PRINCETON UNIVERSITY
ZERO LAB
Zero-carbon Energy Systems Research and Optimization Laboratory

POLICY MEMO

Pathways to European Independence from Russian Natural Gas

July 28, 2022

Based on analysis and modeling of European electricity and gas systems, this report identifies several feasible paths for European countries to eliminate imports of natural gas from Russia by October 2022. Success requires augmenting measures planned in the European Commission's REPowerEU plan with additional reductions in gas use for electricity generation and recalibration of gas storage targets to reflect reduced gas demand. In addition to scaling up wind and solar power, achieving requisite reductions in gas-fired power generation requires a temporary increase in the use of coal, which depends on securing additional imports from allies such as the United States. Despite increased reliance on coal for electricity generation, all core scenarios result in significant declines in European greenhouse gas emissions as lower gas demand offsets emissions from increased coal combustion. The overall strategy for European independence from Russian natural gas depends on a combination of (1) increased pipeline gas and liquified natural gas imports from alternative sources, (2) reducing gas demand in heating and industry, and (3) reducing gas-fired electricity generation by temporarily increasing coal use and reducing electricity demand while accelerating renewable energy deployment. We also identify multiple combinations of these three levers that can eliminate Europe's dependence on Russian gas, giving policymakers leeway to craft a preferred approach based on national priorities.

Background

Russia's unprovoked invasion of Ukraine has devastated the country and drastically inflamed geopolitical tensions between NATO and Russia. In response, US and EU sanctions have targeted Russian banks and individuals, causing widespread economic impacts. To date, Russian energy exports have remained largely untouched by sanctions due to **Europe's historical dependence on imports from Russia, which supplied more than 40% of the EU's 2021 natural gas consumption as well as 27% of oil imports and 46% of coal imports.**[1] While European nations have pledged and delivered military and financial support to Ukraine, they have also paid Russia nearly $70 billion for fossil fuels since the start of the war, including $31 billion for natural gas alone.[2,*] Much of this funding flows directly to the Kremlin via Russian state-owned energy companies, meaning that Europe is literally funding both sides of the conflict in Ukraine. Energy exports also provide Russia with its last major source of foreign currency exchange, playing a critical role in helping the Russian economy weather the impacts of financial sanctions. All of this raises the urgency and importance of securing European energy independence and security.

[*] €66 billion for fossil fuels, €29 billion for natural gas

The EU recently announced a complete ban on imports of Russian coal and a planned 90% reduction in imports of Russian oil.[3,4] Ending imports of Russian natural gas presents a more significant challenge, as 90% of Russian gas imports enter Europe via pipelines.[1,5] This makes it much more difficult for Europe to secure alternative supplies than seaborne coal and oil imports. For this reason, the REpowerEU framework released by the European Commission aims to reduce the use of Russian gas by two-thirds within the next year and to achieve complete independence "well before 2030."[1,6] REpowerEU proposes a combination of behavioral energy demand reduction, increased imports of non-Russian pipeline gas and seaborne liquefied natural gas (LNG), and accelerated renewable energy deployment to achieve its near-term reduction goals. In the longer term it envisions increased reliance on biogas and fossil-free hydrogen (imported or produced locally via renewable electricity) as substitutes for Russian gas.[1,4]

While successful implementation of the REpowerEU plan would significantly reduce imports of Russian gas in the next year, any remaining imports would likely generate greater revenues for Russia due to elevated prices. Moreover, reducing but not eliminating Russian gas imports leaves Europe critically vulnerable to a sudden cessation of gas flows, particularly in winter months, when such an action would be both economically devastating and potentially deadly for European citizens that depend on gas for heat. Russia has demonstrated a willingness to curtail or completely shut off gas exports, as it has already done with Poland, Bulgaria, Finland, Germany, and others.[6,7] Europe must thus be prepared to completely eliminate reliance on Russian natural gas in the near term, either proactively or in response to Russian action.

Feasible Strategies to Eliminate Russian Natural Gas Imports

We have modeled the European natural gas and electricity systems at a high temporal resolution and country-level spatial resolution to assess the feasibility and potential impact of a near-complete embargo on imports of Russian natural gas to Europe beginning in October of this year. This theoretical embargo would be phased in gradually and would exempt both Hungary and Slovakia to maintain alignment with the recently-announced oil embargo.[4] We use a 37-zone[†] model of the European ENTSO-E electricity system with an hourly resolution to assess the impact of reductions in gas-fired electricity generation on the European grid.[‡,§] These results ensure electricity reliability and quantify electricity sector gas consumption, which is then passed into a model of the European ENTSO-G natural gas network,[**] which optimizes imports, storage and pipeline transport between countries to minimize country-level gas supply shortfalls for 28 countries at a monthly resolution. We model both electricity and gas systems from April 2022 until March 2024, capturing both the 2022/2023 and 2023/2024 'heating years.' We assume 1) domestic natural gas production at historical levels, 2) maximum pipeline imports from non-Russian sources equal to those observed over the winter of 2021/22, 3) transmission pipelines within Europe operating up to 90% capacity, and 4) liquefied natural gas (LNG) import limits corresponding to countries' regasification terminal capacities in operation and due to be operational before the end of the modeling time horizon.[††] Our core scenarios assume a complete cessation of Russian gas flows to participating European countries by October 2022, and the model's objective function seeks to minimize any Russian imports before that date.

† Countries modeled: Albania, Austria, Bosnia, Belgium, Bulgaria, Switzerland, Czechia, Germany, Denmark, Estonia, Spain, Finland, France, UK, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Montenegro, North Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia

‡ Input data sourced from https://github.com/PyPSA/PyPSA.

§ Model code available at https://github.com/GenXProject/GenX. Input data sourced from Eurostat: https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_GASM__custom_3126194/default/table?lang=en

**Countries modeled: Austria, Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, France, Greece, Croatia, Ireland, Italy, Latvia, Lithuania, Luxembourg, Moldova, The Netherlands, Poland, Portugal, Romania, Spain, Slovenia, Finland, North Macedonia, Serbia, UK. Note: Hungarian and Slovakian demand, production, and storage have been removed from the model due to their objections to the EU's planned embargo of Russian oil. Slovakia may be added with 8 bcm/yr additional demand mitigation or fuel-switching.

†† See Table 3 and Table 4 for list of planned capacity additions.

Our modeling and analysis finds that participating European countries can eliminate Russian gas imports by October 2022 by implementing the proposals outlined in REpowerEU, including increased LNG imports, behavioral energy demand reduction, and renewable energy deployment, augmented by an additional temporary switch from gas-fired to coal-fired power in the electricity sector and a smart recalibration of gas storage targets. This embargo would be sustainable for at least the next two winters, and temporary emergency measures, including behavioral demand reduction and increased coal generation, would be steadily replaced by increased renewable generation, electrified heating, and LNG imports over time. Securing European independence from Russian natural gas imports can be accomplished despite constraints in natural gas transmission and imports across the continent, which are captured in our model. All core scenarios result in significant declines in European greenhouse gas emissions over the April 2022 to March 2024 period.

Figure 1 illustrates the contribution of various measures to a unified strategy that eliminates imports of Russian natural gas to participating countries by October of 2022. To ensure no shortfall in supply, European countries must import roughly 24 bcm of Russian pipeline gas between April and October 2022. This requirement is in line with the actual trajectory of imports from April through June,[7] and can be reduced via more extreme demand-reduction measures than are proposed in our central strategy. Alternative strategies that minimize Russian gas imports or achieve other priorities are discussed below.

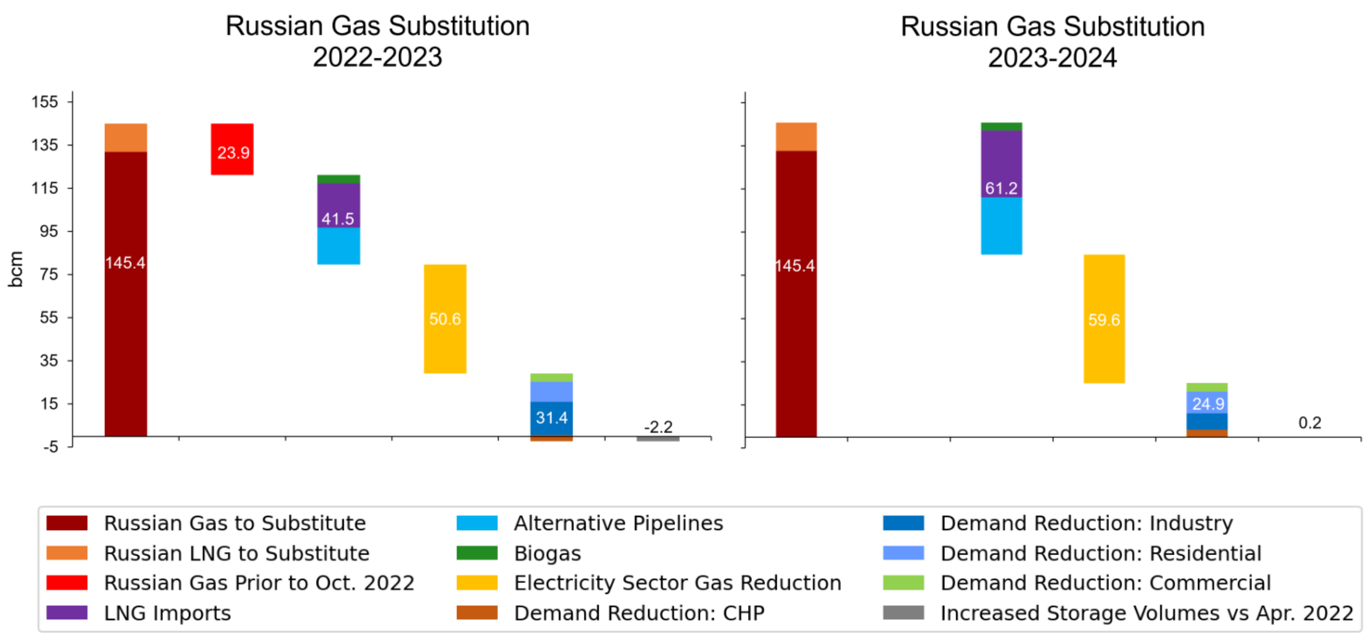


__Figure 1:__ Relative contributions towards eliminating Russian gas from the European energy mix by different technologies and sectors, with shifts given as changes relative to 2021 values.

Additional LNG imports play an important role in reducing reliance on Russian pipeline gas, though to a slightly lesser degree in our modeling than envisioned in REpowerEU. We find that European countries should aim to import roughly 100 bcm of LNG in the period from April 2022 to March 2023, and 110 bcm in the period from April 2023 to March 2024, an increase of more than 7 and 17 bcm/yr relative to 2021. Factoring in the need to also replace the roughly 15 bcm/yr of LNG imported to Europe from Russia in 2021 results in **a necessary 32 bcm/yr increase in LNG imports from non-Russian sources**, short of the 50 bcm/yr envisioned in REpowerEU.‡‡ This increased LNG demand does not reach the 124 bcm/yr limit imposed on global LNG supply during the modeled period, which is based on an analysis of the near-term global LNG market by Fulwood et al. (Oxford Institute for Energy Studies).[8] We find that this is still the case in modeled scenarios where gas supply shortfalls occur, suggesting that there is a limit to the effectiveness of LNG as a direct substitute for Russian pipeline gas. Lack

‡‡ Our total also includes imports to the UK, which are not considered in the REpowerEU framework.

of transmission capacity connecting countries with significant LNG regasification capacity to those without prevents greater use of LNG from offsetting Russian imports in the near-term. Note that our analysis includes floating regasification facilities due to come online in Germany, Poland, Estonia, and elsewhere during the modeled period, which we find to be critical to ensuring adequate supply in these countries and minimizing Russian imports.

Pipeline gas from non-Russian sources can help replace Russian pipeline imports, but to a lesser degree than LNG. In our analysis, alternative pipeline imports during the period from April 2022 to March 2023 are 17 bcm greater than the 2021 total, largely due to greater year-round utilization of existing pipelines. Connection of new supply from Norway and Azerbaijan increases non-Russian pipeline flows by an additional 10 bcm during the period from April 2023 to March 2024. It is unlikely that additional pipelines beyond those currently planned could be brought online during the next two years. Should suppliers be unable to provide adequate piped gas within the year (i.e. the assumption of year-round utilization turns out to be optimistic), LNG imports can likely compensate to some extent. For example, constrained pipeline supplies in Norway could be directed toward Germany rather than the UK, which has ample LNG import capacity.

Our strategy for eliminating Russian gas imports relies on modest gas demand reductions in heating and industry during the modeled period, in line with what has been proposed in REpowerEU. We assume that demand in gas-consuming industrial sectors such as paper, metals, and chemical falls by 11% in the first modeled year, in line with observed reductions, but that demand curtailment in industry settles back to a 5% reduction compared to 2021 levels in the second modeled year.[9] We also assume that gas demand for residential, commercial, and district heating is reduced by 8% and combined heat and power (CHP) by 4%. The smaller reduction in CHP reflects the high efficiency of this end use. Heating demand reductions in the immediate term must be accomplished by behavioral changes, including turning down thermostats by 1-2 degrees Celsius during winter heating periods.[10] More permanent measures including electric heat pump installations and building efficiency retrofits can replace these behavioral demand reductions over time. Aggregate reduction in gas demand across the industrial and heating sectors due to these measures is roughly 6%, slightly above the 5% behavioral demand reduction envisioned in REpowerEU.[5]

Critically, we find that eliminating Russian natural gas imports to Europe is possible only via a major near-term reduction in gas-fired electricity generation, exceeding that contemplated in REPowerEU. In our central scenario, gas use in the electricity sector must decline by roughly 60 bcm/yr during the modeled period, leading to a total economy-wide gas demand reduction of 17%. In the first modeled year, from April 2022 to March 2023, total gas-fired electricity generation in Europe falls by 272 TWh compared to 2021 levels. **This reduction can be accomplished via three primary levers: renewable electricity deployment, electricity demand reduction, and increased coal-fired generation**. These measures must not only replace 272 TWh of gas-fired electricity generation, but also roughly 100 TWh of reduced nuclear generation (relative to 2021 levels) due to maintenance issues and plant retirements, and reduced hydropower generation due to droughts.[11] Table 1 and Figure 2 show three scenarios by which this replacement can be accomplished, relying more or less heavily on the three levers described above. In the High Coal scenario, electricity demand is reduced by 2.5% and wind and solar capacity additions proceed in all countries at the rates projected by Bloomberg NEF.[12] The modest contributions of both of these measures must be supplemented by 203 TWh of additional coal generation, a 51% increase from 2021 levels. In the Balanced scenario, electricity demand is reduced by 5%, reducing the increase in coal generation to 149 TWh. The Accelerated RE scenario, in which the pace of renewable energy additions is increased by 50% compared to BNEF projections, reduces the near-term increase in coal generation by a further 20 TWh to 130 TWh (a 33% increase relative to 2021). All scenarios assume very low nuclear fleet availability in France reflecting current EDF projections, but also assume that currently scheduled retirements of nuclear plants in Germany are postponed in response to the crisis.[13,14] Retiring German nuclear plants in accordance with the current schedule would increase the required coal burn by 30 TWh/yr from January 2023 onward, or alternatively increase gas use by more than 5 bcm/yr. These scenarios also assume expansion of the interconnection between the ENTSO-E and Ukrainian grids to an eventual 1 GW, which reduces the required coal burn by 9 TWh/yr from 2023 onward.

Electricity Scenario	Gas Use Reduction (bcm/yr)	Increase in Year 1 Coal Power (TWh)	Electricity Demand	New Renewables
High Coal	60	203	-2.5%	1 x BNEF Projection
Balanced	60	149	-5%	1 x BNEF Projection
Accelerated RE	60	130	-5%	1.5 x BNEF Projection

Table 1: Parameters for three possible electricity sector scenarios enabling complete independence from Russian natural gas. Changes in parameters are given with respect to a 2021 baseline.

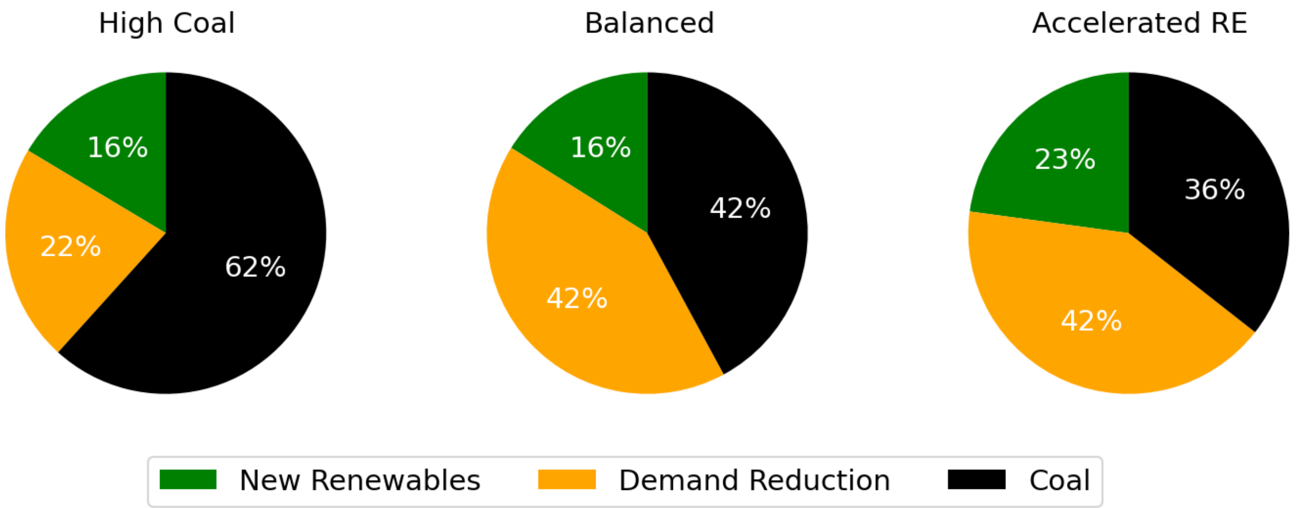


Figure 2: Proportional reliance on new renewables, electricity demand reduction, and increased coal generation for displacement of 272 TWh of gas generation during the period from April 2022 to March 2023, under three scenarios listed in Table 1.

As illustrated in Figure 3, **all electricity sector scenarios require a near-term increase in coal generation that is gradually replaced by renewable energy deployments and restoration of France's nuclear fleet availability**. From April 2022 to March 2023, generation from coal-fired power plants is 130-203 TWh greater than in 2021 across the three scenarios in Figure 2. This is equivalent to 39-61 MT of additional hard coal consumption, 114-178 MT of additional lignite consumption, or some combination of the two.[§§] Additional coal consumption occurs primarily in the Third and Fourth Quarters of 2022, providing some time to arrange for additional supplies. From April 2023 to March 2024, the additional coal generation compared to 2021 declines to 25-155 TWh (8-47 MT hard coal or 22-136 MT lignite). Inter-annual declines in coal generation are fastest in the Accelerated RE scenario, for which coal generation less than the 2021 baseline by the end of the modeled period. In all scenarios, additional renewable deployment is supplemented by a gradual increase in the availability rate for the French nuclear fleet, and delays on either of these fronts could prolong the required increase in coal generation. Failure to maintain operation of existing nuclear plants would also increase coal generation by more than 30 TWh in 2023 and beyond.

Europe will require significant additional near-term coal imports under any of the pathways shown in Table 1. Europe is generally self-sufficient for lignite production, which rose 13% (33 MT, equivalent to ~10 MT of hard coal) between 2020 and 2021 and could plausibly rise by a similar amount in 2022.[15] Local hard coal production, however, was flat during this period and is unlikely to see significant increases. Current hard coal stocks in Europe are on the order of 10 MT.[16] Recent sanctions already require that the EU replace roughly 50 MT/yr of hard coal imports from Russia, but this will likely be achieved by a reshuffling of fungible seaborn coal supplies within the global market. **Assuming domestic lignite production increases by 30 MT/y in 2022, Europe must secure an increase of 29-51 MT of hard coal from the global market during the**

[§§] Calculations assume an average coal power plant thermal efficiency of 41% and average energy contents of 8.13 TWh/MT for hard coal and 2.78 TWh/MT for lignite.

period from April 2022 to March 2023. Unless offset by reduced consumption in other importing countries, this amount represents new supply in the global seaborn coal market. Across the three primary electricity sector pathways, the required additional hard coal during the first modeled year is equivalent to 4-10% of the global thermal coal trade.[17] Securing this new supply will likely depend on concerted action by the United States and other European allies (see more below on the US role). Although this increase in demand will put upward pressure on global coal prices, Europe's greater past reliance on coal imports has left it with more than enough spare infrastructure capacity to handle the increased throughput.

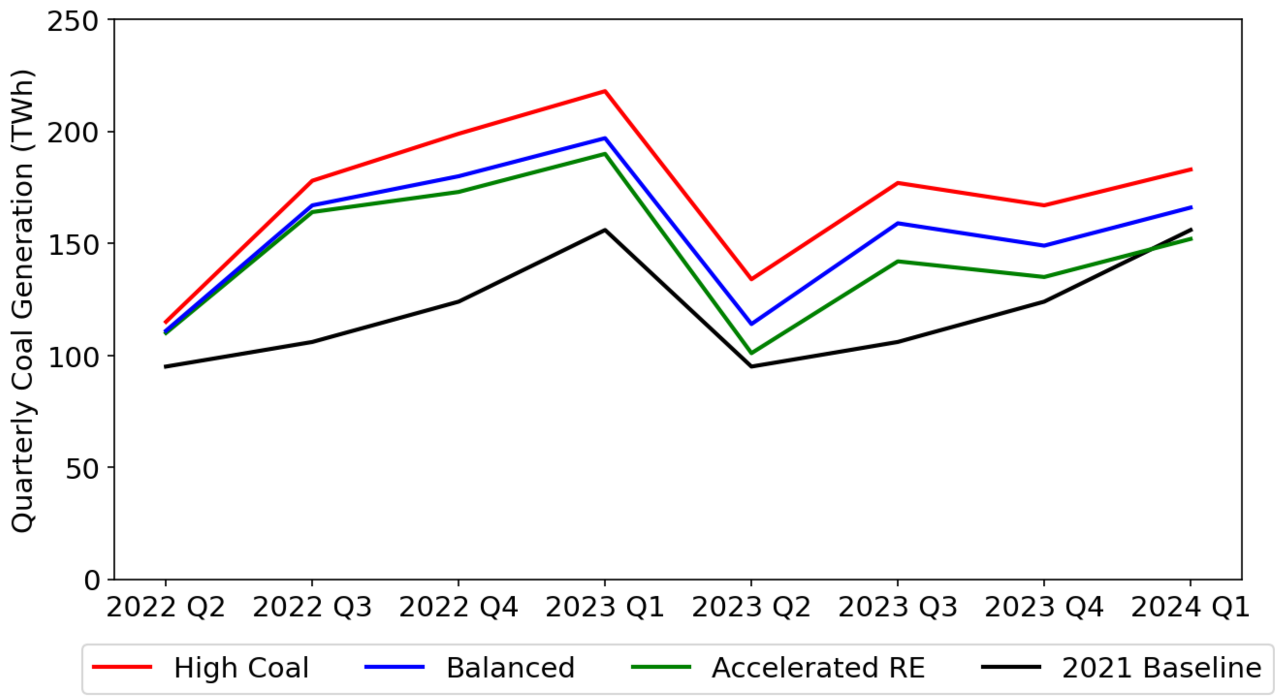


Figure 3: Required quarterly coal-fired generation for three electricity sector scenarios listed in Table 1, as well as a baseline where annual coal generation is fixed at 2021 levels.

To assess the climate impact of the proposed shifts, we compared each scenario's emissions against provisional economy-wide 2021 EU emissions data, including the UK and excluding Hungary and Slovakia. Our core scenarios for eliminating Russian natural gas imports result in significant declines in European greenhouse gas emissions from April 2022 to March 2024, with additional reductions in upstream emissions from gas extraction and transportation (Figure 4). In the Balanced scenario, aggregate in-territory GHG emissions decrease by 115 Mt CO2-equivalent ($MtCO_2e$) from April 2022-March 2023 and 248 $MtCO_2e$ from April 2023-March 2024 relative to 2021 emissions levels, a change of -2.8% and -6.1%, respectively. With Accelerated Renewable deployment, in-territory emissions decline by 137 $MTCO_2e$ in 2022/2023 and 299 $MTCO_2e$ in 2023/2024, a change of -3.4% and -7.3% relative to 2021 emissions levels. The High Coal pathway results in an in-territory emissions decrease of 49 $MTCO_2e$ in 2022/2023 and of 182 $MTCO_2e$ in 2023/2024, -1.2% and -4.4% relative to 2021 EU emissions. Including out-of-territory emissions from gas extraction and transportation results in additional emissions reductions of 95 $MTCO_2e$ in 2022/2023 and 108 $MTCO_2e$ in 2023/2024 in all cases due to reduced fossil fuel demand and switching away from leakage-prone Russian gas transmission.

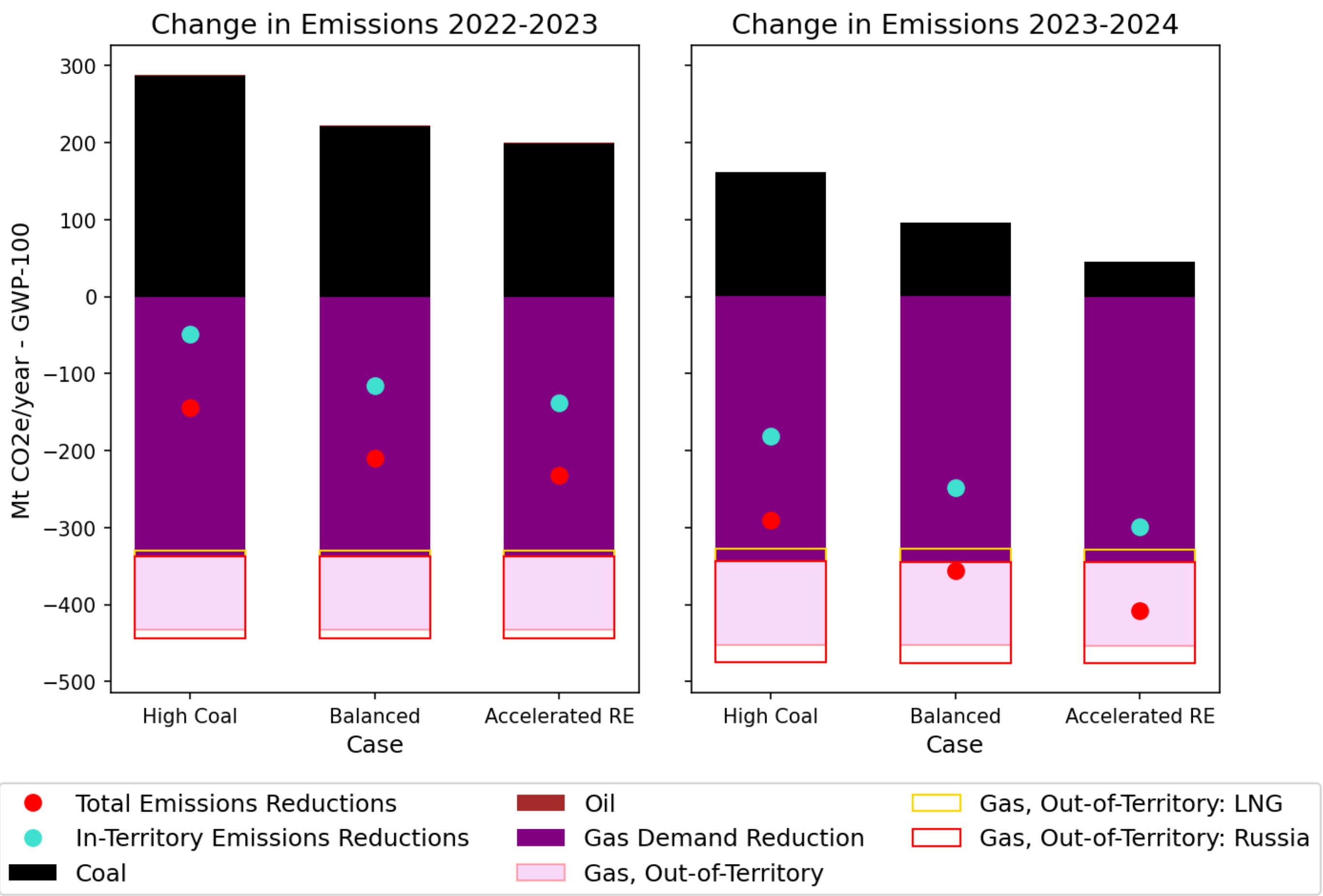


Figure 4: Change in emissions by fuel type and jurisdiction for all central scenarios relative to 2021 European levels including the UK and excluding Hungary and Slovakia for April 2022-March 2023 and April 2023-March 2024.

Finally, **European decision-makers must update gas storage volume targets to reflect reduced gas demand in the context of an embargo on Russian gas imports.** The current EU policy of requiring gas storage facilities to be at least 80% full by October 1, 2022 and 90% full by October 1, 2023 effectively locks the EU into buying significantly more Russian gas than is necessary (based on our modeling) in order to avoid curtailing gas consumers or exacerbating shortfalls by about 10 bcm over the next two years. Modeled import capability is insufficient to meet both increased demand from gas storage adhering to current EU policy and constant or moderately declining demand in gas-consuming sectors. As illustrated in Figure 5, intelligent seasonal storage requirements, scaled to deliver security of supply while reflecting reduced aggregate winter demand in these scenarios,[***] rather than an arbitrary percentage of total storage capacity, are essential to achieving lower gas shortfalls. As currently calculated, these storage requirements remain high enough to fulfill 5 weeks of peak demand across the 28 countries modeled. Even in the most constrained months, storage volumes are sufficient to fulfill 2-3 weeks of demand, providing security of supply in case of unexpected outcomes.

[***] Our proposed seasonal storage requirements scale the current EU storage capacity requirement of 80% full on October 1st by the ratio of projected gas demand from October through March for the year in question and a reference year's winter gas demand. This method maintains an equal level of security without overwhelming import capabilities.

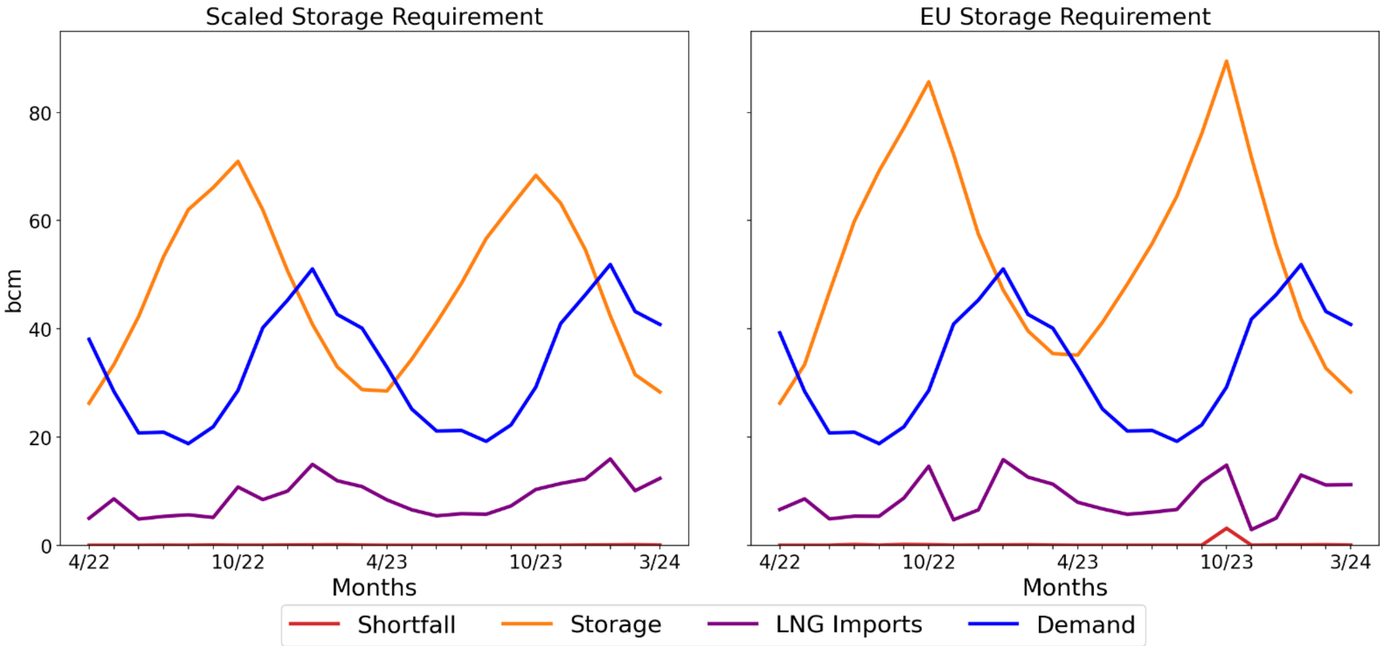


Figure 5: Accelerated renewable energy scenario European gas sector operational characteristics under demand-scaled and EU gas storage requirement.

Alternative Pathways

In addition to the balanced central strategy outlined above, multiple alternative strategies exist that minimize or maximize the role of certain mitigation measures. Table 2 and Figure 6 illustrate a range of these alternative strategies. As illustrated, it is possible to achieve a near-zero gas supply shortfall with lower demand reductions, but only via increased reliance on LNG imports and fuel-switching from gas to coal in the electric power sector. Conversely, deeper behavioral demand reductions enable reduced reliance on coal power resulting in further emissions reductions. Demand reductions deeper even than those assumed in our central case have already been observed in some parts of Europe.[7] Even among alternative pathways that achieve zero supply shortfall, deeper demand reductions reduce the amount of Russian gas that must be imported before the October cutoff. European decision-makers therefore have some leeway to choose a strategy that accommodates their own priorities or constraints while still achieving the goal of independence from Russian natural gas. We do find, however, that LNG imports to Central European countries should be maximized in all cases to minimize shortfalls and Russian pipeline imports.

Mid-Term Outlook

European energy independence can be maintained through 2025 and beyond while phasing out both behavioral demand reductions and the increase in coal combustion for electricity generation. Key medium-term actions include a combination of increased reliance on clean electricity, energy efficiency, hydrogen substitution, increased biogas production, heating electrification measures, the completion of contracted LNG terminals, and construction of the previously-canceled Spain-France MidCat pipeline. Electric heat pump deployment and efficiency upgrades can gradually replace behavioral reductions in gas demand over this period. Meanwhile, ongoing wind and solar deployment and a return to historical availability rates for Europe’s remaining nuclear reactors can accommodate increased demand due to electrification and displace coal-fired generation.

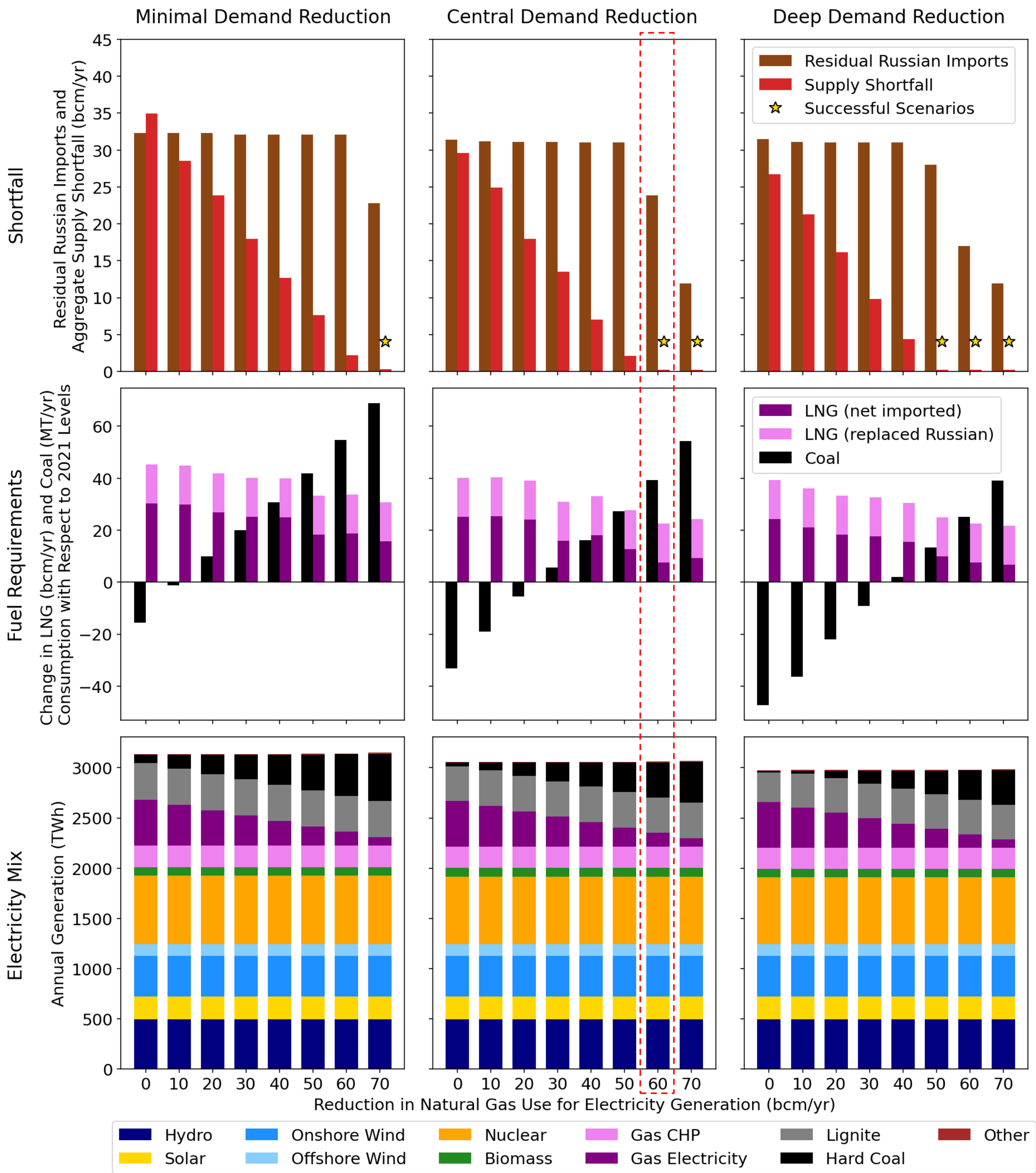
Figure 7 shows plausible scenarios by which Europe could maintain independence from Russian fossil fuels in the April 2025-March 2026 period. 'Business As Usual' assumes the same levels of gas demand reduction as our Lesser near-term scenario (see Table 2), but now attributed entirely to electrification and efficiency rather than behavioral demand reductions. Electricity demand is assumed to increase 5% to accommodate electrification. All remaining nuclear power plants are assumed to maintain at least 85% availability, and wind and solar capacity additions are assumed to follow BNEF mid-case projections. Under the 'Accelerated Deployment' scenario, electrification and efficiency installations are accelerated to deliver gas demand reductions in heating equivalent to the Deeper near-term scenario and wind and solar additions proceed at 150% of the rate projected by BNEF.

Under all 2025/26 scenarios, **additional clean electricity generation and increased LNG availability allow Europe much more leeway to follow its preferred pathway in the medium-term**. Coal use can be reduced to below 2021 levels even in the Business As Usual scenarios through increased LNG imports. Under Accelerated Deployment, coal use falls significantly compared to 2021 levels. **Increased coal generation and behavioral demand reduction could thus reasonably be limited to the next two years and would not imperil Europe's longer-term energy transition or 2030 climate goals.**

The Role of the United States

The United States can support European energy independence from Russian fossil fuels by reducing domestic fossil fuel use, increasing energy exports, and guaranteeing supply to its allies. In the near-term, **US LNG will be critical to quickly replace the ~15 bcm/yr of LNG supply that Europe currently sources from Russia.** Any additional US LNG exports can help to meet Europe's need for further LNG. In the longer term, completing the Golden Pass LNG export facility currently under construction and scheduled to come online in 2024[18] is sufficient for the US to meet its pledge to supply the EU with 50 bcm/yr of LNG by 2030.[19] **Given long-term EU plans to reduce natural gas use, further increases in US LNG export capacity beyond Golden Pass are likely unnecessary to secure Europe's energy supply.**

The most important near-term role for the United States in any plan to eliminate Europe's reliance on Russia gas is as a supplier of coal. It is not feasible for Europe to quickly ramp up domestic coal production to the level required to offset Russian gas imports. While coal can be imported from overseas much more easily than natural gas, new coal supply must be guaranteed to free Europe of Russian gas dependence until 2025. The EIA projects that US coal exports will decrease marginally in 2022, despite an increase in production and a decrease in consumption.[20] Instead, US coal inventories are projected to rise to 115 MT by year's end. Drawing down inventories by ~24 MT for a single year could guarantee all or a majority of Europe's hard coal needs, and stocks could be rebuilt in future years. Near-term reductions in coal use in the United States, primarily through substitution with natural gas in the electricity sector, could free up additional supply for export to European allies. In addition to securing supply, logistical challenges must be overcome to deliver this supply where it is needed. Although more than enough rail and port terminal capacity exists on the US Atlantic and Gulf coasts to handle the required quantities of coal,[21,22] a rapid ramp-up in exports could face issues with congestion and labor shortages. Alleviating these potential bottlenecks to additional coal exports should be a priority of any U.S. government action in support of European energy independence. With concerted and strategic effort, we estimate that **the United States could increase near-term exports to Europe by on the order of 30-55 MT/yr. This would be sufficient to meet the deficit in global coal trade, play a pivotal role in underwriting Europe's energy security, and enable the elimination of Russian gas imports.**



<u>**Figure 6:**</u> European gas and electricity sector scenarios for the April 2022 - March 2023 period, assuming renewables additions at 1.5x the rate projected by BNEF. The central feasible strategy (assuming the Accelerated RE electricity sector scenario) is highlighted.

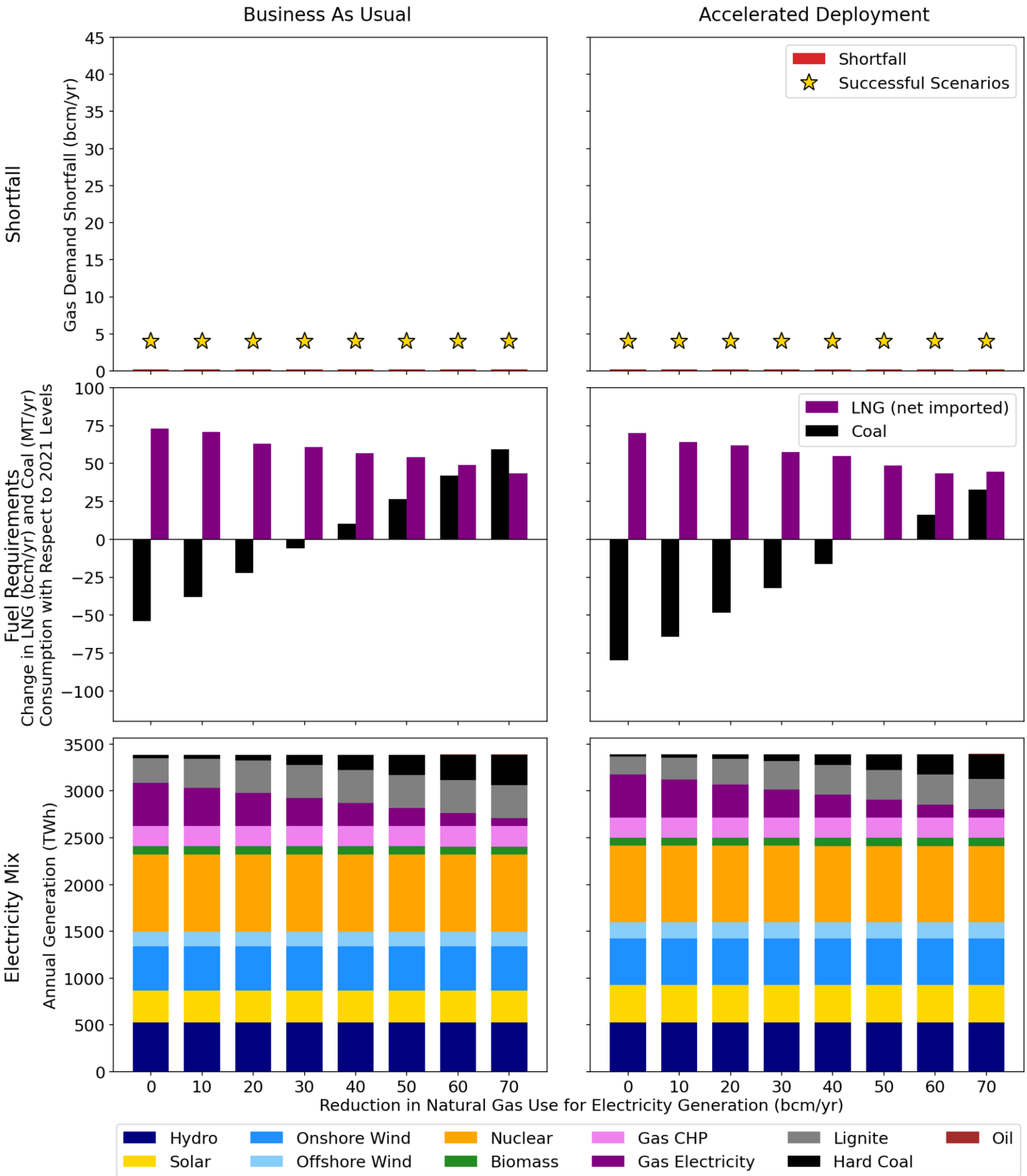


Figure 7: European gas and electricity sector scenarios for 2025 and 2026, maintaining a complete embargo on imports of Russian natural gas to participating countries.

Demand Reduction Case	Industrial Demand	Res/Com Heating Demand	Combined Heat and Power Demand	Electricity Demand
Minimal	-2.5%	-4%	-2%	-2.5%
Central	-11% -> -5%	-8%	-4%	-5%
Deep	-11% -> -5%	-12%	-4%	-7.5%

Table 2: Parameters for demand reduction scenarios in Figures 6 and 7. Reductions are given relative to 2021 demand in each category.

Name	Type	Capacity (bcm/yr)	Location	Modeled Date
Porto Levante Expansion	LNG Terminal	1.0	Italy	Mid 2022
Swinoujscie Expansion	LNG Terminal	6.5	Poland	Mid 2022
Unnamed	FSRU	~4.0 (estimated)†††	Finland/Estonia	Oct. 2022
Transpower/Transgas	FSRU	7.5	Germany	Jan. 2023
Dioryga Gas	FSRU	2.5	Greece	Jan. 2023
Skulte Terminal	LNG Terminal	1.5	Latvia	Jan. 2023
Alexandroupolis Terminal	LNG Terminal	6.1	Greece	Late 2023
Zeebrugge Expansion	LNG Terminal	5.9	Belgium	Late 2024
Fos Cavaou Expansion	LNG Terminal	4.1	France	Late 2024
Mag Mell	FSRU	2.6	Ireland	Late 2024
Porto Levante Expansion	LNG Terminal	0.5	Italy	Late 2024
Gate Terminal	LNG Terminal	0.5	Netherlands	Late 2024
Unnamed	FSRU	19.5	Germany	Late 2024
Paldiski Terminal	LNG Terminal	2.5	Estonia	Mar. 2025
Montoir-de-Bretagne Terminal	LNG Terminal	10.0	France	Mar. 2025
Baltic Sea Coast	FSRU	4.5	Poland	Mar. 2025
Isle of Grain Terminal	LNG Terminal	5.0	United Kingdom	Mar. 2025

Table 3: List of LNG import capacity additions incorporated within the gas system model.[23]

††† Due to lack of published information on the capacity of this addition, we estimated the capacity of the terminal based upon the funds allocated and other FSRU contracts.

Name	Type	Total Capacity (bcm/yr)	Origin-Destination	Modeled Date
Gas Interconnector Poland-Lithuania	Pipeline	1.9	Lithuania-Poland	May 2022
Gas Interconnector Poland-Lithuania	Pipeline	2.0	Poland-Lithuania	May 2022
Poland/Slovakia Connector	Pipeline	5.1	Poland-Slovakia	July 2022
Poland/Slovakia Connector	Pipeline	6.1	Slovakia-Poland	July 2022
Interconnector Greece-Bulgaria	Pipeline	3	Greece-Bulgaria	Sep. 2022
Interconnector Greece-Bulgaria	Pipeline	3	Bulgaria-Greece	Sep. 2022
Baltic Pipeline	Pipeline	10	North Sea-Denmark-Poland	Jan. 2023
Trans-Anatolian Pipeline	Pipeline Expansion	17	Azerbaijan-Turkey-Greece	Jan. 2023
Interconnector Serbia-Greece	Pipeline	0.15	Serbia-Greece	Sep. 2023
Interconnector Serbia-Greece	Pipeline	1	Greece-Serbia	Sep. 2023
Interconnector Greece-Bulgaria	Pipeline Expansion	5	Greece-Bulgaria	Mar. 2025
Interconnector Greece-Bulgaria	Pipeline Expansion	5	Bulgaria-Greece	Mar. 2025
Trans-Anatolian Pipeline	Pipeline Expansion	23	Azerbaijan-Turkey-Greece	Mar. 2026

Table 4: List of pipeline additions incorporated within the gas system model.[5]

References

[1](2022) *REPowerEU: Joint European Action for more affordable, secure and sustainable energy*. European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN
[2] (2022) *Payments to Russia for fossil fuels.* [Online]. Center for Research on Clean Air. Available at: https://crea.shinyapps.io/russia_counter/
[3] (2022) *Europe agrees to ban Russian coal, but struggles on oil, gas.* The Associated Press. Available at: https://apnews.com/article/russia-ukraine-business-european-commission-europe-european-union-15aaf010196af8e66bc6deac13ceb26f
[4] Abnett, K., Strupczewski, J., and Melander, I. (2022) *EU agrees Russia oil embargo, gives Hungary exemptions; Zelenskiy vows more sanctions.* Reuters. Available at: https://www.reuters.com/world/europe/best-we-could-get-eu-bows-hungarian-demands-agree-russian-oil-ban-2022-05-31/
[5] (2022) *REpowerEU Plan*. European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483
[6] Clinch, M. (2022) *Russia will shut off gas to Finland starting Saturday, Finnish energy provider says*. CNBC. Available at: https://www.cnbc.com/2022/05/20/finlands-gas-flows-from-russia-to-be-shut-off-from-saturday-energy-provider.html
[7] McWilliams, B. and Zachmann, G. (2022) *European Union demand reduction needs to cope with Russian gas cuts*. Bruegel. Available at: https://www.bruegel.org/2022/07/european-union-demand-reduction-needs-to-cope-with-russian-gas-cuts/
[8] Fulwood, M. *et al.* (2022) *The EU plan to reduce Russian gas imports by two-thirds by the end of 2022: Practical realities and implications*. Oxford: The Oxford Institute for Energy Studies. Available at: https://www.oxfordenergy.org/publications/the-eu-plan-to-reduce-russian-gas-imports-by-two-thirds-by-the-end-of-2022-practical-realities-and-implications/
[9] Ruhnau, O. et al. (2022) Gas demand in times of crisis. The response of German households and industry to the 2021/22 energy crisis. Working Paper. Kiel, Hamburg: ZBW – Leibniz Information Centre for Economics. Available at: https://www.econstor.eu/handle/10419/261082 (Accessed: 24 July 2022).
[10] (2022) *A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas.* International Energy Agency.
[11] Toreti, A., Masante, D., Acosta Navarro, J., Bavera, D., Cammalleri, C., De Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magni, D., Mazzeschi, M., Spinoni, J. and De Felice, M. (2022) *Drought in Europe July 2022*. EUR 31147 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-54953-6, doi:10.2760/014884, JRC130253
[12] Bloomberg NEF, Accessed April 18, 2022.
[13] (2022) *Energy Availability Factor.* [Online]. IAEA PRIS. Available at: https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsEnergyAvailabilityFactor.aspx
[14] Mallet, B. and Hummel, T. (2022) *EDF cuts 2023 French nuclear output estimate.* Reuters. https://www.reuters.com/business/energy/power-group-edf-cuts-2023-french-nuclear-output-estimate-2022-02-11/
[15] (2022) *Coal production and consumption statistics*. Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Coal_production_and_consumption_statistics
[16] (2022) *EU coal terminal stocks swell to 20-month high*. Montel. Available at: https://www.montelnews.com/news/1324282/eu-coal-terminal-stocks-swell-to-20-month-high-
[17] (2021) *Coal 2021*. International Energy Agency.
[18] Evans, C. (2021). *Golden Pass LNG Said 'on Schedule' for 2024 Start-Up*. Natural Gas Intelligence. https://www.naturalgasintel.com/golden-pass-lng-said-on-schedule-for-2024-start-up/
[19] Renshaw, J. and Chestney, N. *U.S., EU strike LNG deal as Europe seeks to cut Russian gas*. Reuters. Available at: https://www.reuters.com/business/energy/us-eu-strike-lng-deal-europe-seeks-cut-russian-gas-2022-03-25/
[20] (2022) *Short-Term Energy Outlook: June 2022*. U.S. Energy Information Administration
[21] (2019) *Estimated U.S. Coal Port Capacity (mst) - 2019 Update*. U.S. Energy Information Administration
[22]Blandford, B. et al., (2016) *An Intermodal Network Model of Coal Distribution in the United States and Its Economic Implications for the Inland Waterway System*. Kentucky Transportation Center, Technical Report No. KTC-16-02/MTIC-8-14-11F.
[23] (2022) *LNG Database*. Gas Infrastructure Europe. Available at: https://www.gie.eu/transparency/databases/lng-database/