

The EU's path out of the energy crisis

OUT WITH THE OLD, IN WITH THE NEW?

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Layout and figures: Lone Ravnkilde.
Cover illustration: Cecilie Castor von Spreckelsen
Printed in Denmark by Johansen Grafisk
All DIIS Reports are printed on Ecolabel and FSC certified paper

ISBN 978-87-7236-133-8 print
ISBN 978-87-7236-134-5 pdf

DIIS publications can be downloaded free of charge or ordered from www.diis.dk.
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TABLE OF CONTENTS

List of abbreviations	4
Prefixes and units of power and energy used in the report	5
Executive summary	6
Introduction	9
Diversification of energy imports	15
Diversification of oil	16
Diversification of piped gas	17
diversification of liquefied natural gas imports	19
diversification of nuclear fuels	28
Energy savings and efficiency	33
Strategies for energy saving and efficiency	34
Regulatory measures and market interventions	36
Implementation and future outlook	38
Electricity market design	41
Renewable energy generation	47
Capturing wind energy	48
Capturing solar energy	57
Heat pump deployment	63
Biogas/biomethane	65
Hydrogen	66
Conclusion	73
Notes	75
References	76

LIST OF ABBREVIATIONS

ACER	(EU) Agency for the Cooperation of Energy Regulators
APIS	Accelerated Program for Implementation of secure VVER fuel Supply
CCS	Carbon capture and storage
CEE	Central and Eastern Europe
EHPA	European Heat Pump Association
ENNOH	The European Network of Network Operators for Hydrogen
ETS	(EU) Emissions Trading Scheme
EU	European Union
FSRU	Floating storage and regasification unit
GHG	Greenhouse gases
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied natural gas
NECPs	National Energy and Climate Plans
NPP	Nuclear power plant
NSEC	The North Seas Energy Cooperation
PCIs	Projects of Common Interest
PMIs	Projects of Mutual Interest
RE	Renewable energy
REMIT	(EU) The Regulation on Wholesale Energy Market Integrity and Transparency
TEN-E	Trans-European Networks for Energy
VVER (reactors)	Water-water energetic reactor

PREFIXES AND UNITS OF POWER AND ENERGY USED IN THE REPORT

Symbol	Name	Value	
W(h)	Watt (hour)	10^0 W	1 W
kW(h)	Kilowatt (hour)	10^3 W	1,000 W
MW(h)	Megawatt (hour)	10^6 W	1,000,000 W
GW(h)	Gigawatt (hour)	10^9 W	1,000,000,000 W
TW(h)	Terawatt (hour)	10^{12} W	1,000,000,000,000 W
Area			
m²	Square meters	10^0 m ²	1 m ²
Natural gas/LNG			
m³	Cubic meters	10^0 m ³	1 m ³
mcm (/y)	Million cubic meters (/per year)	10^6 m ³	1,000,000 m ³
bcm(/y)	Billion cubic meters (/per year)	10^9 m ³	1,000,000,000 m ³
Expression and comparison of different sources			
toe	Tonne of oil equivalent	10^0 toe	1 toe
Ktoe	Kilo-tonne of oil equivalent	10^3 toe	1,000 toe
Mtoe	Mega-tonne of oil equivalent	10^6 toe	1,000,000 toe

EXECUTIVE SUMMARY

The Russian attack on Ukraine in February 2022 triggered an energy crisis in Europe and a U-turn in Brussels–Moscow energy relations. Despite the major dependence on Russian fossil fuels, which covered 45% of the EU's gas, 30% of its oil and 46% of its coal needs, and infrastructure lock-ins in the form of import pipelines that made phasing out Russian gas (and to a lesser extent, oil) a challenge, the EU made notable strides in energy policy within two years of the invasion:

- The EU phased out Russian coal, reduced Russian oil imports and diversified its gas supply. Piped Russian gas imports to the EU plummeted by 82.45% between 2021 and 2023, with a 59.64% drop recorded between 2022 and 2023 alone.
- The completion of regional projects improved the European gas infrastructure, enhancing both the interconnectedness of the bloc and providing alternative supply routes through new pipeline connections and enlarged LNG terminal import capacity.
- Energy efficiency measures proved highly effective, reducing the primary and final energy consumption.
- Notable strides have been made in the green energy transition, particularly in the solar and wind power sectors. EU solar power registered record new added capacity in 2022 (41.4 GW) and 2023 (56 GW), and the bloc appears to be almost on track to reach its 2030 target. Similarly, there were record-setting new wind capacity additions in 2022 (16.3 GW) and 2023 (17 GW).

However, multiple pressing challenges remain:

- Despite the major drop in Russian gas imports overall, the share of EU imports of Russian LNG between 2021 and 2023 increased by 14.3%. Diversification away from Russian LNG must be pursued to achieve the phase-out of Russian fossil fuels by 2027. Moreover, the expansion of LNG infrastructure in the EU might need to be revised and scaled down to better match future demand and the EU climate agenda, avoiding potential overinvestment and long-term infrastructure lock-in.
- In the midst of the energy crisis, some EU states reactivated coal-powered plants as a short-term solution. Due to increased coal-fired electricity generation, the EU was the only large-scale consuming region in the world in 2022 that saw a year-on-year increase in CO₂ emissions (+7%). This number is forecast to decline slightly as electricity generation from fossil fuels decreases.
- Scaling up the deployment of renewable energy (e.g. offshore wind power, biomethane, green hydrogen) poses multiple challenges and will require continuous, major financial investments, flexible technological solutions and adequate policy frameworks. The EU is not currently on pace to reach its 2030 wind capacity and biomethane production targets, while green hydrogen sector development remains in nascent stages.

Therefore, continued dialogue among Member States and tracking progress in line with the common agenda are essential to achieve European transition goals and greater European energy independence.

INTRODUCTION

There is little doubt that 24 February 2022 marked a tectonic shift. Two years into the Russian invasion of Ukraine, the European policy landscape has changed dramatically, not least in the realm of energy.

The outbreak of war sparked a European energy crisis, exacerbating an already complicated EU energy market situation. Natural gas and electricity prices surged in the second half of 2021. This was driven by a combination of exceptional weather conditions, including prolonged heatwaves increasing air conditioning use and unexpected cold snaps boosting heating demands. Further compounding the situation was a drought-induced reduction in hydroelectric power production. These factors, coupled with a post-pandemic surge in energy demand and technical challenges in upstream production sectors, contributed to spiking prices (Mišík 2022). Moreover, exceptionally low levels of natural gas in the EU underground storage systems – especially those controlled by Gazprom (Zachmann, Sgaravatti and McWilliams 2022) – coupled with a disrupted Russian gas supply in the autumn and early winter months of 2021 raised concerns regarding potential gas shortages (Wilson and Astrasheuskaya 2021).

The high EU dependence on Russian fossil fuels (prior to 2022) that covered its consumption of gas (45%), oil (30%) and coal (46%) (European Commission 2022e), together with its infrastructural lock-ins in the form of import pipelines for Russian energy, rendered the phase-out of Russian fossil fuels a major challenge. These efforts were additionally complicated by a prolonged reduction in hydropower generation, particularly in the European alpine regions, due to extended droughts linked to climate change (Dunne 2023; Ellefsen 2022). The nuclear power outages in

2022 further complicated the situation. Nevertheless, in March 2022, the European Commission issued the REPowerEU Communication proposal for a Russian fossil fuels phase-out by 2027, and the REPowerEU Plan was released in May 2022 (European Commission 2022f). The main objective of REPowerEU is to reduce EU dependency on Russian fossil fuels, primarily by diversifying the energy supply and accelerating the green energy transition.

Although these ambitious plans pose a major challenge for the EU Member States, the EU track record reveals significant progress in dealing with the energy crisis. First, the EU has implemented sanction packages banning imports of all Russian coal (August 2022), most of the Russian crude oil (December 2022) and refined oil products (February 2023), while efforts to diversify gas supply routes and import infrastructure in the EU have intensified. Some key agreements have also been reached, including the windfall tax and introduction of a cap on power plant profits (except for gas and hard coal), a commitment to reduce gas consumption by 15% in the period August 2022-March 2023, a gas price cap, and a commitment to joint gas purchasing and solidarity in the event of gas supply cuts.

Numerous policy targets regarding renewable energy (RE) and energy efficiency have also been advanced and accelerated (European Commission 2022i). The REPowerEU Plan established ambitious targets for accelerating the 2018 Energy Efficiency Directive and expediting industry decarbonisation. This includes a focus on electrification, renewable hydrogen and investments in low-carbon manufacturing capabilities. In response, the Energy Efficiency Directive was revised in September 2023, which involved raising the EU's binding RE target for 2030 from the previous 32% to a minimum of 42.5% (European Commission 2024b). The Renewable Energy Directive has also been updated to streamline and expedite the RE permit processes and grid infrastructure projects, which includes more efficient procedures and clearer deadlines for issuing permits for various projects, including solar and wind energy and heat pumps (EU2022.cz 2022).

The EU agreed on the acceleration of Fit for 55¹ objectives, the formulation of the EU Solar Energy Strategy (European Parliament 2022), the European Wind Action Plan (European Commission 2023h), the Grids Action Plan (European Commission 2023i), the Heat Pump Action Plan (to be adopted), the Biomethane Action Plan (European Commission 2022a), and it adopted a final agreement on the hydrogen and decarbonised gas package in December 2023 that concretised the EU Hydrogen Strategy (European Commission 2020a). In October 2023, the EU also adopted the Delegated Regulation (European Commission 2023c), which identified 166 PCIs/

PMIs (Projects of Common Interest based in the EU and Projects of Mutual Interest based in EU-connected countries). These projects are key for developing priority electricity corridors, offshore grids, hydrogen and electrolysers, as well as prioritised areas such as smart electricity grids, smart gas grids and cross-border CO₂ networks. Prioritisation of the above projects is a crucial step for meeting the EU's 2030 energy and climate targets and its 2050 climate-neutrality objective. The first PCIs and PMIs based on the revised TEN-E Regulation will be afforded streamlined permitting and regulatory processes, together with eligibility for EU financial support (Radley-Gardner, Beale and Zimmermann 2016).

Numerous key challenges remain, however, and new dilemmas are taking centre stage. First, the EU energy sanction regime is marked by some exceptions (e.g. allowing for emergency seaborne oil purchases), and a lack of urgency regarding the phasing out of Russian gas imports. Despite Russian gas imports via pipelines dropping significantly (–21.4% in share of imports) within a year of the Russian invasion of Ukraine, the EU remains a significant buyer of Russian gas, and purchased 40 bcm of gas from Russia in 2023 (Biroi 2023). Second, the revised Renewable Energy Directive (European Commission 2023t) and Energy Efficiency Directive (European Commission 2023e) lack some strong compulsory measures, which may slow the progress. Third, much like its predecessor, the European Green Deal, the REPowerEU plan has been criticised for promoting measures such as a temporary increase in fossil fuel power generation. Several EU Member States reactivated coal-powered plants as a short-term solution to the energy crisis. Due to increased coal-fired electricity generation, the EU was the only region² in 2022 that saw a year-on-year CO₂ emissions increase (+7%). This number is forecast to decline slightly (by around 1% annually) in 2023 and 2024 as electricity generation from fossil fuels decreases (IEA 2023b, 29). Fourth, multiple and often hasty plans for expanding the EU gas import infrastructure in the form of new pipelines and liquefied natural gas (LNG) terminals have raised questions regarding their economic feasibility and potential overinvestment, resulting in long-term infrastructural lock-ins. Moreover, importing LNG over long distances, including gas extracted through fracking, does not align with the EU climate agenda. This situation underscores the inherent trade-offs facing the EU in balancing immediate geopolitical needs with long-term climate goals. Fifthly, many current plans for the future energy supply rely on new technologies (e.g. CCS³, green hydrogen), yet the latter remain in early development stages and will pose a challenge to scale up. Lastly, the current shift in EU energy policy has profound economic and geopolitical implications. In the short run, phasing out Russian fossil fuels will incur high costs for the European industry and economy,

especially in countries formerly highly dependent on Russian gas (e.g. Germany). Furthermore, if the EU extends its new geopolitical outlook and its focus on de-riskification to include China's RE sector – a sector on which the EU relies – this could lead to shortages and price increases in critical minerals and green technologies (e.g. solar photovoltaics, wind turbines, batteries).

This report dives into these pressing issues to provide a broad overview of the EU's progress thus far in tackling the energy crisis. The sections below track the progress in the diversification of energy imports, energy demand reduction, energy efficiency measures, electricity market design and deployment of renewables. While the report offers an overview of the current policy landscape and developmental projections towards 2050, it does not cover all energy sectors or technologies. Nor does it intend to address the multiple technical aspects of the green transition. Rather, this analysis is designed to evaluate the progress made in reaching the energy policy targets set forth in the EU's REPowerEU Plan, presented in spring 2022. By highlighting the main shortfalls and challenges encountered so far, the report aims to contribute to informed and effective EU energy policy.

The report can be read in its entirety or selectively by focusing on individual chapters. It also includes a series of detailed cases providing in-depth insights into various related issues.

THE EU PATH TO CLIMATE NEUTRALITY

The climate agenda started making its way into energy policy following the first assessment report published by the Intergovernmental Panel on Climate Change (IPCC) in 1990, adoption of the Kyoto Protocol in 1997, and the Marrakesh Accords in 2001. Within the EU, this translated into the EU Climate Strategy in 1992, EU Emissions Trading Scheme (ETS) in 2005, followed by a revolutionary 2007 EU climate and energy policy proposal, colloquially known as the 20/20/20 objectives, which included a 20% share of renewables in energy consumption, a 20% improvement in energy efficiency by 2020 and at least 20% reduction in greenhouse gas (GHG) emissions by the same date as compared to 1990 levels (Commission of The European Communities 2007b; 2007a). The 2020 agenda was succeeded by the 2030 Framework, also known as the 'Fit for 55' package, which encodes legislative strategies from 2020 onwards. This framework expands and enhances the objectives set in the 2020 targets (see Siddi 2020), which are further developed in the European Green Deal (henceforth the 'Green Deal'), a pledge to transform the EU into a sustainable, resource-efficient and carbon-neutral economy by 2050.

DIVERSIFICATION OF ENERGY IMPORTS

The REPowerEU plan to phase out Russian fossil fuels by 2027 (European Commission 2022i) → the EU's fifth sanctions package bans the Russian coal imports from 10 August 2022 → the EU's sixth sanctions package bans Russian crude oil imports from December 2022 and refined oil products from 5 February 2023.

When the war in Ukraine erupted in February 2022, the EU was highly dependent on Russian gas, oil and coal imports, which covered 45%, 30% and 46%, respectively, of its total consumption (European Commission 2022e). Hence, energy import diversification became one of the fundamental points in the new EU energy policy.

The 'REPowerEU Communication' issued by the European Commission in spring 2022 emphasised the urgent need to end EU reliance on Russian fossil fuels, particularly in the gas sector. The emphasis on gas – despite oil being the primary source of Russian revenue – reflected the greater vulnerability of the EU gas sector due to its high dependency on Russia, limited diversification options and the role of gas as a transitional fuel in the green energy transition. In May 2022, the REPowerEU Plan called for the phasing out of all Russian energy imports by 2027 (European Commission 2022c). To ensure adherence to the phase-out policy across the bloc, energy trade with Moscow was covered by several EU sanctions packages (2022-23) targeting Russian coal and oil imports. Consequently, the EU import of various Russian energy sources (coal, natural gas and petroleum oils) have all been systematically decreasing since the second quarter of 2022.

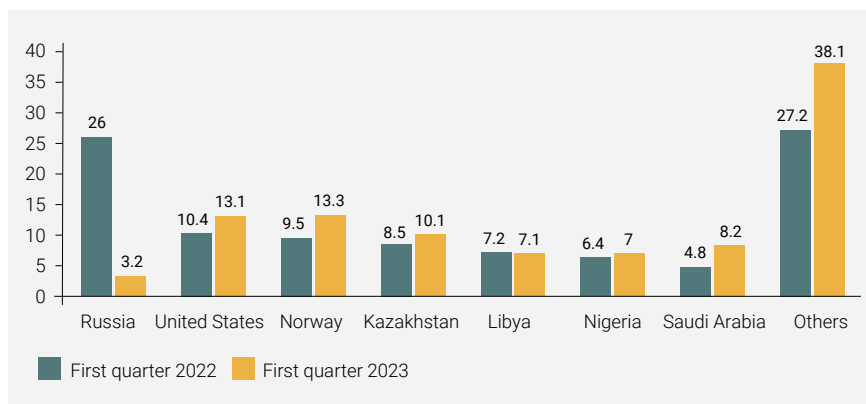
As a consequence of the coal ban, Russian coal imports were already at near-zero in September 2022 (Eurostat 2023c). To cover the missing volume, the EU states increased their coal imports between the first quarters of 2022 and 2023 from other suppliers, most notably South Africa (+12%), the United States (+10%), Australia (+9%) and Columbia (+5%), among others (Eurostat 2023c).

DIVERSIFICATION OF OIL

In the first quarter of 2023, EU petroleum oil imports from Russia plummeted from 26% to just 3.2% (see Figure 1). This shift was facilitated by the inherently global nature of the oil market, which allowed for a smoother transition to alternative suppliers, such as the US, Norway and Saudi Arabia. Unlike gas – which is often traded regionally due to infrastructural constraints in the form of existing transit pipelines (except for LNG) – the flexibility of the oil market and more versatile infrastructure for seaborne trade have enabled the EU to rapidly diversify away from Russian oil.

This significant drop owed to the EU sanction regime, despite the oil sanctions imposed on Russia in June 2022 being marked by certain exceptions, such as allowing piped oil deliveries through the southern branch of the Druzhba pipeline to countries such as Hungary, Slovakia and Czechia (McWilliams, Tagliapietra and Zachmann 2023). In a November 2023 resolution, the European Parliament proposed tougher sanctions against Russia and highlighted the inefficacy of two key strategies

Figure 1. EU imports of petroleum oil by country (share (%) of trade in value)



Source: The graph is made by the authors, based on Eurostat data.
<https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230704-1>

against Russian oil exports: the EU oil price cap and the Price Cap Coalition. The oil price cap is a regional measure that the EU set to limit the sale price of Russian oil within its Member States and to cut Russian oil revenue while ensuring global market stability. In contrast, the Price Cap Coalition is an international agreement involving the G7 countries and Australia aimed at enforcing a global price ceiling on Russian oil. This requires broader international collaboration. However, the resolution highlighted a critical loophole in both measures allowing Russia to circumvent set price limits by exporting crude oil to countries like India, where it is processed into petroleum products ultimately destined for the EU market. Although the Russian oil exports to the EU fell further in 2023, India became the leading importer of Russian crude oil, and EU imports of Indian oil products soared by 115% in the same year (Sharma 2024). This practice effectively bypasses both the EU regional cap and the price ceiling of the global coalition, which challenges the enforcement of effective economic sanctions on Russian oil. More comprehensive measures are needed to prevent such loopholes; especially as the EU remains one of Russia's major fossil fuel consumers, maintaining pipeline gas and LNG imports together with various exceptions to the ban on the import of Russian crude oil and oil products (European Parliament 2023b).

DIVERSIFICATION OF PIPED GAS

Reducing EU reliance on Russian gas presents a major challenge for the diversification policy, as Russian gas previously covered 40% of the EU's demand. The longstanding EU dependency necessitates substantial infrastructure overhaul, securing alternative suppliers and navigating complex economic and political landscapes in the process. In line with the REPowerEU, the bloc seeks to cut its dependence on Russian gas by 155 bcm by 2030. This task is challenging, as gas has been envisioned as a 'bridge fuel' in the energy transition of many European states, with some major EU gas-consuming countries largely relying on Russian gas imports prior to 2022; for example, Germany (55%) (Gordon 2022). Moreover, the existing infrastructure for importing Russian gas and the substantial costs associated with building new LNG facilities in Europe add further complexity. Consequently, market and infrastructural constraints have rendered the immediate phase-out of Russian gas unattainable.

Even without a formal EU embargo, however, numerous countries (e.g. Bulgaria, Lithuania, Latvia, Estonia and Poland) already ceased importing Russian gas through pipelines in 2022 (Holmes 2022; Jarco et al. 2022; Kotseva and Nikolov 2023). The EU drive towards diversification was further bolstered by Russia strategically cutting the gas supply to Europe, often in response to EU countries refusing to participate in the ‘gas for roubles’ scheme via Gazprombank. While some (especially Eastern European) countries strongly opposed the scheme, the European Commission guidelines did not provide a definitive conclusion as to whether such a payment mechanism violates the EU sanctions regime (Yafimava 2022). Not wanting to interfere with market rules, numerous EU Member States opted for a less radical approach. Consequently, the Russian gas continued to flow into Europe via the Hungarian MVM, German VNG, RWE and Uniper, French Engie, Italian Eni, Austrian OMV, Czech ČEZ, Slovakian SPP and Slovenian Geoplin (Hernandez 2022).

The gas diversification policy continued nevertheless, especially amid an increasing number of incidents involving Russian energy blackmail. While Russia has frequently been using energy exports as an instrument of political pressure in its ‘near abroad’ ever since the early 1990s (Slakaityte, Surwillo and Berling 2023), its weaponization of energy post-2022 received extensive media attention. For instance, the anti-Moscow stance adopted by the new liberal Bulgarian government dried up the Russian gas supply in the same year (Fisch and Gera 2022).

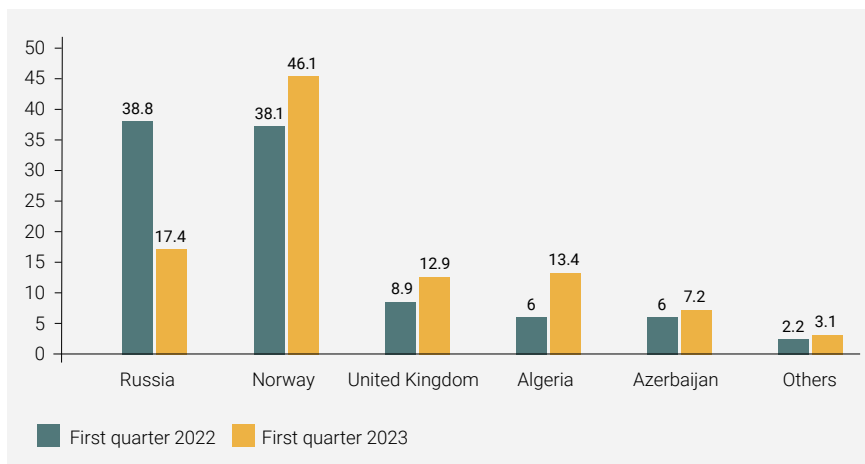
Overall, the level of EU gas dependency on piped Russian gas was more than halved less than a year after the outbreak of war in Ukraine (see Figure 2). The mild 2022-23 winter also played to the EU states’ advantage. Consequently, Russian piped gas exports dropped to 10 bcm in the first five months of 2023 (as compared to 42 bcm in 2022 and 62 bcm in 2021 in the same period) (Kardaś 2023). In 2023, piped gas imports from Russia had fallen dramatically from 41% in 2021 to just 8% (European Commission 2024a).

To compensate for the diminished Russian supply, Member States began securing increased gas volumes through long-term contracts with alternative suppliers, including Norway, the UK, Algeria and Azerbaijan (see Figure 2).

The European gas infrastructure has also become more interconnected since 2022, especially in Central and Eastern Europe (CEE), where several strategic projects reached completion, improving regional security of gas supply. The autumn 2022 launch of the Baltic Pipe project, enabling Norwegian gas transit to Poland via Denmark, marked a significant stride in regional energy infrastructure. This

Figure 2. EU imports of natural gas in gaseous state by country

(share (%) of trade in value)



Source: The graph is made by the authors, based on Eurostat data.
<https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230704-1>

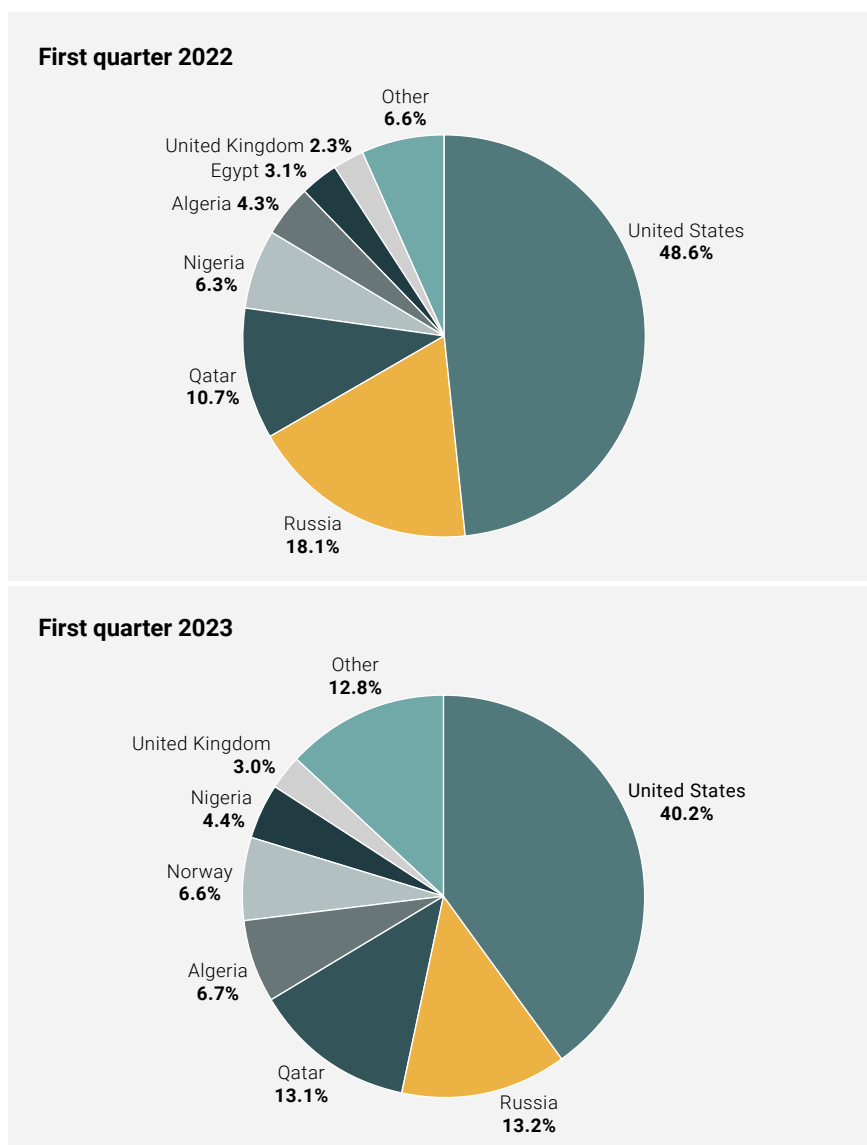
was complemented by the activation of the Poland–Lithuania and Poland–Slovakia interconnectors, as well as the enhanced Latvian–Lithuanian connection. Consequently, CEE states gained access to Norwegian gas and LNG terminals in Gdansk (Poland) and Klaipeda (Lithuania), a capacity further boosted by the Finnish–Estonian LNG terminal in Inkoo. In the south of Europe, a gas interconnector between Greece and Bulgaria also started operations in 2022. Moreover, several pipeline projects for importing gas to the EU are currently under consideration. Although frequently of limited capacity, some of the projects (e.g. interconnectors between Bosnia–Croatia and Bulgaria–Serbia) are of strategic importance for regional gas diversification among the Energy Community⁴ members.

DIVERSIFICATION OF LIQUEFIED NATURAL GAS IMPORTS

The need to diversify gas supplies also had a major impact on the EU LNG market. The EU is the largest LNG importer in the world, importing 130 bcm equivalent of regasified LNG⁵ in 2022 (a 60% increase on the previous year) (IEA 2024a). Russia was the EU's second largest supplier, amounting to almost 20% of the total share of EU LNG imports in the first quarter of 2022 (see Figure 3). Given the need to diversify the LNG routes, the EU shifted its focus towards securing greater volume on the global market and expanding its domestic import infrastructure.

To facilitate this process and as the REPowerEU Plan envisioned, the EU established the Energy Platform for the voluntary common purchase of gas, LNG and hydrogen (European Commission 2022i). The Platform uses the AggregateEU mechanism implemented in April 2023, which currently allows the aggregation of gas demand at

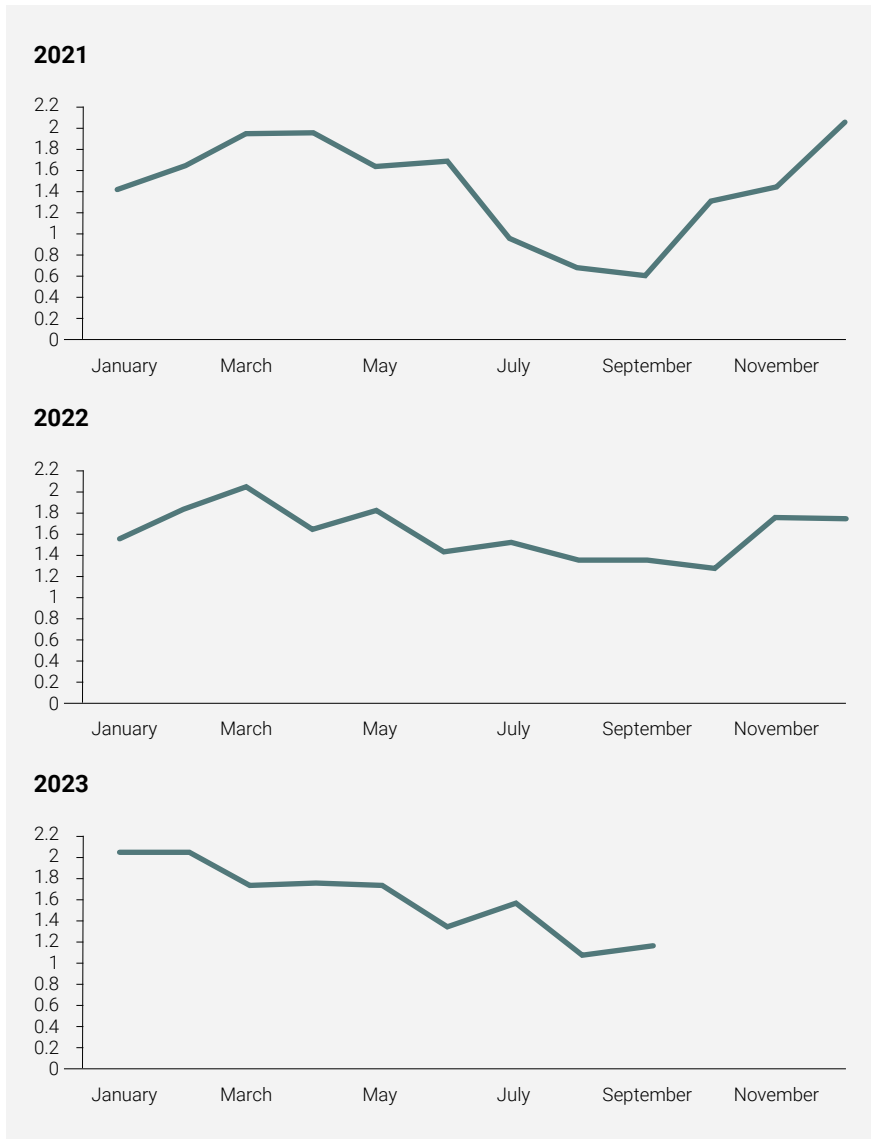
Figure 3. LNG imports to the EU



Source: The graph is made by the authors, based on Eurostat data.
<https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230704-1>

the EU level and to match the Member States with the most competitive global suppliers, thereby facilitating joint gas purchases (European Commission 2023m). Member States are obliged to aggregate demand for gas volumes amounting to at least 15% of their storage filling obligations. Apart from pooling demand, the Platform

Figure 4. Russian LNG imports to Europe 2021-2023



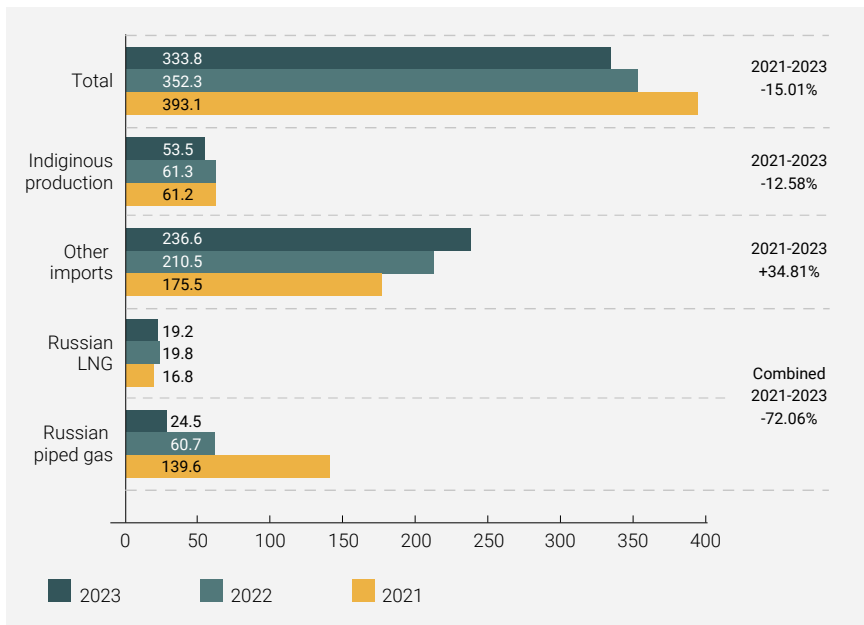
Source: IEEFA, <https://ieefa.org/european-lng-tracker>

is also utilised to negotiate political commitments and regulatory conditions for the increased gas import volumes together with optimisation of the EU gas infrastructure (e.g. LNG import capacity) (European Commission 2023g).

A year after the Russian invasion of Ukraine, the EU share of Russian LNG imports dropped by 5%, while LNG imports from Norway, Qatar and Algeria, among others, increased significantly (see Figures 3 and 4). In the first half of 2023, EU Member States paid nearly EUR 41 bn for the LNG imports coming from the US (EUR 17.21 bn), Russia (EUR 5.51 bn), Qatar (EUR 5.37 bn), Algeria (EUR 3.52 bn), Norway (EUR 2.16 bn) and Nigeria (EUR 1.94 bn) (Jaller-Makarewicz and Russi 2023).

It is worth noting, however, that if we track EU LNG imports from Russia since 2021, the figures look different. According to Global Witness analysis of the Kpler data, a company tracking marine and tanker traffic, the EU Member States purchased 22 mcm of regasified LNG from Russia between January and July 2023, as compared to 15 mcm during the same period in 2021 (Global Witness 2023).

Figure 5. EU natural gas supplies in BCM (2021-2023) and yearly change



Source: S&P Global Commodity Insights • 2023 based on actual data through November, estimates for December.

Similarly, the data reported by S&P Global Commodity Insights indicates that Russian LNG imports have increased by 14.29% between 2021 and 2023 (see Figure 5). In total, LNG accounted for 42% of the EU energy supply in 2023 (European Commission 2024a); although the percentage increased, it did so at a much slower pace than in 2022.

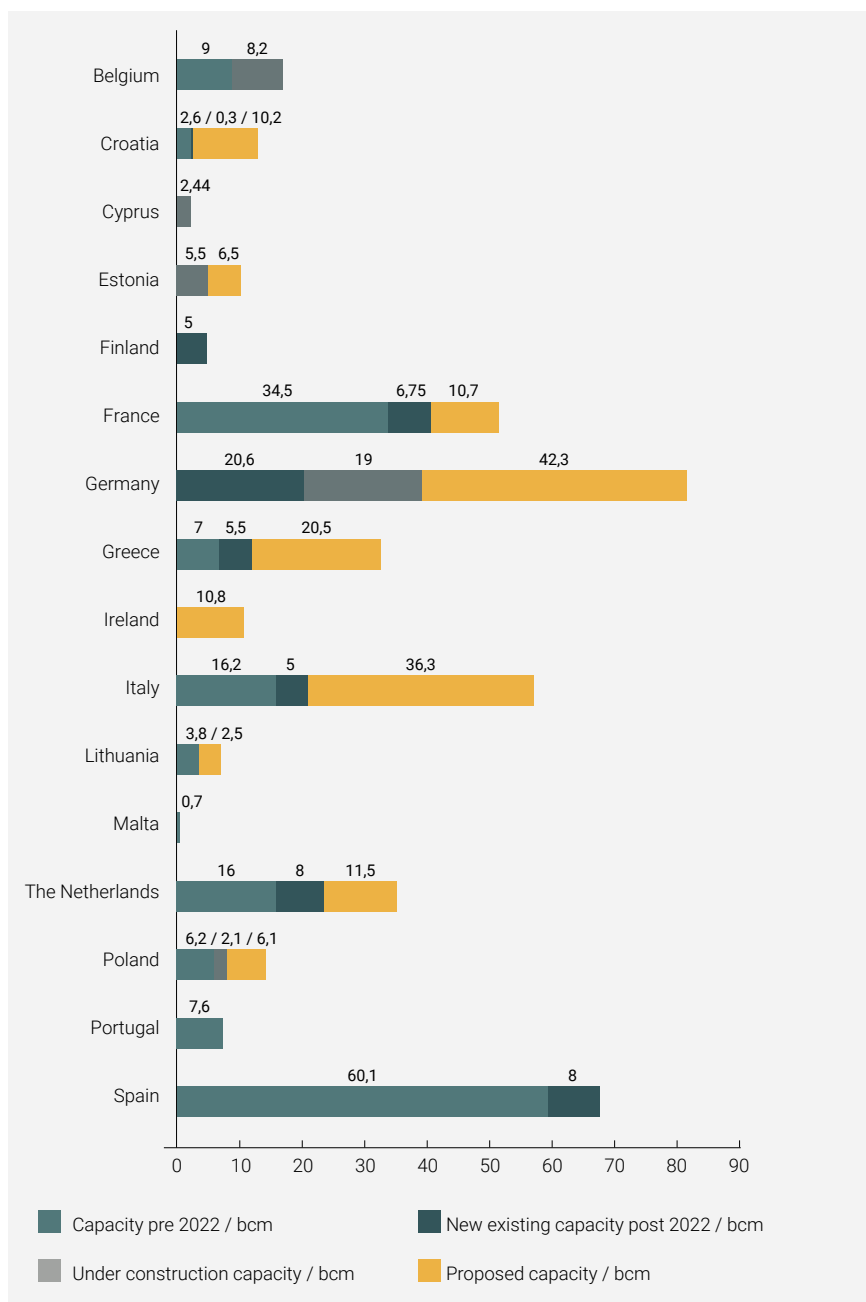
Moreover, EU imports of Russian LNG volumes in 2023 amounted to 52% of Russian exports, as compared to 49% of Russian LNG volumes bought by the EU in 2022 and 39% in 2021. This means that the EU became the largest importer of Russian LNG, with the shipments entering the EU market mostly through Spanish and Belgian terminals (Global Witness 2023).

Unsurprisingly, the EU strategy seeks to prioritise the diversification of its LNG imports, a move bolstered by a substantial increase in LNG production capacities, especially in the US and Qatar. This growth is projected to increase the global LNG supply dramatically and to add an additional liquefaction capacity of 250 bcm by 2030, fundamentally altering market dynamics. IEA Director Fatih Birol noted that this increase will not only lower LNG prices but also reduce the Russian influence on the energy sector. The bulk of these new projects, set to start between 2025 and 2027, will address the current concerns with supply security and price volatility, issues that have become more pronounced following Russian cuts to gas exports to Europe (IEA 2023d).

While LNG terminals in the EU are crucial for diversifying the natural gas supply, their utilisation rates vary. Most operate below capacity, raising questions about expanding gas infrastructure amid the EU push to reduce GHG emissions. Partly driven by a need to address immediate energy security concerns in the context of the gradual Russian gas phase-out, this expansion must be balanced with the long-term EU climate goals. Moreover, importing LNG from distant geographical locations (e.g. Qatar), both produces higher emissions and involves greater geopolitical risks, as seen in recently disrupted LNG shipments through the Red Sea due to Houthi attacks.

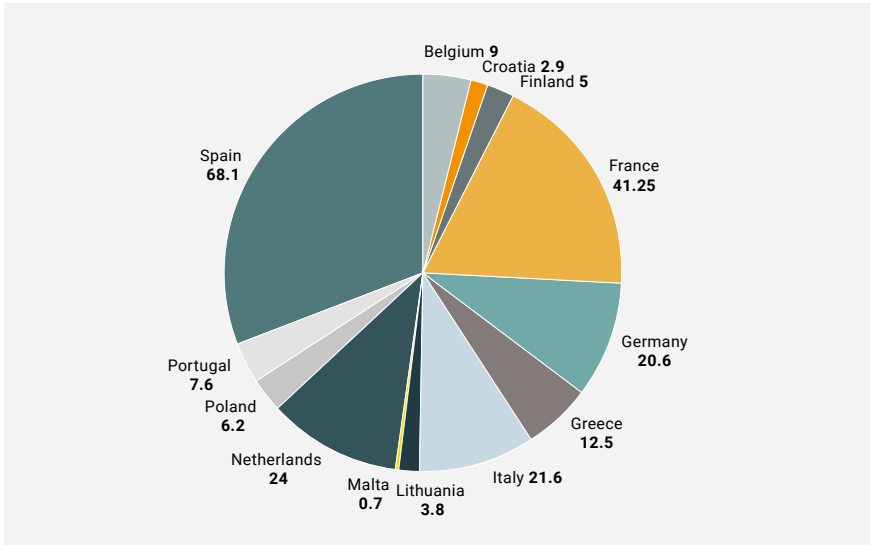
Nevertheless, as the immediate crisis unfolded, attempts were made to bolster LNG import capacity, prompting several European countries to accelerate investments in both onshore LNG facilities and floating storage and regasification units (FSRUs) (Energy Intelligence Group 2022). While FSRUs require half the time to build as onshore LNG terminals (Songhurst 2023), they have lower capacity.

Figure 6. LNG capacities in the EU



Source: The graph is made by the authors, using ENTO-G, GIE, and GEM datasets.
https://www.entsog.eu/sites/default/files/2024-01/ENTSOG_GIE_SYSCAP_2024_1600x1200_168L.pdf
<https://www.gie.eu/transparency/databases/lng-database/>
<https://globalenergymonitor.org/projects/global-gas-infrastructure-tracker/>

Figure 7. Total EU LNG capacity by country in bcm



Source: The graph is made by the authors, using ENTO-G, GIE, and GEM datasets.
https://www.entsog.eu/sites/default/files/2024-01/ENTSOG_GIE_SYSCAP_2024_1600x1200_168L.pdf
<https://www.gie.eu/transparency/databases/lng-database/>
<https://globalenergymonitor.org/projects/global-gas-infrastructure-tracker/>

Since February 2022, 59.15 bcm of new LNG regasification capacity has been installed across the EU including in Croatia, Finland, France, Germany, Greece, Italy, the Netherlands and Spain (see Figure 6). Germany in particular – heavily reliant on Russian gas imports prior to 2022 (55%) (Gordon 2022) – invested heavily in new LNG infrastructure to offset the loss of piped Russian gas (see Figures 6 and 7). The construction of new or the expansion of existing LNG import capacity are currently underway in Belgium, Cyprus, Estonia, Germany, and Poland, while additional LNG projects are proposed across the EU (see Figure 6).

Expanding the EU LNG import infrastructure will ease some of the current infrastructural bottlenecks. Despite relatively high EU LNG import capacity prior to 2022 (approx. 157 bcm/y regasified) that could cover almost 40% of the total demand, the LNG terminals are currently spread unevenly across the bloc (European Commission 2022f). Spain, which boasted much of the entire EU LNG regasification capacity prior to the Russian invasion of Ukraine (approximately 27%), exemplifies one such key bottleneck, as the Iberian Peninsula is currently only linked to the central European gas system by two interconnectors with a combined annual capacity of 8 bcm (Energy Brief 2022).

Although numerous new projects are addressing European gas supply issues, they also raise concerns about costs, the risk of oversized investments and the potential for long-term infrastructural lock-ins.

The Gas Tracker Report (Langenbrunner et al. 2023, 7) highlighted how the construction and commissioning of all planned LNG terminals and pipeline transmission projects in the EU would incur costs of around EUR 53.5 bn. More recent World Energy Outlook (IEA 2023d) estimates forecast that EU spending on LNG import capacity from 2022 to 2030 will be between EUR 51–65 bn. However, the costs of developing LNG import infrastructure are relatively modest compared to constructing export infrastructure.

A more pressing concern could be the risk of oversized LNG investments relative to future demand, leading to sunk costs and long-term lock-in effects that may not align with EU climate objectives. The Institute for Energy Economics and Financial Analysis estimates that the European LNG demand (including EU27, the UK and Turkey) will not surpass 150 bcm/y by 2030. This projection indicates a potential surplus of roughly 256 bcm in unused capacity, highlighting a significant mismatch between the forecasted demand and actual investment plans (Jaller-Makarewicz and Russi 2023).

According to the latest LNG terminal buildout plans in the EU, the proposed projects⁶, if realized, would add an additional 157.4 bcm/y of LNG import capacity, supplementing the 37.24 bcm/y already under construction (see Figure 6). Moreover, over half of the projected expenditure on new gas import infrastructure is anticipated to be borne by just three Member States: Greece, Italy and Germany. This geographical concentration increases the risk of overinvestment in these countries. As gas is a transitional fuel, the infrastructure risks becoming obsolete within a few decades. Although there are hopes that some of the LNG infrastructure (e.g. FSRUs) could be repurposed for hydrogen use in the future, its adaptability remains uncertain. Such discussions have often been used to support new gas projects amid climate concerns.

In the medium term, the mobility of FSRUs provides a key advantage, as they can be moved to different geographical locations to meet shifting gas demand (IEA 2023d, 220). Looking ahead, similar flexibility exists with the transport of hydrogen – which possesses the same qualities for transportation as LNG – offering adaptable solutions in the evolving energy landscape.

The rapid diversification of the EU gas supply drove costs up substantially. In 2022, EU expenditures on natural gas imports exceeded EUR 280 bn, representing a threefold increase compared to the average spending over the previous five years. The surge in import costs contributed to significantly higher end-user prices for both natural gas and electricity (IEA 2023d, 216). The cost increases were driven not only by the EU decision to procure more expensive gas from alternative sources but also by the worldwide surge in gas prices due to the global energy crisis triggered by the Russian invasion of Ukraine.

Gas storage

The EU committed to filling underground gas storage to 80% capacity by 1 November 2022, in preparation for the 2022/2023 winter season → The yearly target for the coming winters to fill storage to 90% of capacity by 1 November each year.

Since the outbreak of war in Ukraine, the EU Member States have succeeded in filling their gas storage facilities ahead of the two consecutive winter seasons. In 2022, EU gas storage was filled to 95% capacity by 1 November, exceeding the 80% target. In 2023, the 90% target was reached in mid-August, far ahead of time (European Commission 2022j).

The new EU regulations also oblige the states to share gas with each other in periods of sudden acute shortages that would affect electricity production (Šefčovič 2023). A solidarity mechanism based on Regulation (EU) 2017/1938 (2017) would only come into effect in the event of an extreme gas crisis and ensure the protection of the most vulnerable customers (e.g. households, hospitals). For the mechanism to work, EU states must agree on the necessary bilateral technical, legal and financial arrangements. Since the outbreak of war in Ukraine, the bilateral agreements have been signed under this regulation between Estonia and Latvia (4 January 2022), Lithuania and Latvia (10 March 2022), Italy and Slovenia (22 April 2022), Finland and Estonia (25 April 2022), Denmark and Sweden (8 May 2023) and Slovenia and Croatia (14 July 2023) (European Commission 2023v). Germany signed solidarity agreements with Denmark (14 December 2020) and Austria (2 December 2021) prior to that. Moreover, some countries had similar agreements in place long before the 2022 crisis, e.g. Latvia-Lithuania, with the underground gas storage facility in Inčukalna (Latvia) used to ensure the security of supply for the vulnerable consumers in Lithuania in case of emergency (European Commission 2014).

DIVERSIFICATION OF NUCLEAR FUELS

Fossil fuels aside, EU dependency on nuclear fuel, particularly for countries operating Soviet or Russian-built VVER reactors (water-water energetic reactor) remains a critical issue. The critical dependency here relates to processed nuclear fuel rather than unenriched uranium alone.

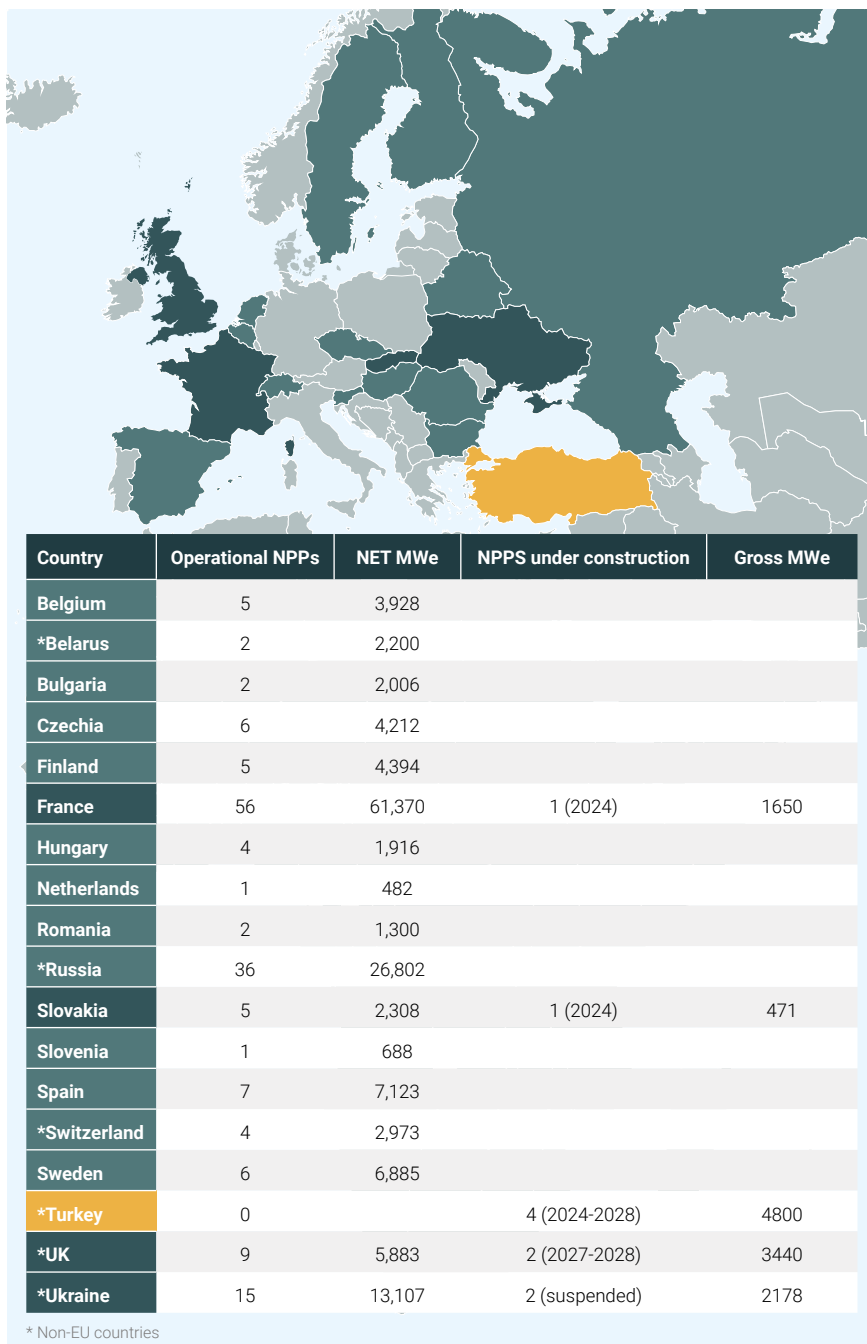
In 2022, the EU imported 97% of its uranium demand, with Russia providing 17% of it. Controlling around half of the global enrichment capacity, Russia plays a pivotal role in the nuclear sector, influencing the competitive landscape (Smyth 2023).

This reliance is evident in 19 Russian nuclear power plant (NPP) reactors in five countries, including Bulgaria, Czechia, Finland, Hungary and Slovakia, which are designed for and dependent on Russian nuclear fuel for both power generation and non-power uses (European Commission 2022i). Bulgaria, the Czech Republic, Hungary, Finland and Sweden have established contracts with Westinghouse, an American nuclear fuel supplier now owned by Canadian corporations, with Cameco and Brookfield Business Partners holding 49% and 51% of the shares, respectively. Additionally, Bulgaria, Czechia, Slovakia and Hungary have obtained alternative nuclear fuel from the French Framatome. Notably, Framatome produces this fuel under a licensing agreement with Russian Rosatom, ensuring compatibility with Russian-designed reactors (AFP 2022). Meanwhile, Slovakia continues to rely on Russian nuclear fuel for its VVER-440 nuclear power plants, with ongoing discussions with potential alternative suppliers.

In the nuclear energy sector, Hungary remains the most Russia-dependent country in the EU. Although the options for alternative fuel suppliers are being explored, Hungary remains reliant on Russian technology and nuclear fuel and new NPP Paks II (to be developed by 2030) have a Russian vendor.

Although France does not house Russian NPPs, its longstanding dependency on Russian-enriched uranium has notably increased, with imports rising from 110 tonnes in 2021 to 312 tonnes in 2022 (Mendoza and Litvinova 2023). Additionally, within the EU context, French energy company EDF remains partially dependent on Russia for the recycling of its spent nuclear fuel (uranium) (European Commission 2023u). It is also worth noting, firstly, that despite the volatile geopolitical climate, Russia has not restricted nuclear supplies or cooperation in this area, as opposed to

Figure 8. Nuclear power in the EU and vicinity



Source: The graph is made by the authors, using WNA, WNN datasets.
<https://world-nuclear.org/information-library/country-profiles/others/european-union.aspx>
<https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx>
<https://www.world-nuclear-news.org/Articles/Akkuyu-unit-1-gets-commissioning-permit>

the disruptions experienced in the natural gas sector; and secondly, a substantial portion of the French unenriched uranium comes from Niger, which experienced a *coup d'état* last year, potentially impacting the supply chain stability.

Overall, the diversification of nuclear fuel away from Russia will take time, and the EU is currently co-funding an APIS (Accelerated Program for Implementation of secure VVER fuel Supply) programme to accelerate this shift between 2023 and 2025 (APIS Project 2024).

ENERGY SAVINGS AND EFFICIENCY

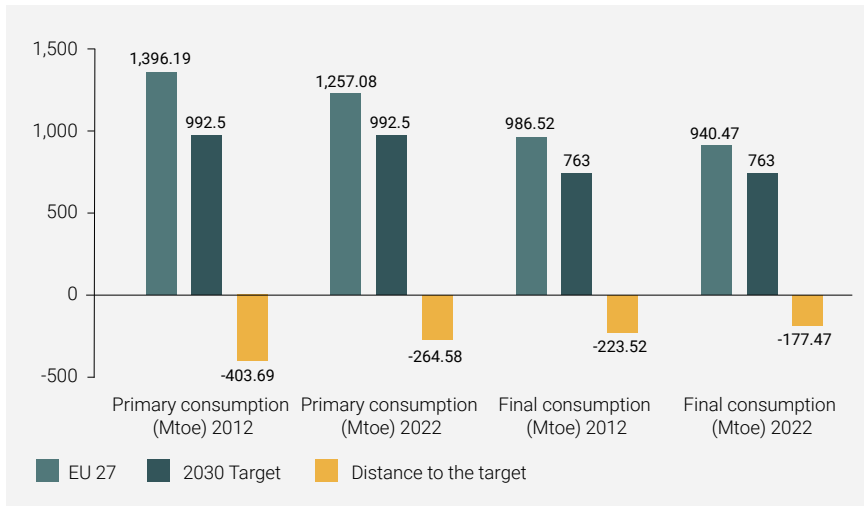
Fit-for 55 – Energy Efficiency Directive Recast (COM(2021) 558) sets energy efficiency target at 9% by 2030 → REPowerEU (2022) proposal at 13% by 2030 → Parliament's (2022) proposal at 14.5% by 2030 → Energy Efficiency Directive Recast 2023/955 (recast) at 11.7% by 2030.

Energy savings and efficiency are among the most cost-effective and sustainable means of tackling the energy crisis and speeding up sustainable energy transition. In the REPowerEU Plan published in May 2022, the European Commission proposed boosting the energy efficiency target to 13% from the 9% previously envisioned in the Fit for 55 package. While the Parliament called for an even more ambitious goal in September 2022 (14.5%), the amendment to the Energy Efficiency Directive from July 2023 settled at the 11.7% binding target for reduced energy consumption by 2030 (European Commission 2023e). This equals a primary energy consumption target of 992.5 Mtoe and a final energy consumption target of 763 Mtoe by 2030 (European Commission 2023f). The new measures mandate EU Member States to progressively reduce national energy consumption by approximately 1.5% annually (Kurmayer 2023).

Reflecting on the EU progress towards the 2030 energy efficiency target, the data from the decade leading up to the Russian invasion of Ukraine in 2022 shows a notable progression in energy conservation across the Member States (Figure 9). The graph depicts a comparison between primary and final energy consumption in 2012 and 2021 alongside the set targets for 2030. The EU has cut energy consumption and made obvious progress towards the 2030 goals, with both primary and final energy usage seeing a decline over that period. Notably, the EU 2020 energy

Figure 9. Energy efficiency: EU's distance to the 2030 targets.

Million tonnes of oil equivalent



Source: The graph is made by the authors, using Eurostat dataset.
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_efficiency_statistics

efficiency targets for both primary and final energy consumption were overachieved, amounting to 1,236 Mtoe and 907 Mtoe, respectively (EU Monitor 2024). Although national lockdown measures due to COVID-19 significantly contributed to energy-demand reduction at the time, the pre-2019 pandemic values already indicated a decreasing trend in energy consumption despite the 2019 values for primary (1,354 Mtoe) and final (986 Mtoe) energy consumption exceeding the 2020 target (Ibid.).

The overall trajectory suggests a positive trend in energy efficiency, underscoring the EU commitment to sustainable energy practices. Nevertheless, sustained efforts will be crucial in ensuring the attainment of the projected targets by the end of the decade.

STRATEGIES FOR ENERGY SAVING AND EFFICIENCY

Moving forward, the means to cutting energy consumption further can be subdivided into three main areas: consumer behaviour changes, motivational fiscal measures and contingency plans. Here, local and national governments will both play a pivotal role in collaborating with citizens and businesses to harness these savings. Collectively, if all EU citizens scrupulously followed these recommendations at home

and work, up to 220 million barrels of oil and up to 17 bcm of natural gas per year could be saved (IEA 2022d). However, except e.g., for some measures imposed on public buildings, energy-saving measures are currently largely voluntary; incentivisation is therefore of paramount importance.

Firstly, it is estimated that short-term behavioural changes could contribute to cutting oil and gas demand by 5%; 13 bcm and 16 Mtoe per year, respectively (Vezzoni 2023). It is therefore crucial for the Member States to prepare awareness-raising campaigns targeting households and industry alike. Current proposals include the publicly supported energy consumption assessments as well as targeted advisory services and support for households, in particular people affected by energy poverty, vulnerable customers, and those living in social housing; targeted advisory services for SMEs and microenterprises; information provision in accessible form to people with disabilities; exemplary projects; workplace and training activities; digital tools; and engagement strategies. A few notable examples of such actions have been taken thus far across the EU. In Italy, for instance, a public campaign promoted shorter showers, unplugging appliances (to avoid standby mode), and using dishwasher and washing machines only when full (Osborne Clarke 2023); in Belgium, the Walloon public service launched a website advising residents on how to reduce their energy bills (The Brussels Times and Belga 2022). Some other notable examples are the IEA's 10-Point Plans to reduce oil and gas use, launched in March 2022 (IEA 2022b; 2022a). Additionally, the joint IEA–European Commission report 'Playing my part' is instrumental in enhancing public awareness about energy-saving benefits. Adherence to such guidelines could save the average EU household approximately EUR 500 annually (European Commission 2022h).

Secondly, the changes in the Energy Efficiency Directive (European Parliament and The Council 2023) propose a range of fiscal instruments aimed at promoting behavioural changes. These measures include fiscal incentives, access to finance, vouchers, grants and subsidies, which are crucial in promoting the development and implementation of energy-efficient measures. Since the beginning of the energy crisis triggered by the post-pandemic supply–demand imbalances in September 2021, EU Member States have allocated EUR 758 bn to shield consumers from rocketing prices (Sgaravatti et al. 2023). The Lithuanian plan, for instance, includes an investment of EUR 2.26 billion for 'Mitigation of the Effects of Inflation and Strengthening Energy Independence.' Allocations feature EUR 275 million for a renovation investment platform and EUR 277 million for green renovations of multi-apartment buildings. It also earmarks EUR 46 million for private electric vehicle charging infrastructure, EUR 60 million for solar power station promotion, and

EUR 19 million for upgrading biomass and fossil fuel boilers, totalling EUR 677 million. Additionally, EUR 254 million is designated for business energy independence and EUR 193 million for public projects (Lithuanian Ministry of Finance 2022). Similar examples can be found across the EU Member States (see Sgaravatti et al. 2023).

Lastly, the adoption of contingency plans significantly enhances preparedness during crises. In this vein, the Council – recognising the urgent need for action – implemented temporary and extraordinary measures in October 2022. These measures, effective from 1 December 2022 to 31 December 2023, are specifically designed to mitigate the impact of soaring energy prices (European Council 2022a). To start with, the targets for the reduction of energy consumption applicable until 31 March 2023 included a non-binding 10% gross electricity consumption reduction target as well as a binding 5% consumption reduction during peak hours, with Member States responsible for the implementation of the context-appropriate measures.

REGULATORY MEASURES AND MARKET INTERVENTIONS

In response to the Russian invasion of Ukraine, the EU implemented a series of regulatory measures designed to stabilise the volatile energy market and advance the EU towards its ambitious climate neutrality goal.

In October 2022, the EU Member States formally adopted emergency measures to tackle high energy prices. Central to these efforts is a regulatory strategy targeting energy operators, specifically in the electricity market. A crucial element in this approach is the implementation of a market cap on inframarginal revenues exceeding 180 EUR/MWh. This cap is directed at coal and gas electricity producers, aiming to balance their financial gains against operational costs without deterring RE investments. Effective until 30 June 2023, this price control measure is a strategic step towards mitigating the energy crisis by ensuring affordable electricity prices while fostering sustainable energy development.

In parallel, various national initiatives have been rolled out across the EU to protect consumers from escalating prices. A prominent example is a joint initiative by Spain and Portugal: the so-called ‘Iberian exception’. This untargeted assistance program caps coal and gas prices for electricity production. Since its implementation in Spain in June 2022, this measure helped to reduce wholesale electricity prices while

simultaneously increasing electricity exports. This policy also contributed to a significant rise in gas-fired power generation, which saw an increase of approximately 25% (an additional 18 TWh) compared to 2021. It is noteworthy, however, how Spain recorded its lowest industrial and commercial sector consumption in 2022 in over two decades, highlighting the intricate connection between market interventions and economic activity (IEA 2023a). Despite implementing a cap on wholesale gas prices, Spain had the second-highest wholesale electricity prices, trailing only the UK (Ibid.).

Furthermore, the EU strategy to navigate the energy crisis involves a temporary measure focusing on the fossil fuel sector. This legislative action introduces a solidarity contribution targeting the profits of businesses dealing in fossil fuels. This contribution is applicable for the fiscal years starting in 2022 and/or 2023. It is calculated based on taxable profits exceeding a 20% increase relative to the average profits recorded since 2018. This additional financial charge is levied alongside the regular taxes and fees already imposed on these businesses in the EU Member States. This initiative reflects a concerted effort to ensure that the fossil fuel sector contributes fairly to the economic challenges posed by the energy crisis.

The Council also set a temporary measure for small and medium-sized companies that are struggling to afford the high energy prices. Member States can impose – on exceptional bases – a temporary set price for supply of electricity below the market cost. The costs can be covered by, for example, redistributing the extra profits from fossil fuel businesses to SMEs and households in need (European Council 2022a).

In August 2022, the European Council introduced a strategic initiative aimed at the gas sector, proposing coordinated demand-reduction measures (The Council of the European Union 2022). This plan set an ambitious target to slash gas consumption by 15% from August 2022 to March 2023, benchmarked against the average consumption during the same period over the previous five years. The framework established by these rules enhances coordination and mandates rigorous monitoring and reporting of national gas demand-reduction measures. Significantly, it also empowers the Council to declare a so-called Union alert, based on a proposal from the Commission. This alert signifies a critical crisis level across the EU, activating a compulsory demand-reduction obligation that spans all Member States (Council Regulation (EU) 1369 2022).

IMPLEMENTATION AND FUTURE OUTLOOK

The EU reduced its natural gas demand rather remarkably over the course of 2022, cutting it by 55 bcm (World Energy Outlook, p. 219). In line with the Council Regulation on the coordinated demand-reduction measures from August 2022, the average natural gas consumption across the EU dropped by 17.7% by March 2023 (as compared to the corresponding period over the past five consecutive years) (Eurostat 2023b) and continued to drop from April to June 2023 (to 65 bcm) (European Commission 2023r). The overall gas consumption across the EU 27 dropped by over 7% in 2023 (A'Hearn 2024).

While the majority of EU Member States successfully met the 15% reduction target between August 2022 and March 2023, Ireland, Slovakia, Spain, Poland, Slovenia and Belgium were among the countries failing to do so (Eurostat 2023b). The most significant drops in gas demand were seen in Finland (-55.7%), Lithuania (-40.5%) and Sweden (-37.2%). Leveraging this 2022 success, the 15% target has been extended to March 2024, aiming to save approximately 60 bcm of gas (European Commission 2023b). It is important to note that this sharp decrease was partly due to the closure or reduced operations of energy-intensive industries (e.g. fertilizer producers). Malta was the only EU state that saw a growing demand for gas (12.7%) in that period. Crucially, the Member States with the highest gas demand in Europe – Germany, Italy and France (Eurostat 2023e) – all managed to meet the new target.

The World Energy Outlook 2023 (IEA 2023d) Stated Policies Scenario (STEPS) projects a significant shift in EU energy consumption patterns. By 2030, the report anticipates a substantial fall in gas demand by an additional 50 bcm, marking a 15% drop from 2022 levels (IEA 2023d, 219). This trend is mirrored in oil consumption, with a forecasted decline of 15%. Furthermore, coal demand is set to experience the most pronounced decrease, with an expected reduction of 55%. These figures highlight a decisive move towards reduced reliance on traditional energy sources in the EU.

While the Russian invasion of Ukraine has also significantly disrupted the global oil market – where Russia is a key player – measures such as self-imposed oil production cuts by OPEC+ countries rested on a voluntary basis. The turmoil has led to extreme oil price fluctuations threatening the global economic recovery. The measures – in addition to the EU sanctions, such as the US, Canadian and British restrictions on Russian oil imports – exacerbate market volatility. While the EU has not established a specific target for reducing oil consumption, its approach to

natural gas reflects a more proactive stance, highlighting diverse strategies for different energy sectors. Between 2021 and 2023, there was a general fall in EU energy consumption, which is attributable to various factors, including soaring prices and the implementation of targeted reduction goals.

Price inflation now appears to be cooling down. Although not yet at pre-crisis levels, the wholesale price of gas is progressively settling. As a consequence of the various energy-saving and efficiency measures, the EU is not experiencing major energy disruptions despite the high costs. And as the emergency measures are coming to an end, the newly updated (July 2023) National Energy and Climate Plans (NECPs) are expected to contribute to the Member States' progress towards meeting the 2030 objectives. As the NECP revisions were scheduled around this critical juncture, it was an opportunity to accentuate national plans for security of supply – a dimension previously not included in the plan. Furthermore, other elements landed on the broadened NECPs agenda (e.g. energy infrastructure, energy poverty) (European Commission 2023I).

ELECTRICITY MARKET DESIGN

Electricity is a unique commodity, as its production overarches fossil fuels and renewables. In recent years, geopolitical turmoil has impacted the EU electricity market. It experienced a demand boom following the lifting of COVID-19 restrictions in 2021 (Jamassb, Nepal, and Davi-Arderius 2023), followed by a 3.5% fall in the demand for electricity in 2022 due to exceptionally high prices (IEA 2023a). EU electricity consumption fell further by 3.2% in 2023, bringing the demand to its lowest in 20 years (IEA 2024b).

These fluctuations are partly due to high gas prices, which significantly impact electricity generation costs, since nearly 20% of all electricity in the EU is gas-generated (European Council 2023b). Market participants anticipate that energy prices will remain elevated, albeit to a slightly lesser extent, until at least 2024–2025. Given these challenges, a sustainable and long-term optimisation of the electricity market design is essential.

Moreover, following the Russian invasion of Ukraine, multiple European net-importers of electricity (Lithuania, Latvia, Estonia and Finland) stopped commercial electricity imports from Russia in May 2022 (Ekonomikas Ministrija 2022). This meant that Russian electricity was no longer entering the European electricity market. The overall drop in electricity demand largely resulted from the inability of energy-intensive industries (e.g. fertilizer producers) to cope with the high energy prices (IEA 2023c). In the years 2021–2022, industrial demand for electricity fell by 52%, followed by a 31% reduction in heating, and 20% decrease as a direct consequence of behavioural changes in consumption (IEA 2023b).

Extreme weather conditions in 2022 resulted in deficits in French nuclear and hydro energy and also prompted Germany to extend its initial nuclear phase-out deadline from the end of 2022 to mid-April 2023. This further escalated the situation, causing a temporary 3% surge in demand for fossil fuel-generated electricity. However, EU fossil fuel generation already hit a record low (drop of 17%) in the first half of 2023, driven by the waning demand for gas and coal (Ember 2023b). While coal-powered production is expected to decline further, gas-generated electricity is predicted to fall the fastest, as it is likely to remain more expensive than coal until at least 2025 (Ember 2023a). Nevertheless, fossil fuels remain crucial for meeting energy demand and preventing blackouts amid unfavourable weather conditions that affect renewable power generation. The transition to electricity supply from RE sources has posed a challenge to the grid due to the intermittent surges of electricity injected into the system (e.g. during sunny days from solar, and windy ones from wind turbines). This intermittence complicates the task of upholding a steady supply–demand balance within the grid (Bjørndal et al. 2023). Currently, the electricity generated must always match the demand; at least before mass-scale electricity storage is developed, which would enable greater grid stability.

Following the disruptions to the electricity market, the EU initiated several reforms to increase its resilience against short- and long-term shocks. In October 2021, the European Commission presented the Member States with ‘the toolbox’ for addressing the immediate impact of the price increases, including the protection of the most vulnerable segments of the economy. The short-term measures included emergency income support and targeted tax reductions. In the medium-term, the EC emphasised investments in RE and energy efficiency, decarbonisation and energy-resilience-building measures. Some concrete proposals included energy storage capacity development (e.g. batteries, hydrogen) or increasing the role of consumers by empowering them to choose suppliers, generate their own electricity and join energy communities (European Commission 2021a). Furthermore, the REPowerEU Communication issued in March 2022 proposed revisions of the Electricity Regulation, the Electricity Directive, and the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT). The document drew on a series of measures to counteract the impact of the rising energy prices and to limit the spill-over effect of gas prices on electricity prices.

In June 2023, as part of a comprehensive overhaul of the EU electricity market framework, the Council achieved consensus on the proposed amendments to REMIT, aimed at prohibiting trades based on privileged information and preventing market manipulation. The amendments also meant more stringent requirements for

EU market participants based outside the EU and enhanced the role of the Agency for the Cooperation of Energy Regulators (ACER) in significant cross-border cases. Additionally, national regulatory authorities saw their roles reinforced to maintain a balance with ACER, and Member States were granted the discretion to determine the scale of administrative fines, with guidelines for imposing reduced fines (European Council 2023a). Furthermore, in March 2023 of that year, the European Commission had introduced significant legislative initiatives to further reform the EU electricity market design. These initiatives, comprising amendments to Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944, were designed to respond to the recent energy crisis by addressing price volatility and security-of-supply concerns. Central to these reforms was the aim to decouple short-term market fluctuations from consumer electricity bills, thereby reducing the impact of price spikes and ensuring stable, predictable energy costs. The initiatives also promoted longer-term contracting to bring stability to energy pricing and enhanced existing regulatory frameworks for better coordination among EU Member States. Protection from market manipulation in the wholesale energy market was also a key focus. These measures, aligning with the Green Deal objectives, underscored the need for a transition to cleaner energy sources and enhanced energy efficiency throughout the EU. These initiatives bear witness to the EU commitment to evolving and strengthening its electricity market design in the face of contemporary challenges (European Commission 2023q; European Parliament 2023a).

While these are positive changes, the market reform is still lacking in resilience building and fostering price stability amidst turbulent times. The task is especially complicated, as electricity can be generated using different sources, and the national electricity markets vary significantly depending on the economic situation, market and cost structure of the individual Member State, as well as the energy mix. The most appropriate strategies to mitigate crises therefore differ across contexts and remain best determined at the discretion of the Member States.

The crisis has impacted the Member States to varying degrees, owing largely to the disparity in the magnitude of support, including various targeted direct financial support and retail price measures that the Member States have implemented. In Italy, for instance, the government facilitated tax credits equivalent to 30% of energy bills for businesses. Meanwhile, Austria introduced an electricity price cap and a profit ceiling for oil and gas companies to mitigate the crisis impact (European Commission 2023w; Carter 2023). While these context-specific measures are better-fit to help ease the industries out of crises, the discrepancy harms the competition

between the EU producers (IEA 2023a). At this intricate juncture, the energy-intensive industries are, on the one hand, presented with an option to initiate a shift to high-value goods and low(er) carbon economy. On the other hand, the loss of the domestic energy-intensive industry subjects the EU to yet another import dependency in sectors such as fertilisers, chemicals and construction materials. And while firing up heavy industry with green energy might be the solution, this necessitates a mass-scale roll out of renewables bearing significant upfront costs (IEA 2023b).

While a rapid shift to renewables is costly and complicated, they are expected to increasingly overtake the electricity mix. To facilitate this transition, the EU has prepared a series of policy solutions to ensure the optimal path to climate neutrality by 2050. The next section scrutinises the specifics of deploying solar, wind and heat-pump technologies throughout the EU.

RENEWABLE ENERGY GENERATION

Renewable Energy Directive 2018/2001/EU established a binding target of 32% renewable energy by 2030 → in July 2021 EC proposes target of 40% RES by 2030 → the REPowerEU plan from May 2022 increases the RES target to 45% by 2030 → the revised Renewable Energy Directive EU/2023/2413 sets the binding target of minimum 42.5% RES by 2030.

The energy crisis sparked by the Russian invasion of Ukraine marked a pivotal moment for the European RE sector and accelerated the rollout of RE technologies. Simultaneously, historical European drought conditions posed unprecedented challenges to hydropower generation, which dropped significantly in Italy, Spain, France and elsewhere (IEA 2023b), highlighting the need to diversify the green energy portfolios. The most recent amendment to the EU's Renewable Energy Directive, which entered into force on 20 November 2023, raised the binding RE target from 32% to 42.5% by 2030, with the aspiration to reach 45% (European Commission 2024b). This translates into an almost two-fold increase in the existing share of RE in the EU by 2030.

Going forward, wind power emerges as a key source of energy, with capacity targets surging to impressive heights. Similarly, solar energy will be a driving force of energy transition due to the plummeting costs of solar technology, its adaptability and potential to democratise⁷ energy production. Additionally, in the quest for a carbon-neutral Europe by 2050, heat pump technologies hold particular promise for a more efficient and cleaner heating and cooling future. This chapter delves into the recent developments in each of these sectors across the EU.

CAPTURING WIND ENERGY

Revision of Renewable Energy Directive 2018/2001/EU from July 2021 sets target of 40% RES by 2030, translating into 451 GW of wind power capacity by 2030 → amendment of the Renewable Energy Directive from November 2023 increasing the RE target to at least 42.5%, aiming for 45%, translating into over 500 GW by 2030.

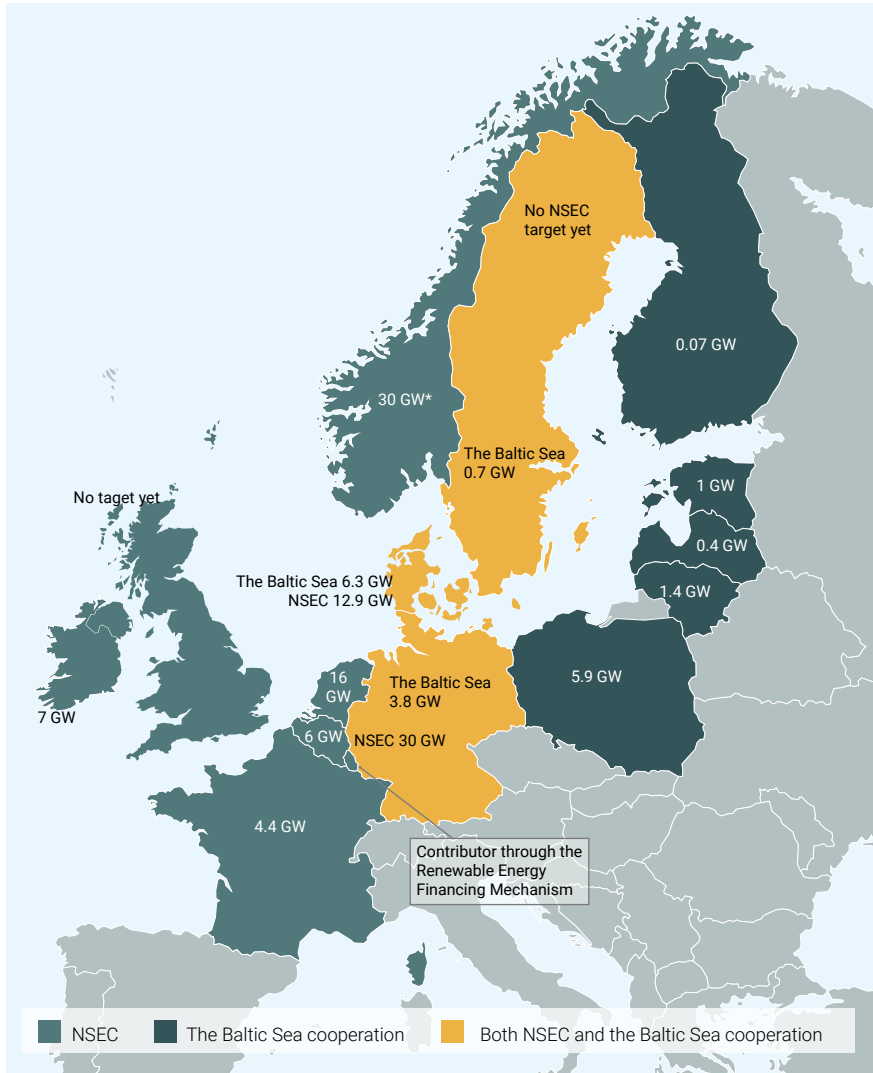
According to the International Energy Agency (IEA 2019), ‘the best offshore wind sites could supply more than the total amount of electricity consumed worldwide today’, therefore offering enormous prospects. The European Green Deal and the EU’s 2050 Energy Strategy (European Commission 2021c), enlisted offshore wind energy as the pivot in delivering targets, thereby increasing the offshore EU capacity five times by 2030 and 25 times by 2050 (European Commission 2024b).

In 2021, the Commission approved a series of accelerated climate targets under the Fit for 55 package, moving the GHG emission target from 40% to 55%. To attain this, the RE target was boosted from 32% to 40%, necessitating revisions to the EU Renewable Energy Directive. The increased target meant that the EU shall house 451 GW of wind power capacity by 2030. The recent amendment of the Renewable Energy Directive from November 2023 increased the RE target to at least 42.5%, aiming for 45% (European Commission 2023t), with the installed wind capacity expected to grow from 204 GW in 2022 to over 500 GW in 2030 (European Commission 2023d). In 2022 alone, the European wind energy capacity increased significantly with the addition of a record 16.3 GW, a record that was broken the very next year with an additional 17 GW (Memija 2024). However, this expansion falls notably short of the required 37 GW/y needed to meet the 2030 targets. Looking ahead, the ambition to achieve climate neutrality by 2050 is even more daunting, necessitating the installation of 760 GW of onshore and 450 GW of offshore wind capacity. This underscores the urgent need for accelerated development in the wind energy sector (European Commission 2023d). Within this context, policy considerations must address the challenges posed by environmental impact assessments and local opposition. Navigating these assessments efficiently and responding to community concerns is vital to ensure that the expansion of solar and wind energy projects is both sustainable and socially accepted.

A Wind Europe report investigated the optimal cost-efficient locations for deploying 450 GW of offshore wind capacity across Europe by that date (Walsh et al. 2019). According to the findings, approximately 212 GW should be situated in the North Sea, 85 GW in the Atlantic region (including the Irish Sea), 83 GW in the Baltic Sea

and 70 GW in Mediterranean and other waters in southern Europe. The EU's Offshore Renewable Energy Strategy (European Commission 2023o) enlists 60 GW of offshore wind capacity as the target for 2030, and 300 GW by 2050. The recently revised National Energy and Climate Plans (European Commission 2023n) reveal that Member States are now aspiring to a remarkably higher goal, aiming to achieve

Figure 10. Renewable energy targets in the North Sea and Baltic Sea regions



Source: RABOBANK.
<https://www.rabobank.com/knowledge/d011347929-great-efforts-required-to-achieve-eu-countries-national-offshore-wind-energy-targets>
 *Norway has not set a target for 2030 within the NSEC plan but plans to contribute 30 GW of installed offshore wind capacity by 2040.

111 GW of offshore RE capacity by 2030. This target is nearly double the ambition originally set by the European Commission in 2020. As of 2022, the cumulative offshore installed capacity across the EU-27 stood at 16.3 GW. Bridging the substantial gap to the ambitious 111 GW target necessitates an average annual installation of almost 13 GW. This rate of expansion is a tenfold increase over the 1.2 GW installed in 2022, highlighting the significant acceleration required in offshore RE deployment to meet these elevated goals (European Commission 2020b). In 2023, an additional offshore capacity of 3 GW was installed (while 14 GW was added onshore); the Netherlands led in offshore expansion, notably with the 1.5 GW Hollandse Kust Zuid, the current world's largest offshore wind farm (Memija 2024). Two maritime zones seem to host the majority of offshore wind turbines: the North Sea and Baltic Sea, established through two Declarations: the Esbjerg Declaration (2022) and Marienburg Declaration (Baltic Wind 2023), respectively. Furthermore, the Ostend Summit in April 2023 – bringing together Belgium, Denmark, Germany and the Netherlands, France, the UK, Ireland, Norway and Luxembourg – further increased the ambition to 300 GW by 2050 in the North Sea ('The North Sea Summit' 2023).

THE ESBJERG DECLARATION

The Esbjerg Declaration is a pledge by four EU Member States (Denmark, Belgium, the Netherlands and Germany) to install at least 65 GW of offshore wind power by 2030 and to further increase the capacity to 150 GW by 2050. This will deliver more than half of the needed capacity to reach the EU's climate neutrality target. The expansion of wind capacity is also paired with several other initiatives: a bilateral agreement between Denmark and Belgium to establish interconnectors for the inaugural energy island (of 10 GW before 2040), plans for additional energy islands, missions to secure the greater allocation of EU funds for offshore projects, advocating for smoother approval processes, and elevating the priority of offshore energy projects in the maritime zones. The countries have also committed to large-scale onshore and offshore production of hydrogen to reach 20 GW capacity by 2030. Denmark intends to build 12.9 GW, Germany has the most ambitious target of 30 GW of installed capacity by 2030, Belgium intends to contribute with 6 GW capacity, and the Netherlands are aiming at 16 GW capacity in the North Sea by 2030. Following the Esbjerg Declaration, in September of 2022, the North Seas Energy Cooperation (NSEC) further accelerated the offshore wind capacity target to 76 GW by 2030 and an ultimate 260 GW by 2050 (Janipour 2023). The contracting parties also include: Norway with a 30 GW target for 2040, France with a contribution of 4.4 GW by 2030, Ireland, planning for 7 GW by 2030 (Mc Gowran 2022), while Luxembourg and Sweden have yet to set targets. In April 2023, the North Sea Summit II concluded with an even higher target of 300 GW set for 2050 ('The North Sea Summit' 2023).

THE MARIENBORG DECLARATION

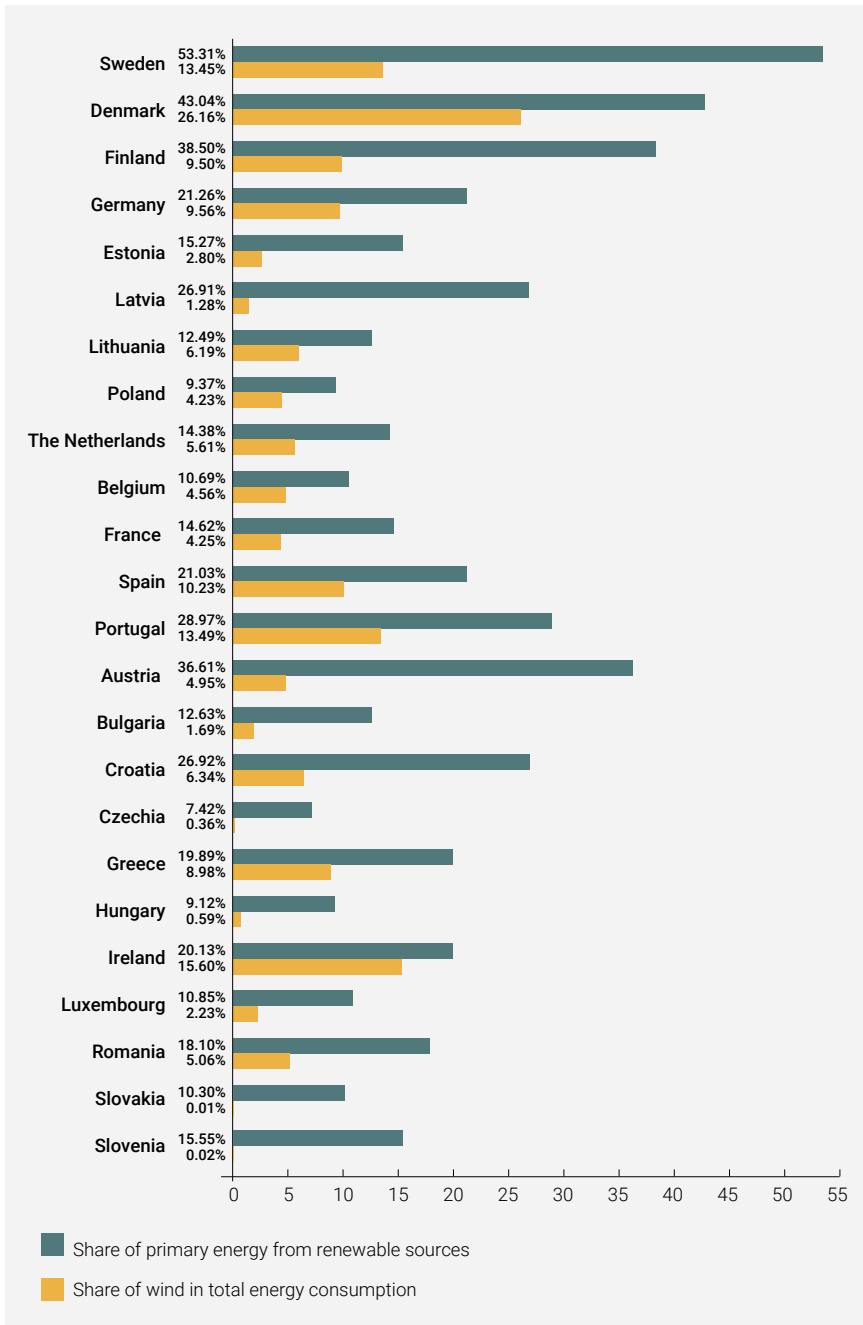
The Marienborg Declaration is a commitment signed by eight Member States around the Baltic Sea: Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Finland and Sweden. The cooperation agreement entails a substantial increase in wind capacity from the current 2.8 GW to 19.6 GW by 2030. While Denmark and Germany are currently the only parties in the consortium with large-scale offshore wind farms in the Baltic Sea, the other parties proposed the following capacities: Poland intends to develop 6 GW by 2030 and 11 GW by 2040, Lithuania indicates a 1.4 GW commitment for 2030, Latvia enlists 0.4 GW, Estonia 1 GW, and Finland and Sweden 0.7 GW each. Denmark and Germany intend to contribute to the Baltic wind capacities with 6.3 GW and 2.8 GW, respectively (Janipour 2023).

In 2022, the cumulative installed wind capacity in the EU was approximately 255.5 GW (Statista 2023). Countries such as Denmark (26.16%), Ireland (15.60%), Portugal (13.49%) and Sweden (13.45%) took the lead regarding the share of wind in total domestic energy consumption (see Figure 11).

In 2023 alone, the EU built 17 GW of new wind infrastructure, which is a significant increase from 16.3 GW in 2022 (Wind Europe 2023) and the 11 GW installed the previous year (Wind Europe 2022). While the EU plans to add an additional 20 GW of wind capacity annually over the following five years (2023–2027), this is insufficient to attain the 2030 targets. Wind Europe (2023) indicates that an annual expansion of 31 GW is needed to stay on track. With six years left to expand the European capacity by 179 GW, the potential success hinges on various factors. While simplified permitting procedures and the development of large-scale, multijurisdictional offshore wind parks are crucial, the strategy for sourcing technologies warrants careful consideration. Investment in domestic European wind energy value chains can strengthen local industries and reduce geopolitical risks. Nevertheless, assessing global market options for efficiency and cost-effectiveness is crucial. Balancing deployment speed with strategic de-risking and economic factors will be key in this expansion.

To date, the most prominent obstacles to achieving a mass-rollout of wind energy have been slow and complex permitting procedures (see Figures 12 and 13). Before the amendments to the Renewable Energy Directive from March 2023, obtaining a permit for a wind farm project was taking up to nine years, resulting in the collapse of multiple projects before permits were obtained. Currently, approximately 97 GW worth of wind power capacity is jammed in the permitting procedures; in other words, there are five times more wind projects in the permitting phase than under

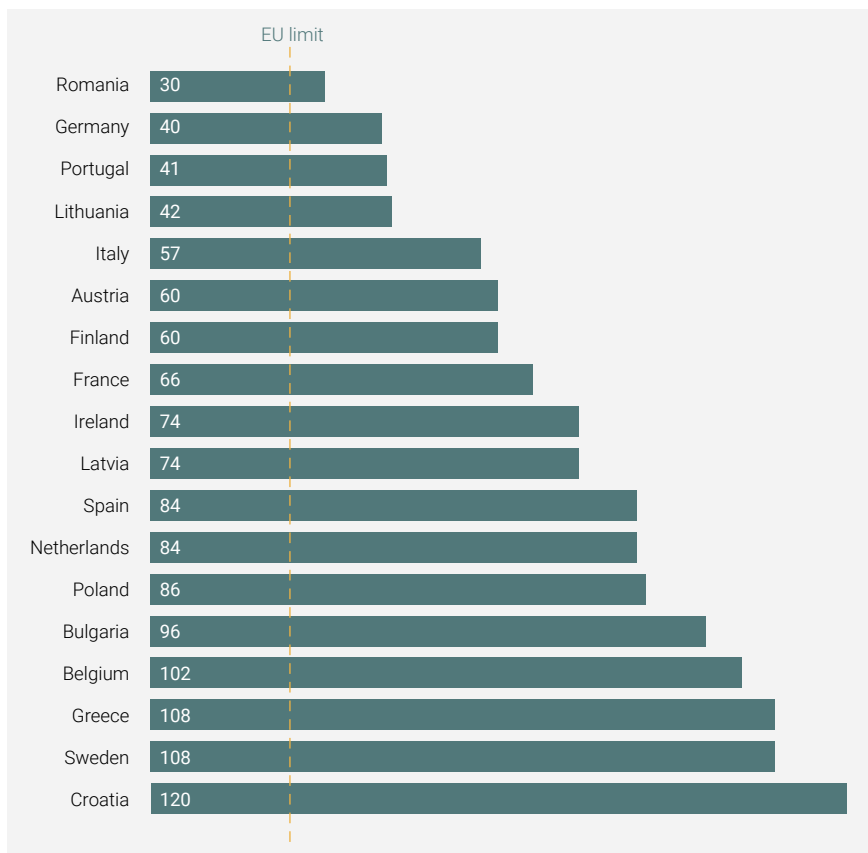
Figure 11. Share of primary energy from renewable sources 2022



Source: The graph is made by the authors, using data available on 'Our world in data' datasets (24 in total). <https://ourworldindata.org/energy>

construction (Ferris 2023). To improve the permitting times in the Member States long-term, the Commission proposed a recommendation on permitting RE projects (European Commission 2022b). In November 2022, the Commission proposed the categorisation of RE as a matter of public importance, which would allow the streamlining of permit procedures. In December 2022, the Council adopted a temporary framework (for 18 months) aimed at speeding up the deployment of the RE projects with the greatest potential for rapid implementation and minimal environmental repercussions (European Council 2022b). The revised Renewables Directive builds on these developments, requiring the Member States to declare wind and solar energy as projects of overriding public interest, while also introducing permit-processing timeframes: a two-year limit for new projects and a one-year limit

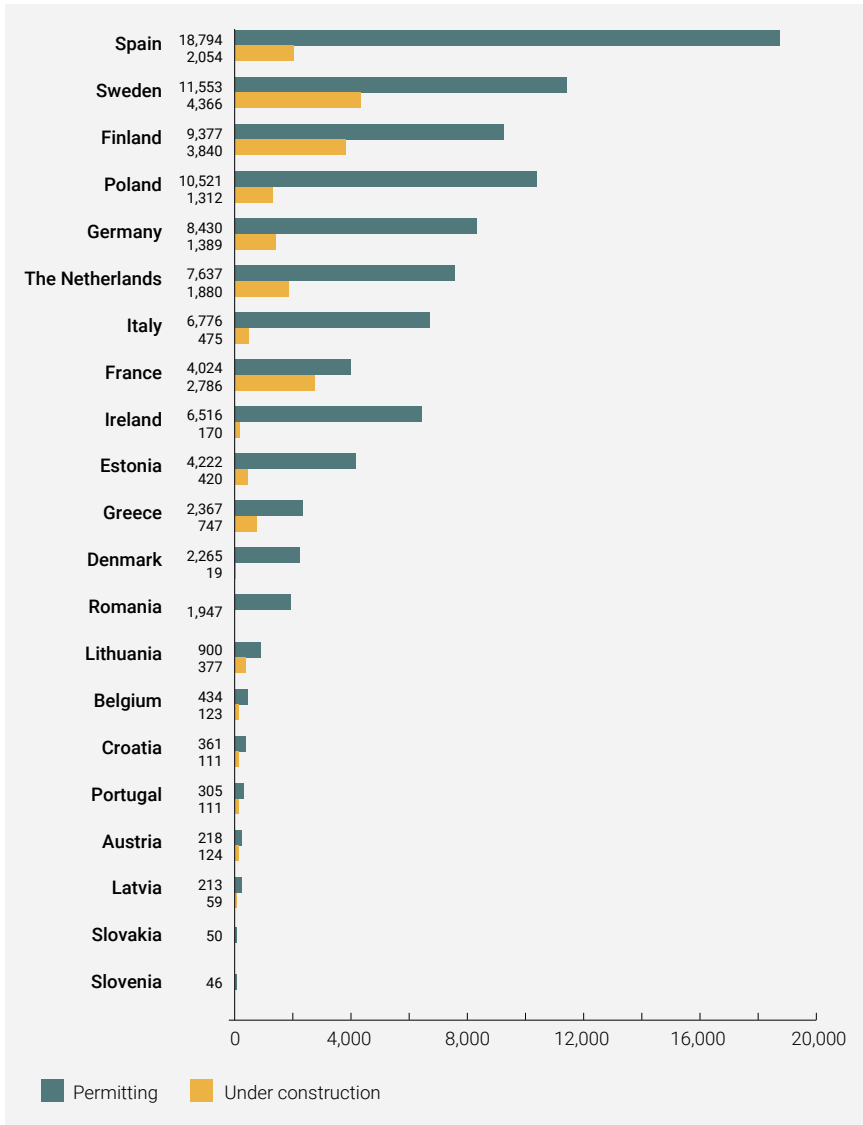
Figure 12. Wind permitting times currently massively exceed the EU limit. Standard onshore permitting times in selected countries, 2022 (months)



Source: Ember, chart: Nick Ferris/Energy Monitor.

for repowering projects; a three-year target is set for permitting offshore wind projects. Here, the digitalisation of permitting processes plays a pivotal role, as it can significantly reduce administrative delays (Ford 2023). To further boost RE deployment, Member States are to develop special zones by 2025 where permitting

Figure 13. There is five-times more wind permitting than under construction in the EU. EU utility wind capacity permitting vs under construction (MW)



Source: GlobalData, chart: Nick Ferris/Energy Monitor.
<https://www.energymonitor.ai/sectors/power/could-too-much-permitting-reform-hurt-eu-renewables/>

is completed within a year for the new projects – and within six months for the repowering projects (Ibid.). However, it is worth noting that the accelerated permitting in the special zones is enabled by an exemption from the environmental impact assessments (Ferris 2023). This exemption could lead to significant opposition from civil society, given its potential negative impact on the environment. Furthermore, emphasising expediency over thorough evaluation contradicts the principles of energy democracy, which values inclusive and comprehensive decision-making. These concerns necessitate careful consideration. Especially how Member States undertake the mapping, assessment and assurance of suitable land and sea spaces for project development in the special zones based on area-wide evaluations rather than individual project assessments; consequently, once a zone is designated, projects within it can be implemented more swiftly.

In addressing the unique challenges of renewable energy, the EU has devised an all-encompassing action plan (European Commission 2023d). In addition to the accelerated deployment and efficient permitting, the plan unfolds across five additional key domains:

Optimised auction design:

Anchored in the proposed Net-Zero Industry Act⁸ and the reform of the Electricity Market Design, the EU is set on revolutionising auction processes. This strategy entails formulating criteria that not only prioritise high-value equipment but also guarantee the timely completion of projects. The Action Plan goes beyond Europe, including procurement standards in Global Gateway projects (focused on sustainability, health and supply chain strength) and cybersecurity assessment.

Accessible financing for wind energy:

To catalyse investment and financing in the wind energy sector, the Commission pledges to streamline access to crucial EU funding sources, notably the Innovation Fund. Concurrently, the European Investment Bank is geared up to offer de-risking guarantees. The Commission also encourages Member States to exploit the potential of the amended Temporary State aid Crisis and Transition Framework, thereby invigorating wind manufacturing throughout the EU.

Establishing an international equilibrium:

The Commission is ardently committed to cultivating a fair and competitive landscape in the wind sector. This commitment encompasses rigorous monitoring and mitigation of unfair trade practices that may benefit non-EU wind manufacturers. Additionally, the leveraging of trade agreements to facilitate market access and the

promotion of EU and international standards play a pivotal role. Engagement with investors to identify and address investment impediments is also a crucial element in this strategy.

Cultivating skills and expertise:

The Large-Scale Skills Partnerships for Renewable Energy is poised to become an instrumental forum for skill development within the sector. Augmented by the Net-Zero Industry Act, the initiative will propel the creation of European net-zero industry skills academies, including a specialised academy for wind energy.

Industry engagement and national commitments:

In a concerted effort, the Commission is set to work hand in hand with Member States and key industry players to establish the EU Wind Charter. This charter is envisaged as a catalyst, enhancing the operational and competitive landscape for the European wind industry, thereby fostering innovation and sustainability.

Furthermore, the lack of social acceptance of large-scale renewable projects is another factor that might hinder wind energy development. Arguably, fast-tracking the permitting procedures without tackling the public dissatisfaction will likely exacerbate public protests and local resistance, potentially also raising legal challenges (Ford 2023). Frequent issues with the popular acceptance of the onshore wind projects together with the vast potential of energy site development in the sea have increasingly shifted the focus to offshore development. While onshore wind farm development might facilitate dispersed ownership, offshore energy installations are inherently tailored to international ownership models due to the intricacy and magnitude of these structures (Linnerud, Dugstad and Rygg 2022). Interestingly, however, although societal approval often tilts in favour of offshore installations (Ibid.), they often take a long time to be deployed due to the complexity of the installation, grid connections and expansion of transmission networks (IEA 2022c).

Lastly, the ability of offshore wind farms to meet decarbonisation targets hinges on institutional support for essential supporting infrastructure, including power grids, hydrogen systems and electrolyzers. The adoption of the Projects of Common Interest (PCIs) and Projects of Mutual Interest (PMIs) list on 28 November 2023, under the binding Regulation (C(2023) 7930 final), is a critical step towards developing interconnected infrastructure networks in Europe. Based on the revised TEN-E Regulation, the list supports the Member States' non-binding offshore goals of reaching 111 GW by 2030 and over 300 GW in 2050 (European Commission 2023s).

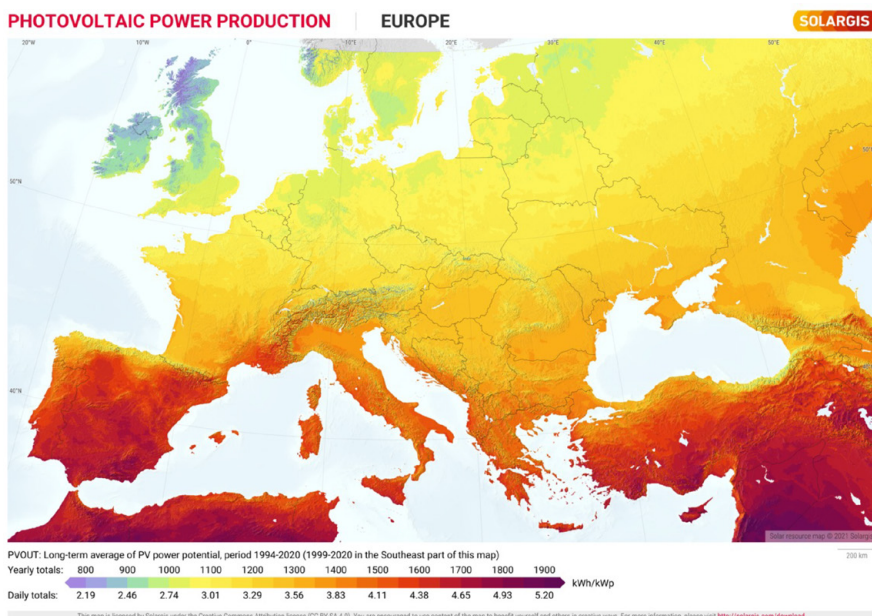
CAPTURING SOLAR ENERGY

The Solar Strategy accompanying the REPowerEU plan sets a target of 320 GW by 2025 and 600 GW by 2030.

Over the past decade, solar energy has become one of the most important sources of RE. In the EU, solar energy technologies that convert sunlight into electricity or heat have been advancing rapidly: from 17.2 GW (EPIA 2012) in 2012 to 263 GW in 2023 (Solar Power Europe 2023).

The rapid expansion of solar energy in the region is largely attributable to a sharp decrease in the price of technology: over a ten-year period, its cost dropped by over 80%. Paired with the clean, modular and flexible nature of the technology, the low price has rendered solar power one of the most competitive sources of electricity production in multiple European regions, especially in the south of the continent (see Figure 14), for industrial and household uses alike. The current shift towards strategic autonomy might threaten this cost reduction. However, as the growing geopolitical competition with China may disrupt its dominant role in the renewable technologies supply chain, it may lead to price increases (Lewis 2024).

Figure 14. Photovoltaic electricity potential



Source: Solar resource map © 2021 Solargis. <https://solargis.com/maps-and-gis-data/download/europe>

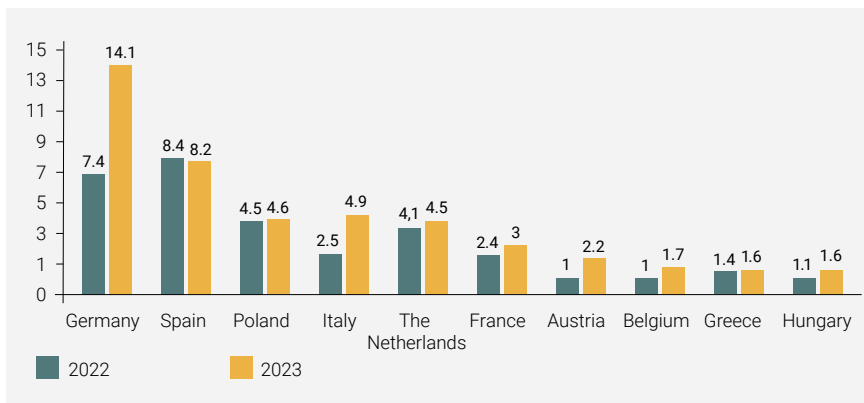
In May 2022, as part of the REPowerEU plan, the EU adopted the Solar Strategy that should result in an additional solar capacity of 110 GW by 2025 and a further 280 GW by 2030. This means that the total EU solar capacity would stand at 320 GW and 600 GW by 2025 and 2030, respectively (European Commission 2022d).

In line with the new policy course, Europe saw a significant increase in its solar capacity with a remarkable 41.4 GW added in 2022 (Solar Power Europe 2022) and a record 56 GW added in 2023, resulting in a total of 263 GW solar capacity and almost 17 million European homes powered by solar in 2023 (Solar Power Europe 2023). As such, 2023 marked the third year of annual growth rates of at least 40%, although a slower growth of about 11% (an additional 62 GW) is predicted for 2024 (Ibid.).

The recent surge in the adoption of solar energy is primarily attributable to the substantial energy price increases resulting from the war in Ukraine, which have rendered solar energy an increasingly cost-effective alternative. One of its most appealing attributes is its modularity, which allows for rapid deployment; from the time of purchase, solar technology can be set up and start generating power in just a matter of days.

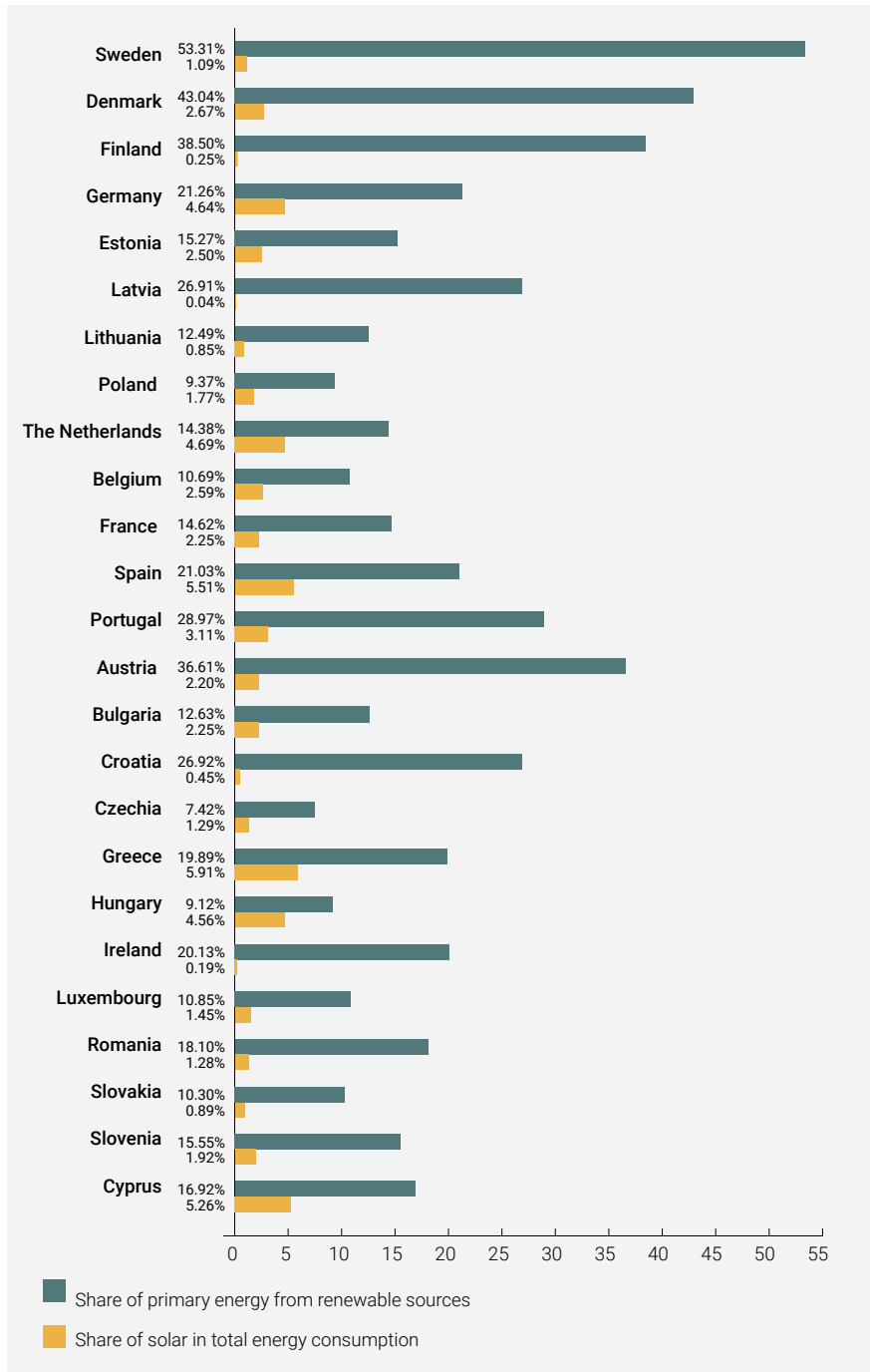
In both 2022 and 2023, many European countries installed significant added solar capacity, with Germany taking the lead (see Figure 15).

Figure 15. The leading EU-27 solar markets (GW) 2022-2023



Source: The graph is made by the authors, Solar Power Europe dataset.
<https://www.solarpowereurope.org/press-releases/new-report-eu-solar-reaches-record-heights-of-56-gw-in-2023-but-warns-of-clouds-on-the-horizon>

Figure 16. Share of primary energy from renewable sources 2022



Source: The graph is made by the authors, using data available on 'Our world in data' datasets (24 in total). <https://ourworldindata.org/energy>

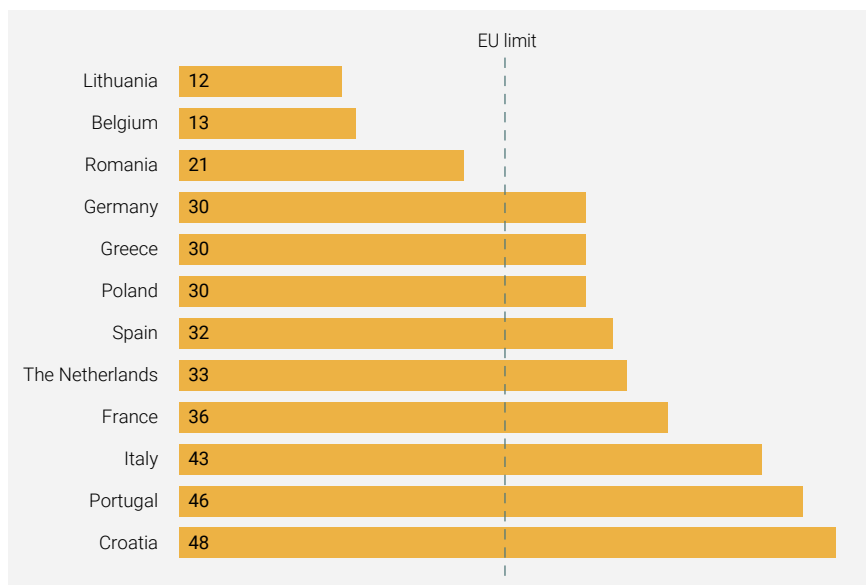
As Figure 16 illustrates, the highest share of solar power in the national energy mix was in Greece (5.91%), Spain (5.51%), Cyprus (5.26%), Germany (4.64%) and Hungary (4.6%).

In 2022 alone, the EU generated 203 TWh of energy using solar technology, which equates to approximately 35 bcm of natural gas (Ember 2023a).

Maintaining the momentum surrounding solar power in the EU will be challenging, however, due to continuous issues with delayed auctions, higher grid fees, an inflationary environment, long permitting processes and long grid connection times. To achieve the Solar Growth Strategy targets, improvements in both administrative and physical procedures are necessary; not least, more efficient permitting and the more rapid connection of industrial solar projects to the grid.

The permitting speed – or lack thereof – is especially worrisome (see Figures 17 and 18), as most EU countries exceed the two-year limit, with delays of up to four years (Ferris 2023). The slow permitting also means that many projects get stuck in the administrative stage, which currently houses eight times the solar capacity in the

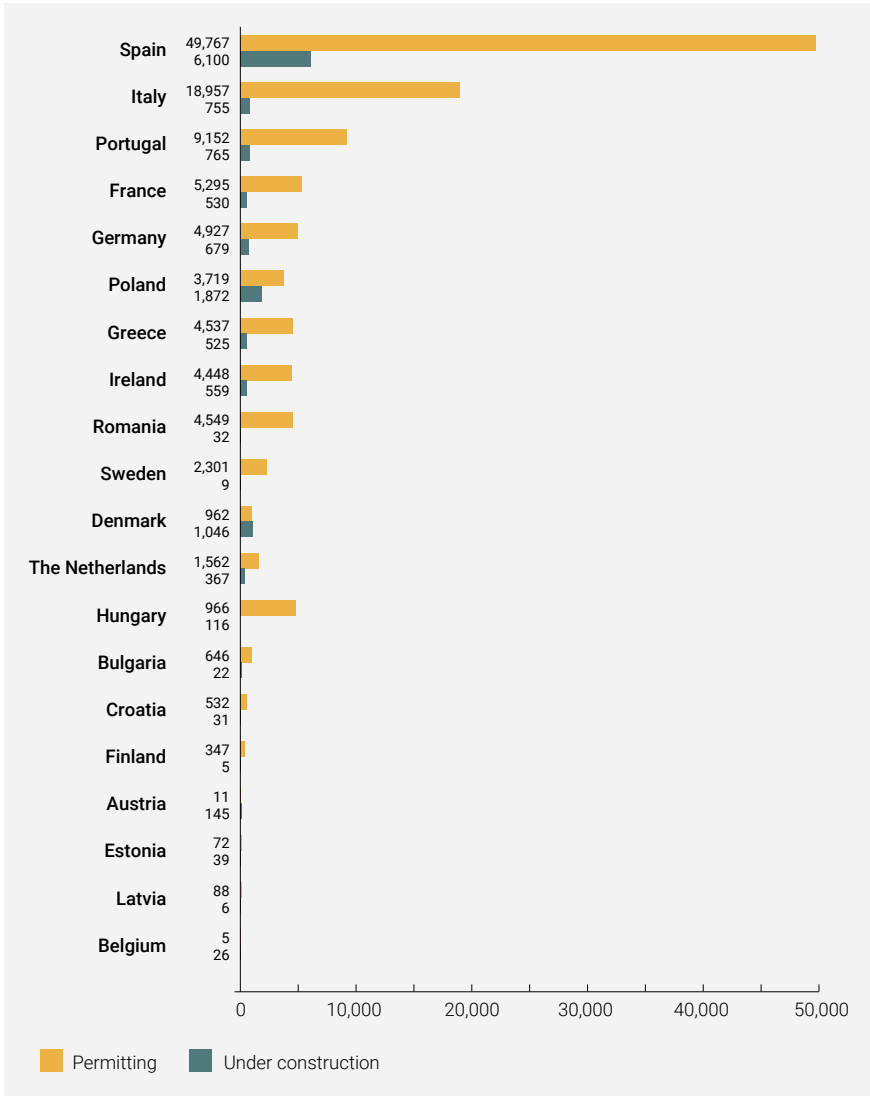
Figure 17. Solar permitting times currently exceed the EU limit in most countries. Standard solar permitting times in selected countries, 2022 (months)



Source: Ember, chart: Nick Ferris/Energy Monitor.
<https://www.energymonitor.ai/sectors/power/could-too-much-permitting-reform-hurt-eu-renewables/>

permitting phase (113 GW) with a mere 14 GW under construction (Ibid). To ensure the successful implementation of the Solar Energy Strategy, three initiatives were launched: the European Solar Rooftops Initiative, EU large-scale skills partnership and EU Solar PV Industry Alliance.

Figure 18. There is eight-times more solar in permitting than under construction in the EU. EU utility solar capacity permitting vs under construction (MW)



Source: GlobaData, chart: Nick Ferris/Energy Monitor.
<https://www.energymonitor.ai/sectors/power/could-too-much-permitting-reform-hurt-eu-renewables/>

The European Solar Rooftops Initiative

The European Solar Rooftops Initiative is the EU-wide initiative seeking to exploit underutilised spaces for solar generation. The initiative is legally binding for certain types of buildings, including newly constructed public and commercial sites, as well as residential buildings. According to Bodis et al. (2019), solar energy housed on rooftops could cover as much as 25% of the EU electricity consumption. Crucially, as such solar installations can be deployed at a rapid pace and shield consumers from price volatility, the initiative offers a speedy solution to the energy crisis. The initiative envisions three stages gradually involving more buildings: First, all newly constructed public and commercial buildings with a total floor area exceeding 250 m² by 2026; Second, all existing public and commercial buildings with a total floor area exceeding 250 m² by 2027; Lastly, all new residential buildings by 2029 (European Commission 2022d). The initiative is expected to accelerate the installations significantly and, if fully implemented, yield 58 TWh of additional solar energy by 2025. This would more than double the Fit for 55 package projections (Ibid.). The provisional agreement on the Energy Performance of Buildings Directive revision reached by the co-legislators in December 2023 is pending the formal adoption process, expected to begin in early 2024.

Importantly, the solar installations on rooftops and in the 'accelerated deployment areas' are exempt from environmental impact assessments; while this cuts the permitting time significantly, it also raises concerns regarding environmental and cultural heritage protection. For instance, stringent regulations governing the installation of solar systems in historical city centres in Italy are in place to ensure the preservation of their picturesque vistas and iconic landscapes (Formolli et al. 2022).

The EU large-scale RE skills partnership

The EU large-scale RE skills partnership serves as a platform for the industrial ecosystem. The initiative focuses on supply chain diversification, support for domestic industry and the empowerment of the skilled labour needed to attain the objectives for 2030 and climate neutrality by 2050. To improve the domestic value chain, an objective of 30 GW manufacturing capacity by 2025 has been set. This boosts European GDP while also creating a new pool of jobs. It is estimated that the solar energy sector will employ approximately one million workers by 2030 (European Commission 2023p), with the Pact for Skills under the REPowerEU plan helping to bridge the employment gap through upskilling and reskilling efforts.

The EU Solar PV Industry Alliance's

The EU Solar PV Industry Alliance's primary goal is to expand the innovation-driven and resilient European industrial solar value chain, focusing primarily on the manufacturing side (Solar Alliance 2023). By bringing stakeholders together from different sectors (industrial, research, consumers etc.), the alliance aims to identify and coordinate a better portfolio for the European solar ecosystem, paying attention to circularity. Importantly, a coherent framework for coordinated actions will be established, meaning that new, more efficient and sustainable technologies can be developed and implemented faster throughout the EU.

HEAT PUMP DEPLOYMENT

REPowerEU framework sets a target of additional 60 million pumps by 2030.

Heat pumps play a crucial role in facilitating the shift towards clean energy and realising the EU objective of achieving carbon-neutrality by 2050. As IEA Director Fatih Birol has noted, 'heat pumps are an indispensable part of any plan to cut emissions and natural gas use, and an urgent priority in the European Union today' (IEA 2022e). Data shows that approximately 50% of the energy consumed in the EU is for heating and cooling purposes, over 70% of which is fossils-based (predominantly from gas). In the residential sector, space and water heating take up to 80% of the final energy consumption (European Commission 2023j). Heat pumps are therefore a fitting technology for more efficient and sustainable heat production, and – in some cases – also for cooling. By extracting ambient energy – either heat or cold from outside, or geothermal sources – the pumps amplify and transfer the energy to where it is needed. As the heat pumps utilise electricity to move hot or cold air between locations instead of creating it, they can provide an energy output up to 15 times greater than the energy they consume. Notably, advanced heat pumps are able to heat rooms with an efficiency rate of 600%, while gas heaters typically range from 50-95% efficiency (AGL 2022).

Today, nearly 20 million heat pumps are operating in the EU, covering 16% of the heating and cooling demand in residential and commercial buildings (EHPA 2023). In line with the European Green Deal targets, the REPowerEU strategy advocates for reducing the reliance on fossil fuel imports by accelerating the implementation of expansive heat pump systems for district heating and cooling networks. Additionally, the Green Deal Industrial Plan proposes EUR 250 bn for green measures under the

NextGenerationEU to facilitate industry decarbonisation by accelerating wind and heat pump deployment (European Commission 2023a). The Plan also addresses eco-design regulations that include the discontinuation of standalone boilers by 2029. The majority of the replacement installations will be hydronic systems,⁹ including hybrid models (European Commission 2023j). Furthermore, the access to the Social Climate Fund – which offers dedicated funding to Member States that ensures support for vulnerable groups, such as energy or transport-poor households – from 2026 that foresees the installation of heat pumps for vulnerable households and micro-enterprises significantly improving their deployment. The overarching goal – following the REPowerEU framework – is to install an additional 60 million pumps by 2030; a minimum of 10 million heat pumps is set to be installed by 2027 already (Ibid.). According to the IEA Report (2022e), heat pumps will contribute to approximately 21 bcm in gas demand reduction by 2030.

Since the outbreak of the war in Ukraine and the subsequent rise in gas prices, the heat pump market has seen a record 40% growth in sales (IEA HTP 2023). The EU houses 22 million old heating appliances, however, as well as thousands of fossil-based heating units requiring replacement and at risk of being replaced by other fossil-based boilers unless appropriate support schemes are put in place (European Commission 2023j). In REPowerEU Communication published in May 2022, the Member States are advised to implement supporting measures – namely, reduced VAT rates – for high-efficiency heating systems that would encourage the switch to more efficient appliances, including heat pumps (European Commission 2022g). In the Commission report, published in 2022, the heat pumps are listed as necessary for meeting the reinforced climate objectives. Consequently, in April 2023, the EU has initiated the Heat Pump Action Plan (European Commission 2023j).

EUROPEAN HEAT PUMP MARKET

While the deployment of heat pumps is expected to accelerate across the EU, most growth is projected in western Europe (Cooling Post 2023). France stands out as an EU leader in the heat pump market, with a strategy to deploy 8 million additional heating and hot-water pumps by 2030. Together with Germany and Italy, the trio is expected to account for nearly half of the EU's heat pump market share (Ibid.). However, countries that do not use gas for heating are the most likely to install heat pumps as an alternative to biomass, district heating and electricity-powered heating. Examining heat pump installation per 1,000 households, the leading countries therefore predominantly consists of smaller northern countries: Finland (39), Estonia (29), Denmark (28), Sweden (24) and Lithuania (15), followed by France (14) (Petkova 2022).

The upgrading of heat pumps – especially if subsidies are not in place – is expensive, with purchase and installation adding up to EUR 10,000–30,000 per unit (for comparison: a fossil-based gas boiler costs around EUR 7,000) (King 2023). The European Heat Pump Association (EHPA) also attributes several obstacles encountered by the industry to the prevailing imbalance favouring fossil fuels in terms of subsidies and taxation (Cooling Post 2023). EHPA also notes that reaching the 2030 target will be insufficient to decarbonise the heating/cooling sector by 2050. Lastly, delivering on the target necessitates at least 500,000 skilled installers (European Commission 2023j), which raises concerns over the availability of such workforce at scale.

BIOGAS/BIOMETHANE

The Fit-for-55 package sets the biomethane target at 18 bcm by 2030 → REPowerEU boosts biomethane production to 35 bcm by 2030.

REPowerEU aims to increase biomethane production to 35 bcm by 2030, estimating that EUR 37 bn investment is needed to achieve that goal (European Commission 2022g, 8).

The Biomethane Action Plan lists a number of actions to accelerate this process and integrate biomethane into the EU internal gas market, including the establishment of an industrial biogas and bio-methane partnership, incentivising biogas producers to create energy communities¹⁰ and to upgrade biogas into bio-methane, investments in infrastructure for the transport of bio-methane through the EU gas grid, fostering further research and development in this sector, and facilitating various funding schemes (European Commission 2022g). Crucially, to prevent the misuse of food crops, which could negatively affect the food supply, the EU is promoting biomethane production from waste, including plant residues, manure, communal waste and industrial wastewater.

However, the increase of biomethane production of 3.5 bcm in 2022 envisioned in the REPowerEU Communication from 8 March 2022 was not reached, and the EU currently does not appear to be on track to achieve its 2030 target of 35 bcm of biomethane (Corbeau and Losz 2023).

HYDROGEN

European Green Deal 5 million tonnes of renewable hydrogen domestic production by 2030 → the REPowerEU increases the renewable hydrogen target to 10 million tonnes of domestic production plus 10 million tonnes of EU imports by 2030.

There are different types of hydrogen, depending on the energy source and technology used to produce it (see Figure 19). Green hydrogen is made by using clean electricity from surplus RE sources (e.g. solar, wind) to electrolyse water. Through electrochemical reactions, electrolyzers split water into hydrogen and oxygen, emitting zero-carbon dioxide in the process (National Grid 2024).

Renewable hydrogen is viewed as a key source for replacing fossil fuels in hard-to-decarbonise EU industries, as it can be used in diverse applications, including heat and power generation, transport, and manufacturing. The EU hydrogen and gas markets decarbonisation package from December 2021 (European Commission 2021b) introduced policy measures for decarbonising gas consumption, the creation of dedicated infrastructure and a market for hydrogen. New rules covered access to hydrogen infrastructures, separation of hydrogen production and transport activities, a certification system for low-carbon gases and tariff-setting. The latter aims to ease access to the existing gas grid for RE and low-carbon gases by removing tariffs for cross-border interconnections and lowering tariffs at injection points. In March 2023, the Council further clarified the rules; for example, by differentiating between tariff discounts for RE (100%) and low-carbon gases (75%) in the gas system and allowing the blending of hydrogen into the natural gas system of up to 2% of volume (instead of 5%) to ensure the harmonised quality of gas (European Commission 2021b). A final agreement on the hydrogen and decarbonised gas package was reached in December 2023, which concretised the EU Hydrogen Strategy (COM/2020/301) (2020c) by differentiating between hydrogen transmission and distribution networks (enabling efficient unbundling regime) and introducing the European Network of Network Operators of Hydrogen (ENNOH) (development and operation of EU hydrogen infrastructure), among others.

Green hydrogen currently comprises a small percentage of the overall hydrogen due to its high production costs. In 2022, hydrogen accounted for less than 2% of EU energy consumption and was largely (96%) produced from natural gas (so-called grey hydrogen) (European Commission 2023k). To switch to its more sustainable form, the REPowerEU document set a target of 10 Mtoe of domestic renewable hydrogen production by 2030, and another 10 Mtoe to be additionally imported to

Figure 19. Color-coded hydrogen production methods and their environmental impact



Source: The graph is made by the authors based on hydrogen classifications.

the EU by the same date. Ensuring a sufficient green hydrogen supply in the future is also key for the EU diversification efforts. In 2021, Russia announced plans to capture up to 20% of the global hydrogen market by 2030 (Patonia 2022). While it plans to produce hydrogen from nuclear and renewable sources, gas will play the biggest role in its energy production (Griffin and Dmitrieva 2022). It is therefore crucial that imported Russian gas is not merely replaced in the future with imported Russian hydrogen.

To proceed with those plans, it is necessary to develop hydrogen infrastructure for the production, import and transport of 20 Mtoe of hydrogen by 2030. Costs have been estimated at around EUR 28–38 bn for EU-internal pipelines and 6–11 bn EUR for storage (European Commission 2022g, 7). The newly formed European Hydrogen

Bank is backed by EUR 800 million of European funding and will be complemented by additional private sector financing to facilitate the EU's domestic production and import of renewable hydrogen. In spring 2024, the European Hydrogen Bank will launch the second round of auctions estimated at the value of EUR 3 bn (von der Leyen 2023).

The EU is set to work on the development of the global hydrogen market and ensuring the diversification of green hydrogen imports. Hydrogen partnerships have already been signed with Egypt, Kenya, Namibia and several Latin American countries, among others (von der Leyen 2023). While countries in the Global South have the highest potential for a sustainable green hydrogen production, the EU should ensure that future cooperation also takes into account those countries' own needs for green hydrogen use, as well as the local impact of green hydrogen production, such as potential water shortages (IRENA 2023).

To facilitate the import and transit of hydrogen within Europe, the development of three major hydrogen corridors is of crucial importance: via the Mediterranean, the North Sea, and in the future also via Ukraine (European Commission 2022g, 7). Several hydrogen pipelines have been proposed. In the south of Europe, CelZa pipeline (Portugal–Spain) and BarMar offshore pipeline (Spain–France) are meant to connect the Iberian Peninsula with the rest of Europe, allowing for the transport of green hydrogen to the rest of the continent by 2030 (en:former 2023; Djunusic 2022). In the north, the AquaDuctus offshore hydrogen pipeline will transit green hydrogen directly from the North Sea to continental Europe by 2035 (Pipeline Technology Journal 2021). Another pipeline project seeks to transit blue (and later also green) hydrogen from Kårstø in Norway and the North Sea to Germany by 2030 (Murphy 2023). Additionally, the Baltic Sea Hydrogen Collector will connect Sweden, Finland and Germany by 2030 (Kuusniemi 2023).

REPURPOSING PIPELINE INFRASTRUCTURE FOR HYDROGEN

The cost of repurposing a gas pipeline for hydrogen transit is estimated at around 10–35% of new construction costs. Due to this potential saving, more than 50% of global natural gas pipelines could possibly be repurposed for hydrogen use (Aarnes and Monsma 2023). However, whereas field tests were conducted for carrying of 5–10% hydrogen blended into gas pipelines, higher-percentage blends are untested, possibly posing higher risks and incurring higher storage and transport costs (Langenbrunner et al. 2023, 15).

The EU has also shifted more resources towards domestic hydrogen infrastructure development. The NextGenerationEU and REPowerEU initiatives aim to invest in hydrogen valleys, hydrogen trains and clean-steel factories. While REPowerEU allocated additional EUR 200 million to develop Hydrogen Valleys in Europe, the European industry committed to a tenfold increase of its electrolyser manufacturing capacities by 2025 (European Commission and H2 Valleys Platform 2023). While 23 hydrogen valleys existed in the EU as of 2022 (European Commission 2022g), more than EUR 17 bn in state aid is to be directed to the development of around 80 hydrogen valley projects across the bloc (von der Leyen 2023).

HYDROGEN VALLEYS

Hydrogen Valleys concentrate renewable hydrogen production, storage, distribution and end-use in a single geographical area (European Commission and H2 Valleys Platform 2023). They are key in developing local and regional hydrogen value chains and fostering research and innovation.

Hydrogen Valley sectors of end use in Europe include user mobility (80%), industrial use as feedstock (67%) and energy (50%). When it comes to energy-related end use applications of hydrogen produced in Europe, around half of the projects will supply hydrogen to gas-fired power plants, while more than half plan to inject the hydrogen supply into the gas grid. One-third of the valleys will also use hydrogen for stationary fuel cells for distributed generation (Ibid.).

According to a recent EC-commissioned study entitled 'The impact of industry transition on a CO₂-neutral European energy system' (Fleiter et al. 2023), EU-produced hydrogen would be cheaper than imports from outside of the continent by 2050 (Collins 2023). The latter would become cost-effective again in case of less optimal deployment of RES and electrolysers in the EU. The same study found that in the cost-optimised scenario, France and Spain would become the most important European hydrogen producers due to favourable conditions for RE generation, while hydrogen production would be unprofitable for Germany; casting some doubts on the current German plans to install an electrolysis capacity of 10 GW by 2030 (Clean Energy Wire and Table.Media 2023). Constructing a Europe-wide hydrogen network that would connect the Nordics, Baltics, the UK, the Iberian Peninsula and France, with Germany, Benelux, Austria and Italy is crucial for the future cost-optimal solutions that are driven by varied RE generation potential and costs across the EU (Fleiter et al. 2023).

Despite the significant investment plans for the green hydrogen industry in the EU, it remains in its early development phase, and only a modest fraction of initiatives is expected to come to fruition by 2030. This situation is indicative of a broader pattern observed in the worldwide green hydrogen market.

CONCLUSION

The path for the EU out of the climate crisis has been paved with numerous obstacles, which have been further complicated by the war in Ukraine and the subsequent energy crisis. Nevertheless, within two years of the Russian invasion of Ukraine, which drastically reoriented EU energy policy, the bloc has achieved several milestones.

The EU Member States managed to phase out Russian coal, drastically reduce Russian oil imports, and make significant efforts to diversify their gas supply from other geographical locations. Piped Russian gas imports to the EU were cut by a staggering 82.45% between 2021 and 2023, with a 59.64% drop recorded between 2022 and 2023 alone. Simultaneously, the European gas infrastructure became better connected due to a variety of regional projects coming to completion (especially in the CEE). Furthermore, numerous new LNG terminals are set to increase the bloc's import capacity. The EU States also fared remarkably well regarding their new yearly gas storage requirements.

The track record of implementing energy efficiency measures across the bloc has also been positive, which follows a wider, years-long trend in the EU. Since 2022, there was also a significant gas-demand reduction achieved on the part of both businesses (partially due to a drop among the fertilizer producers) and citizens (despite the voluntary nature of gas-saving measures). The EU has also proceeded with the acceleration of its green energy transition, with the solar and wind power sectors taking centre stage. EU solar power recorded a record high new capacity

added in 2022 (41.4 GW) and 2023 (56 GW), and the bloc appears to be almost on track to reach its 592 GW of solar PV by 2030 target. Similarly, there was a record new wind capacity added in 2022 (16.3 GW) and in 2023 (17 GW).

However, numerous challenges remain. Despite the overall major drop in Russian gas imports, the share of Russian LNG imports to the EU between 2021 and 2023 increased by 14.3%. Moving forward, diversification away from Russian LNG must be pursued to achieve the phase-out of Russian fossil fuels by 2027. Simultaneously, many plans for the expansion of LNG infrastructure in the EU might need to be revised and scaled down to better match future demand and the EU climate agenda. Moreover, scaling up the deployment of RE, such as offshore wind power, biomethane or green hydrogen, will require ongoing major financial investments, flexible technological solutions, and adequate policy frameworks. The EU is currently falling short of reaching its 2030 wind capacity and biomethane production targets. Despite initial optimism, the green hydrogen sector remains in nascent stages, with only a small percentage of projects expected to materialise before 2030, which reflects a wider trend in the global green hydrogen market.

Overall, proceeding with the required policy and behavioural changes together with investments across a variety of energy sectors, as presented in the REPowerEU Plan, is crucial for achieving European energy independence from Russian fossil fuels and the EU energy transition goals. Should all REPowerEU measures be implemented, the European Commission estimates that approximately 124 bcm of gas can be saved yearly in the EU. These savings would result from a combination of behavioural changes (10 bcm), energy efficiency measures in the residential (37 bcm) and industrial (12 bcm) sectors, increased biomethane production (17 bcm), the development of renewable hydrogen (27 bcm), as well as other renewable sources (e.g. solar, wind) (21 bcm). Keeping track of current targets and focusing policy and resources more on areas that are currently lagging is therefore of paramount importance going forward.

The REPowerEU Plan sets broad goals for the entire bloc, but the intricacies of energy policy are tailored by individual Member States within their National Energy and Climate Plans, updated in June 2023. While many of these national targets surpass the EU's average ambition, as seen in the robust offshore wind expansion initiatives in the Baltic and North Seas, other Member States have less ambitious approaches that not only hinder their own progress but also pose challenges to the collective EU objectives. The collective EU efforts should therefore be channelled towards maintaining the dialogue among the Member States and tracking the progress of national energy and climate policies in line with the common agenda.

NOTES

- 1 A legally binding commitment to reduce net GHG emissions by at least 55% by 2030 (as compared to 1990 levels).
- 2 As compared to large-scale energy-consuming regions, such as USA, China and India.
- 3 Carbon capture and storage.
- 4 The Energy Community is an international organisation that integrates EU energy policies with neighbouring countries, primarily in southeast Europe and the Black Sea region. Established in 2005, it focuses on market liberalisation, environmental standards, RE and energy efficiency to promote an integrated, sustainable European energy market. In addition to the EU, the Energy Community includes Albania, Bosnia and Herzegovina, Kosovo, North Macedonia, Georgia, Moldova, Montenegro, Serbia and Ukraine. Armenia, Norway and Turkey have observer status.
- 5 It is worth noting that liquefied natural gas capacities are often reported in millions and billions of cubic meters. However, this is not entirely accurate. One should keep in mind that the capacities reported in million cubic meters (mcm) and billion cubic meters (bcm) reflect the volume of natural gas when it is regasified from its liquefied state (LNG).
- 6 Including proposed projects without start dates or with dates beyond 2026.
- 7 'Energy democracy' is the idea of decentralising energy production to enable community and individual participation, typically through renewable sources like solar and wind power. This concept promotes local control over energy and aims to make energy access more equitable and sustainable.
- 8 The Net-Zero Industry Act is a part of the Green Deal Industrial Plan, which seeks to increase the production of clean technologies in the EU.
- 9 Hydronic systems use water circulated through pipes by a heat pump to efficiently heat or cool buildings. This approach combines sustainability with effective temperature control.
- 10 In the context of the Renewable Energy Directive, energy communities are locally organized groups of individuals who collaborate on RE projects to advance sustainability, reduce energy expenses and boost local energy self-reliance. These communities align with the goals of the directive by facilitating the deployment of RE sources at the community level.

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