030

(b) Conflict - 2030

Fig. 10. European gas prices, net gas import and extra-Europe import partner country concentration in 2030. The colours reflect gas prices, the pie charts represent the concentration ratio of the trade partners measured by the percentage of gas imports accounted for by the largest trade partner country (dark blue area); and the size of the pie charts shows the net gas import volumes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: Own work, based on WGMM results.

two years in 2022–2023. This result is similar to latest IMF forecasts, which suggest about -2% decrease (YoY real GDP growth) for 2022 and a weak, 0.7% growth for 2023 [38]. Meanwhile, North America seems to be profiting from the shock in terms of economic activity: export growth coupled with increased investments (linked to export growth) have an initial +0.5% effect on GDP.

7. Energy security in Europe

As a response to the crisis various new policies were introduced in 2022 all around the world to accelerate the transition towards renewable energy sources (China's 14th Five-Year Plan and market reforms, the REPowerEU plan, and the US Inflation Reduction Act [39]). According to the IEA [39], renewable capacity expansion is projected to surpass previous expectations, with a significantly faster growth rate over the next five years.

The invasion of Ukraine has proved a game-changer for energy security in Europe [40]. The analyses of Mišík [41] and Osička and Černoch [42] have highlighted the importance of diversification strategies in Europe, which encompass reshaping external energy security, forming new supply partnerships, and increasing investments in decarbonization and renewable energy sources.

In our modelling European countries can successfully diversify their gas trade partners. Reliance on a single partner decreases in all the large European economies. Fig. 10 shows that the concentration ratio of gas imports decreases in Germany, Italy, the UK, France and Spain as well by 2030. While in the Reference scenario Russia remains a key trade partner of European countries, in the Conflict scenario the US and Nigeria takes the place of Russia along with several other producers. As a result, the overall concentration of European gas trade decreases by more than 27% by 2030.[7] Overall reliance on gas imports also shrinks due to the lower gas consumption: in Germany, net trade volume decreases by 12% and by almost 8% in Europe.

The pipeline infrastructure between Europe and Russia is well developed and shipping costs are relatively low, therefore replacing it with LNG imposes costs. In 2022, average gas prices in Europe are simulated to be almost four times higher in the Conflict scenario, in 2030 the difference is still 55%. Even though macroeconomic modelling presented earlier shows that Europe might be able to adapt to these higher prices.

There is criticism that the expansion of natural gas infrastructure, however, may hinder a renewable energy future due to lock-ins and stranded assets [43]. Nevertheless, it is envisaged that the gas infrastructure may be repurposed in the future to facilitate the import of green hydrogen [44]. Moreover, according to the modelling outcomes, despite the investment stimulus provided by the gas shock, both the total gas consumption and emissions within the EU stay below the Reference case.

8. Conclusions

Following the Russian invasion of Ukraine the Kremlin has tried to weaponise Russian gas exports and the EU's dependency on gas imports, in order to discourage EU support for Ukraine. However, the EU choose to resist and decide on a strategy of decreasing reliance on energy imports, especially from Russia. Through integrated macroeconomic-energy modelling we show that while the EU initially might have suffered some direct economic impacts in the medium-term it will be able to adapt to the new situation without suffering an economic slowdown. Adaptation happens through a combination of diversifying import sources (modelled with WGMM) and fuel- and technology-switching as well as demand reduction (modelled with E3ME).

Importantly, adaptation has medium-term consequences for the EU, which go beyond the timeline of the shock. Once technology change in power generation, in residential heat and fuel substitution in industry happens it is unlikely that change is rolled-back when gas prices normalize. Therefore, as a silver lining to the shock the gas price hike actually pushed the EU for a quicker decarbonization that at the same time results in a higher energy security situation for the bloc.

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[7] Herfindahl index in 2030: Reference scenario: 954, Conflict scenario: 695.

Table 1
Regional definitions.

Region	Countries
Africa	AGO, BDI, BEN, BFA, BWA, CAF, CIV, CMR, COD, COG, COM, CPV, DJI, ERI, ESH, ETH, GAB, GHA, GIN, GMB, GNB, GNQ, KEN, LBR, LSO, MAR, MDG, MLI, MOZ, MRT, MUS, MWI, NAM, NER, NGA, RWA, SDN, SEN, SLE, SOM, SSD, STP, SWZ, SYC, TCD, TGO, TUN, TZA, UGA, ZAF, ZMB, ZWE
Central Asia	KAZ
East Asia and Pacific	AUS, BRN, CHN, IDN, JPN, KHM, KOR, LAO, MMR, MYS, NZL, PHL, SGP, THA, TWN, VNM
Europe - Baltics	EST, LTU, LVA
Europe - Eastern Europe	CZE, HRV, HUN, MKD, POL, ROU, SVK, SVN, TUR
Europe - Southern Europe	CYP, ESP, GRC, ITA, MLT, PRT
Europe - Western Europe	AUT, BEL, CHE, DEU, FRA, GBR, IRL, LUX, NLD
Latin America	ARG, BOL, BRA, CHL, COL, CRI, CUB, DOM, ECU, GTM, GUY, HND, HTI, MEX, NIC, PAN, PER, PRI, PRY, SLV, SUR, TTO, URY, VEN
Middle East and North Africa	ARE, DZA, EGY, IRN, IRQ, KWT, LBY, QAT, SAU
Nordics	DNK, FIN, ISL, NOR, SWE
North America	CAN, USA
Rest of the World	AFG, AIA, ALB, AND, ARM, ASM, ATG, AZE, BES, BGD, BHR, BHS, BIH, BLZ, BMU, BRB, BTN, CCK, COK, CUW, CYM, DMA, FJI, FLK, FSM, GEO, GIB, GRD, GUM, HKG, ISR, JAM, JOR, KGZ, KIR, KNA, LBN, LCA, LIE, LKA, MAC, MCO, MDA, MDV, MHL, MNE, MNG, MNP, MSR, NCL, NFK, NIU, NPL, NRU, OMN, PCN, PLW, PNG, PRK, PSE, SHN, SJM, SLB, SMR, SRB, SXM, SYR, TCA, TJK, TKL, TKM, TLS, TON, TUV, UZB, VAT, VCT, VGB, VIR, VUT, WSM, YEM
Russia	RUS
South Asia	IND, PAK
Ukraine	UKR

There were also voices raising concerns about whether the Russian *energy weapon* will cause the EU's economy to suffer and slower economic growth and depress consumption. The modelling presented here shows that while there might be strong adverse economic impacts initially, adaptation in the EU can have a positive four-fold dividend: (1) as we are adapting, the strength of the *energy weapon* continuously decreases and inflationary pressures from gas prices shrink; (2) adaptation itself requires massive investments, which boosts economic activity and provides new income sources and jobs; (3) adaptation (incl. diversification) establishes energy security for the long-term for the EU; and finally (4) adaptation brings environmental benefits by reducing emissions across the economy.

Given the modelled technology changes, fuel substitution and reductions in energy demand, the macroeconomic impact of these higher prices, combined with the gains in economic activity from transition investments, suggest that the Russian energy weapon will not cause serious damage to the European economy, at least in the medium-term. Continued efforts over the past decade to accelerate the green transition and develop an extensive LNG network have put the EU in a good position to disarm the weapon through a strategy of diversifying energy imports and localizing production through the use of renewables.

CRediT authorship contribution statement

Áron Dénes Hartvig: Conceptualization, Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Bence Kiss-Dobronyi:** Conceptualization, Formal analysis, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Péter Kotek:** Conceptualization, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft. **Borbála Takácsné Tóth:** Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft. **Ioannis Gutzianas:** Formal analysis, Software, Writing – original draft. **András Zsombor Zareczky:** Investigation, Validation, Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bence Kiss-Dobronyi reports financial support was provided by National research Development and Innovation Office.

Data availability

The authors do not have permission to share data.

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Appendix. Regional definitions

In the analysis we used the regional definitions presented in Table 1.

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