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Is Russian gas still needed in the European Union? Model-based analysis of long-term scenarios

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ABSTRACT

Aligned with the war in Ukraine, Russia has significantly withheld natural gas exports to Europe since 2021. As there are no EU-wide sanctions on imports of Russian natural gas, the Ukraine transit as well as imports via Turkey and LNG have remained active during 2022–24. However, the Russian-Ukrainian transit agreement expires at the end of 2024 and discussions about new sanctions on natural gas as well as the threat of further supply disruptions continue to pose uncertainty for European markets. We use the Global Gas Model (GGM) to investigate the necessity of Russian gas exports for European gas consumption. Our results of different scenarios indicate that the EU's gas consumption can be largely satisfied in all demand and Russian supply scenarios. This result holds also for a complete disruption of Russian exports to the EU thanks to diversification and some demand side response.

1. Introduction

Following the Russian invasion of Ukraine in February 2022, European natural gas markets have been subject to severe geopolitical tensions. Already since 2021, Russia had withheld natural gas exports to Europe and further intensified this during the summer 2022 when the gas transits via the Yamal–Europe and Nord Stream pipelines were shut down. Yet, the EU member states could not agree on joint sanctions for natural gas imports from Russia, as have been imposed on coal and pipeline oil imports since 2022. Indeed, a large share of the import reduction from Russia has been borne by Western European countries, the Baltics and Poland. These are countries with quick access to alternative supplies in the form of pipeline gas, e.g., from Norway, and LNG. In contrast, some EU member states, in particular in Central Europe, have continued to rely on natural gas imports from Russia to a large extent. For example, in January 2024, Austria imported 97% of its natural gas from Russia [1].

Historically, the Soviet Union had supplied natural gas to Europe via the Ukraine transit which became subject to political tension after the collapse of the Soviet Union. Consequently, Russia started to diversify its supply infrastructure with the Yamal–Europe pipeline in the 1990s and the Nord Stream 1 and 2 projects in the 2010s, despite ample capacity being available in existing Ukrainian transit infrastructure. In addition, some of the gas in the Russian-Turkish TurkStream pipeline, open since 2020, is sent to the European market.

In the first two quarters of 2021, imports of Russian natural gas to the EU reached over 40 bcm per quarter, constituting over 45% of total imports. During the course of 2022, first, exports via the Yamal–Europe pipeline and then via Nord Stream were interrupted by the Russian side, followed by the explosion of the Nord Stream pipelines in September 2022 (see Fig. 1). In addition, supplies via the Ukraine transit were drastically cut. In the first quarter of 2024, less than 14 bcm of natural gas were imported from Russia to the EU, of which about 6 bcm were LNG [2]. This compares to over 40 bcm in Q1 of 2021.

Paradoxically, even after the Russian invasion in 2022, about 50% of the Russian pipeline gas exports to Europe have flown through Ukraine. However, the transit agreement between Russia and Ukraine expires at the end of 2024 and will likely not be continued. In light of discussions about a more active role of EU member states in the conflict, it appears plausible that Russian exports to the EU may come to a full stop. In addition, new sanctions from the European side remain a plausible pathway.

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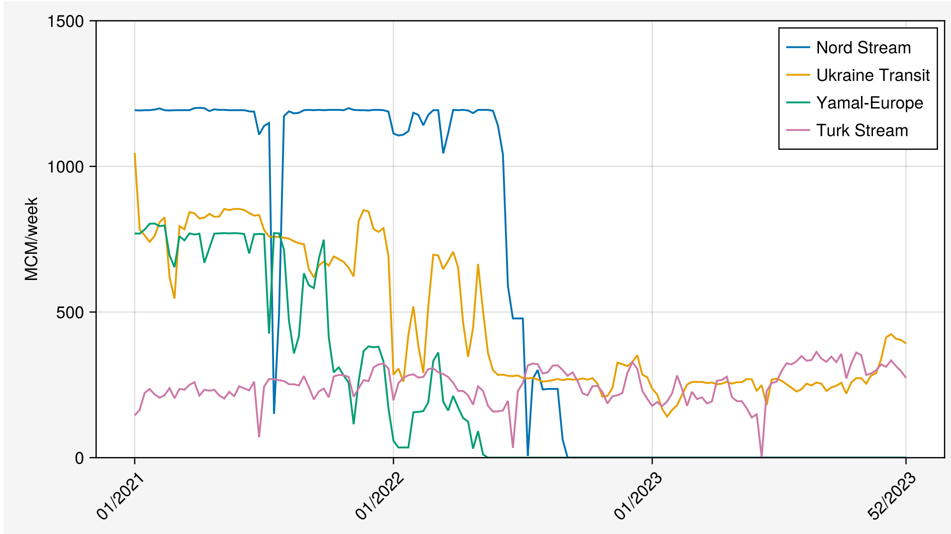


Fig. 1. Russian Natural Gas Exports to Europe between 2021 and 2024 by Route.
The figure depicts weekly Russian natural gas exports by route. Following the invasion of Ukraine in February 2022, Russia has stopped exports via the Yamal–Europe and Nord Stream pipelines and reduced flows via the Ukraine transit.
Source: Own depiction based on data by [2].

We use the Global Gas Model (GGM) to investigate whether there is need for Europe to return to importing gas from Russia at large scale or whether, on the contrary, all EU countries could abstain from Russian gas entirely. For this, we quantify and analyze long term scenarios for the European Union in two dimensions, namely Russian supplies and climate policy ambition. Thereby, we provide an updated analysis compared to the literature by taking into account new pipeline and LNG capacities and by using up-to-date scenarios rooted in the political realities. This updated analysis with real-world data allows us to derive sound policy recommendations, in particular as regards the feasibility of sanctions on Russian gas imports.

The rest of the paper is structured as follows. Section 2 presents an overview of pre- and post-war modeling efforts of Russian supply disruption scenarios in European natural gas markets. Section 3 briefly describes the partial equilibrium model used for our analysis, as well as data inputs and scenario design. Section 4 presents some insights from the analysis across different scenarios. Sections 5 and 6 discuss the results and conclude.

2. Modeling disruptions of Russian gas supplies to Europe in the literature

Owing to the growing dependency on gas supplies from Russia in many European countries since the 1990s, Russian supply disruptions have been a possibility discussed and modeled in the literature already prior to the Russian withholding in 2021/22. In particular the transit via Ukraine was repeatedly considered uncertain since the end of the Soviet Union and was the focus of disruption scenarios. Prior to the 2014 Russian aggression on Ukraine, studies with the European Gas Model [3], the World Gas Model [4], but also with other modeling tools [5–10] considered failing Russian supplies to the EU.

Since 2014, the possibility of a Russian supply disruption became more realistic and was modeled with different details, i.e., either with a full disruption across all supply routes, including Nord Stream [11] or again with a focus on the Ukrainian transit [12,13]. Previous deterministic and stochastic versions of the model utilized in this paper, the GGM, were also used to analyze different variants of Russian supply disruptions to Europe [14–17].

More recently, following the Russian war in Ukraine since February 2022, gas supply disruptions have been analyzed by [18] in an optimization model of the EU gas flows, by [19] in an energy systems model that includes the interaction with other sectors such as electricity, and by [20] in a computable general equilibrium model. [2] have monitored EU gas imports since early 2022 and have underlined the ability of European importers to sustain their gas consumption without Russian gas. They have relied on gas flow data monitoring and processing, using publicly available data as we do, but without using numerical modeling for quantifying scenarios. The paper closest to ours is [21] that use a different model to quantify the near-term impacts of Russian supply scenarios similar to ours. However, they do not consider long-term demand developments and do not include Russian LNG in their disruption scenario even though it has substantially gained importance in the last few years (see Section 2).

Other analyses show that the interaction between Russia, the EU, and transit countries or alternative suppliers is more complex than flow or welfare optimization. For example, cooperative games can depict profit sharing from a transit agreement [22–24]. [17,25,26], among others, stress that there has increasingly been a competition between Russian gas and US LNG in the European market. Finally, [27] emphasize that long-term contracts may lead to different market outcomes than short-run dynamics would indicate, and [28] argue, that supply of Azeri natural gas to the EU would be dominated by non-cost motives, e.g. the diversification of supply.

3. Methodology

3.1. The global gas model

In the subsequent analysis, we employ the GGM to compute the outcome of several scenarios (see Section 3.3). In its original form [29], the GGM is a multi-period mixed complementarity problem that depicts the global natural gas value chain in great detail. In contrast to other models, it explicitly considers strategically behaving agents in accordance with a Nash-Cournot equilibrium. Strategic behavior is characterized by the supplier's ability to purposefully withhold quantities from final demand in order to increase prices and, hence, profits, an effect frequently observed in imperfectly competitive markets such as oil and natural gas.

The GGM version utilized in this paper is a convex reformulation of the original mixed complementarity problem [30] to an optimization problem, appended by some scenario specific restrictions. The convex reformulation allows for better computational tractability, while at the same time providing results equivalent to the original complementarity problem.

The GGM distinguishes between various market agents, including producers, traders, storage and transmission in both liquefied and gaseous form via pipelines or LNG tankers. To represent for LNG trade, liquefiers and regasifiers are also included as agents in the problem formulation. Each representative model agent is assumed to maximize profits, given perfect information about the other players' decision space. Traders may exert market power via a conjectural variation approach when selling to final demand. The model ignores long-term contracts but rather determines sales volumes and trade flows as well as investments in each modeled year based on costs, demand functions and infrastructure constraints.[1]

3.2. Data

The GGM represents the natural gas value chain and infrastructures in great detail and with comprehensive geographical coverage [31]. The data set includes 239 nodes in the global gas sector, of which 136 are nodes with consumption, in addition to 37 LNG liquefaction nodes and 66 LNG regasification nodes. With very few exceptions, we have one model node per country. Very large countries are split in several (regional) nodes. LNG nodes are aggregating capacities along the same coast such that large countries with different coasts have several LNG nodes (e.g., France has two nodes, Atlantic and Mediterranean). The data is collected from publicly available sources and the data set is available open source. The base year is 2020, but potential future production and infrastructure capacities are also included with the possibility of endogenous investment decisions. Production in EU countries of about 55 bcm in 2020 (without Norway with 115 bcm and the UK with almost 40 bcm) is included and is assumed to decline in the coming years, depending on the scenario (see Section 3.3).

Subcountry-level LNG liquefaction and regasification capacities are based on [32]. Pipeline data are based on [33] for European infrastructure, and [34] as well as installation-specific sources for assets across the world. Storage data are from [35] for European capacities, from [36] for the US, and from [37] otherwise, where possible updated with installation-specific information.

The linear demand function in each node and modeled year is built using a set of assumptions that include a so-called reference price, a reference quantity and a price elasticity. Gas-based hydrogen is part of the use of natural gas and, hence, is included in the reference gas demand quantity. We assume that it plays a sizeable role in gas-rich countries like Norway and the US in the scenarios with moderate climate ambition (see Section 3.3). Conversely, electricity-based hydrogen as a competitor for natural gas or gas-based hydrogen is implicitly assumed to play a strong role in the scenarios with high climate ambition. For a full set of assumptions and the model data underlying the subsequent analysis, please see the link in "Data availability".

3.3. Scenarios

European natural gas markets will be influenced by two major trends, both of which we reflect in our set of scenarios. On the one hand side, there is a possibility of extended supply disruption of Russian exports, be it due to EU sanctions or to Russian withholding. On the other hand side, the days of fossil gas in energy systems are clearly counted under ambitious climate targets, which limits the space of economically reasonable investments in gas infrastructure in the short term.[2] In this wake, the narrative of natural gas as a bridge technology has lost much of its charm [38], not only due to massive cost reductions of renewable energy [39]. We introduce a total of twelve scenarios that take into account these two trends and that vary in two dimensions, namely Russian supplies to Europe and global climate policy ambition.

3.3.1. Climate policy ambition

In the climate policy dimension, we develop four scenarios, two low and two high ambition pathways (Table 1). The low ambition scenarios can roughly be compared to the IEA's "World Energy Outlook" STEPS and APS scenarios [40] in terms of supply and demand patterns of world regions. In contrast, the high ambition climate policy scenarios True Zero Emissions (TZE) and Fossil and Fissile Free (FFF) assume a complete fossil natural gas phase out by 2050. We leave it open as to how the trajectory of decreasing natural gas demand is achieved but a policy mix of carbon pricing and phase-out mandate is likely. Fig. 2 depicts global consumption in the world regions in these four scenarios.[3] Each climate policy scenario is briefly explained in the following.

TZE. The *True Zero Emissions* scenario is the most ambitious one in terms of carbon emissions reduction. It assumes the global phase out of fossil natural gas by 2050 in the EU and worldwide and encompasses a drastic reduction of natural gas demand across all sectors and regions in the next decades. In comparison to the rest of the world, Europe starts phasing out natural gas quicker, i.e., as early as 2025. In the reference case, EU consumption declines by 38% from 2020 to 2030, with similar decreases in domestic production.

FFF. The *Fossil and Fissile Free* scenario equally builds on the premise of a complete phase out of fossil fuel consumption by 2050. However, this scenario assumes a delay in the reduction of natural gas demand because, in the meantime, nuclear power is entirely phased out and partially compensated for by natural gas. This leads to a stable natural gas demand in Europe and globally until the 2030s, and even an increasing gas demand in countries where nuclear energy is currently prevalent. Despite the sustained gas consumption until 2030, EU production decreases by more than 50% from 2020 to 2030 due to the short payback period of production assets with the gas phase-out by 2050. This scenario is purposefully designed to reflect an extreme situation for EU imports.

Moderate Climate Policy Ambition (MCA). The scenario of *Moderate Climate Ambition* follows a similar shape to the IEA's [40] APS scenario in terms of aggregate regional consumption. It does include an emissions reduction pathway, especially in Europe, but natural gas is not phased out by 2050. In the reference case, EU gas consumption reduces by 35% until 2030 and by 88% until 2050. EU gas production declines by 66% until 2030 and by 96% until 2050.

No Climate Policy Ambition (NCA). The scenario with *No Climate Ambition* aims in a similar direction as the IEA's [40] STEPS scenario. In terms of regional aggregate consumption, it depicts a situation far from compliance with any internationally agreed upon climate targets and is in particular not compatible with the Paris Agreement. Europe, as region with the highest climate ambition, sees a reduction of consumption by 2050 of 39% with 54% reduction of production.

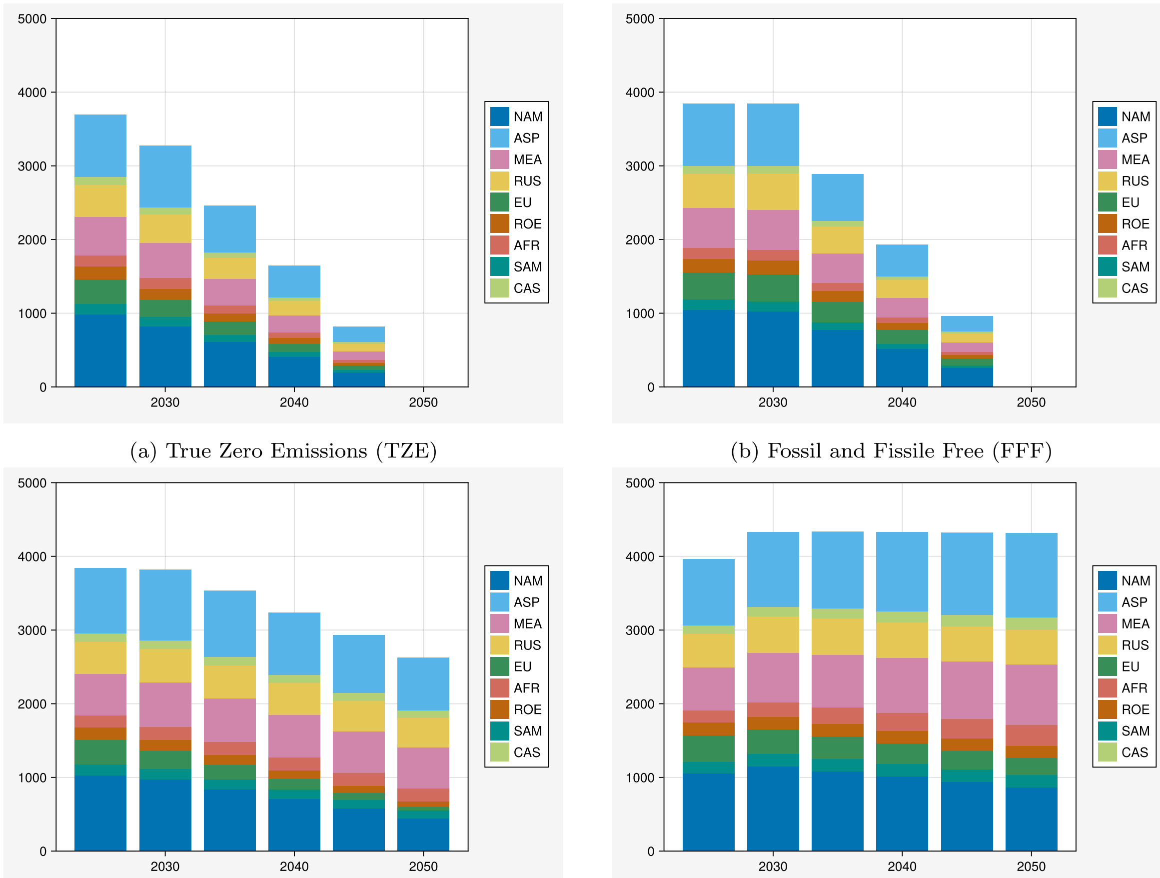
3.3.2. Russian supply scenarios

For the Russian supply scenarios, we develop three clearly distinguished geopolitical pathways that vary in terms of the potential for Russian natural gas exports to Europe (Table 2). Each of the three supply scenarios is applied to each of the four climate ambition scenarios, leading to a total of twelve scenario combinations. The three supply scenarios focus on Europe and include the following main assumptions.

[1] Five-year steps are modeled between 2020 and 2060, i.e., 2020, 2025, 2030, etc.

[2] In this vein, for example, the German LNG acceleration law strictly forbids that any gas infrastructures built under granted privileges operate on natural gas beyond 2043.

[3] See Table 3 for the abbreviations of countries and regions in this and the following figures.



(a) True Zero Emissions (TZE)

(b) Fossil and Fissile Free (FFF)

(c) Moderate Climate Policy Ambition (MCA)

(d) No Climate Policy Ambition (NCA)

Fig. 2. Global Consumption in bcm across Scenarios for the Geopolitical Reference Case New Normal (NENO).
The global consumption of natural gas is disaggregated by world regions across climate policy scenarios in the New Normal (NENO) case. Annual consumption can be compared to a global demand of around 3900 bcm across all modeled nodes in 2020.
Source: Own depiction.

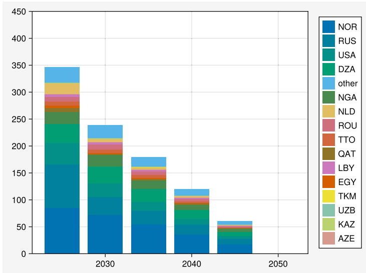
Table 1
Overview of climate policy scenarios.

Scenario	Main characteristics
True Zero Emissions (TZE)	Global phase out of fossil natural gas by 2050 in the EU and worldwide. Early decline of consumption, especially within Europe.
Fossil and Fissile Free (FFF)	Complete phase out of fossil natural gas by 2050. However, consumption remains high until 2030. Domestic production in Europe quickly declines, implying high import requirements in the close future with short payback periods.
Moderate Climate Policy Ambition (MCA)	Emissions from natural gas are reduced, especially in Europe. However, some natural gas remains in the energy mix across the world even in 2050.
No Climate Policy Ambition (NCA)	Natural gas remains a significant part of the energy mix across all parts of the world.

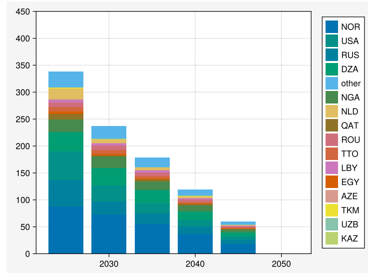
Table 2
Overview of characteristics of Russian supply scenarios.

Scenario	Main characteristics
Status Quo Ante Bellum (SQAB)	Return to the pre-war situation, albeit at a lower level of supplies to Europe. In addition, Russian exports are more evenly spread across European countries.
New Normal (NENO)	Continuation of the current situation, with some Russian exports to the EU via Ukraine, Turkey and LNG.
EU Supply Disruption (EUSD)	No flows from Russia to the EU, both via pipeline and LNG.

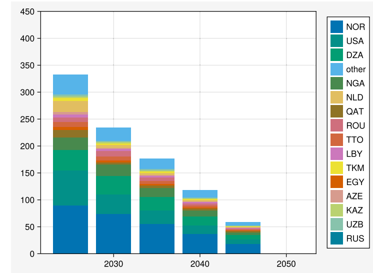
Status Quo Ante Bellum (SQAB). This scenario envisions somewhat of a return to the pre-war situation, the "Status Quo Ante Bellum". However, it is assumed that Nord Stream is not available, but can be rebuilt (at a cost). *Ex ante*, imports from Russia to the EU are possible



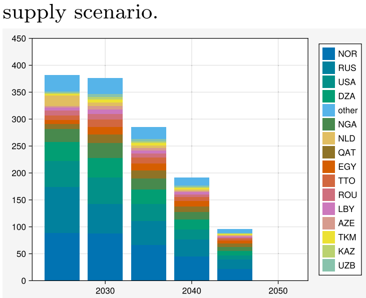
(a) Combination of True Zero Emissions (TZE) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



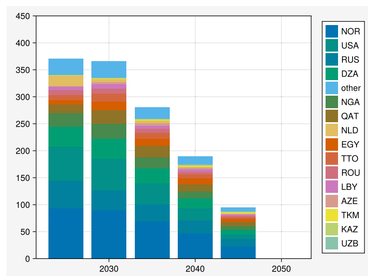
(b) Combination of True Zero Emissions (TZE) climate policy scenario and New Normal (NENO) supply scenario.



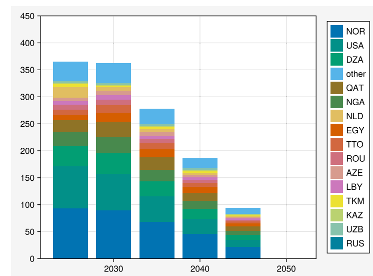
(c) Combination of True Zero Emissions (TZE) climate policy scenario and EU Supply Disruption (EUSD) scenario.



(d) Combination of Fossil and Fissile Free (FFF) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



(e) Combination of Fossil and Fissile Free (FFF) climate policy scenario and New Normal (NENO) supply scenario.



(f) Combination of Fossil and Fissile Free (FFF) climate policy scenario and EU Supply Disruption (EUSD) scenario.

Fig. 3. EU Supplies in bcm under High Climate Policy Ambition Scenarios for three Russian Supply Scenarios.
The figure shows the total consumption as well as the sources of natural gas supplied to the EU in the two high climate policy ambition scenarios True Zero Emissions (TZE) and Fossil and Fissile Free (FFF) for all three Russian supply scenarios. Total EU natural gas consumption only varies slightly between the Russian supply scenarios, i.e., Russian exports can be substituted by other sources and some demand response is required.
Source: Own depiction.

Table 3
Abbreviations of countries and regions.

Code	Full name
NAM	North America
ASP	Asia Pacific
MEA	Middle East
RUS	Russia
EU	European Union
ROE	Rest of Europe
AFR	Africa
SAM	South America
CAS	Caspian Region
NOR	Norway
USA	United States of America
DZA	Algeria
NGA	Nigeria
NLD	Netherlands
EGY	Egypt
LBY	Libya
ROU	Romania
TTO	Trinidad and Tobago
QAT	Qatar
AZE	Azerbaijan
TKM	Turkmenistan
UZB	Uzbekistan
KAZ	Kazakhstan

via Ukraine, Poland, Turkey and LNG, but they remain at a lower level than before the war. It is assumed that European countries diversify their imports more and that, at the same time, Russian exports are spread out more evenly across European countries than before the war.

New Normal (NENO). This scenario depicts the current "NEw NOrmal" in European natural gas markets and could be considered the reference setup. The scenario envisions a continuation of the current supply situation in the EU, i.e., imports from Russia to the EU are possible via Ukraine, Turkey and LNG, but the Ukrainian transit is limited to an annual transportation volume of 25 bcm. Imports via Nord Stream and Yamal are not possible.

EU Supply Disruption (EUSD). This scenario is the most extreme and assumes a complete "EU Supply Disruption" with no flows from Russia to the EU, both by pipeline and by LNG. Such a situation can be interpreted in two ways: it can either be achieved with EU sanctions on Russian natural gas imports. Alternatively, Russia may withhold its quantities from markets in the EU, including all LNG, in an attempt to exert geopolitical pressure.

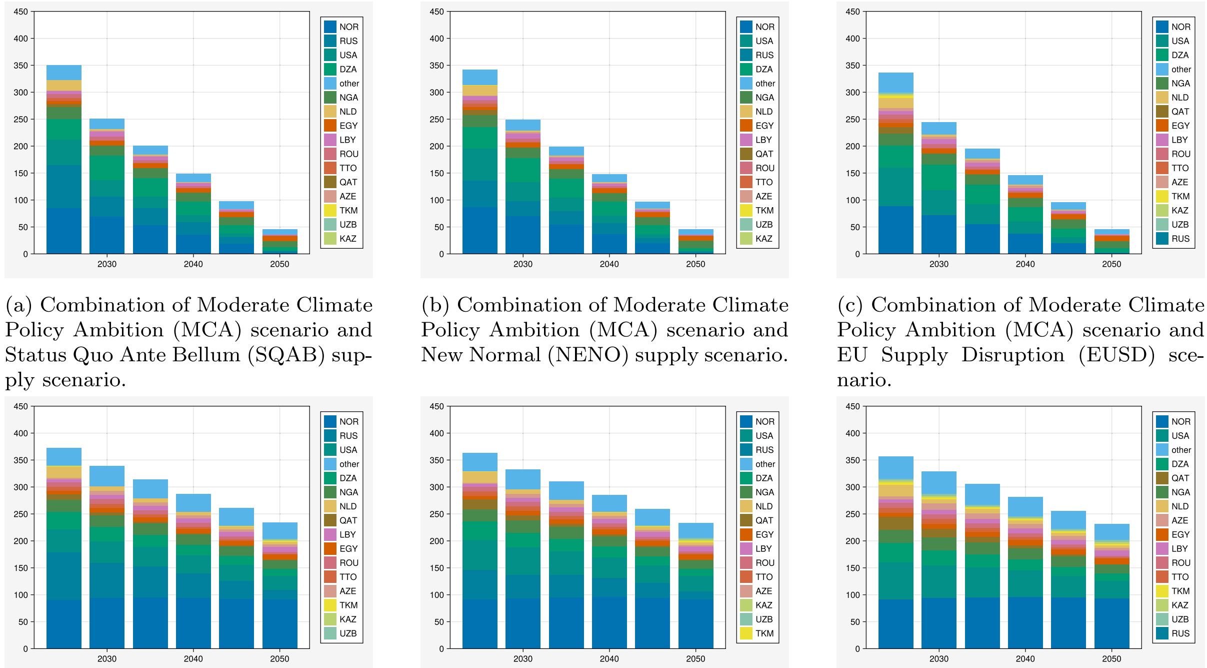
3.3.3. Calibration and reference scenarios

All climate policy scenarios are calibrated for the New Normal (NENO) scenario of Russian supplies that we consider as a reference setup. Calibration focuses on aggregated and nodal consumption and production as well as on the net trade position of countries and world regions. We analyze the effect of the three Russian supply scenarios across all four climate policy scenarios. The EUSD and SQAB scenarios are modeled as shocks to the – calibrated – NENO scenario in each climate policy scenario; in other words, the EUSD and SQAB scenarios are not calibrated.

4. Results

4.1. Development of natural gas demand and supply in the EU

Figs. 3 and 4 show European natural gas demand and supply sources until 2050 across high and low climate policy ambition scenarios. Norway continues to play an important role in European markets,



(a) Combination of Moderate Climate Policy Ambition (MCA) scenario and Status Quo Ante Bellum (SQAB) supply scenario.

(b) Combination of Moderate Climate Policy Ambition (MCA) scenario and New Normal (NENO) supply scenario.

(c) Combination of Moderate Climate Policy Ambition (MCA) scenario and EU Supply Disruption (EUSD) scenario.

(d) Combination of No Climate Policy Ambition (NCA) scenario and Status Quo Ante Bellum (SQAB) supply scenario.

(e) Combination of No Climate Policy Ambition (NCA) scenario and New Normal (NENO) supply scenario.

(f) Combination of No Climate Policy Ambition (NCA) scenario and EU Supply Disruption (EUSD) scenario.

Fig. 4. EU Supplies in bcm under Low Climate Policy Ambition Scenarios for three Russian Supply Scenarios.
The figure shows the total consumption as well as the sources of natural gas supplied to the EU in the two low climate policy ambition scenarios Moderate Climate Policy Ambition (MCA) and No Climate Policy Ambition (NCA) for all three Russian supply scenarios. Total EU natural gas consumption only varies slightly between the Russian supply scenarios, i.e., Russian exports can be substituted by other sources and some demand response is required.
Source: Own depiction.

which is a direct consequence of significant production and pipeline capacities in place, as well as the EU being Norway's most attractive destination. Hence, Norwegian sales remain largely constant across different Russian supply scenarios. By 2030, the market share of Norway ranges between 23–30% in the Status Quo Ante Bellum (SQAB) scenario and up to 25–31% under full supply disruption, depending on climate policy ambition. In comparison, Russia's market share ranges between 14–23% (SQAB scenario) and 0% (EU Supply Disruption (EUSD) scenario) by 2030. Independent of the Russian supply scenario, domestic consumption of natural gas produced in the EU accounts for 6–14% in 2030 (Figs. 5 and 6).

Russian supply disruptions are mitigated by additional imports from other regions, largely via LNG, as well as some pipeline imports from the Caspian region. Most notably, the US significantly gains in importance with a market share by 2030 of 16–19% under full supply disruption, compared to 10–13% if Russia returns to a stronger role in European markets. Overall, the effect of Russian supply disruptions in Europe can be compensated almost entirely by additional imports, as well as some reduction of demand driven by an increase in prices.

4.2. The role of pipeline gas and LNG imports

4.2.1. Pipeline gas and LNG imports and infrastructure utilization

Figs. 5 and 6 depict EU imports differentiated by infrastructure across the various scenarios. The two extremes of import infrastructure utilization happen in the high climate ambition scenarios. In the TZE scenario, a quick reduction of natural gas demand implies significantly lower pressure on existing infrastructure, especially regasification terminals. This manifests in comparably low peak import requirements of 127 bcm via LNG and 168 bcm via pipeline under full Russian supply disruption by 2025.[4] In this situation, gross imports amount to 88.8 % of EU consumption. Over time, this import dependency even increases to over 90%.

In contrast, in the FFF scenario, natural gas demand remains high due to partial substitution of existing nuclear power with natural gas. In this case, import requirements are significantly higher, amounting up to 167 bcm of LNG and 186 bcm via pipeline by 2030. At the same time, gross imports amount up to 97.4 % of EU consumption.

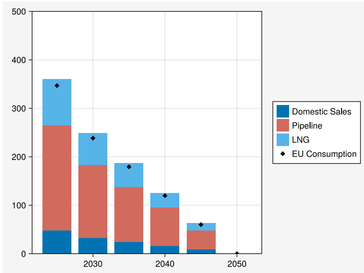
In the lower climate ambition cases, import levels are slightly above the TZE scenario's levels, but remain significantly below the FFF scenario. In the MCA scenario, peak import requirements are achieved by 2025 at 172 bcm via pipeline and 131 bcm of LNG. Here, too, import dependency is very high with over 97%. In the NCA scenario, EU imports increase to 174 bcm via pipeline and 145 bcm of LNG by 2025, with a peak import dependency of 95% in 2050.

Currently planned expansions in the EU could bring aggregate regasification capacity beyond 200 bcm [41], excluding Spain and Portugal due to limited grid interconnection. Comparing these to the import levels in our scenarios shows that the capacity expansion plans are over-dimensioned and are subject to a severe risk of asset stranding, especially under more ambitious climate policy.

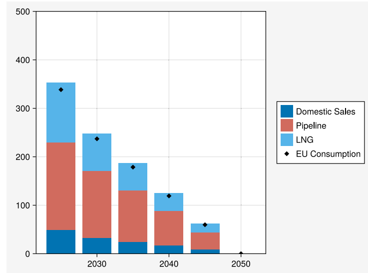
4.2.2. Sources of liquefied natural gas imports to the EU

Fig. 7 visualizes the EU's LNG imports by source across ambitious climate policy scenarios and for all Russian supply scenarios. As seen before, European LNG import volumes differ significantly in both the

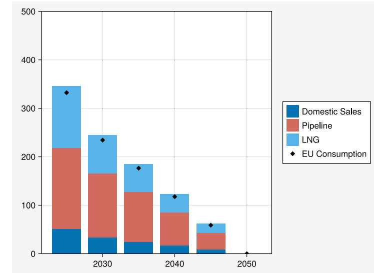
[4] Note that imports referenced are gross imports, i.e., they account for re-exports to non-EU countries. Hence, the sum of domestic sales of gas produced in the EU and imports exceeds total EU consumption. However, accounting for re-exports is important for appropriate dimensioning of infrastructure.



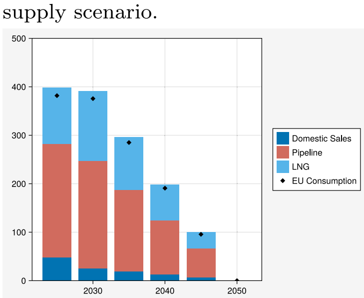
(a) Combination of True Zero Emissions (TZE) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



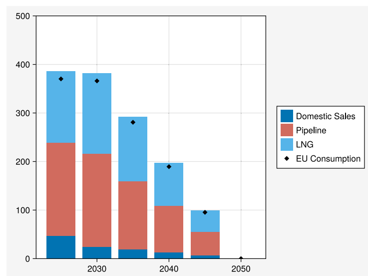
(b) Combination of True Zero Emissions (TZE) climate policy scenario and New Normal (NENO) supply scenario.



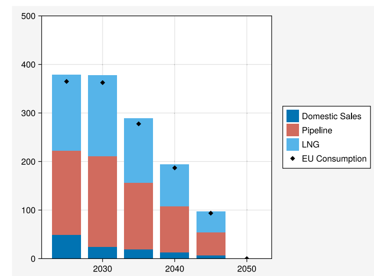
(c) Combination of True Zero Emissions (TZE) climate policy scenario and EU Supply Disruption (EUSD) scenario.



(d) Combination of Fossil and Fissile Free (FFF) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



(e) Combination of Fossil and Fissile Free (FFF) climate policy scenario and New Normal (NENO) supply scenario.



(f) Combination of Fossil and Fissile Free (FFF) climate policy scenario and EU Supply Disruption (EUSD) scenario.

Fig. 5. EU Natural Gas Supplies in bcm by Import Infrastructure including domestic sales in High Climate Policy Ambition Scenarios and for three Russian Supply Scenarios. The figure differentiates EU pipeline from LNG imports and natural gas sales extracted in the EU (e.g., in Romania, the Netherlands) in the high climate policy ambition scenarios True Zero Emissions (TZE) and Fossil and Fissile Free (FFF) and for all three Russian supply scenarios. Disrupted Russian exports are substituted for by an increase in LNG imports. *Source:* Own depiction.

climate policy and Russian supply dimension.

Russia becomes a significant supplier of LNG to the EU if its pipeline exports are restricted (NENO scenario). This has also been observed since the closure of the Nord Stream and Yamal–Europe pipelines in 2022. Russia compensates its lower pipeline exports to Europe to a large extent with higher domestic consumption in Russia. The US is and remains the largest supplier of LNG to the EU, independent of the scenario, but absolute quantities differ significantly. In the TZE and FFF scenarios, US LNG imports in 2025 range between 25 and 60 bcm, depending on the role of climate ambition and availability of supplies from Russia with highest levels when Russian exports are shut and gas demand is high.[5]

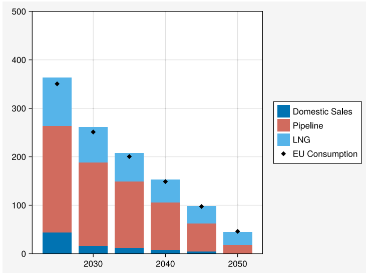
This uncertainty is even stronger for Qatari exports to the EU. In the FFF scenario with high import requirements, Qatar supplies up to 30 bcm to the EU in 2030 but less than 2 bcm in the SQAB variant of the TZE scenario, i.e. if Russia returns as a supplier to the EU. Other LNG suppliers in the EU's import mix include Nigeria, Egypt, and Trinidad & Tobago. Some, like Nigeria, have uncertain supply prospects due to political instability.

5. Discussion of results and limitations

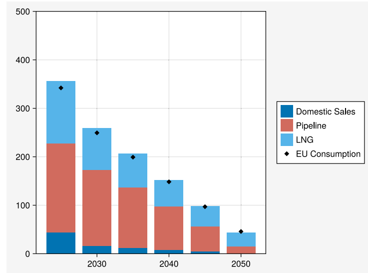
Our results show some robust trends in the EU's gas market across all scenarios. First, Russian (pipeline and LNG) exports in the EU are replaced primarily by LNG from other sources, mostly from the US. The importance of LNG in case of disruption of a large supplier to Europe was also found by some earlier analyses, e.g. [17], and is not due to the recent increase of LNG import capacities in Europe. Rather, the oligopolistic market structure and constraints of alternative pipeline suppliers' capacities give a larger role to LNG. Moreover, the higher willingness to pay in Europe (compared to a scenario with full supplies) ensures that LNG is diverted from other markets such as Asia and directed to Europe. This is the same mechanism as was observed during the energy crisis in 2022 but is in contrast to some theories in the literature that rather assumed a decrease of LNG imports in Europe when prices are higher [12,42]. The prominent role of the USA as replacement supplier is driven by the strong expansion of the US LNG export capacities since 2016. Only in the landlocked part of the Eastern EU would Russian supplies be replaced by imports from the Caspian region to a noticeable extent, with up to 15% of the Eastern EU's supplies. Similarly to Russia, the Caspian countries are also geopolitically difficult trading partners for the EU.

Second, despite traditionally being a pipeline market with strong bilateral dependencies (long-term contracts) between importers and exporters, Europe today has access to a large and diverse set of gas sources due to large import infrastructure capacities in place. This is particularly true for ample LNG capacities that allow to receive imports from the liquid world LNG markets and any LNG exporter. Some of the high regasification capacities in Europe have been built in response to – temporary – crises such as the long drought on the Iberian peninsula in the 2000s and the energy crisis in 2022 in Germany. Other European regasification capacity was built to replace declining domestic production, namely in the Netherlands and the UK, but also Italy. Only a fraction of the regasification capacities was originally intended to provide supply diversification, in particular in Lithuania and Poland, partially also in Italy. All of this LNG import capacity is now available to replace Russian imports in the EUSD scenarios. Even in the highest import demand scenario, the FFF EUSD scenario, LNG import capacity would not have to be expanded as currently planned. If all investment plans for additional regasification capacities are realized, this would

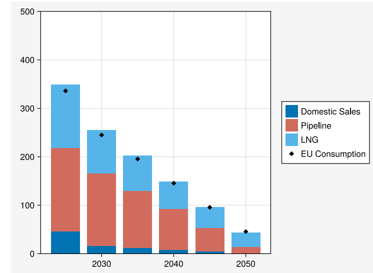
[5] Note that this only includes direct LNG imports. Re-exports of US LNG by pipeline, for example from the UK to the EU, are not counted here.



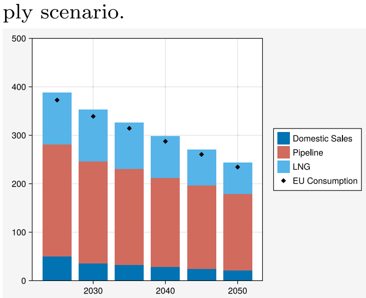
(a) Combination of Moderate Climate Policy Ambition (MCA) scenario and Status Quo Ante Bellum (SQAB) supply scenario.



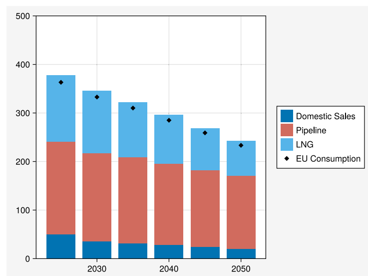
(b) Combination of Moderate Climate Policy Ambition (MCA) scenario and New Normal (NENO) supply scenario.



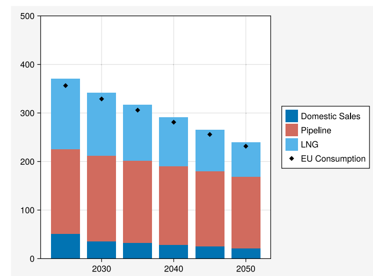
(c) Combination of Moderate Climate Policy Ambition (MCA) scenario and EU Supply Disruption (EUSD) scenario.



(d) Combination of No Climate Policy Ambition (NCA) scenario and Status Quo Ante Bellum (SQAB) supply scenario.



(e) Combination of No Climate Policy Ambition (NCA) scenario and New Normal (NENO) supply scenario.



(f) Combination of No Climate Policy Ambition (NCA) scenario and EU Supply Disruption (EUSD) scenario

Fig. 6. EU Natural Gas Supplies in bcm by Import Infrastructure including Domestic Sales in Low Climate Policy Ambition Scenarios and for three Russian Supply Scenarios. The figure differentiates EU pipeline from LNG imports and natural gas sales extracted in the EU (e.g., in Romania, the Netherlands) in the low climate policy ambition scenarios Moderate Climate Policy Ambition (MCA) and No Climate Policy Ambition (NCA) and for all three Russian supply scenarios. Disrupted Russian exports are substituted for by an increase in LNG imports.
Source: Own depiction.

lead to substantial over-capacities that risk to become stranded assets. This can also be seen in the market where, since the end of the gas price spikes of 2022, the enthusiasm for new LNG import capacity has ended. Only government-backed (subsidized) investments have been realized while commercial projects are not getting a final investment decision.

Third, the share of LNG in EU gas consumption increases substantially compared to the levels of the 2010s. For example, in 2015, the share of LNG was 11%. We calculate an LNG share around 30% in all scenarios for the next decades. Unsurprisingly, we find the lowest LNG share in the scenarios where Russia returns to the EU market (SQAB scenarios), with the lowest value in the TZE scenario close to the complete gas phase-out (24% of LNG in 2040 and 2045). The share of LNG is even higher in the scenarios with high demand during the 2020s and/or a continuous disruption of Russian deliveries, i.e. in the FFF and the EUSD scenarios, with LNG share levels up to 48%. Earlier literature found that it needs expansion of LNG capacities to be able to increase the share of LNG imports, e.g. [13]. In contrast, we find that the higher share of LNG imports is achieved with higher capacity utilization results of LNG import terminals and does generally not require additional capacity building.

Fourth, if a reduction of the import dependency in natural gas were a political target, it would only be effectively achieved when natural gas consumption is completely phased out. Expanding extraction in the EU is not cost-competitive, so we find very high import dependency rates (90% and higher), regardless the role of Russia and the ambition level of climate policy. However, absolute levels of imports go down over time if demand decreases. This frees up import capacities, in particular of LNG. Fifth, Russia compensates for missing revenues from the European gas market by turning East, i.e. to Asia. This trend persists independently of any geopolitical pathway and is only accelerated by interruptions of supply to Europe.

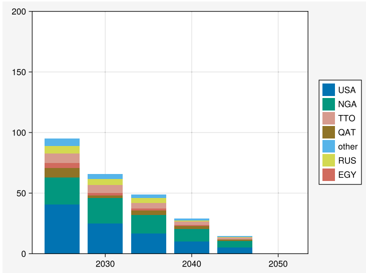
Lastly, the lower the EU gas consumption level in the near term (i.e., 2025 and 2030), the lower the need for demand response (i.e., higher prices) and/or infrastructure expansion. In contrast to [21] who find that their Russia-no-flow scenario leads to ca. 80% higher prices than in the scenario that resembles our SQAB scenario, we find only moderately higher prices by less than 10% (EUSD vs. SQAB), even for 2025. This is in line with [14,17] and due to the equilibrium model setup of the Global Gas Model, which cannot represent temporary (non-equilibrium) shock situations.

Overall, the results presented in this analysis indicate that the effects of a supplier cutoff to the EU can be mitigated, even if it is a large supplier as was Russia. Expiration of the Ukraine transit agreement or sanctions can largely be compensated by utilizing existing import infrastructures, both pipeline and LNG. We find LNG import levels that are significantly below current capacity, let alone planned expansions. Hence, these projects face a severe risk of asset stranding, especially in the more ambitious climate policy scenarios.

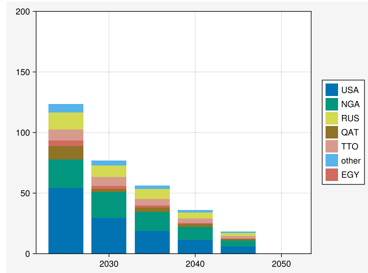
6. Conclusions

Our modeling exercise shows that the replacement of Russian gas in European imports can be sustained in the long term. Sufficiently large import capacities and ample global supplies have allowed for uninterrupted gas flows to the EU during the crisis of 2022 and would also enable a complete cutoff from Russian gas supplies in the future. In other words, the EU could also impose sanctions on all Russian natural gas pipeline exports, as it did on coal and pipeline oil supplies. LNG exports from Russia, too, could be sanctioned by the EU, because a redirection of global LNG flows would flexibly replace them in Europe.

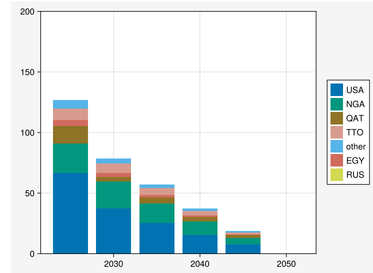
Russia, in contrast, will not be able to fully replace its former export revenues from selling natural gas to the EU. In contrast to ship-based



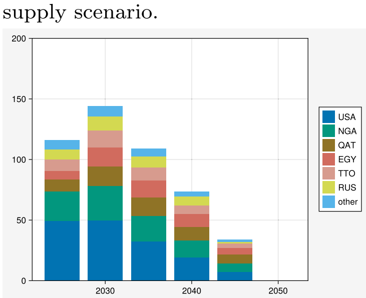
(a) Combination of True Zero Emissions (TZE) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



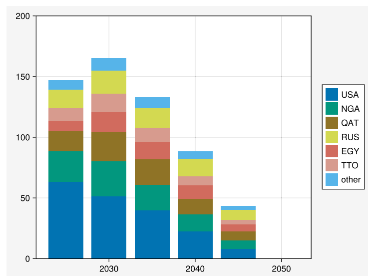
(b) Combination of True Zero Emissions (TZE) climate policy scenario and New Normal (NENO) supply scenario.



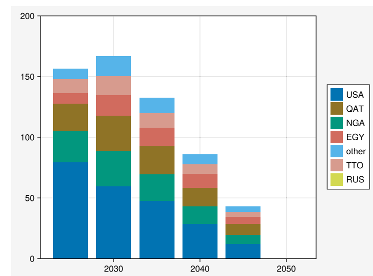
(c) Combination of True Zero Emissions (TZE) climate policy scenario and EU Supply Disruption (EUSD) scenario.



(d) Combination of Fossil and Fissile Free (FFF) climate policy scenario and Status Quo Ante Bellum (SQAB) supply scenario.



(e) Combination of Fossil and Fissile Free (FFF) climate policy scenario and New Normal (NENO) supply scenario.



(f) Combination of Fossil and Fissile Free (FFF) climate policy scenario and EU Supply Disruption (EUSD) scenario.

Fig. 7. EU LNG Imports in bcm by Source under High Climate Ambition Scenarios for three Russian Supply Scenarios.
The figure shows LNG imports by source to the EU under high climate policy ambition scenarios True Zero Emissions (TZE) and Fossil and Fissile Free (FFF). Russian LNG exports to the EU are substituted by an increase from other sources, mostly from the US.
Source: Own depiction.

oil sales, it is much harder to re-route pipeline-based exports, in this case to Asia, even though pipeline capacity to China can potentially be expanded in the next years. Also, Russian LNG supplies can be rerouted relatively at will.

All efforts in the EU to abstain from imports of Russian natural gas become easier if natural gas consumption is quickly reduced in line with existing climate policy targets. In addition to energy efficiency efforts, this can be achieved with replacement of natural gas with low-emission energy sources, such as renewable electricity. The EU's REPowerEU Plan [43] has attempted to combine these different solutions to mitigate the dependency on Russian gas. If the climate neutrality target is taken seriously, natural gas consumption should be completely phased out by 2050 which would, in turn, finally end a period of high import dependency in the EU.

We use a comprehensive model of the global natural gas market, the Global Gas Model, that has a unique nodal resolution and breadth in terms of included agents of the natural gas value chain. We provide a large scale data set that includes production, consumption, transport infrastructure (LNG, pipeline), and storage open source to other interested modelers that may define alternative scenarios to ours. As any model based analysis, our results have some limitations. For example, the GGM does not include specific considerations regarding (existing) long term contracts. Further, the influence of short-term disruptions from extreme weather, unplanned outages and/or hostile actions against critical infrastructure is not considered in our equilibrium setup. This includes the ignorance of political instability in alternative supply countries, for example in Nigeria. However, disruptions for any of these reasons can have a considerable effect on quantities and, in particular, on prices in the short time.

Also, since the focus of our analysis lies on supply scenarios with respect to Russian natural gas, we do not consider additional political constraints, such as potential export restrictions on liquefaction in the USA. Finally, there is yet little consensus about the precise effect of climate change policies on natural gas consumption. We make an attempt to define climate-neutrality scenarios and find that it requires a complete global natural gas phase-out to achieve the target. This contrasts with assumptions of the IEA, which sees a role for fossil natural gas also in more ambitious climate policy scenarios. Additional research should further explore the impacts of climate change policy on natural gas markets, in particular in regions with currently rising demand such as North America and Asia.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data and model code are openly available in Github (https://github.com/Franziska-Holz/GGM_public). The link is provided in the paper.

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