Breaking free from fossil gas

A new path to a climate-neutral Europe

STUDY

Agora Energiewende

Artelys TEP Wuppertal Institut

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In addition to overseeing the power sector and infrastructure, Artelys was entrusted with the coordination of the consultants. TEP Energy was responsible for the buildings sector modelling, as well as the derivation of emission reduction targets. Wuppertal Institute took care of the industrial sector.

Preface

Dear reader,

In view of the accelerating climate crisis, the European Union has set itself a legally binding target to be climate neutral by 2050 at the latest. Climate neutrality means no more burning of unabated fossil fuels. No oil, no coal, no fossil gas.

The escalation of Russia's war against Ukraine and the resulting fossil gas crisis put a spotlight on Europe's high dependency on imports of cheap Russian pipeline gas. The REPowerEU plan is a testament to the resolve of European leaders to rapidly end this dependency and to find a balance between structurally reducing demand and replacing Russian gas with imports from elsewhere or non-fossil molecules such as renewable hydrogen and biomethane.

Against this background, this report presents a structural transition pathway away from fossil gas use by 2050 based on detailed sectoral modelling of the energy, buildings, and industry sectors. We also draw several insights from this work with implications for EU energy and climate policy-making.

I wish you a pleasant reading!

Sincerely yours,

Matthias Buck
Director Europe, Agora Energiewende

Key findings at a glance:

1. **Fossil gas use in Europe can be halved by 2030 and completely phased out by 2050.** This is possible while maintaining today's level of industrial production and fully ensuring security of supply, without disruptive behavioural changes. The phase-out requires a fast ramping up of energy efficiency and renewable energy, as well as the electrification of applications in the buildings and industry sectors.

2. **By 2040, EU greenhouse gas emissions could decline by 89% relative to 1990 levels, with a projected remaining Union greenhouse gas budget for the 2030–2050 period of 14.3 Gt.** The sectoral transition pathways developed in this report show that based on latest technological progress, an EU greenhouse gas reduction target of 90% by 2040 is realistic. It would avoid 3.3 Gt more greenhouse gas emissions than projected in the EU's 2020 Climate Target Plan.

3. **Europe will need a significant amount of renewable hydrogen to become climate neutral, but the demand by 2030 could be only a fifth of that foreseen in REPowerEU.** By prioritising direct electrification and reserving its use for no-regret applications, the EU would need only 116 TWh of renewable hydrogen by 2030, compared to 666 TWh in REPowerEU. This is more cost-effective, more realistic from a security of supply perspective and consistent with the hydrogen sub-targets in the new Renewable Energy Directive. The REPowerEU target should thus be revised.

4. **EU rules on gas, hydrogen, and infrastructure planning must reflect the projected rapid decline in fossil gas demand.**
   (1) A new impact assessment is needed for the EU gas and methane package.
   (2) Governments should evaluate the impact of the decline in gas demand on gas supply and distribution infrastructure, and when updating their National Energy and Climate Plans.
   (3) The sale of new fossil gas-burning equipment in buildings should end quickly.

Content

Executive Summary

The EU Climate Law of June 2021 obliges the EU and its Member States to achieve climate neutrality continent-wide by 2050 at the latest, meaning that all use of unabated fossil fuels must end by this date. With the REPowerEU plan of May 2022, the EU has set the goal of eliminating its dependence on Russian fossil fuel imports well before 2030, signalling the end of cheap pipeline gas supplies from Russia and unravelling the narrative of fossil gas as a "transition fuel" from dirty coal to clean renewables.

However, while much political attention has been focused on the implications of the EU's 2050 climate-neutrality target for the EU's 2030 climate ambition and for the future of coal use, far less attention has been given to the full transition away from other fossil fuels (oil, fossil gas).

This report addresses the role of fossil gas and non-fossil gases in the EU's transition to climate neutrality. Our starting point is the political commitment of the EU's REPowerEU plan of May 2022 to rapidly eliminate Europe's dependency on Russian fossil gas after Russia escalated its illegal war of aggression against Ukraine. This important political commitment has so far not been underpinned with a proper analysis by the EU Commission on how it can be achieved in a cost-effective way consistent with Europe's 2030 climate target.

Our report seeks to fill this gap. It includes:

→ a structural transition pathway away from fossil gas use by 2050 based on detailed sectoral modelling of the energy, buildings and industry sectors;
→ an assessment of what this pathway means for the upcoming debate on the EU's 2040 greenhouse gas reduction target, for energy imports and security of supply, as well as EU financing needs;
→ a critical assessment of the rushed political targets set in the REPowerEU plan for renewable hydrogen and biomethane, based on feasibility, costs and their contribution to Europe's energy security;
→ and reflections on policy implications of Europe's commitment to an accelerated fossil gas phase-out for several policy initiatives currently debated at EU and national levels.

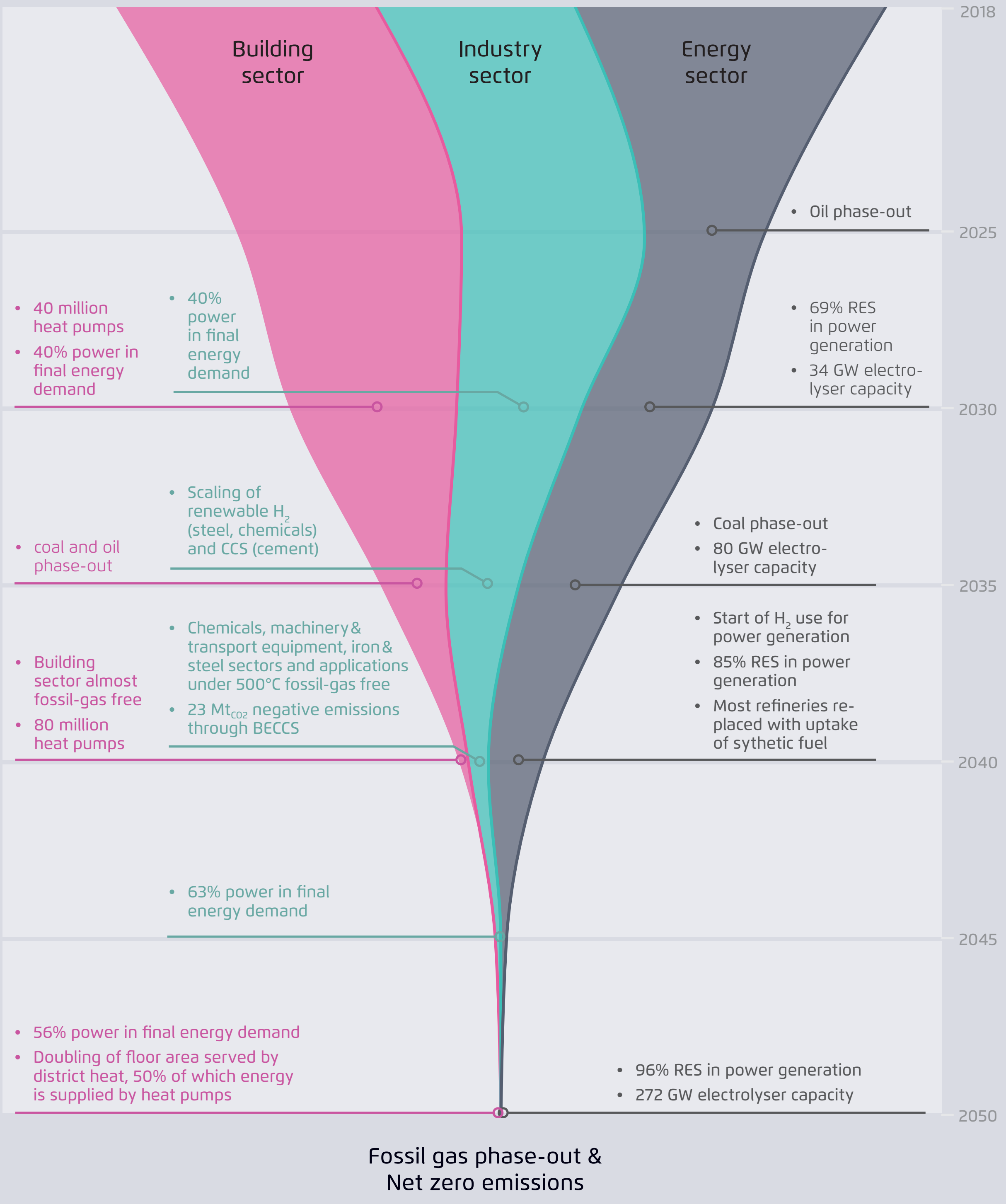
The EU can accelerate the structural phase-out of fossil gas, while meeting its 2030 climate target and achieving climate neutrality by latest 2050

We contracted a consortium of Artelys, TEP Energy and Wuppertal Institute to model detailed transition pathways away from fossil gas use for the EU-27, focusing particularly on changes in the energy, buildings, and industry sectors. The plausibility of emerging results was discussed with partner think tanks in nine Central and Southeast European countries that are historically highly dependent on Russian fossil gas imports (BG, CZ, GR, HR, HU, IT, PL, RO, SI).

The report lays out a detailed *EU Gas Exit Pathway* for fully transitioning away from fossil gas in the coming decades based on structural demand reduction measures, i.e. industrial production remaining in Europe at similar levels as today and not taking into account behavioural changes. In particular, the report highlights the key technology deployment milestones in 2030, 2040 and 2050, with a particular focus on energy, buildings and industry as the main fossil gas-consuming sectors.

The analysis shows that fossil gas use in Europe can be halved by 2030 and completely phased out of the EU energy system by 2050 without disruptive behavioural changes in households or short-term demand destruction in industry, while fully ensuring security of supply. Figure ES 1 below shows important milestones for Europe's transition away from fossil gas use. Notably, the structural reductions of

EU Gas Exit Pathway: technological pathway towards fossil gas phase-out, EU-27 Figure ES 1



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

fossil gas use develop differently in the different sectors and over time.

The **buildings sector** is the first to fully decarbonise in the EU Gas Exit Pathway. Initially, fossil gas demand in buildings decreases by slightly more than a third (-37%) from 2018 to 2030, before significantly accelerating to reach only 45 TWh of residual demand in 2040 (-97% of 2018 levels). Efficiency, heat pumps and decarbonised district heating serve as the key levers for achieving a nearly fossil gas-free building stock by 2040.

The **energy sector**, in particular the power sector, is quickest to reduce its consumption of fossil gas. Fossil gas consumption drops rapidly in the period 2018 to 2030 (-933 TWh), mostly led by the power sector, before declining more moderately in the decades from 2030 to 2040 (-376 TWh) and 2040 to 2050 (-259 TWh). Most of the early displacement of fossil gas is driven by the massive upscaling of solar and wind generation in the power sector, while renewable hydrogen (H_2) and hydrogen derivatives displace much of the existing fossil gas consumption in refineries and for hydrogen production in the decade after 2030. Large-scale heat pumps and deep geothermal also play a crucial role in the displacement of fossil gas in district heating networks, delivering roughly a quarter of district heat production by 2030 and half by 2040.

In the **industry sector**, the structural transformation away from fossil gas proceeds at different paces across the various sub-sectors. The largest reductions in fossil gas consumption up to 2040 are seen in the chemicals (-336 TWh, -100%), food, beverages and tobacco (-128 TWh, -90%), machinery and transport equipment (-88 TWh, -100%), iron and steel (-67 TWh, -100%) and pulp and paper (-60 TWh, -87%) sub-sectors, with several sub-sectors being fossil gas free by then. Nearly half of the residual fossil gas consumption in 2040 is found in the glass and other minerals sub-sectors. Fossil gas demand reductions in industry are initially mostly driven by direct electrification and efficiency increases, complemented later on by renewable H_2 and bioenergy with carbon capture and storage (BECCS).

The EU's greenhouse gas reduction target for 2040 should be set at around 90% reductions compared to 1990 levels

The European Climate Law obliges the EU and the Member States to collectively reduce greenhouse gas emissions (including land-use sinks) by at least 55% by 2030, compared to 1990 levels, and to achieve climate neutrality by latest 2050.

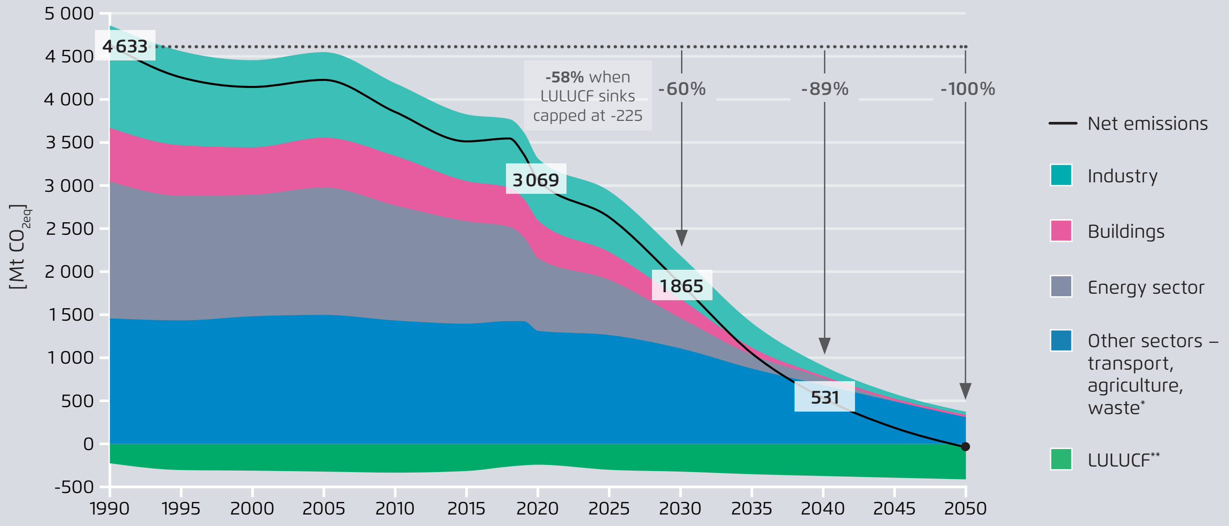
The European Climate Law also obliges the European Commission to propose a greenhouse gas reduction target for 2040 at the latest within six months of the first global stocktake under the Paris Agreement at COP28 in Dubai (30.11.2023–12.12.2023); this means around the time when EU citizens will elect a new European Parliament in May 2024. When presenting its proposal for a 2040 climate target, the European Commission must also publish a projected indicative EU greenhouse gas budget for the period 2030–2050.

Modelling for the EU Gas Exit Pathway suggests that the EU can achieve greater greenhouse gas emissions reductions by 2040 than suggested by existing Commission modelling. Specifically, the EU Gas Exit Pathway achieves net domestic greenhouse gas emissions reductions for the EU of 60% by 2030, 77% by 2035, 89% by 2040, 96% by 2045 and 101% by 2050 (compared to 1990 levels). The resulting EU greenhouse gas budget for the period 2030–2050 is 14.3 gigatonnes (Gt). Our results compare with a 86.4% reduction by 2040 and 17.6 Gt in cumulative greenhouse gas emissions for the 2030–2050 period in the Commission's Climate Target Plan of 2020, which is the modelling underpinning the Fit for 55 legislative package.[1]

1 See Annex 1 for a summary of scenario data

GHG emissions by sector

Figure ES 2



Eurostat, Artelys et al. (2023) *Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste)
**Based on the LULUCF+ scenario from the EC Climate Target Plan impact assessment (assumes a five-year delay)

As such, the analysis demonstrates that the EU can achieve almost 90% greenhouse gas reductions by 2040 compared to 1990 and keep its remaining greenhouse gas budget to 14.3 Gt if the right investment decisions are taken from today onwards. This significant greenhouse gas mitigation potential should be reflected in the upcoming debate on the EU's 2040 climate target.

The EU Gas Exit Pathway shows significant differences to the REPowerEU plan regarding the substitution of fossil gas by (renewables-based) hydrogen and biomethane

The EU Gas Exit Pathway shows that Europe can structurally reduce the consumption of fossil gas by 2027 by an amount that is equivalent to gas imports from Russia before the war. Europe could eliminate its dependency on fossil gas from Russia even earlier if households and industry were to sustain efforts to save energy, similar to winter 2022–23. In any case, the EU Gas Exit Pathway achieves a faster fossil gas consumption reduction than the Commission scenarios underpinning the Fit for 55 policy package, reflecting – like the REPowerEU plan – Europe's increased energy security objectives.

However, a closer comparison of the EU Gas Exit Pathway and the REPowerEU plan shows significant differences:

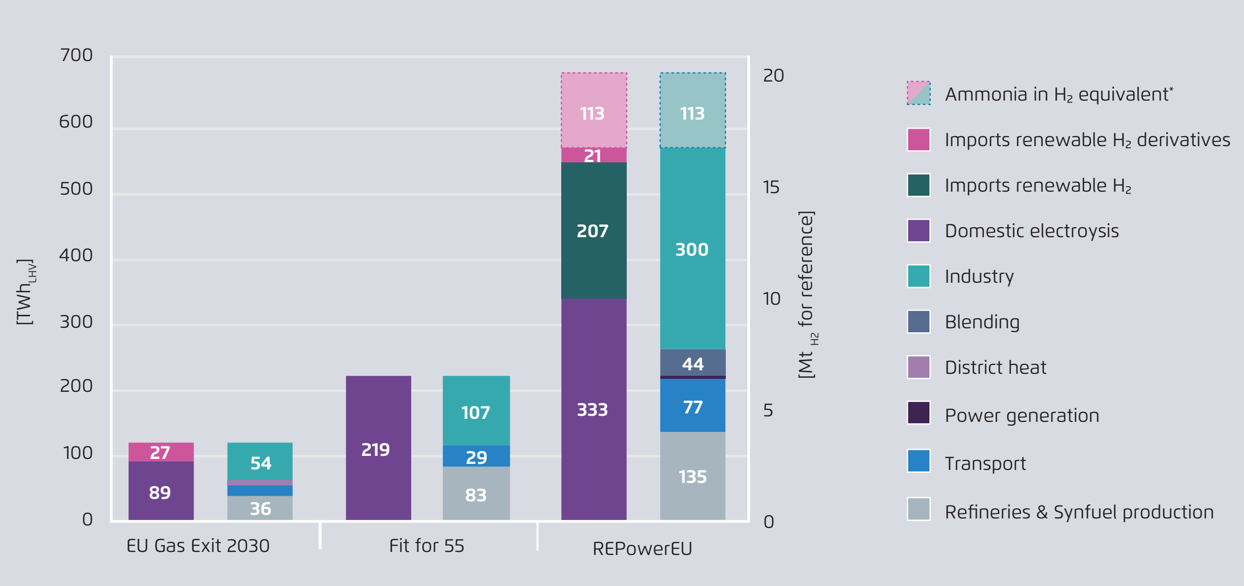
→ The REPowerEU plan achieves higher fossil gas reductions by 2030 (-67% vs 2018 levels) than the EU Gas Exit Pathway (-47% vs 2018 levels). However, modelling for the REPowerEU plan shows that this somewhat faster fossil gas phase-down comes at the expense of oil and coal use that is higher than anticipated in the Fit for 55 package. This counteracts most of the positive climate effects of the accelerated fossil gas phase-down. The EU Gas Exit Pathway, in contrast, achieves faster oil and coal reductions and thus also accelerated emission reductions compared to REPowerEU. Moreover, REPowerEU attributes about 100 TWh of fossil gas demand reduction to behavioural changes in space heating, something not accounted for in the EU Gas

Exit Pathway and explaining roughly 15% of the difference.

→ The REPowerEU plan sets very high political targets for production and import of hydrogen and hydrogen derivatives by 2030. The EU Gas Exit Pathway, in contrast, develops a cost-optimised pathway for the supply and demand of hydrogen and hydrogen derivatives in Europe's transition to climate neutrality. Cost optimisation means that uses of hydrogen and hydrogen derivatives are prioritised for applications where no alternative exists, whereas direct electrification is generally favoured over (more costly) indirect electrification and domestic hydrogen production over (more costly) hydrogen imports. The difference resulting from the modelling is huge. Where the REPowerEU plan foresees absolute consumption of 666 TWh renewables-based hydrogen and its derivatives by 2030, the EU Gas Exit Pathway suggests that 116 TWh by 2030 would be cost optimal. The difference in hydrogen imports is even more pronounced: 333 TWh of hydrogen imports foreseen under the REPowerEU plan contrast with only 27 TWh of hydrogen imports by that date in the EU Gas Exit Pathway. The much lower demand, particularly of imported renewable hydrogen in the EU Gas Exit Pathway, should be welcomed, as it means the EU can achieve its climate targets more cost-effectively, without relying on levels of renewable-hydrogen imports that are unlikely to happen by 2030 and only at significant additional cost compared to renewable hydrogen produced domestically.

→ The REPowerEU plan also sets high political targets for the production of biomethane in 2030 (35 bcm, or 342 TWh). In the EU Gas Exit Pathway, biogas and biomethane consumption remains stable at today's level (196 TWh, or 20 bcm), reflecting a more limited uptake on a cost basis in the modelling and the recognition of an ongoing debate on

Supply by source and sectoral demand for renewable hydrogen and derivatives — Figure ES 3



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).
* Derivatives include ammonia and synthetic fuels. Ammonia has a lower calorific value than H_2. The REPowerEU plan seems to have used the same conversion rate for ammonia as for H_2 for its calculations in Mt. Assuming all of the 20 Mt hydrogen and derivatives in the REPowerEU plan are renewable.

the sustainable potential of biomethane in the EU, particularly when including competing demands for biomass as a feedstock for industry and building material, as well as on bioenergy for high-temperature industry applications in a carbon-constrained world.

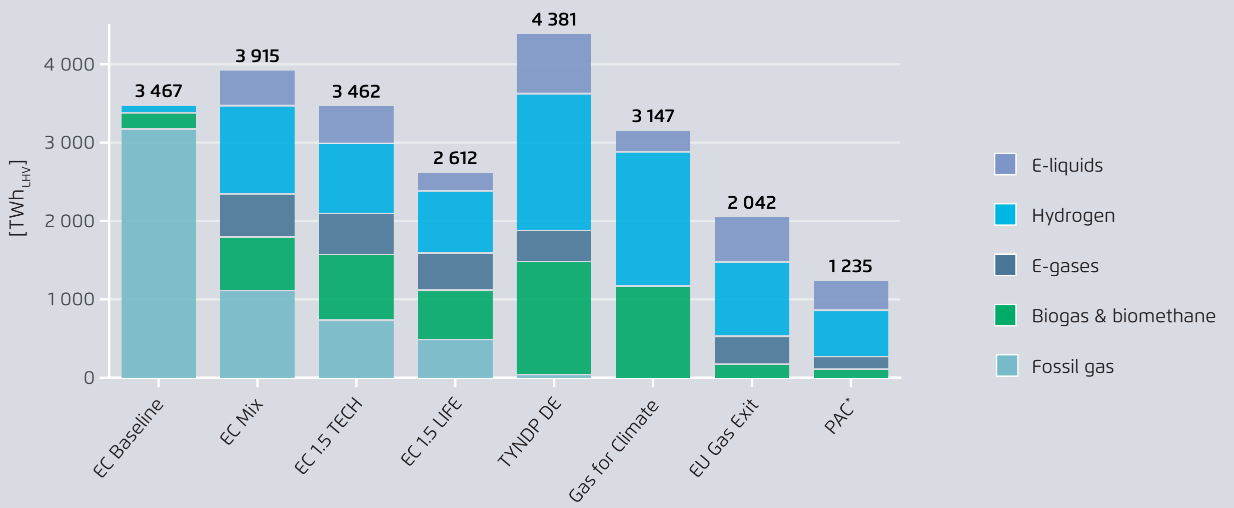
Overall, modelling results of the Gas Exit Pathway suggest that several targets in REPowerEU that were set in a rush under enormous political pressure without proper impact assessment should be critically reviewed. This goes in particular for the trade-off between displacing fossil gas by other fossil fuels and the targets for hydrogen and biomethane demand. On the latter, it may be noteworthy that the much lower figures on hydrogen in the EU Gas Exit Pathway are not only more cost-effective, but still ambitious when considering announced projects and final investment decisions by the industry.

The EU Gas Exit Pathway foresees a lower demand for fossil gas, biomethane, hydrogen and hydrogen derivatives than other long-term scenarios by the EU Commission

A comparison of the EU Gas Exit Pathway for 2050 with other long-term scenarios shows that the EU Gas Exit Pathway has lower demand for fossil gas, biomethane, hydrogen and hydrogen derivatives than any of the European Commission scenarios. This included the European Commission's 1.5LIFE scenario from the EU Long-Term Strategy, which relies heavily on behavioral change and nature-based solutions. None of the long-term scenarios of the European Commission feature a full phase-out of fossil gas by 2050.

Other gas policy-relevant scenarios prepared by gas grid operators and biogas associations also foresee a full fossil gas phase-out by 2050, but rely on high volumes of biomethane, hydrogen and hydrogen derivatives as well as large investments into fossil gas infrastructure, which would lead to significantly

Scenario comparison – gas and H_2 derivatives in 2050 — Figure ES 4



Artelys et al. (2023). EU Commission EU Long Term Strategy (2018) & Policy scenarios for delivering the European Green Deal (2020), Gas for Climate (2020), ENTSO-e and ENTSOG TYNDP 2022, CAN Europe and EEB (2020). The EC 1.5 and PAC scenarios reflect a different geographic scope than the other scenarios (EU-28 with the UK, not EU-27). *Excludes non-energy consumption.

higher system costs and grid tariffs in future years and raises the risk of stranded assets.

Overall, the EU Gas Exit Pathway is not only among the most ambitious scenarios with regards to the phasing-out of fossil fuels in Europe, but also less reliant on building new gas infrastructure. Importantly this suggests the need to prepare for a managed down-sizing of fossil gas infrastructure to contain energy-system costs and tariffs.

The fossil gas demand reduction foreseen in the EU Gas Exit Pathway and projected demand for hydrogen, hydrogen derivatives and biomethane significantly reduce dependency on energy imports and enhance security of supply

The EU imported 84% of its fossil gas supply in 2020. Under the EU Gas Exit Pathway, the share of imports in fossil gas supply remains relatively stable until 2035, as domestic fossil gas production and foreign imports decline together with total domestic fossil gas consumption. However, by 2040 the rate of decline in fossil gas import and consumption begins to outpace the decline in domestic fossil gas production, so the energy import dependency for fossil gas declines to 71% in 2040. Finally, the EU becomes energy independent by 2045, as all remaining methane consumption can be covered by domestic fossil and bioenergetic gas production.

Fossil liquified natural gas (LNG) imports are estimated to decline from 700 TWh in 2021 to 578 TWh in 2030. As a result, the utilisation rate of LNG terminals also drops to around 25% in 2030, down from 39% in 2021. This follows the current short-term surge of LNG imports in 2022 (about 1 550 TWh or 160 bcm), which is expected to remain until at least winter 2023–24. LNG imports further decline to 76 TWh in 2040 and can be fully eliminated by 2045 as demand for fossil gas rapidly shrinks in later decades and can be fully met by domestic fossil gas and biomethane production. While the rapid build-up of LNG import capacity in 2022–23 was critical for

EU gas supply by source and import dependency in the EU Gas Exit Pathway — Figure ES 5

Artelys, TEP Energy, Wuppertal Institute modelling (2023)

regaining Europe's energy security, the EU Gas Exit Pathway analysis indicates that the utilisation rate of Europe's existing LNG terminals will significantly decline already by 2030. An in-depth assessment is thus needed if energy security concerns can justify building further LNG terminals or not.

When looking at all gases (fossil gas, biogas and biomethane, hydrogen and hydrogen derivatives) as a whole, the import picture is more dynamic. Thanks largely to increases in domestic renewables-based hydrogen production, energy import dependency in the EU Gas Exit Pathway quickly declines from 79% today to 29% in 2040. From these relatively low levels, energy import dependency declines further to 17% in 2045, before increasing again to 26% in 2050 as EU imports of hydrogen derivatives (e.g. industrial feedstocks, synthetic fuels for aviation and navigation) increase.

Production of renewables-based hydrogen in Europe is presumed to be cheaper compared to importing hydrogen and its derivatives by ship. As a result, hydrogen imports are limited and almost exclusively provided in the form of hydrogen derivatives that are used directly in the industry and transport sectors (e.g. green ammonia for fertiliser production and synthetic fuels for international shipping and aviation). Renewable hydrogen-derivative imports rise sharply over time from 28 TWh of imports in 2030 to 95 TWh in 2040 and 894 TWh in 2050, while renewable hydrogen remains overwhelmingly domestically produced.

With regards to the available import supply infrastructure, we estimate that existing and planned import infrastructure and projects for hydrogen derivatives are roughly sufficient to meet the demand for imports in the EU Gas Exit Pathway until 2040. Meanwhile, the above-described declining utilisation of fossil LNG terminals indicates the potential to gradually repurpose existing fossil-based infrastructure for importing hydrogen derivatives after 2040. The economic and engineering challenges involved should be explored.

Hydrogen transport by pipeline is projected to be several times cheaper than transporting hydrogen and its derivatives by ship. Another promising strategy to secure competitive hydrogen supply in Europe is therefore to import hydrogen by pipeline from non-EU countries such as Norway, Ukraine, Algeria or Morocco. Against this background, the EU Gas Exit Pathway foresees a significant increase in hydrogen pipeline imports in the long term, from 3 TWh in 2030 to 81 TWh in 2040, and 155 TWh in 2050. Importantly, this only represents about 15% of total hydrogen demand over the transition.

Another approach for reducing the dependency on renewable hydrogen imports is to import intermediate goods produced with renewable hydrogen, rather than the renewable hydrogen itself. One example would be to import green iron for steel production in Europe, rather than producing the green iron in Europe with imported renewable hydrogen. Importing "embodied renewable hydrogen" has several benefits. It would be easier and more cost-efficient to transport to and within Europe with existing infrastructure and would come with reduced risks as regards security and hydrogen leakages throughout the supply chain.

Domestic biogas and biomethane production make a smaller contribution to providing energy security in the EU Gas Exit Pathway than in the REPowerEU plan, and its role declines further towards 2050. This is a result of an exogenous assumption to keep biogas and biomethane production constant at today's levels at most. Increasing the domestic production of biogas and biomethane beyond current levels could accelerate the decarbonisation of the EU's energy system and reduce the EU's import dependence on fossil and decarbonised gases. However, these benefits must be carefully and thoroughly weighed against multiple existing economic, environmental and social constraints, in particular growing competition for biomass resources across sectors and the need to increase the EU's land-use sinks.

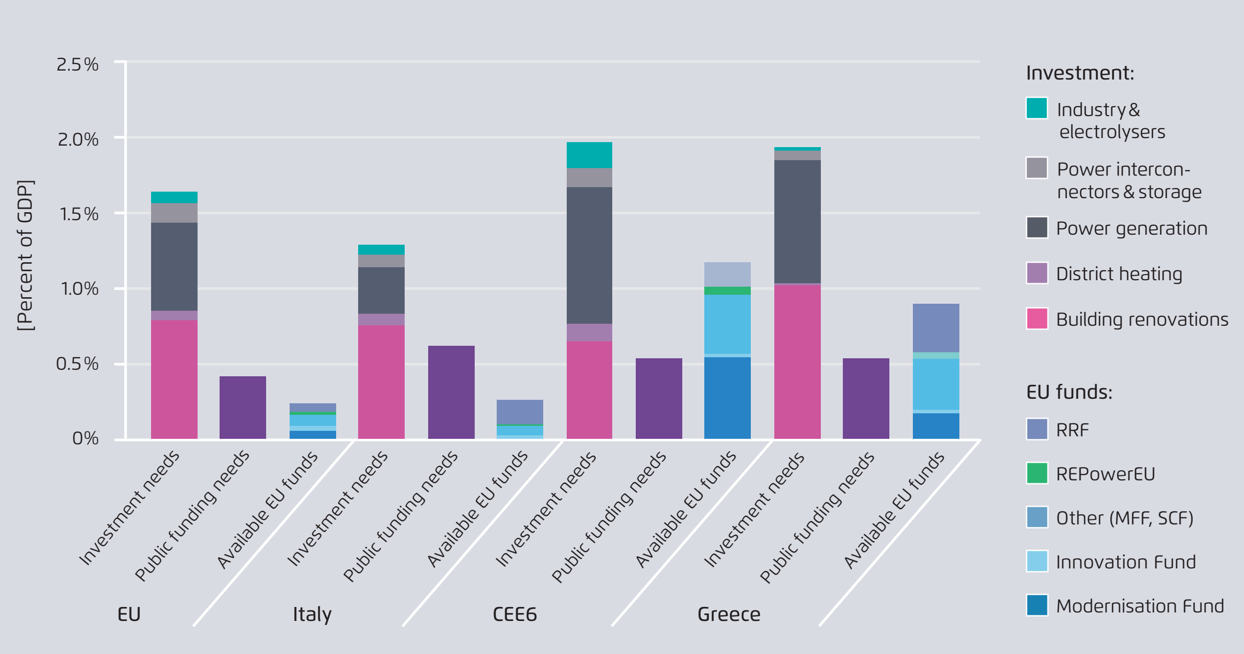
Until 2026, EU funding seems sufficient to support needed investments in industry, buildings and energy supply. After 2026, national budgets will need to contribute a significantly higher share, unless additional EU funds become available

We estimate that the investment needs in buildings, industry and energy supply (excluding grid investments) are around 225 billion euros per year in the current decade, increasing to 285 billion euros per year between 2031 and 2050, representing around 1.6% of the EU GDP through 2050.

Of these total investment needs, we estimate that roughly 29.5% should be covered by the public sector either as direct public investment or grants. The EU funds available for the green transition before 2030 offer as such a solid base for rapidly closing the investment gaps implied by the EU Gas Exit Pathway. The EU's Multiannual Financial Framework (MFF), the Recovery and Resilience Facility (RRF) established by the economic recovery budget "Next Generation EU", REPowerEU and revenues of the EU Emissions Trading System (EU ETS) make available a cumulative 295 to 360 billion euros for green investment, depending on the realised carbon price over the next years. This compares to estimated EU-wide public funding needs of 669 billion euros for the buildings, industry and power generation sectors in that period. As the distribution of EU funds favours Member States with incomes below the EU average, Central and Eastern Europe is especially well covered by these EU funds, which seem sufficient to narrow the investment gap by 2030, even taking into account investments into the power grid that are not part of our figures.

The medium-term outlook, after 2026, is less positive. RRF funding and REPowerEU will end in 2026

Annual average investment needs and EU fundings in 2021-2030 in different regions — Figure ES 6



Agora Energiewende based on Artelys et al. (2023) and European Commission EU funding programmes and REPowerEU plan.

under current agreements, bringing about a large shift in the financing burden to national budgets. Moreover, fiscal constraints will limit the capacity for high-debt countries such as Italy to scale up their climate investment programmes, as the public funding needs become sizable once the transport sector and national-level energy supply infrastructure are also considered.

Policy implications of an accelerated fossil gas phase-out for ongoing gas-related policy initiatives

The results of this study have several important policy implications for gas-related initiatives at EU level, in particular the proposed gas package and the regulatory framework for buildings.

→ **Policy consequence #1: The EU needs to set an ambitious 2040 climate target of around 90% and the debate starts now.** With estimated net domestic GHG emission reductions in the EU Gas Exit Pathway of 60% by 2030 and 89% by 2040 (vs 1990 levels), the EU should feel confident in aiming for an ambitious 2040 EU climate target of around 90%.

→ **Policy consequence #2: The EU should fundamentally revisit the EU gas and methane package as well the REPowerEU targets on hydrogen and biomethane.** The "hydrogen and decarbonised gas market package" was proposed by the European Commission in December 2021 just weeks before the escalation of the war in Ukraine, reflecting outdated assumptions on the role and availability of fossil gas in the transition to a climate-neutral energy system. The EU Gas Exit Pathway not only shows that the transition away from fossil gas can be achieved, but that it can be done with significantly less deployment of hydrogen, hydrogen derivatives and biomethane than featured in the REPowerEU plan and other prominent EU-level scenarios. This suggests that a fundamental re-evaluation of the EU gas and methane package and the political hydrogen and biomethane targets proposed in the REPowerEU plan is needed, including by carrying out a new impact assessment. This is particularly important now that the EU legislator is discussing the Net Zero Industry Act Regulation that could result in legally binding, quantitative targets for hydrogen and biomethane production in Europe in direct reference to the REPowerEU plan. It would directly run against the objectives of the Green Deal Industrial Strategy to lock in structurally higher energy costs than necessary for European industry.

→ **Policy consequence #3: Governments and regulators should prepare for an accelerated decline in gas demand and thoroughly evaluate its impact on gas supply and distribution infrastructure.** The EU Gas Exit Pathway stands in stark contrast to many scenarios used by gas grid operators, which foresee a much larger role for hydrogen, power-to-methane and biomethane in meeting the EU's goal of climate neutrality, as well as a significant role for LNG supply infrastructure into the future. These large differences between the scenarios draw attention to the urgent need to stress test the analytical basis underlying the EU's current electricity- and gas-network planning (including for LNG supply infrastructure) and prepare policymakers and stakeholders for these fundamental changes. A failure to do so could pose a serious risk to the development of stranded assets, especially with regards to distribution grids and LNG supply infrastructure.

→ **Policy consequence #4: The sale of stand-alone fossil gas-burning equipment in buildings should end quickly.** The EU Gas Exit Pathway shows that the building sector can become the first major gas-consuming sector to phase out fossil gas, with unabated fossil gas use in buildings largely coming to an end by 2040. However, delivering on this pathway will require robust regulatory policies that tangibly spur and deliver green investments in the building sector and prevent the lock-in of fossil fuel boilers and stoves, including ambitious Minimum Energy Performance Standards and restrictions on the sale of stand-alone fossil fuel boilers on the EU single market well before 2029.

→ **Policy consequence #5: Member States should quickly update their National Energy and Climate Plans (NECPs) to align them with the Fit for 55 package.** Final updates of the existing NECPs for 2021–2030 are to be submitted by 30 June 2024, while new NECPs for the period 2031–2040 are due by 1 January 2029. It will be critical for Member States to use these strategic policy processes to align their policies and measures with the Fit for 55 package and prepare for the phase-out of fossil gas.

Introduction

With the EU Climate Law of June 2021, the EU has set a legal commitment to achieve climate neutrality continent-wide by 2050 at the latest, meaning that the use of unabated fossil fuels must end by this date. With the REPowerEU plan of May 2022, the EU has set the goal of eliminating its dependence on Russian fossil fuel imports well before 2030, signalling the end of deceptively cheap pipeline gas supplies from Russia.

However, while much political attention has been focused on the implications of the EU's climate-neutrality target for the EU's 2030 climate ambition and the future of coal, far less attention has been given to the full transition away from the other fossil fuels (oil, fossil gas). And despite REPowerEU's planned reduction of fossil gas consumption and diversification of fossil gas supplies by 2030, the transition pathway away from fossil gas and towards climate neutrality is yet to be defined and is of eminent importance given the structural changes required. The new proposals even risk creating new lock-ins and dependences by heavily supporting an over-dimensioned and inefficient use of alternative gaseous fuels such as hydrogen and biomethane.

In short, the EU has yet to fundamentally re-evaluate the role of fossil gas in the long term. This silence is particularly notable and problematic in the context of the EU's ongoing legislative processes on gas and energy markets that will help shape the decisions of energy market actors for years to come and the significant structural changes required to place the EU on a transition pathway of declining fossil gas use until climate neutrality.

Against this backdrop, a fundamental rethinking of the projected role of fossil gas as a "bridge fuel" to a clean economy is urgently needed. This report adds four key aspects to the debate:

→ a clear structural transition pathway away from fossil gas use by 2050 based on detailed sectoral modelling of the energy, buildings and industry sectors;
→ an assessment of what this pathway means for the EU's upcoming debate on the EU's 2040 climate ambitions, energy imports and security of supply, as well as EU financing needs;
→ a critical assessment of some of the rushed targets on feasibility, costs and energy-security set by the REPowerEU plan;
→ and a reflection on the necessary policy implications of a structural fossil gas phase-out pathway until 2050 for the EU's ongoing gas-related policy initiatives.

1 Accelerating the structural phase-out of gas and meeting our 2030 and 2050 climate-neutrality targets

Against the backdrop of the energy crisis, Agora Energiewende, together with Artelys (Power), TEP Energy (Buildings) and Wuppertal Institute (Industry), and input from existing analysis by Transport & Environment (Transport),[2] have developed a modelling scenario pathway aligned with the EU's medium- and long-term climate-policy goals to evaluate how the EU could phase out fossil gas use in the EU energy system by 2050 and the impact of such a pathway on total EU greenhouse gas (GHG) emissions.

The EU-27 modelling work was accompanied by "deep dives" in 9 focus countries with one think tank or research partner per country:

- **Bulgaria:** Center for the Study of Democracy (CSD)
- **Czechia:** Nano Energies
- **Greece:** FACETS S.A.
- **Croatia:** University of Zagreb – Faculty of Mechanical Engineering and Naval Architecture
- **Hungary:** Regional Centre for Energy Policy Research (REKK)
- **Italy:** ECCO Climate
- **Poland:** Forum Energii
- **Romania:** Energy Policy Group (EPG)
- **Slovenia:** University of Ljubjana – Laboratory of Energy Policy (LEST)

Final energy demand in the three key sectors consuming fossil gas today (buildings, industry and power sectors) has been modelled in the EU-27 in five-year steps from 2025 to 2050, as well as domestic energy supply and imports from outside the EU in a logic of cost optimisation under the following constraints:

- At least 55% emissions reduction is achieved by 2030 and net zero emissions by 2050.
- The EU-27 has phased out Russian gas by 2027 at the latest (about 40% less fossil gas demand relative to 2018) and fossil gas consumption is phased out by 2050.
- Only structural gas demand reduction is considered – no behavioural change or temporary fuel switch to other fossil fuels or bioenergies.
- There is no demand destruction in industry, nor reduction in industrial output in total until 2050. Even if some industrial sub-sectors move from one Member State to another due to more favourable resource conditions, there are no significant losses in the EU as a whole.
- Limited sustainable hydrogen and bioenergy resources are prioritised for sectors for which there are no more efficient alternatives, in particular industry and international shipping and aviation.
- The power sector is close to decarbonised by 2040, coal being phased out at the end of 2035 in the whole EU-27. The national objectives for the deployment of generation capacity are achieved.
- Stand-alone fossil fuel boilers are no longer installed for heating in buildings from 2027.

The transport sector was based on the Road2Zero scenario of the T&E study "Advanced renewable fuels in EU Transport", while emissions reductions from the agriculture, waste and LULUCF sectors are aligned with analysis performed by the European Commission for the EU Climate Target Plan and the EU Long-Term Strategy (LULUCF and LULUCF+ scenarios from the EU Commission). More details on the modelling approach and assumptions behind this "EU Gas Exit Pathway" can be found in Annex 4 of this report.

2 Transport & Environment (2021)

Key insights with regards to fossil gas consumption

The modelling shows that fossil gas can be completely phased out of the EU energy system by 2050 without disruptive behavioural-change measures in households or short-term demand destruction in industry and while fully ensuring energy security of supply and achieving EU climate targets.

The EU Gas Exit Pathway achieves a reduction in total fossil gas consumption of roughly half (-46% versus 2018 levels) by 2030, 90% by 2040 and a complete phase-out by 2050 compared to historic levels (see figure 1). Similar fossil gas demand reductions (-37% by 2030, -88% by 2040) are also achieved when comparing the EU Gas Exit Pathway to the European Commissions's most recent 2020 reference scenario largely representing EU and national targets set in the last European Commission.[3]

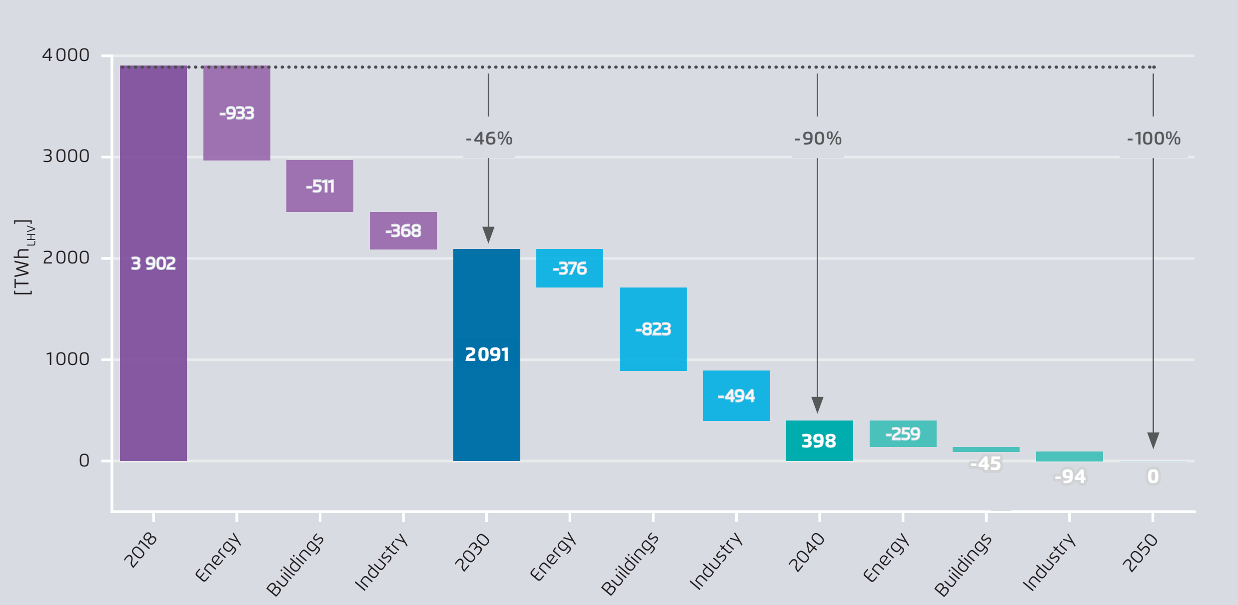
3 https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

This happens all while coal is being phased out by 2035 in the power sector and oil consumption is also reduced at a steady pace in the transport sector (1% less per year until 2030, then 5% less per year until 2050). The 2030 and 2050 climate targets are thus achieved without elevated short-term reliance on fossil gas as a so-called "bridge fuel" from coal to clean.

These reductions develop differently across the different sectors and over time and are the result of three key activities:

- → reducing fossil methane consumption by structurally reducing energy and feedstock demand (e.g. energetic renovations of buildings);
- → substituting fossil methane by cleaner non-methane alternatives (e.g. wind, solar, ambient heat, renewable hydrogen);
- → and supplying a growing share of the residual methane demand with domestically produced and sustainably sourced biogas and biomethane.

Evolution of total fossil gas consumption in the EU-27, 2018-2050 — Figure 1



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

An overview of key developments in each of thes sectors until 2050 can be found below.

Where is fossil gas consumed today?
Fossil gas consumption in the EU has increased significantly over the last decades, rising from around 2 900 TWh (about 300 bcm) in 1990 to nearly 4 000 TWh (about 410 bcm) in 2021, a 37% increase in relative terms over this time period (see figure 2). With economic recovery after the EU financial crisis and COVID-19 pandemic, fossil gas consumption was on a worrying upward trend, quickly approaching the previous peak consumption levels of about 4 200 TWh (about 430 bcm) achieved in 2010. However, 2022 saw a significant reversal due to the ongoing energy crisis, delivering an estimated 12–13% decline in fossil gas demand. Particularly large reductions in fossil gas consumption were seen in the buildings and industry sectors due to mild temperatures, short-term behavioural changes, demand destruction and fuel switching, while electricity and heat generation experienced smaller declines due largely to uncommonly low nuclear and hydro production.

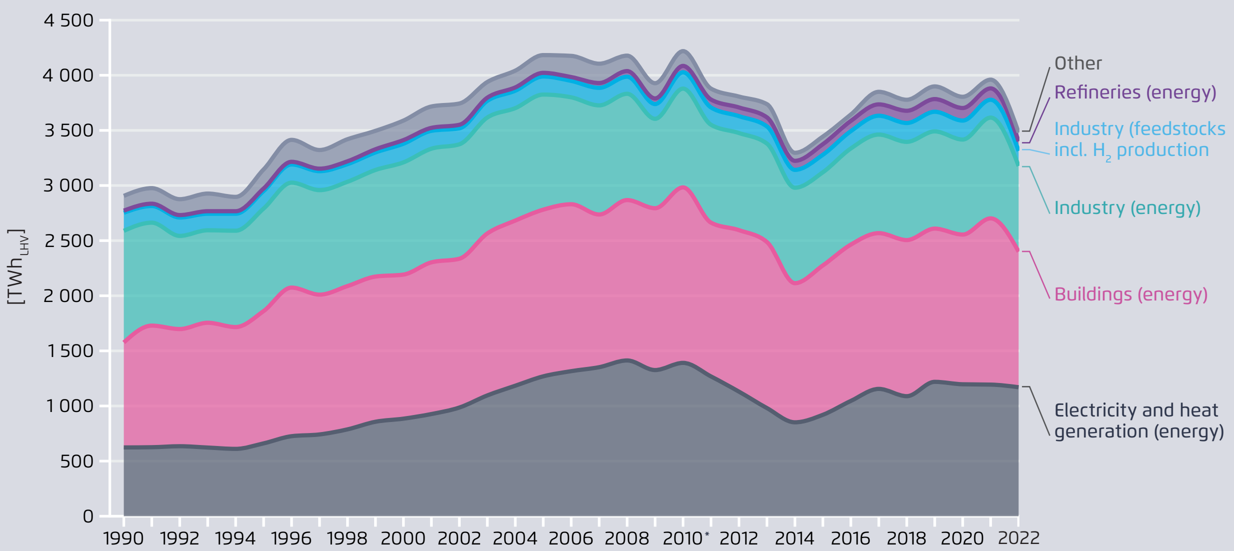
In 2018, the base year for the modelling in the EU Gas Exit Pathway, the EU consumed around 3 900 TWh (about 400 bcm) of fossil gas in the main applications.

The largest sector with regards to fossil gas consumption was the **energy sector** with around 1 570 TWh (about 160 bcm), dominated first and foremost by fossil gas used in power plants for electricity generation (910 TWh). Additional large use-cases in the energy-sector were CHP plants and boilers supplying heat to district heating networks (288 TWh), dedicated “on purpose” hydrogen generation from steam methane reforming (SMR, 198 TWh) and fossil gas consumed for energy purposes in refineries (170 TWh).

The second largest sector was the **buildings sector**, which consumed around 1 380 TWh (about 140 bcm)

Fossil gas consumption in the EU by sector, 1990–2022

Figure 2



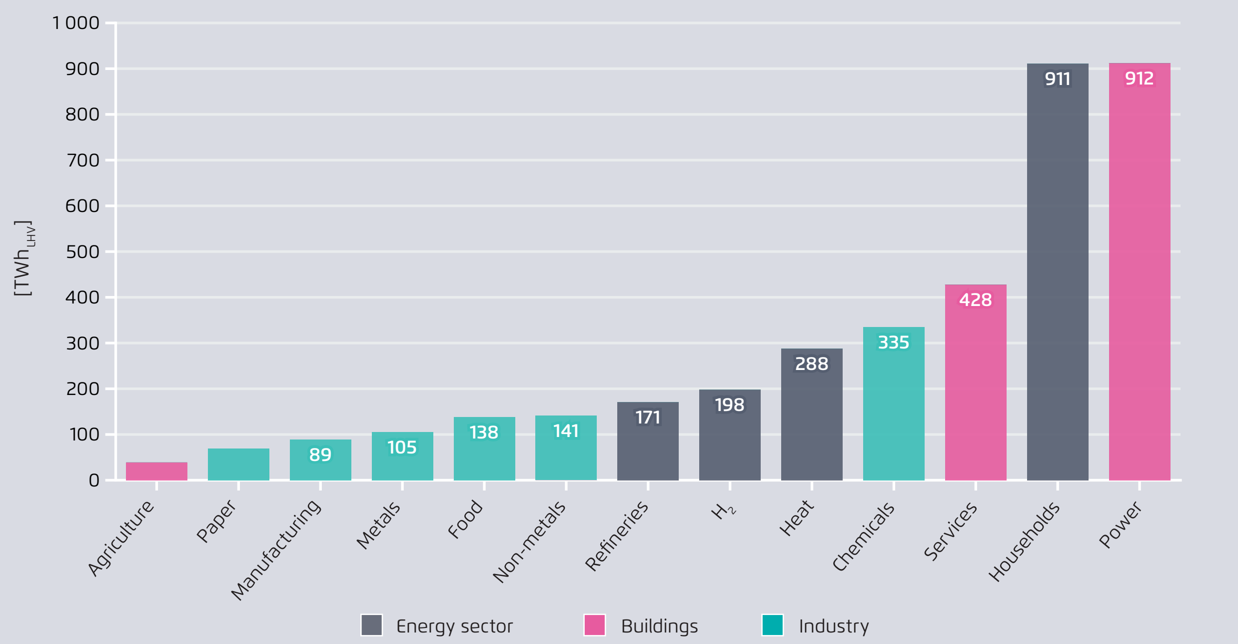
Historic data for 1990-2021 based on Eurostat complete energy balances (2023). Fossil gas demand for 2022 based on Eurostat (2023) monthly data. Sectoral split for 2022 estimated based on Bruegel (2023) and IEA (2023). *Historic peak fossil gas consumption.

of fossil gas, largely for space heating, water heating and cooking in residential, commercial and public buildings, as well as a smaller share for the heating of agricultural buildings such as livestock stables and greenhouses.

Finally, the **industry sector** consumed around 950 TWh of fossil gas in 2018 (about 100 bcm). Most of this fossil gas consumption was for energy use, most notably in the chemicals and petrochemicals sub-sector (339 TWh). Additional large fossil gas-consuming sub-sectors in industry were non-metallic minerals such as glass, lime, ceramics and cement (145 TWh), food, beverages and tobacco (142 TWh), iron and steel and other metals (105 TWh), the manufacturing of transport equipment and machinery (90 TWh), as well as paper and pulp production (69 TWh). While most of the industry sub-sectors use fossil gas as an energy source for heat and steam production, the chemicals industry today uses almost half of its fossil gas as feedstock. It goes into hydrogen and ammonia production to be further transformed into fertilisers, or into methanol used to produce plastics or solvents.

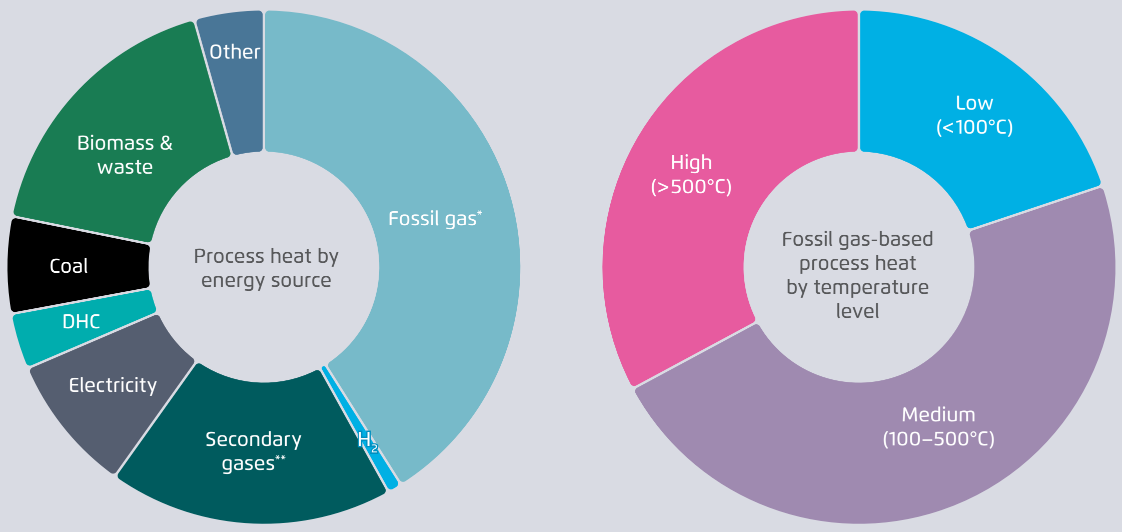
With regards to energy consumption for process heating, industry requires process heat at different temperature levels. Especially in steel production and other metallurgical processes, but also for example in glass production, high temperatures of over 500 degrees Celsius are required. High-temperature heat is also required in the chemical industry, for example, to break down chemical molecules (cracking). The temperature of the required process heat is of crucial importance for the selection of suitable transformation strategies and technologies, as low- and some medium-temperature processes are more easily electrified using highly efficient industrial heat pumps and electric boilers.

Fossil gas consumption in the EU by sector in 2018 — Figure 3



Artelys, TEP Energy and Wuppertal Institute based on Eurostat and other available data sources.

Overview of process heating in industry in 2018 by energy source and temperature level | Figure 4



Wuppertal Institute (2023). *Fossil gas includes natural gas, refinery gas and LPG. **Secondary gases include coke oven gas, blast furnace gas, basic oxygen furnace gas and steam cracker by-products.

Fossil gas currently represents roughly 40% of total energy consumption for process heating. Of this energy consumption roughly 20% is used for producing process heat at temperatures below 100 degrees Celsius and about 50% is used for the production of steam at medium temperatures (100–500 degrees Celsius).

Energy Sector

The **energy sector** sees the largest early decline in fossil gas consumption and is almost fossil gas free by 2045 (see figure 5). Fossil gas consumption drops rapidly in the period 2018 to 2030 (-933 TWh), mostly led by the power sector, before moderating in the decades from 2030 to 2040 (-376 TWh) and 2040 to 2050 (-259 TWh). Most of the early displacement of fossil gas is driven by the massive upscaling of solar and wind generation in the power sector, while direct electrification of road transport, as well as renewable hydrogen and hydrogen derivatives, displace much of existing fossil gas consumption in refineries and for hydrogen production in the decade after 2030. Large-scale heat pumps and deep geothermal also play a crucial role in the displacement of fossil gas in district heating networks, delivering roughly a quarter of district heat production by 2030 and half by 2040.

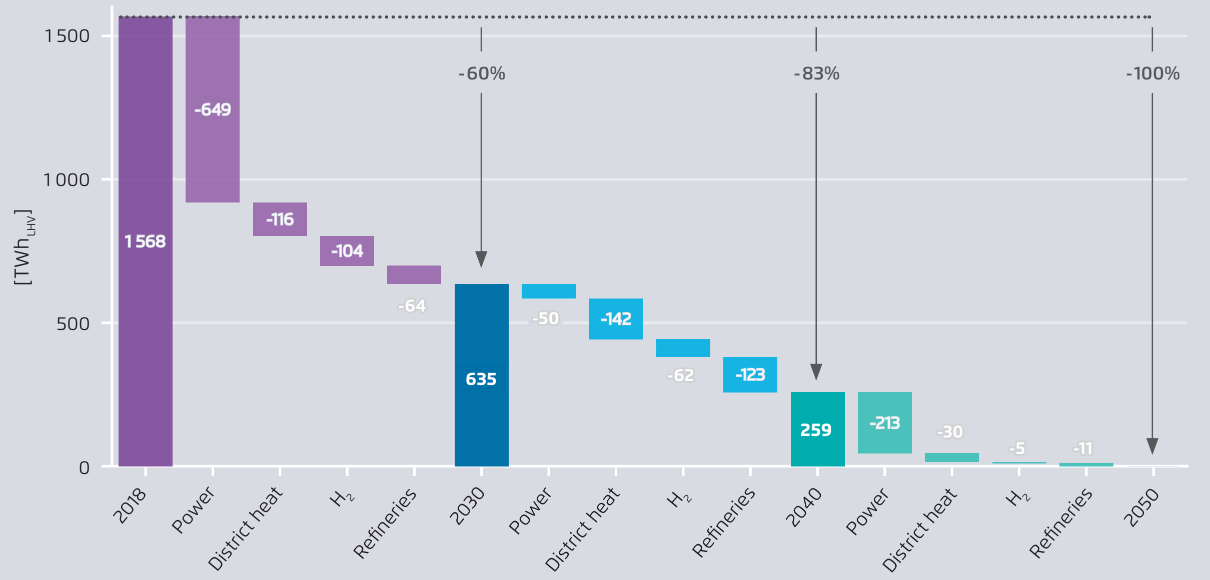
Power sector

The power sector experiences a rapid reduction in fossil gas consumption, by 71% in the period from 2018 to 2030, falling to 262 TWh before declining a mere 50 TWh further in the decade from 2030 to 2040. As a result, power generation has by far the largest residual fossil gas consumption in 2040 at 213 TWh (54% of total – see figure 6), for a total of 120 TWh of generated power (2.5% of total).

These trends are largely shaped by six key factors:

→ Renewables deployment – largely wind and solar – increases significantly due to declining costs and the significant targets set to date by national governments for 2030 and beyond. Renewables gener-

Evolution of total fossil gas consumption in the energy sector in the EU-27, 2018-2050 — Figure 5



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

ation reaches 70% of the power mix in 2030 (2 277 TWh), 85% in 2040 (4 227 TWh) and 96% in 2050 (5 936 TWh). Installed capacity of wind and solar triples to 478 GW wind and 572 GW solar in 2030, increases sixfold to 923 GW wind and 930 GW solar in 2040 and rises almost ninefold to 1 200 GW wind and 1 280 GW solar in 2050 (compared to 2018 levels).

→ Power generation from oil and coal declines by 76% by 2030 (144 TWh remaining). Oil power generation is almost phased out by 2025, while coal power generation takes until the end of 2035 for a complete phase-out.

→ Power demand is expected to grow significantly, especially after 2030. It increases by 22% between 2018 to 2030 to about 3 250 TWh, and almost doubles to 6 000 TWh in 2050, largely due to the electrification of transport, buildings and industry as well as growing renewable-based hydrogen production after 2030.

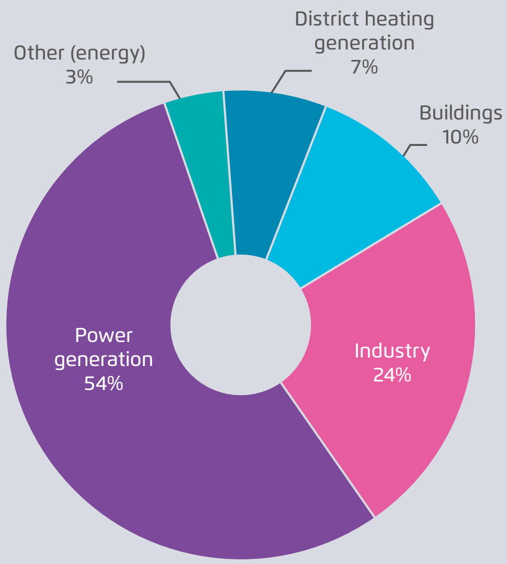
→ A limited number of new gas power plants continue to be built until 2035, to reach a total capacity of 201 GW, while older plants begin to be decommissioned at the end of their economic lifetime over the whole period and more quickly after 2035. These plants, partially run with biomethane, experience a significant decline in their capacity factor over time, falling from around 30% in 2021 to about 10% from 2025 to 2040, and even lower levels thereafter.

→ Bioenergy in the form of solid biomass, biogas and biomethane in electricity-only power plants will decline over time and only remains to a limited extent in 2050.

→ Some of the newer plants initially running on fossil gas are converted to be run on hydrogen in the period after 2030, with power production based on renewable hydrogen slowly increasing after 2035.

These trends in the power sector go hand in hand with a more profound transformation of the system overall. In order to manage the increased variability from a predominantly wind- and solar-based power supply, the system mobilises a mix of short- and long-term flexibility options in the form of increased

Residual fossil and renewable methane consumption in the EU-27 in 2040 — Figure 6



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

interconnections, a more flexible demand, storage and flexible power generation.

Interconnectors: In order to optimise the use of available wind and solar resources over the continent and stabilise the power system, the interconnector capacity needs to increase by 25% between 2025 and 2030 (to 225 GW) and double to 443 GW by 2050. Intra-EU power exchanges as well as exchanges with Norway, Switzerland, the UK and the Western Balkan countries increase by a similar percentage point, namely 27%, from 639 TWh in 2025 to 814 TWh in 2030, then almost double to about 1 540 TWh by 2050.

Flexible demand: The uptake of water electrolysis to produce renewable hydrogen will provide the largest share of new long-term and short-term flexibility in the power system, next to electric vehicles. Hydrogen production will provide up to 10% of both short- and long-term flexibility demand by 2030, and 50% and 60% respectively by 2050, gradually replacing some of the flexibility services currently being provided by conventional power plants. Electric vehicles will mostly provide short-term flexibility during the day thanks to smart charging solutions, going from about 5% of the required flexibility in 2030 to 20% in 2050. Heat pumps were considered not to provide much flexibility to the system, which can change with technological advances. Overall, flexible demand can provide 60–70% of the power system flexibility needs by 2050.

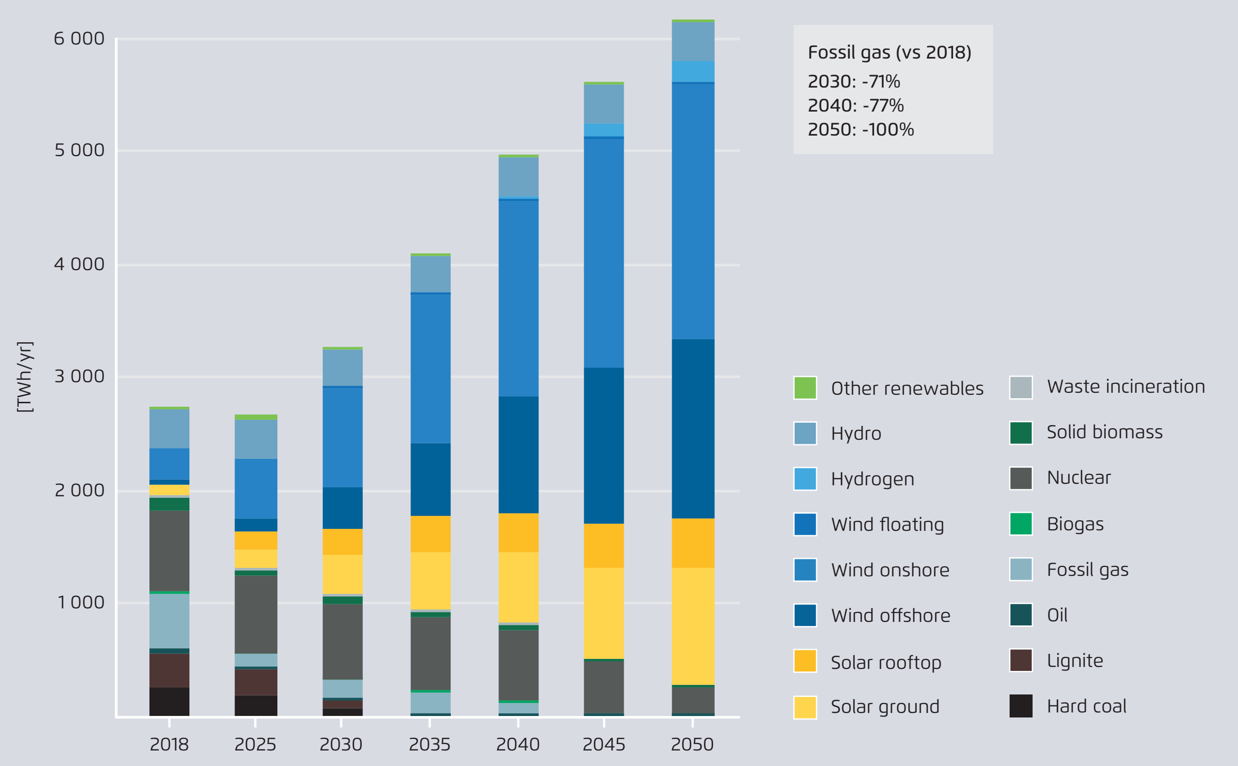
Storage: Hydropower and pumped storage play a significant role today in Europe, providing about 45% of short-term flexibility and 15% of long-term flexibility. Its production in absolute numbers will remain stable over the transition, but its share will decline over time as hydrogen and battery storage rise in importance. While in 2030 there will only be 8 GW of hydrogen storage capacity (compared with 616 GW for fossil gas), covering about 10% of long-term flexibility, by 2050 hydrogen storage capacity will increase to 154 GW and cover most (70%) of the long-term flexibility needs for the few hours in the year when wind and solar power generation are low due to natural conditions (the "dark doldrums" or "Dunkelflaute"). Stationary batteries will also offer some intra-day flexibility services to the system, in an increasing but limited scale until 2050.

Flexible power generation: From now to 2035/2040, seasonal system flexibility need is mainly met by conventional power plants (fossil gas, nuclear and initially also coal), going from about 80% in 2025 to 58% in 2040. About half of the short-term flexibility need is also covered by conventional power plants (mostly coal and fossil gas) in 2025, though this will decline to less than 30% by 2035, substituted by other forms of flexibility.

Total fossil fuel-based power generation declines quickly until 2035, but at differing paces over time. In order to achieve a quick fossil gas demand reduction as foreseen in the scenario, gas demand in the power

Net-electricity generation in the EU Gas Exit Pathway

Figure 7



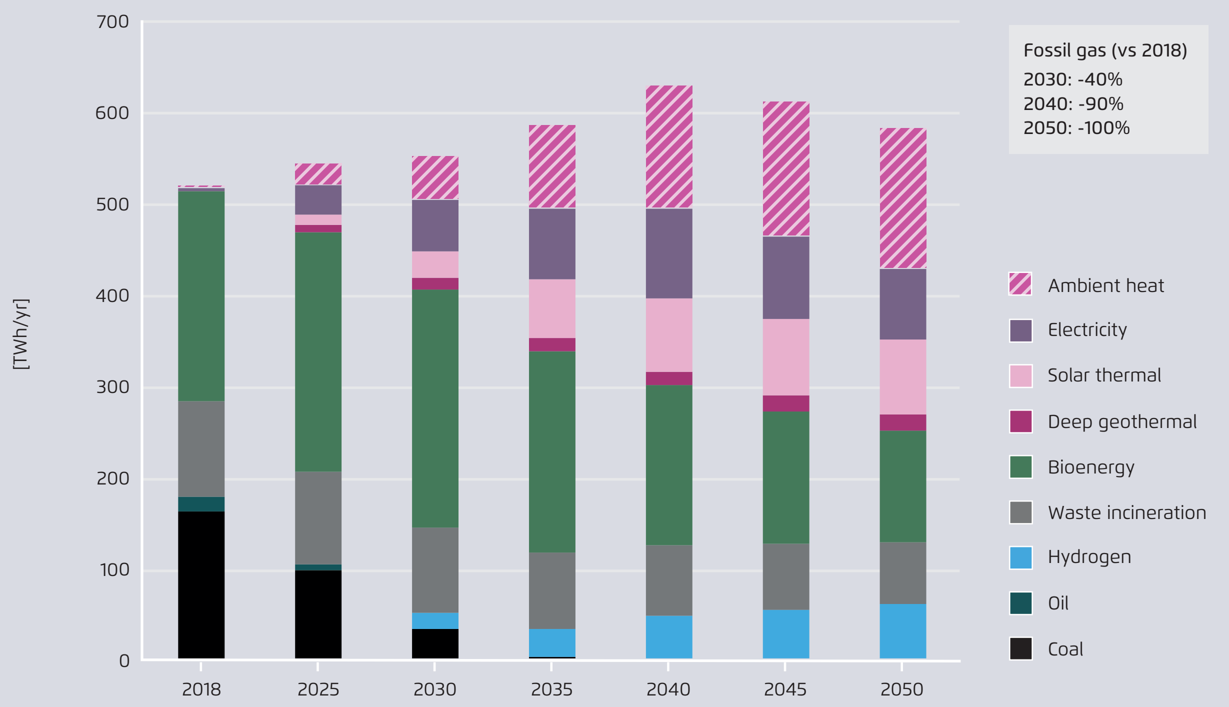
Artelys, TEP Energy and Wuppertal Institute modelling (2023)

sector declines more quickly in the 2020s than coal power generation, which is mostly run when there is not enough renewables generation. However, from 2030 to 2050 some residual fossil gas continues to be made available for the power sector to provide flexibility services and enable a complete coal phase-out by the end of 2035 and growing electrification of the end-use sectors, before being replaced by hydrogen-run power plants, hydropower and demand-side flexibility. This mostly explains a fluctuation of fossil gas demand in the power sector over this time period, first declining to 114 TWh in 2025, before gradually rising again to 357 TWh in 2035, and dropping again to 212 TWh in 2040. The phase-out happens then quickly, with demand reaching a mere 20 TWh in 2045 before finally being phased out by 2050. By 2050 only a limited amount of power is generated in the remaining gas power plants from biomethane (13 TWh) to offer flexibility services.

District heating

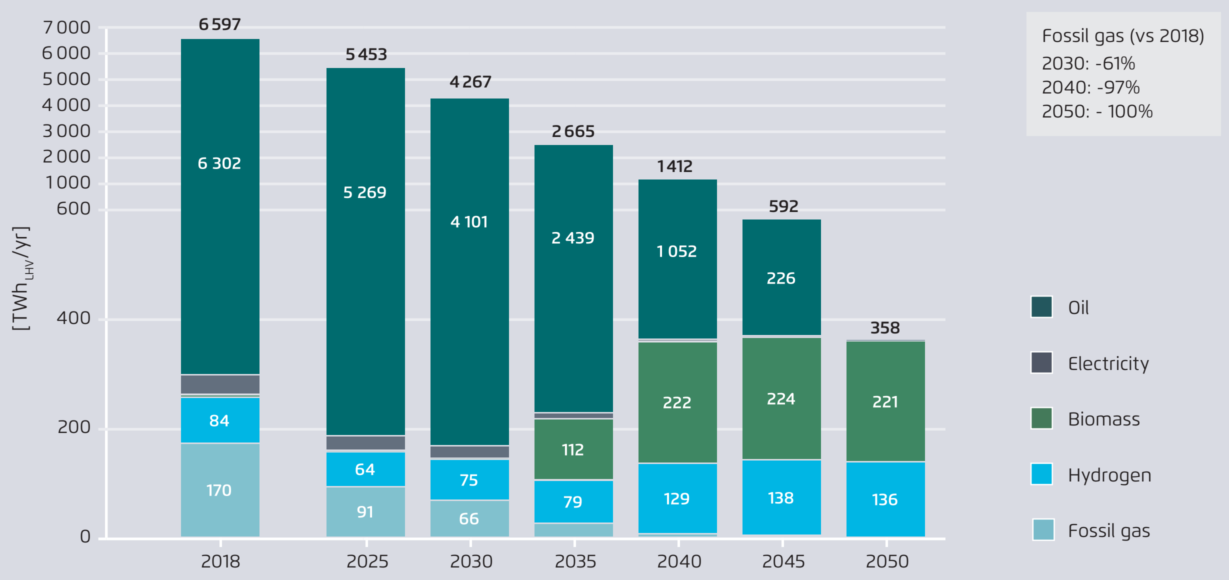
District heating sees steadier reduction in fossil gas demand over time, declining by 40% in the period from 2018 to 2030, reaching 90% reduction by 2040 and nearly phasing out by 2045. The slightly slower fossil gas reduction before 2030 can be explained by growing demand for district heating, as more homes are connected to new and existing district heating networks to displace fossil gas in decentralised heating. At the same time, increased operational and system efficiency measures (e.g. modernisation of networks, decreasing supply temperatures) and the scaling of renewables and waste heat help to secure a parallel displacement of fossil gas from district heating generation. Large-scale heat pumps are expected

Energy consumption for district heat generation, EU-27 — Figure 8



Artelys, TEP Energy and Wuppertal Institute modelling (2023)

Energy and non-energy consumption for refineries and synfuels production, EU-27 — Figure 9



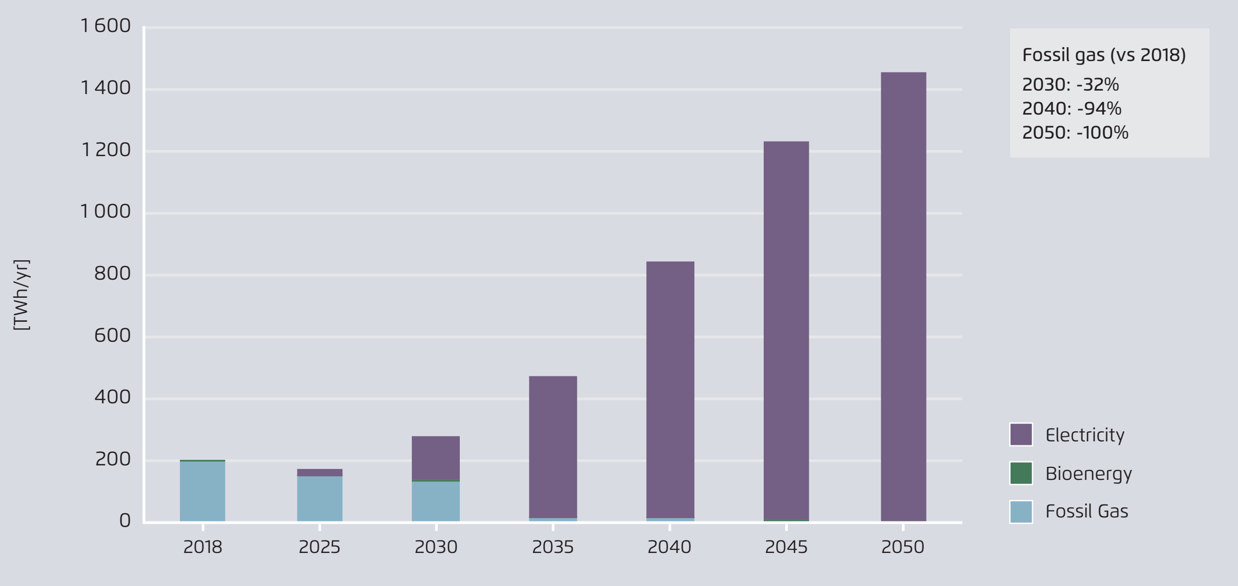
Artelys, TEP Energy and Wuppertal Institute modelling (2023)

to play a particularly significant role in the decarbonisation of district heating networks, with the supply of ambient and waste heat to district heating increasing rapidly, from roughly 2 TWh in 2018 to 48 TWh in 2030, 133 TWh in 2040 and 154 TWh in 2050. Direct renewable heat sources such as bioenergy (biomethane and solid biomass), solar thermal and deep geothermal also play a crucial role in displacing fossil methane demand.

Refineries

Refineries see a large relative reduction in fossil gas demand in the period from 2018 to 2030 – falling by 61% to 66 TWh – before experiencing a near-complete phase-out by 2040 (-97%). This significant decline in fossil gas demand largely results from the direct electrification of road transport and indirect electrification of shipping and aviation with synthetic fuels, which are largely imported. These dynamics lead many of the remaining refineries in Europe to begin to close or reduce output beginning in the 2020s. In fact, by 2040 the residual demand for fossil gas in refineries is below the volumes of refinery gas by-products produced in the remaining refineries, meaning the energetic demand served by fossil gas can be covered by own production. At the same time, to fully meet demand for fuels and feedstocks, domestic production of renewable synthetic fuels and feedstock in refineries also begins in the 2030s, with renewables-based synthetic fuels production rising from 52 TWh in 2035 to around 144 TWh in 2040 and 153 TWh in 2050. For the production of these products, a biomass-to-liquids process using Fischer-Tropsch synthesis is assumed, requiring hydrogen and CO-rich syngas from the gasification of solid biomass as a feedstock (e.g. wood chips, straw). Additional renewables-based hydrocarbon by-products (e.g. LPG, naphtha, methane) are also produced as part of this synfuel production process and used in the petrochemical industry (in steam crackers), helping to partially compensate the decline in fossil fuel-based hydrocarbon production and decreasing Europe's import dependency for fuels and feedstock.

Energy consumption for hydrogen production, EU-27 — Figure 10



Artelys, TEP Energy and Wuppertal Institute modelling (2023)

Hydrogen production

Hydrogen production based on fossil gas sees a reduction in fossil gas input demand by 32% to 134 TWh in the period from 2018 to 2030, before experiencing a near-complete phase-out by 2040. The initially slow decline in fossil gas demand can largely be explained by the fact that renewables-based hydrogen is expected to remain costly in the short-term and not play a significant role until after 2030 when hydrogen based on electrolysis powered by renewable electricity begins to dominate the market. By contrast, fossil gas-based hydrogen produced using SMR with CCS is expected to play a marginal role in both the short and medium term due to high costs. This implies that hydrogen production in Europe largely remains a high-carbon activity until 2030 and will require hydrogen production and infrastructure incentives to scale renewable or clearly defined low-carbon hydrogen to levels that conventional hydrogen is replaced.

Buildings Sector

The **buildings sector** is the first to fully decarbonise in the EU Gas Exit Pathway, achieving a nearly fossil gas-free building stock by 2040. Initially, fossil gas demand in buildings decreases by slightly more than a third (-37%) from 2018 to 2030, before significantly accelerating to reach only 45 TWh of residual demand in 2040 (-97% of 2018 levels).

Given the high cost of hydrogen, the need to prioritise its use in no-regret applications, such as industry and other sectors, and the limited uptake of biomethane in buildings, the phase-out of fossil gas in the buildings sector also results in the near-complete phase-out of total gas demand (fossil, renewable and low-carbon gases) at the distribution-grid level. The scale of this change is all the more noteworthy when compared with other policy-relevant scenarios. For example, total gas demand is significantly higher for the buildings sector in European Commission modelling for the Fit for 55 package and key scenarios used by the electricity and gas grid operators ENTSO-E

Final energy consumption in buildings, EU-27 — Figure 11

Artelys, TEP Energy, Wuppertal Institute modelling (2023)

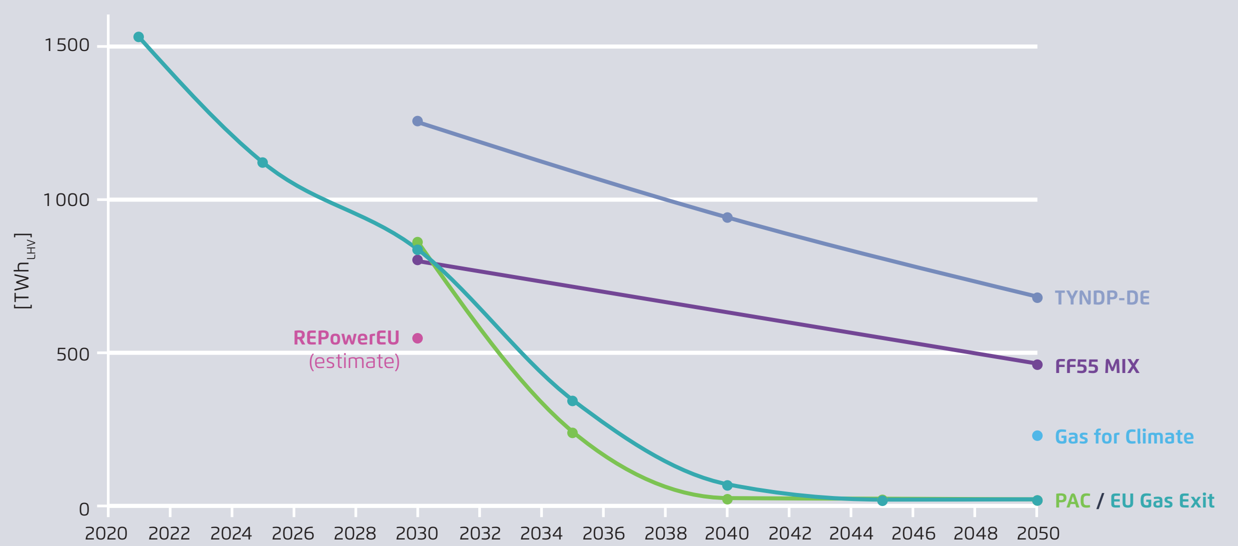
and ENTSOG for the EU Ten-Year Network Development Plan (TYNDP) (see figure 12). Such a sharp decline in gas infrastructure utilisation could have important implications for policymakers given the enormous risk for stranded assets, in particular for new investments into the gas distribution grid.

The four main technology levers for achieving this reduction in gas consumption in the building sector are energy efficiency, heat pumps, district heating and direct renewables:

→ **Efficiency:** Final energy demand in buildings is substantially reduced over the period 2018 to 2040 through significant improvements in energy efficiency, including the replacement of older and less efficient heating appliances with more efficient technology (e.g. heat pumps), as well as reduced heat losses due to the increased thermal insulation of buildings. In total, the average specific energy demand of the residential building stock in the EU-27 falls from 228.4 kWh/m² in 2018 to 184 kWh/m² in 2030 (-19.4%), 147.9 kWh/m² in 2040 (-35.2%) and 131.2 kWh/m² in 2050 (-43%), while it declines slightly less in non-residential buildings (-30% by 2050 vs 2018 levels). Improving the energy performance of buildings to this extent will require significant deployment in insulation materials to improve the thermal envelope. Average annual investment into building components (wall, window, roof and basement) is estimated at 38.5 billion euros in 2021–2030, rising to 52.9 billion in 2031–2040 and 68.3 billion in 2041–2050. It will also require a significant increase in the capacity of the construction industry to achieve this scale of building renovations. Key measures to achieve this capacity include the scaling and upskilling of the construction sector workforce, improvements in construction project management and the mainstreaming of industrial-scale building renovation approaches (e.g. standardised prefabrication and off-site construction).

→ **Heat pumps and geothermal:** Air-source and ground-source heat pumps are the key technological lever for displacing fossil gas in the building sector. The building floor area heated directly by

Scenario comparison – total (fossil and renewable) gas consumption in buildings | Figure 12



Artelys et al. (2023), EU Commission Policy scenarios for delivering the European Green Deal (2020), Gas for Climate (2020), ENTSO-e and ENTSOG TYNDP 2022, CAN Europe and EEB (2020). Includes direct energy consumption in the residential, tertiary and agriculture sectors.

heat pumps increases nearly threefold (+180%) by 2030, sixfold (+482%) by 2040 and sevenfold (+579%) by 2050 compared to 2020 levels. We estimate this to correspond to 40 million heat pumps by 2030, 80 million by 2040 and 82 million by 2050 and a deployment rate of more than 6 million heat pumps per year in 2030. Accelerated deployment of heat pumps at this scale will require a significant increase in manufacturing capacity of heat pumps and their components, as well as the number of skilled heating technicians capable of quality heat-pump installations. Mobilising this workforce will require reskilling heating engineers with previous transferable knowledge of designing and installing fossil-based heating systems as well as training new entrants and apprentices. It will also require increasing the productivity of the heating installer industry, for example through the adoption of new digital tools, as well as by increasing company sizes and enabling workers to specialise in different skills involved in the installation of a heat pump.[4]

→ **District heating:** The floor area served by heat networks rises by more than two-thirds by 2030 (+68% vs 2020 levels) and more than doubles by 2040 (+123%), before declining somewhat towards 2050. In parallel, building renovations and improved operational efficiency of district heating systems help to reduce the amount of energy needed to supply homes connected to these networks. As a result, consumption of derived heat from district heating only increases by roughly a quarter (+24%, 75 TWh) between 2020 and 2030, and a third by 2040 (+37% vs 2020 levels, 125 TWh), while helping to directly displace an estimated 69 TWh of fossil gas demand by 2040. These savings are additional to the reductions in fossil gas consumption achieved in the supply of district heating networks (see energy sector). Achieving this increase in heat supply via district heating will require expanding, modernising and constructing new district heating grids across the EU, as well as additional works inside the building, such as installing district heating sub-stations and adjusting existing hydronic heating systems. These investments will also require a significant increase in the skilled workforce needed for these works, such as specialised heating engineers and pipe welders, as well as efficient urban planning to minimise the cost and disruption from the underground construction works needed to expand the system.

→ **Other direct renewables:** Additional gas displacement is also achieved through an increase in other direct renewable heat sources, notably solar thermal, which triples production from 2018 to 2030 (+25 TWh), and doubles again between 2030 and 2040 (+35 TWh) before stabilising between 2040 and 2050. While bioenergy consumption for heating in buildings declines by 300 TWh by 2050 (-55%), its continued use at significant levels (464 TWh in 2030, 373 TWh in 2040 and 249 TWh in 2050) helps to avoid fossil fuel consumption and additional pressures on other renewable-heating supply chains.

Several policy-levers also play a very important role in driving these changes, with the modelling of the building sector largely reflecting EU policies currently being discussed in the context of the Fit for 55 package. This includes the introduction of an EU Emissions Trading System for buildings and road transport, the introduction of stricter building efficiency requirements via minimum energy performance standards for existing buildings, as well as a ban on the sale of stand-alone fossil fuel boilers.

4 Nesta (2022)

Managing the impact of heat pump deployment on the distribution grid

The efficient integration of a growing share of heat pumps, electric vehicles and rooftop PV into the electricity distribution grid was not explicitly modelled in this project. However, previous work by Agora Energiewende has shown that an energy transition in the distribution grids can be successful given targeted investments into distribution grids, demand-side flexibility measures (e.g. smart EV charging) and broader systemic changes (e.g. modal shift in transport to shared mobility).[5] A study by Eurelectric estimated that the electrification of buildings and industry will require roughly 7–8 billion euros per year in additional investment in distribution grids in the decade from 2020 to 2030, representing about 19% of the total investment and roughly one-third of today's investment levels.[6] However, numerous measures can help to reduce or defer some of the necessary grid investments and manage the growing uptake of heat pumps. Changes to the thermal envelope (e.g. wall insulation) and maintaining a high operational efficiency of heat pumps at low-flow temperatures can help to reduce the overall electrical load of the system, especially at peak hours. At the same time, thermal storage systems, including both insulated hot water tanks and the thermal inertia of well-insulated buildings, can be used to flexibly shift the electrical load of heat pumps to other points in time in order to reduce strain on the grid and better integrate variable renewables. A decline in direct electric heating, more efficient light bulbs and home appliances and smart home energy management systems coupling rooftop PV and home battery storage can further smooth the accelerated electrification of buildings.

5 Agora Energiewende and Agora Verkehrswende (2019)

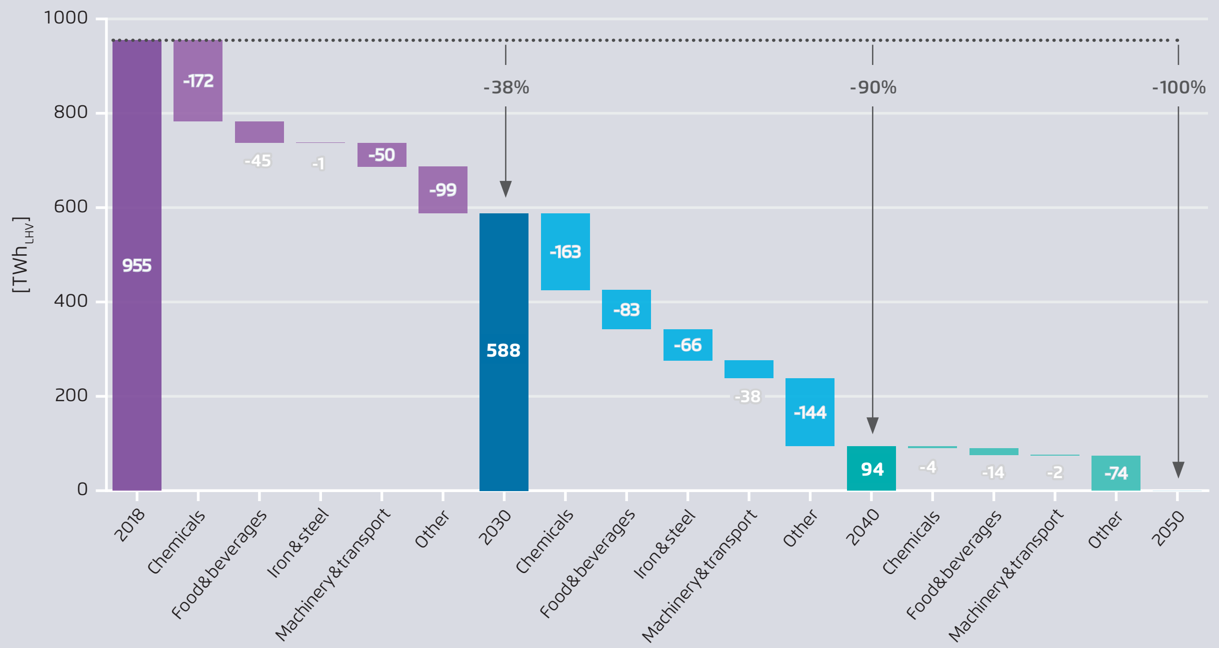
6 Eurelectric (2021)

Industry Sector

In the **industry sector**, the structural transformation away from fossil gas proceeds at different speeds across the various sub-sectors. The largest reductions in fossil gas consumption up to 2040 are seen in the chemicals (-336 TWh, -100%), food, beverages and tobacco (-128 TWh, -90%), machinery and transport equipment (-88 TWh, -100%), iron and steel (-67 TWh, -100%) and pulp and paper (-60 TWh, -87%) sub-sectors, with several sub-sectors being fossil gas free by then. Nearly half of the residual fossil gas consumption in 2040 is thus found in the non-metallic minerals sub-sectors such as glass, lime and cement. Fossil gas demand reductions in industry are initially mostly driven by direct electrification and efficiency increases, but this is complemented by renewables-based hydrogen and bioenergy with carbon capture and storage (BECCS) later on.

Initially fossil gas demand in industry is largely reduced in the medium- and low-temperature segments through efficiency measures and the direct electrification of heating processes. From 2018 to 2030, demand declines by -242 TWh (-54%) in mid-temperature steam production (100–50 °C) and by 63 TWh (-48%) in low-temperature space heating and cooling (below 100 °C), representing nearly 90% of the total gas demand reduction in the period. With regards to space heating, this demand reduction is spread across different, especially non-energy intensive sub-sectors, and can mostly be explained by the deployment of low-temperature heat pumps and efficiency increases in industrial buildings through building insulation. With regards to mid-temperature steam production, these reductions are in particular achieved through the deployment of high-temperature heat pumps for temperatures up to 200 °C and electric boilers for higher temperatures. These tech-

Evolution of total fossil gas consumption in the industry sector in the EU-27, 2018-2050 Figure 13



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

nologies largely replace centralised steam production based on fossil gas and coal, including both boilers and combined heat and power (CHP) plants. Fossil gas demand reduction in the mid-temperature segments is strongly concentrated in the chemical industry (70%), for example in the production of plastics, followed by the pulp and paper industry (12%), mainly with regards to drying processes.

The role of electric heating technologies in delivering process heat

With regards to fossil gas consumption for heating in industry, roughly 20% of fossil gas consumption is estimated to be for space heating and cooling of industrial buildings and other low-temperature process (<100 °C) that are well within the remit of industrial heat pumps. These technologies are able to efficiently leverage ambient or recycled waste heat, allowing them to move around more heat energy than they consume in electricity and achieve performance factors exceeding 100%. Indeed, industrial heat pumps are already found in the food and beverage, packaging, textile and chemical industries.

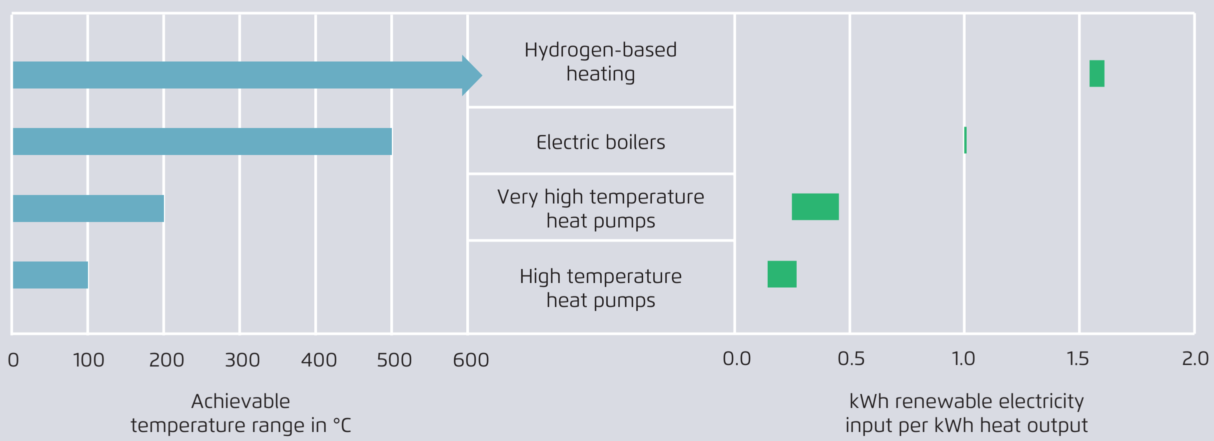
For temperatures exceeding 100 °C, which account for the remaining 80% of fossil gas used in industrial process heat, commercially available industrial heat pumps are available for producing output temperatures up to 100 °C when waste heat of about 100 °C is available as input. Moreover, demonstration projects already exist today for heat pumps that can achieve upwards of 200 °C. For example, the pharmaceutical company Takeda recently announced an innovative heat pump project that can reach temperatures of

200–260 °C, exceeding temperature needs of steam supply at 184 °C required for their manufacturing processes.[7]

For temperatures exceeding 200 °C, electric boilers are efficient in the direct conversion of electricity into heat at temperatures of up to 500 °C. They are simple heating systems that can be installed at relatively low cost and operated flexibly and in a way that reinforces the power system. Moreover, while they do require more electricity than heat pumps, they are still significantly more efficient than hydrogen-based systems. Efficiency losses in the production and use of renewable hydrogen mean that a great deal of electricity is required. Compared to direct electrification with electric boilers, hydrogen-based heat requires about 60% more electricity. Compared to an efficient heat pump, the use of hydrogen to provide low-temperature process heat requires up to six times more renewable electricity.

At the same time, available power-to-heat technologies can cover all temperature levels needed in industrial production. A total of eight mechanisms for electric heating are commercially established, of which six can produce temperatures in excess of 1 000 °C (see figure 14). A well-known example is the electric arc furnace in steel production, which reaches temperatures of up to 3 500 °C.

Achievable temperature ranges and electricity requirements of electricity-based technology options for climate-neutral heat Figure 14



Agora Industry and FutureCamp (2022)

7 See Takeda (2023): Takeda Unveils First Industrial Application of Natural Gas-Free Steam Generation in Pharmaceutical Industry in Partnership With Austrian Government and Institute of Technology. Online at https://www.takeda.com/de-at/newsroom/2023/takeda-unveils-first-industrial-application-of-natural-gas-free-steam-generation-in-pharmaceutical-industry

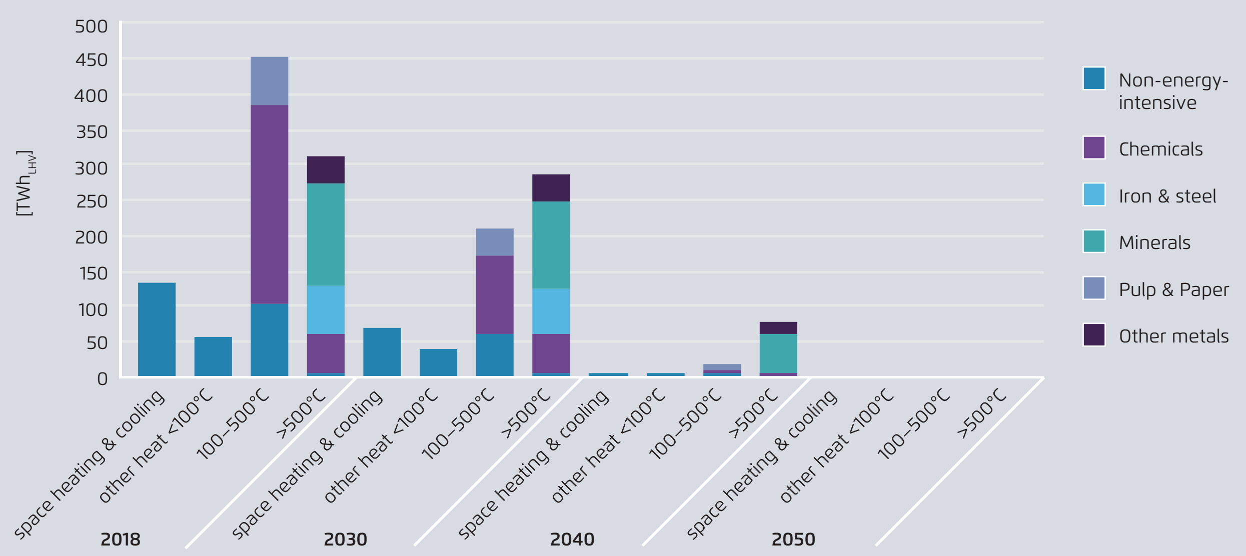
Between 2030 and 2040, fossil gas is almost completely displaced in space heating and cooling and the low-temperature heat segment through additional electrification with heat pumps and the deployment of biomass heaters, while fossil gas consumption in the mid- and high-temperature heating segments declines by about 400 TWh (-80%), in particular in the chemicals, food, beverage and tobacco, pulp and paper and iron and steel sectors. With regards to mid-temperature heat, production continues to largely be electrified through the use of electric boilers and high-temperature heat pumps, helping to displace a growing number of CHP plants. To a lesser extent, renewables-based hydrogen in hydrogen boilers also comes into play for mid-temperature steam production in chemicals and refineries, being largely operated during times of high electricity prices.

Significant reductions in fossil gas demand are also achieved in this decade for high-temperature heat production above 500 °C. A variety of technologies are used to achieve fossil gas demand reductions in this segment, including electric, hydrogen, waste and biomass ovens, as well as electrified steam cracking furnaces in the chemicals sector. Some of the biomass applications in the iron and steel as well as cement sectors are also complemented with CCS to provide high-temperature heat coupled with negative emissions. Finally, a larger share of ammonia than today is imported rather than produced in Europe after 2030, and a similar trend can be observed for methanol starting 2040.

The steel industry also invests in this decade in direct-reduction processes based on renewable hydrogen to replace blast furnaces, allowing to almost phase out coal completely by the end of 2035. As a result of these changes, most of the fossil gas demand in 2040 remains in the high-temperature processes (78 TWh, 75%) especially in the minerals sector (cement, bricks, ceramics etc), before being completely phased out by 2050 (see figure 15).

To summarise, several technological levers enable fossil gas demand reductions while sustaining durable economic activities in the industrial sector:

Evolution of fossil-gas* consumption in the industry sector by sub-sector and heat type, EU-27 — Figure 15

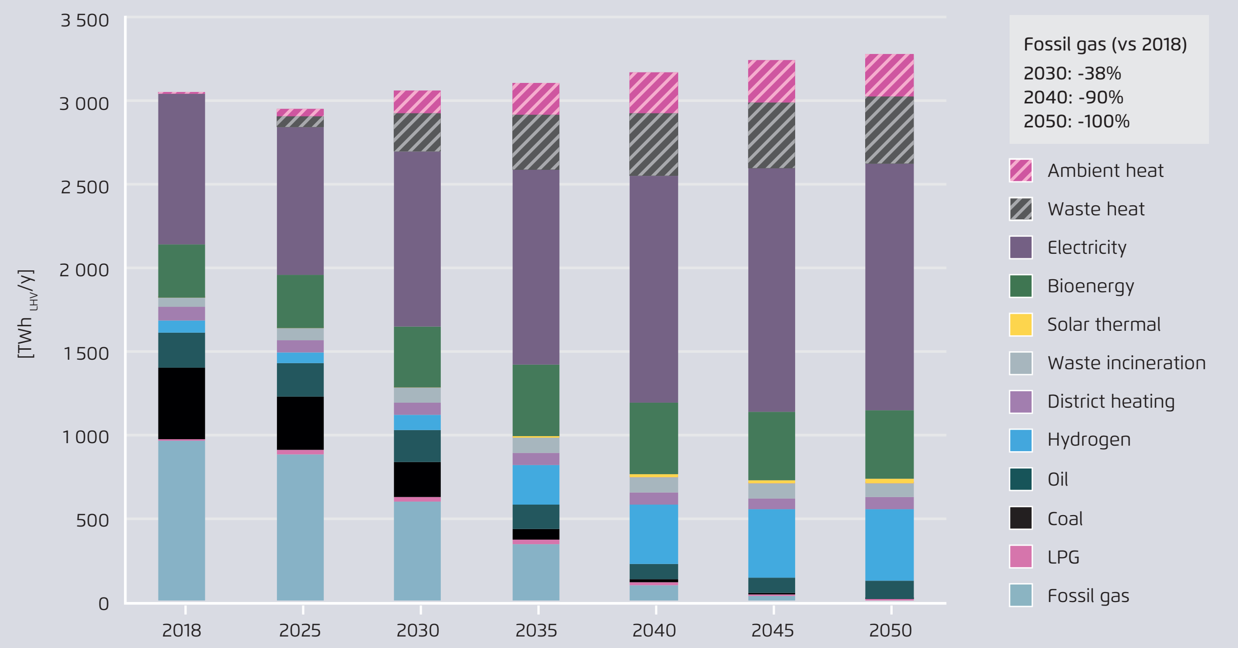


Artelys, TEP Energy, Wuppertal Institute modelling (2023). *Fossil gas includes natural gas, refinery gas and LPG.

- Many industrial processes are electrified through the deployment of heat pumps and electric boilers, sometimes combined with the use of waste heat, especially in the low- to medium-temperature segments, through 2030.[8] Direct electrification also plays a significant role in the higher-temperature segment especially after 2030, which reduces the amount of power needed compared with indirect electrification using renewable hydrogen.
- Combined heat and power (CHP) plants are partly phased down already by 2030, as they are decommissioned at their economic end-of-life or running with fewer full-load hours.
- In Southeast Europe, concentrated solar power (CSP) will produce steam for the chemical sector, starting before 2030 but increasing significantly from 2030 to 2040, in hybrid operation with other technologies.
- Starting 2040, some remaining fossil gas in high-temperature processes is replaced with biomass and CCS, e.g. in the minerals and steel sectors, as well as renewable hydrogen for some applications. For example, in the steel sector, blast furnaces that are coming to their end-of-life are replaced with direct reduction plants that run primarily on hydrogen and are partially supplemented by biomass (BECCS).
- In parallel, additional energy efficiency measures keep the power demand increases in industry limited to 32% over the decade. For example, industrial buildings are far better insulated, especially by 2030.
- Early investments are also made into circular material flows, including higher shares of secondary raw materials, so that these solutions can reach their full potential in the 2030s and help reduce the strain on energy and material demands from virgin-material production.

8 40% of today's industrial natural gas use in the EU goes to heat below 100°C and can be supplied with heat pumps. See Agora Energiewende and AFRY Management Consulting (2021), p.12.

Final energy consumption in industry, EU-27 Figure 16



Wuppertal Institute modelling (2023). *H_2 and bioenergy demand includes non-energy demand

2 Kick-starting a discussion on the 2040 climate targets

In July 2021 the EU adopted a new EU Climate Law placing the EU's medium- and long-term climate targets into a binding legal framework.[9] According to the law, the EU has committed to achieving net collective greenhouse gas emissions reductions (including land-use sinks) of at least 55% compared to 1990 levels by 2030,[10] as well as climate neutrality by 2050. However, the EU Climate Law also puts in place a clear obligation and process for strengthening and further specifying the EU's midterm climate ambition for 2040.

More specifically, Article 4 of the EU Climate Law specifies that the European Commission must make a legislative proposal to amend the EU Climate Law with a 2040 climate target, as well as publish a projected indicative EU greenhouse gas budget for the period 2030–2050 at the latest within six months of the first global stocktake, which is set to conclude at COP28 from 6–17 November 2023.[11] This implies that the European Commission will have to make its legislative proposal for a future 2040 target by 17 May 2024, i.e. ahead of the next European Parliament elections, which are likely to take place in the second half of May 2024.

Next to the adopted Fit for 55 package, the EU's 2040 target could also represent a core element of the EU's next revision of its Nationally Determined Contribution (NDC) under the Paris Agreement. According to the Paris Agreement, parties are requested to submit the next round of NDCs (new NDCs or updated NDCs) to the UNFCCC by COP30 in November/December 2025. With a new European Commission office in the second half of 2024 and the need to have sufficient time to debate the proposals of the European Commission at a technical and political level, policymakers will need to begin with the work on the legislative proposal for the 2040 target very soon if it is still to be adopted in time for being made part of the EU's next NDC. As such, the European Commission can be expected to present a proposal for the 2040 climate target as soon as Q4 2023 / Q1 2024 (see indicative timeline figure 17). This raises the question of what the implications of recent developments and the EU Gas Exit Pathway are for the EU's 2040 climate target and 2030–2050 emissions budget.

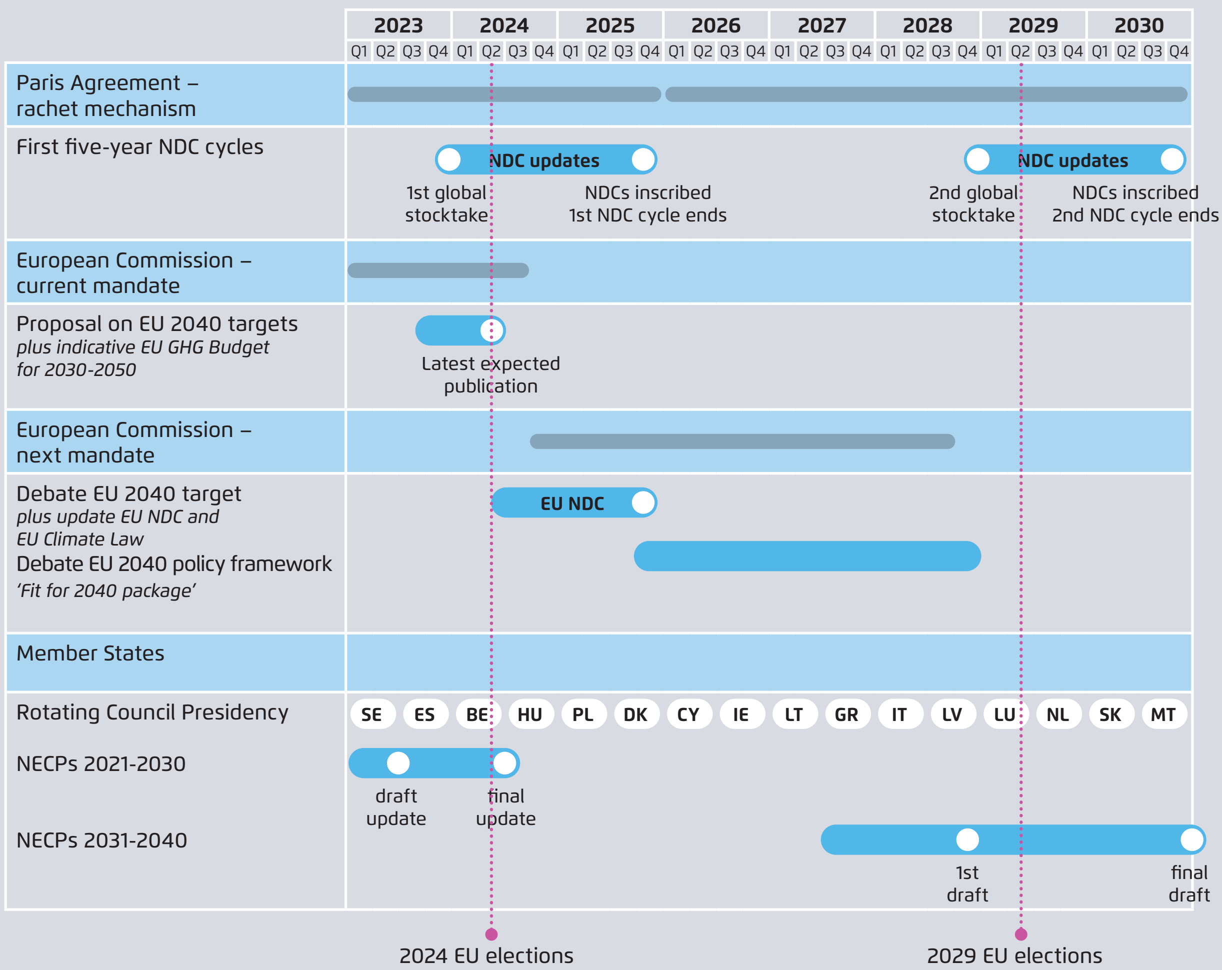
We estimate that within the EU Gas Exit Pathway, net GHG emissions will decline by 89% relative to 1990 levels by 2040 in the scope of the EU Climate Law and result in total GHG emissions in the period 2030 to 2050 of 14.3 Gt, compared to 86.4% reduction by 2040 and 17.6 Gt in cumulative GHG emissions in the European Commission's Climate Target Plan. This is if we assume emissions reductions for the non-modelled sectors (agriculture, waste, LULUCF) are aligned with the EU Climate Target Plan and the EU Long-Term Strategy. Additional details on these alternative scenarios can be found in Annex 2 of this report.

9 European Parliament and Council (2021)

10 The EU Climate Law also specifies that the contribution of net removals to the Union 2030 climate target shall be limited to 225 million tonnes of CO_2 equivalent and the EU shall aim to achieve a higher volume of its net carbon sink in 2030.

11 UNFCCC (2021)

Timeline of the various milestones and processes — Figure 17



Agora Energiewende based on European Parliament and Council (2021) and UNFCCC (2021)

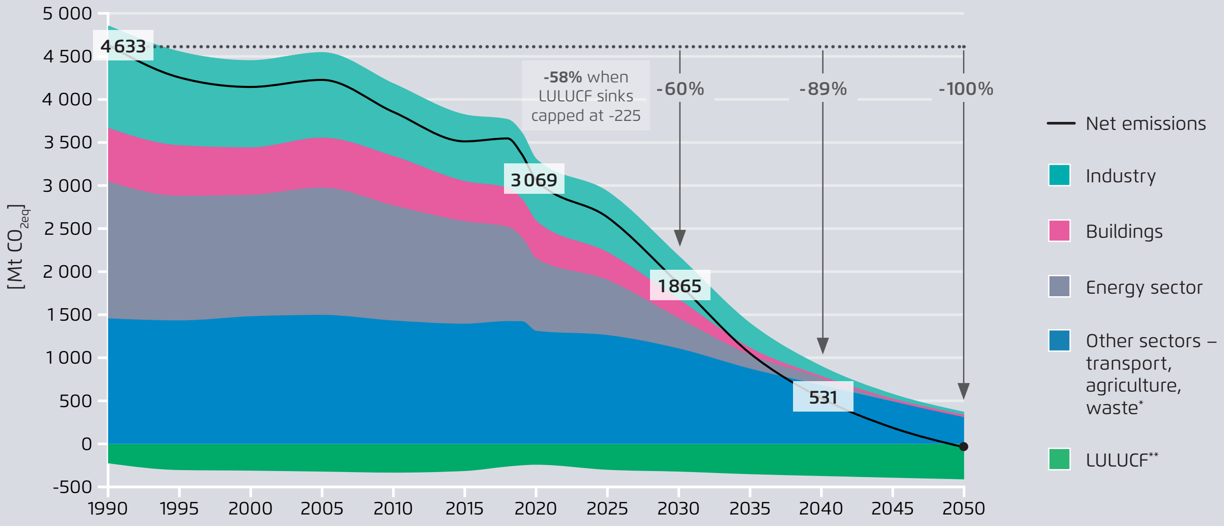
As such, the EU Gas Exit Pathway shows that an accelerated energy transition in the energy, buildings and industry sectors in line with the EU's climate-neutrality objective would imply an even faster relative reduction of GHG emissions by 2040 and a more ambitious future trajectory than anticipated by previous European Commission scenarios. It also shows that accelerated climate action towards 2040 can also result in lower cumulative GHG emissions, a fact that should be taken into account when setting the EU's future carbon budget for 2030 to 2050.

At the same time, two points should be noted when interpreting these results. First, achieving this pathway requires strong policy and market signals for deep and fast decarbonisation all the way from today to 2050. Currently Member States are far from being on track to delivering on this pathway and will need to significantly strengthen policies and measures to close the gap.

Secondly, these estimates for GHG emissions reductions only include domestic GHG emissions, thereby excluding GHG emissions associated with bunker fuels used for international aviation and shipping.

GHG emissions by sector

Figure 18



Eurostat, Artelys et al. (2023) *Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste) **Based on the LULUCF+ scenario from the EC Climate Target Plan impact assessment (assumes a five-year delay)

However, with international shipping emissions included in the negotiated outcome for the reform of the EU Emissions Trading System and an extension to international aviation up for review in 2026, the scope of emissions for the EU's GHG target accounting is potentially subject to change in the coming years. Due to the relative difficulty of reducing GHG emissions in international transport, this change of scope can be expected to have a significant impact on the relative emissions reduction target that can be set for 2040. We estimate that an extension of the emissions scope of the EU climate target to international shipping and aviation emissions would reduce the relative emissions reduction in the EU Gas Exit Pathway to 57% in 2030 (-3%) and 86% in 2040 (-2%) and increase the EU's cumulative accounted emissions from 2030 to 2050 to 16.5 Gt (+2 Gt). This slower progress highlights the importance of getting early agreement on the future scope of emissions, as well as the urgent need to accelerate efforts to reduce international shipping and aviation emissions.

3 How does the EU Gas Exit Pathway compare with the REPowerEU plan?

The REPowerEU plan increases the ambition level for several key levers meant to reduce gas consumption, while reaffirming the 55% net GHG emissions reduction target of the Fit for 55 package.

In both the EU Gas Exit and REPowerEU pathways, gas use in the EU will decrease faster than in the Fit for 55 proposals, achieving a phase-out of Russian fossil gas imports by 2027.

The REPowerEU plan and the EU Gas Exit Pathway are also largely aligned with regards to renewable energy deployment and energy savings achieved, as accounted in EU Renewable Energy Directive and Energy Efficiency Directive. The EU Gas Exit Pathway achieves slightly higher reductions in primary energy consumption and slightly lower reductions in final energy consumption compared to the REPowerEU plan, as well as a total renewables share of 43%, compared to 45% in the proposed REPowerEU plan.[12]

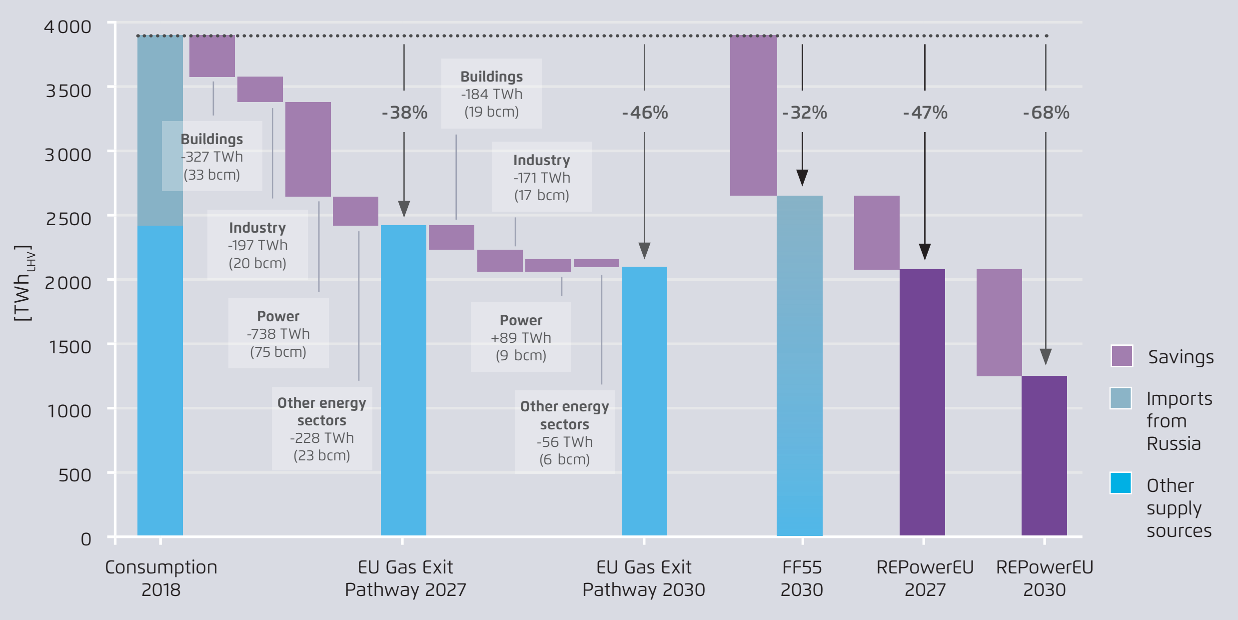
In other aspects, however, the EU Gas Exit Pathway contrasts significantly from the REPowerEU plan:

→ The EU Gas Exit Pathway sees a higher rate of direct electrification, especially through the widespread use of heat pumps in the heat sector (buildings, district heating and industry).

12 For more details see Annex 3 – Renewable energy and energy efficiency target estimates

Reduction of fossil gas consumption in the EU Gas Exit Pathway, Fit for 55 package and REPowerEU plan

Figure 19



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).

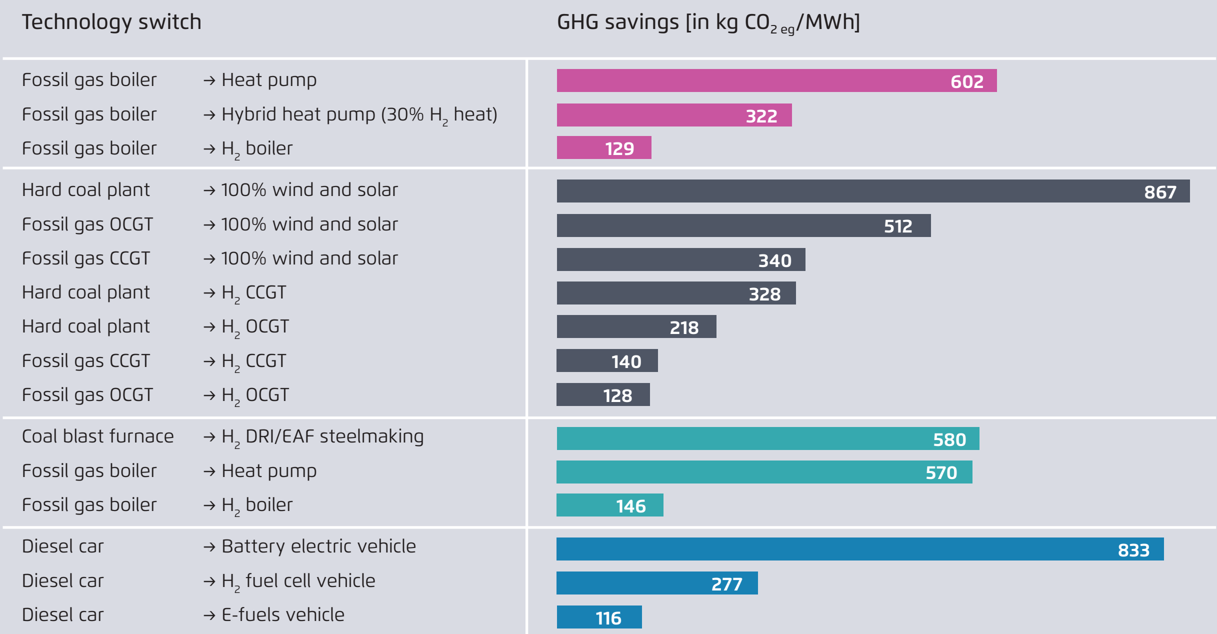
- → The REPowerEU scenario delivers a much faster fossil gas phase-out (-68% vs 2018 levels), however, also at the expense of higher renewables investment needs and higher oil and coal consumption.
- → The REPowerEU plan foresees a much higher use of biomethane and renewable hydrogen and its derivatives, as well as a significantly higher share of hydrogen imports.

Indirect electrification with hydrogen

The EU Gas Exit Pathway favours direct electrification (e.g. electric vehicles and heat pumps) over indirect electrification via power-to-X fuels (e.g. renewable hydrogen) to replace fossil gas, as this is generally the most effective use of scarce resources.

Indeed, indirect electrification is much less efficient and more costly than direct electrification, as signifi-

GHG emissions reductions in kg of CO_{2eq} when using 1 MWh* of renewable electricity to substitute fossil fuels in different applications — Figure 20



Efficiency assumptions

Buildings	Energy sector	Industry	Transport
Hybrid heat pump: 145% (HP 450%, Boiler: 90%) Heat pump: 300% Boiler: 90%	Hard coal plant: 39% OCGT: 39% CCGT: 59%	BF: 2t CO_{2eq}/t steel DRI/EAF: 3.4 MWh_{el}/t steel Heat pump: 300% Boiler: 95%	BEV: 18 KWh/100 km Fuel cell: 0.89 kg/100 km Diesel & E-fuels: 6 l/100km

* 1 MWh represents roughly the annual electricity production of 1 kWp solar PV
Emissions intensities (in g CO_2/kWhPE) = Hard coal (338.2), Fossil gas (200.8), Diesel (266.5)
HP = Heat pump, H_2 = Hydrogen, OCGT = Open cycle gas turbine, CCGT = Closed cycle gas turbine,
BF = Blast furnace, DRI = Directly reduced iron, EAF = Electric Arc Furnace, BEV = Battery electric vehicle

Agora Energiewende (2023)

cant conversion losses are unavoidable.[13] As a result, indirect electrification generally requires the deployment of higher volumes of renewable power generation when displacing fossil fuels, explaining its higher cost (see figure 20).

In this context, the REPowerEU scenario significantly encourages a less efficient indirect electrification through the promotion of hydrogen for end-uses. In total, the REPowerEU scenario foresees 242 TWh of final hydrogen consumption in the end-use sectors in 2030, compared to only 71 TWh in the EU Gas Exit Pathway. Moreover, whereas all final hydrogen consumption in the EU Gas Exit Pathway is used in no-regret applications in industry, we estimate that roughly half of the final hydrogen consumption in the REPowerEU scenario is consumed in lower-priority applications, including road or rail transport (77 TWh, 32%) and blending for consumption in the building sector (44 TWh, 18%).

At the same time, while both scenarios foresee a significant increase in the share of electricity in final electricity consumption (33.1% in the REPowerEU scenario and 34.2% in the EU Gas Exit Pathway compared to 23% today), certain indicators point to some notable differences in the deployment of clean electrification technologies between the two scenarios. For example, we estimate that electricity consumption in transport is roughly 100 TWh (+67%) higher in the EU Gas Exit Pathway.

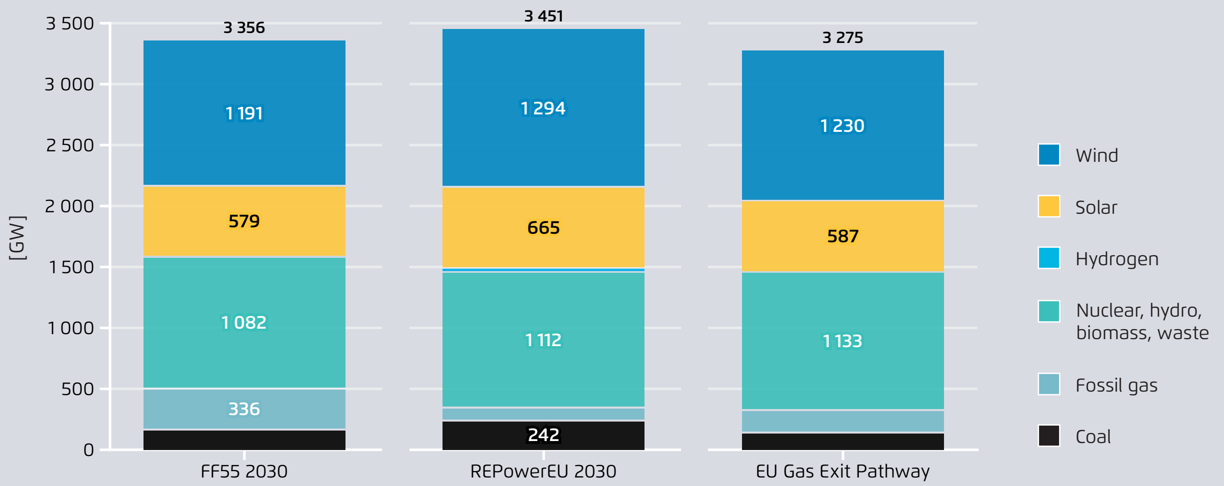
In the short to medium term, the use of limited renewables generation for indirect electrification stands in direct competition with its more efficient use for direct electrification, making it critical to prioritise indirect electrification only in "no-regret" and difficult-to-electrify applications, such as high-temperature processes and feedstock use in industry, especially where it can replace highly carbon-intensive existing fossil-based hydrogen.[14]

13 Agora Energiewende (2022)

14 The transport sector has not been modelled in this exercise. The energy demand from the Road2Zero scenario

Net electricity generation by energy source in the EU Gas Exit scenario, Fit for 55 package and REPowerEU plan

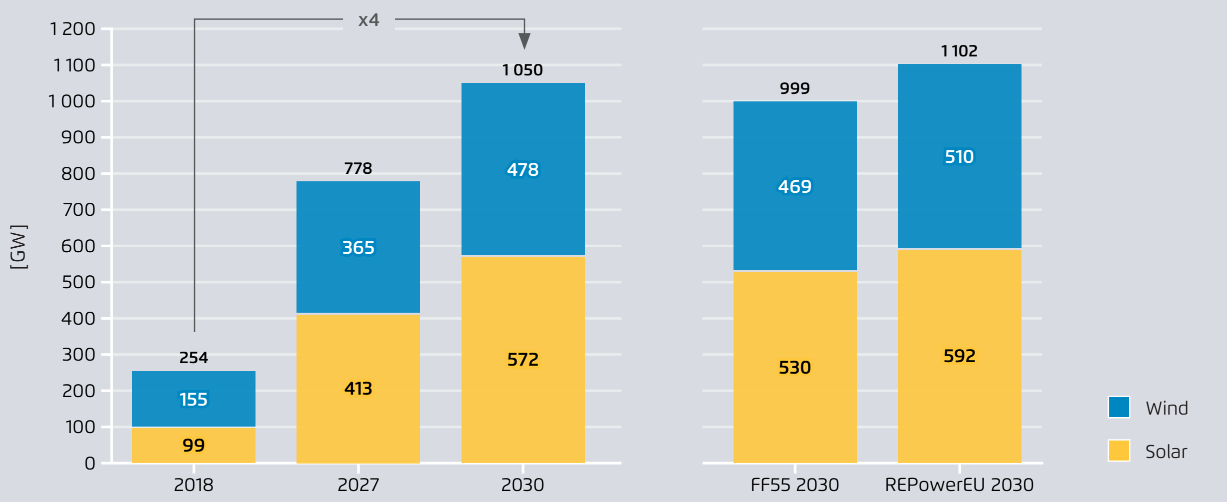
Figure 21



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).

Installed capacity for solar and wind power in the EU Gas Exit scenario, Fit for 55 package and REPowerEU plan

Figure 22



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).

The importance of these differences between the two scenarios becomes particularly visible when comparing the respective applications of electricity in the EU Gas Exit Pathway and the REPowerEU plan. The EU Gas Exit Pathway has a net electricity generation of 3 275 TWh, compared with a net electricity generation of 3 450 TWh (+175 TWh) in the REPowerEU scenario of the European Commission with a key difference between the scenarios being the use of electricity to produce renewable hydrogen and the level of direct electrification (–54 TWh of final electricity consumption in the REPowerEU scenario).

As a result of these differences, the REPowerEU scenario also foresees a significantly higher deployment of wind and solar (+52 GW and +142 TWh) than is already considered in the EU Gas Exit Pathway, in which wind and solar capacity must roughly quadruple by 2030.

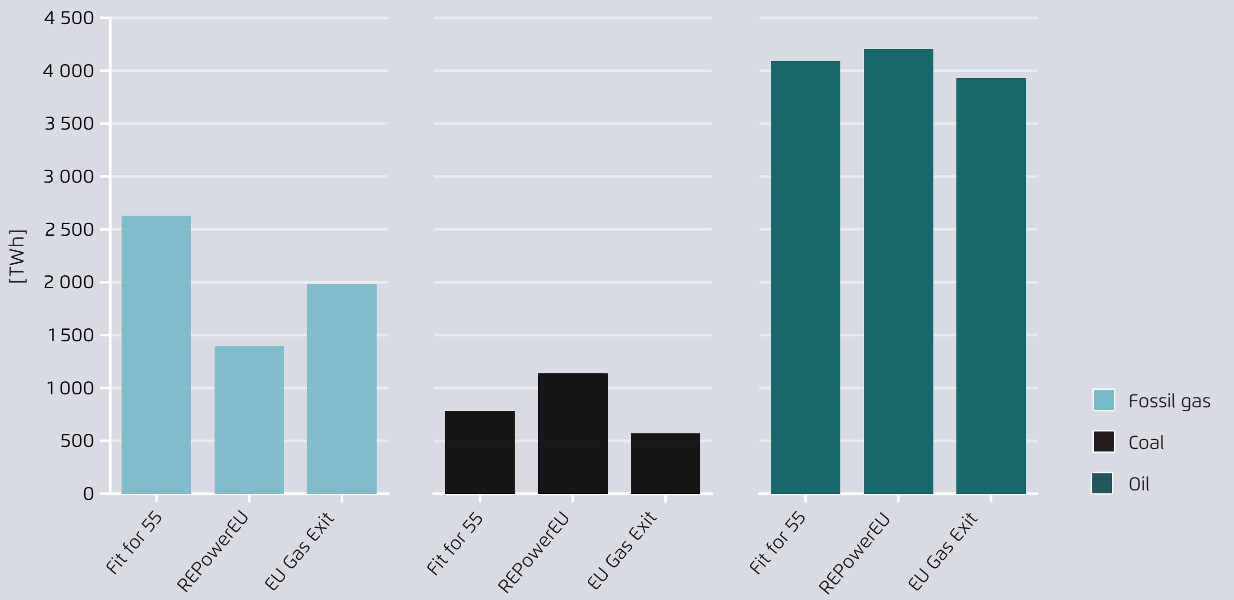
from Transport & Environment has been integrated for the transport sector, which foresees a high electrification in all road transport modes. This scenario considers conventional crop biofuels to be phased-out and hydrogen and synthetic fuels used only for aviation and navigation. Study: Transport & Environment (2021).

Fossil fuel consumption

Another consequence of modelling choices made for the REPowerEU scenario and plan is a more carbon-intensive fuel mix. For example, while electricity generation from fossil gas is 79 TWh lower in the REPowerEU scenario compared to the EU Gas Exit Pathway, it also foresees significantly higher electricity generation from coal (+98 TWh), and thus higher net emissions.

More generally, the fossil gas demand reduction in the REPowerEU plan seems to happen at the expense of other fossil fuel demand reductions, especially with regards to coal. When looking at total fossil fuel consumption for energy and non-energy uses (gross inland consumption), fossil gas consumption is

Energy demand in the EU Gas Exit Pathway and in the REPowerEU plan by type in 2030 — Figure 23



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).
*Estimate based on REPowerEU staff working document for oil, biofuels kept at 2019 levels.

589 TWh lower in the REPowerEU scenario compared to the EU Gas Exit Pathway, while coal and oil consumption are 569 TWh and 275 TWh higher, respectively (see figure 23).

As a result, while total energy-related emissions in the REPowerEU scenario are still likely to be lower than under previous modelling for the Fit for 55 package, these reductions come at a significant opportunity cost (lower emission reductions) compared with the EU Gas Exit Pathway. Given that both scenarios ostensibly achieve the goal of structurally replacing the EU's reliance on Russian fossil fuel imports, this raises the question of whether the REPowerEU scenario represents the optimal pathway for achieving this goal in the context of the EU's commitment to achieving at least 55% net greenhouse gas emissions reductions by 2030.

Hydrogen imports

The domestic production of hydrogen remains much lower in the EU Gas Exit Pathway, given the much lower demand for hydrogen. The EU Gas Exit Pathway sees the installation of about half the electrolyser capacity of the REPowerEU plan (34 GW vs 65 GW) and a demand for domestically produced renewable hydrogen of only 2.7 Mt (89 TWh)[15] compared to 10 Mt (333 TWh) in the REPowerEU plan.

Similarly, the EU Gas Exit Pathway foresees limited demand for imports of hydrogen and hydrogen derivatives by 2030 at 0.8 Mt (27 TWh), compared to 6.16 Mt (206 TWh) of net hydrogen imports and 4 Mt (134 TWh) of ammonia imports by 2030 in the REPowerEU plan. As a result, in 2030 a much larger

15 Net hydrogen demand: hydrogen produced as a by-product (not on purpose) is consumed directly by the industry and deducted from explicit demand, reducing the need for dedicated hydrogen production.

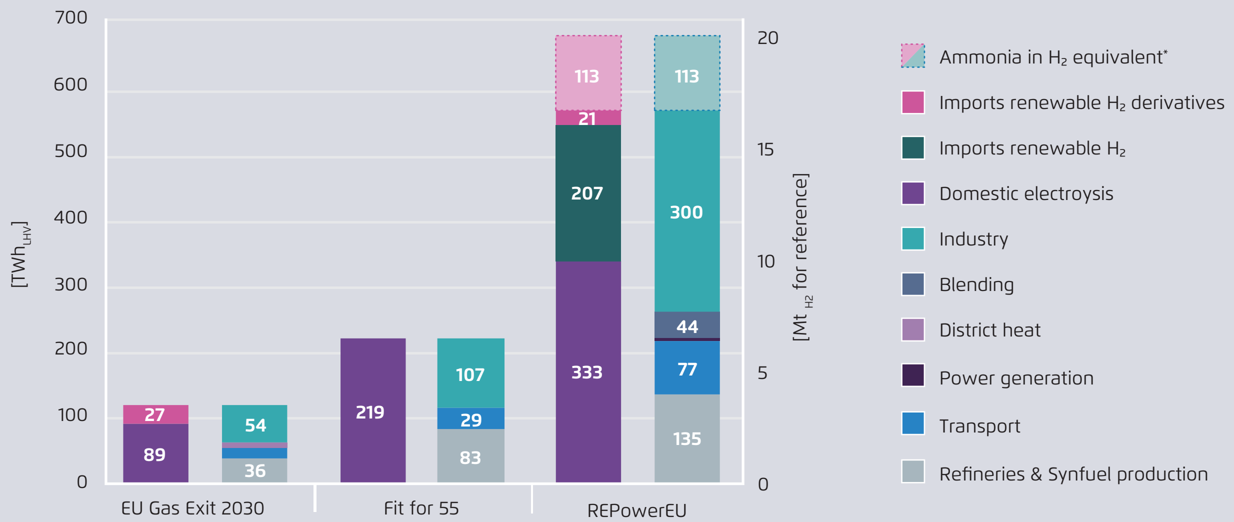
share of total hydrogen and hydrogen derivative consumption is covered by imports (38%) in the REPowerEU plan, rising to half (51%) when considering ammonia imports.

This strategy implies additional investment and operational costs for infrastructure that needs to quickly be developed with the scaling of hydrogen production and imports (pipelines, storage, tankers and liquefaction and regasification terminals for imports, etc) at a time when most of the existing fossil gas infrastructure can neither be easily converted to hydrogen nor be dismantled yet due to high utilisation rates. Long-term multi-energy infrastructure planning based on a solid impact assessment is also still lacking, implying a significant risk of technological lock-in and over-dimensioning, and consequently of stranded assets.

Another risk is that the amounts of renewable hydrogen required by REPowerEU will not be available in time, neither domestically nor as imports. This raises the prospect of either continued use of fossil-based hydrogen in industrial applications well beyond 2030, or greater production of electricity-based hydrogen using either fossil fuels or nuclear power. Both outcomes could directly or indirectly result in higher emissions, especially if demand for hydrogen produced without additional renewable electricity generation was artificially inflated by the lax provisions in the EU's recent delegated act on the sustainability of renewable hydrogen, which foresees limited sustainability safeguards for electricity-based hydrogen production before 2030.

The more cautious approach to the deployment of hydrogen reflected in the EU Gas Exit Pathway would significantly reduce these risks.

Supply by source and sectoral demand for renewable hydrogen and derivatives — Figure 24



Artelys, TEP Energy, Wuppertal Institute modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022).
*Derivatives include ammonia and synthetic fuels. Ammonia has a lower calorific value than H_2. The REPowerEU plan seems to have used the same conversion rate for ammonia as for H_2 for its calculations in Mt. Assuming all of the 20 Mt hydrogen and derivatives in the REPowerEU plan are renewable.

Imports of hydrogen and hydrogen derivatives in 2030

The supply of hydrogen and hydrogen derivatives in the EU Gas Exit Pathway was modelled based on a cost optimisation and reflects a lower cost of domestic hydrogen production in Europe compared to non-pipeline hydrogen imports, especially in the short to medium term. On this basis, hydrogen imports in 2030 are almost exclusively provided in the form of hydrogen derivatives, more specifically 9 TWh of green ammonia for fertiliser production and 18 TWh of synthetic fuels for shipping and transport. By contrast, REPowerEU sets a political target of 10 Mt of hydrogen imports (333 TWh) in 2030 in the REPowerEU plan, of which 4 Mt (133 TWh in hydrogen equivalent) are expected to be green ammonia imports.

According to Bloomberg New Energy Finance (BNEF),[16] the current capacity of existing and planned ammonia import terminals in Europe would be able to import roughly 2.3 Mt of hydrogen annually (83.3 TWh) by 2030, while the methanol and synthetic fuels terminals could support 0.6 Mt/year (20 TWh). At the same time, major announcements for green ammonia import projects have already been made by German and Austrian companies, amounting to an offtake of up to 12 TWh of green ammonia by 2030. As such, existing and planned import infrastructure and projects would be sufficient to meet the demand for hydrogen derivatives in the EU Gas Exit Pathway, but falls well short of the political target of 10 Mt of hydrogen imports and 4 Mt of ammonia imports, as well as just shy of the current fossil-based hydrogen consumption of the EU ammonia sector of 2.5 Mt per year (83.3 TWh).

With regards to global supply, BNEF estimates that globally some 24 Mt of clean hydrogen production capacity (1.1 Mt fossil hydrogen with CCS and 23 Mt of renewable hydrogen) is planned at least partially for export, of which 14 Mt aim to come online by 2030. Of these projects, 87% of the planned capacity is to be shipped in the form of ammonia. At the same time, only part of this global supply can be expected to be secured by the EU and hydrogen exports are not expected to scale significantly further until after 2030, when domestic hydrogen production becomes insufficient and adequate supply infrastructure has been built out. For example, BNEF estimates that only 7.2 Mt, or 30% of the planned export capacity, lies within 20 km of existing ammonia terminals. The remaining capacity is being planned with no liquefaction or chemical-handling facilities, more than 20 km from a potential port (43%) or would need to retrofit LPG or LNG terminals (27%).

Given that costs for hydrogen transport by pipeline are projected to be several times cheaper than the transport costs of importing H_2 and its derivatives by ship, another promising strategy to secure competitive H_2 could be to pursue higher imports of H_2 by pipeline from non-EU countries such as Norway and Morocco. For example, the German government has recently signed an agreement with the Norwegian government for the development of a hydrogen pipeline project by 2030 to transport fossil hydrogen with CCS.[17]

16 BNEF (2022)

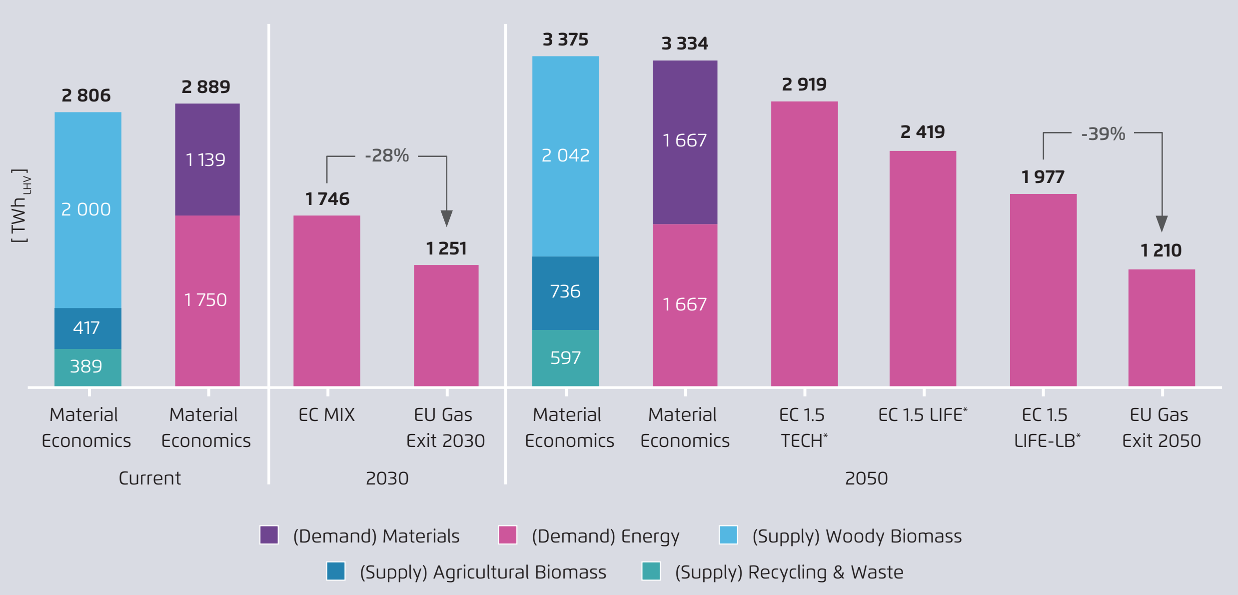
17 https://www.pv-magazine.de/2023/01/05/habeck-in-oslo-wasserstoff-pipeline-von-norwegen-nach-deutschland-beschlossen/

Bioenergy

The EU Gas Exit Pathway also results in a significant difference in total bioenergy consumption. While no detailed results for bioenergy demand are available in the REPowerEU impact assessment, a look to previous European Commission policy scenarios makes these differences apparent. For example, the EU Gas Exit Pathway relies on roughly a third less bioenergy demand than in the EC Mix scenario from the Fit for 55 package and forty percent less than in the EU Long-Term Strategy scenario with the lowest bioenergy demand (titled 1.5LIFE-LB, see figure 25). Meanwhile, the limited information on bioenergy consumption in the modelling scenario for the REPowerEU plan reveals that it relies on a significant increase in the consumption of biomass in power and buildings, as well as a doubling of biomethane production relative to the modelling for the Fit for 55 package.

The reasons for the significantly lower demand for bioenergy in the EU Gas Exit Pathway vary by sector, but they can largely be explained by a greater prioritisation of direct electrification and the application of select restrictions on the use of biomass. For example, willingness to pay for solid biofuels for heating in the buildings sector was reduced in certain countries to reflect an anticipated growth in policies aimed at restricting the use of solid biomass (e.g. local bans on biomass stoves or future carbon dioxide (CO_2) pricing on biomass). The EU Gas Exit Pathway also assumes the gradual replacement of traditional solid biomass stoves, which use firewood, with more modern and efficient solid biomass heating equipment, such as pellet boilers. Conventional liquid biofuels in the transport sector are also assumed to be phased out by 2030, while future advanced biofuels are expected to be prioritised for use in shipping and aviation; both assumptions are in line with the transport scenario developed by Transport & Environment.

Scenario comparison – Biomass consumption vs sustainable supply potentials — Figure 25



Agora Energiewende based on Material Economics (2021), EU Long-Term Strategy (2018), EU Climate Target Plan (2021) and Artelys et al. Modelling (2023). *EU28 (incl. UK)

These restrictions were set to take into account broader sustainability limits for the supply of biomass for bioenergy uses that have been identified in various integrated assessments of long-term biomass demand, as well as an anticipated growth in non-energy related biomass demand for materials that fall outside of the scope of the EU Gas Exit modelling exercise (e.g. woody biomass for building construction).[18] The restrictions also reflect the need to change current agricultural and forestry land-use practices to take into account new environmental and climate priorities related to biodiversity protection and the achievement of the EU's ambitious land-use sink target of 310 Mt by 2030 under the revised LULUCF (land use, land use change and forestry) Regulation.

The EU Gas Exit Pathway has also taken a less supportive approach to the deployment of biogas and biomethane than REPowerEU. The REPowerEU plan proposes a political target of 35 bcm (342 TWh) of sustainable biomethane deployment by 2030, resulting in a near-doubling of biogas and biomethane demand in the REPowerEU scenario compared with previous policy scenarios for the Fit for 55 package. By contrast, biogas and biomethane demand in the EU Gas Exit Pathway was assumed to remain constant at today's level (18.4 bcm = 196 TWh[19]) until 2045 and to decline to 176 TWh in 2050, when fossil methane falls to zero and biomethane is no longer needed at today's volumes to meet residual fossil gas demand.

This exogenous assumption for the deployment of biogas and biomethane was chosen for three reasons: First, the modelling outcome for the assumptions chosen revealed a limited need for biogas and biomethane in 2050 to fully decarbonise the EU's gas supply. As such, it seemed prudent to highlight a pathway that could avoid technology lock-ins and stranded assets on the way to 2050. Second, it accounts for the challenge of ensuring a sustainable supply of biogas and biomethane feedstocks into the future (see box below). Third, it reflects the fact that the demand for biogas and biomethane emerging as an outcome of the modelling was below today's levels in 2030 and 2050, highlighting the potential need for significant policy and financial support that was not explicitly modelled. However, the outcomes of the EU Gas Exit Pathway for biomethane should not be interpreted as a representation of the technical or sustainability limits to the deployment of this energy source, but rather as a reflection of a more cautious approach to integrated energy system modelling for the reasons given.

18 For more background, please consult the following studies: Material Economics (2021); IEEP (2021).

19 European Biogas Association (2022)

Estimating the sustainable and affordable biomethane potentials in the EU

Sustainable production potentials for biomethane have been a subject of heated intellectual debate over the last several years. On the one hand, several studies with close or direct links to the industry have estimated significant additional sustainable methane potentials in the EU by making greater use of animal manure, agricultural residues, industrial wastewater and biowaste, as well as scaling the potential of sequential crops and thermal gasification of woody biomass in the medium to long term. Notably, a gas industry-financed project Gas for Climate estimated that sustainable feedstocks are available to produce 41 bcm (400 TWh) of biomethane in 2030 and 151 bcm (1 475 TWh) in 2050.[20]

20 Gas for Climate (2022)

By contrast, alternative assessments by environmental research institutes have yielded vastly different results. IFEU estimates a "realistic" EU-wide potential for biomethane based on waste and residual at approximately 17 bcm (166 TWh),[21] while an ICCT study from 2018 estimates potentials at 17.5 bcm (171 TWh) in 2030 and 29 bcm (283 TWh) in 2050.[22]

A key concern for environmental researchers is an expected reliance on energy crops (e.g. silage and maize) to meet the biomethane target. It is feared that a dominant use of energy crops, as was the historical case in countries like Germany and the UK, will lead to higher direct and indirect (ILUC) emissions, largely negating the climate benefits of biogas and causing additional social and environmental damage. For example, IFEU has estimated that meeting half of the 35 bcm biomethane target with maize would require 5% of the total arable land in the EU, equal to 20% of the land used for wheat cultivation, while achieving roughly the same GHG emissions reductions as only producing 17 bcm of biomethane from waste and residues. Furthermore, the economic and environmental cost is believed to be much higher when factoring in the potential increase in agricultural prices from competition with food production, as well as the carbon opportunity cost of foregoing carbon farming or increased transition to sustainable farming practices with lower yields (e.g. organic or no-till farming).

Economic constraints have also often been insufficiently taken into consideration in studies when estimating sustainable biomethane potential. These studies often ignored the significant subsidies needed to scale sustainable biomethane production. For example, feed-in tariffs in France and Italy have ranged from 45–125 EUR/MWh.[23] At the same time, the economics of biomethane have recently improved with the rise of wholesale fossil gas prices to around 50 EUR/MWh. Some cost estimates put typical production costs of biomethane at 70–90 EUR/MWh and as low as 55 EUR/MWh, implying that far more limited financial support may be needed to scale biomethane production.[24]

Finally, recent research reviewing estimates of methane emissions from the full supply chain for biogas and biomethane indicates that methane (CH4) emissions from biogas and biomethane production may be significantly underestimated. While biomethane and biogas is still assumed to emit less CH4 in aggregate than fossil oil and gas, the CH4 loss rates are expected to exceed those in fossil oil and gas and be twice as high as previous IEA estimates. It is believed that 5% of the emitters in this supply chain account for 62% of the methane emissions from biogas and biomethane production, highlighting the large impact of super emitters and the importance of targeted efforts to monitor and address these problems.[25]

21 IFEU (2022)

22 ICCT (2022)

23 ICCT (2022)

24 Common Future (2022)

25 Semra Bakkaloglu et al. (2022)

4 How does the EU Gas Exit Pathway compare with other long-term scenarios?

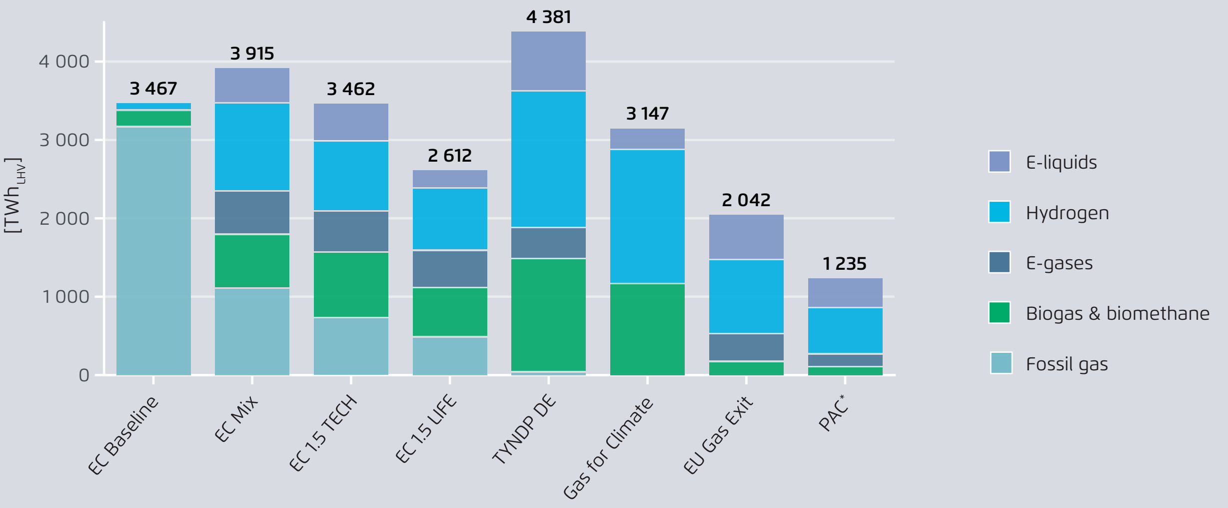
Additional insights can be drawn by comparing the results of the EU Gas Exit Pathway for 2050 with those of other long-term scenarios. Below is a comparison of the demand for fossil methane, hydrogen, biogas & biomethane and hydrogen derivatives (e-liquids and e-gases) in TWh in 2050 across a variety of European Commission and policy-relevant scenarios.

The comparison shows that the EU Gas Exit Pathway has far lower demand for fossil gas, biomethane, hydrogen and hydrogen derivatives than any of the European Commission scenarios, including the European Commission's 1.5LIFE scenario from the EU Long-Term Strategy, which relies most heavily on behavioral change and nature-based solutions. It is also notable that none of the long-term scenarios of the European Commission feature a full phase-out of fossil methane in 2050 in any sector.

By contrast, at least three other policy-relevant scenarios for the EU feature a full fossil methane phase-out by 2050 (see figure 26):

→ the Distributed Energy scenario of the most recent Ten-Year Network Development Plan by ENTSO-E and ENTSOG (TYNDP DE);
→ the "Optimised Gas" scenario of the Gas for Climate study by Navigant (GfC);
→ the Paris Agreement Compatible (PAC) scenario developed by various environmental NGO umbrella organisations, including CAN Europe, the European Environmental Bureau and the Renewable Grid Initiatives.

Scenario comparison – gas and H_2 derivatives in 2050 — Figure 26



Artelys et al. (2023). EU Commission EU Long-Term Strategy (2018) & Policy scenarios for delivering the European Green Deal (2020), Gas for Climate (2020), ENTSO-e and ENTSOG TYNDP 2022, CAN Europe and EEB (2020). The EC 1.5 and PAC scenarios reflect a different geographic scope than the other scenarios (EU-28 with the UK, not EU-27). *Excludes non-energy consumption.

Of these three scenarios, two (TYNDP DE and GfC) achieve climate neutrality by 2050 and rely on significantly higher volumes of decarbonised gases and hydrogen derivatives than the EU Gas Exit Pathway, while the PAC scenario aims for the far more ambitious goal of climate neutrality by 2040 and features a far lower demand.[26] The first two scenarios also showcase a less linear transition, resulting in a sudden decline in fossil gas consumption after 2030, which could lead to significantly higher system costs and grid tariffs in future years.

This comparison highlights that the EU Gas Exit Pathway is not only among the most ambitious scenarios with regards to the phase-out of fossil fuels in Europe but also much less reliant on both bioenergy and gases. As a result, the EU Gas Exit Pathway results in a significant reduction in the energy import dependency for gases into the future. Very importantly, it also ensures a managed decline of the fossil gas infrastructure that will contain energy system costs and tariffs, unlike scenarios that foresee a sudden decline after 2030 and the development of parallel infrastructures until then.[27]

26 It should be noted that next to the earlier fossil fuel phase-out date in 2040, the data for the PAC scenario is for the EU-27+UK and does not include energy inputs for non-energy consumption (e.g. fertiliser production).

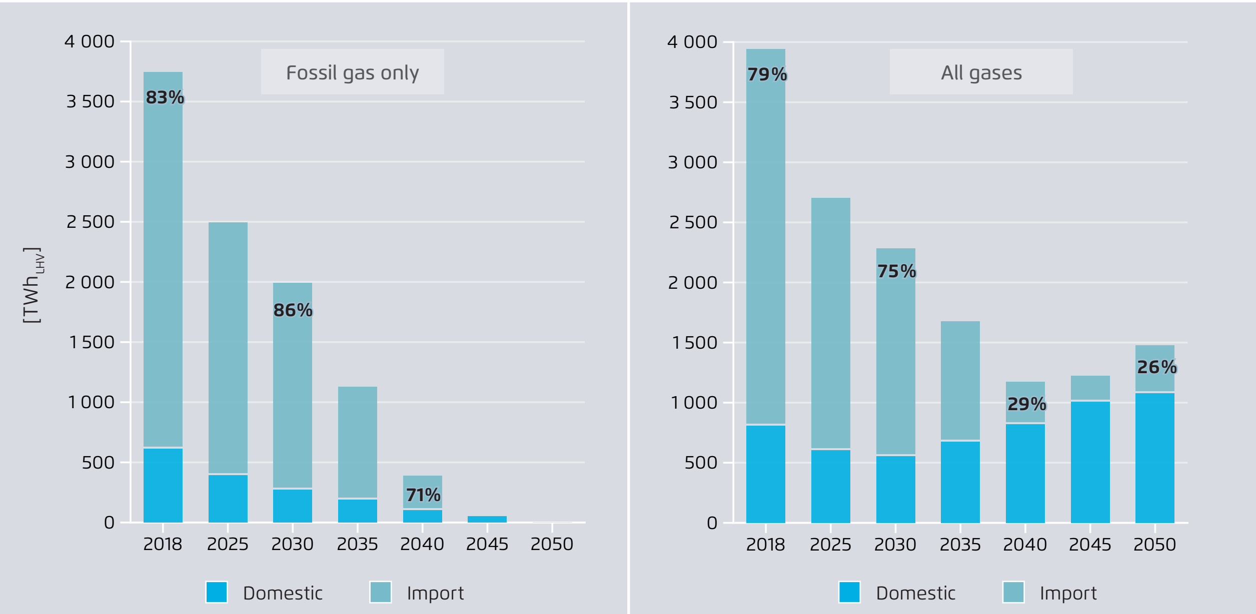
27 Agora Energiewende (2023)

5 What do the long-term fossil gas demand reductions in the EU Gas Exit Pathway mean for energy imports and security of supply?

The EU imported 84% of its fossil gas supply in 2020. Under the EU Gas Exit Pathway, the share of imported fossil gas remains relatively stable until 2035, as domestic fossil gas production and foreign imports decline together with total domestic fossil gas consumption. However, by 2040 the rate of decline in fossil gas imports and consumption begins to outpace the decline in domestic fossil gas production, leading the energy import dependency for fossil gas to decline to 71% in 2040. Finally, the EU becomes energy independent by 2045, as all remaining methane consumption can be covered by domestic fossil and biomethane production.

When looking at all gases (fossil methane, biogas and biomethane, hydrogen and hydrogen derivatives) as a whole, the import picture is more dynamic. As domestic biogas and biomethane production is assumed to remain constant, the main driver of the decline in total gas import dependency in the EU Gas Exit Pathway until 2040 is the growing domestic production of renewable hydrogen via electrolysis. Thanks largely to increases in domestic renewable hydrogen, energy import dependency quickly declines from 79% today to 32% in 2040. From these relatively low levels, energy import dependency declines further to 22% in 2045, before increasing to 32% again in 2050 as imports of hydrogen derivatives increase, especially industrial feedstock and synthetic fuels for aviation and navigation, which can be more efficiently produced in renewables-rich regions (see figure 27).

EU gas supply by source and import dependency in the EU Gas Exit Pathway — Figure 27



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Fossil liquified natural gas (LNG) terminals had a relatively low utilisation rate on average in the EU-27 in 2021 (39%), Spain being the country with the most overcapacity by far. Though most countries have been using their LNG terminals more since 2022, there is still unused capacity that could be tapped, especially in the Northwest European Member States.[28]

In the EU Gas Exit Pathway, fossil LNG imports are estimated to decline to 578 TWh in 2030 from 700 TWh in 2021. This follows a short-term surge with double that amount in 2022 (about 1 550 TWh or 160 bcm), which is expected to remain through 2023 at least.[29] Fossil LNG imports further decline to 76 TWh in 2040 and 0 TWh in 2045 as demand for fossil gas shrinks, while in parallel imports of hydrogen-derivatives (excluding synthetic fuels) grow from roughly zero today to an estimated 24 TWh in 2040, 169 TWh in 2045 and 352 TWh in 2050.

As a result of these trends, LNG average utilisation rate in the EU-27 is estimated to fall to 25% in 2030. Only in Lithuania, Belgium, France and Croatia does the rate remain above 50%. In fact, Germany and Italy see their LNG terminal utilisation rate drop to 3% after demand declines significantly. Though the results are to be interpreted carefully, they point towards a trend and call for an in-depth assessment of the real short-term needs for new LNG terminals, as their mid- and long-term economic viability is seriously in question, even when considering that a portion of these terminals could be repurposed for the import of hydrogen-derivatives.

28 Bruegel 2023

29 https://www.montelnews.com/news/1438175/europe-lng-imports-to-edge-down-2-in-2023--icis

Hydrogen

In the EU Gas Exit Pathway, demand for hydrogen and its derivatives is largely driven by cost optimisation. Due to higher costs compared with direct electrification, it remains heavily concentrated in no-regret applications in industry and stagnates until 2030 before picking up rapidly in the following decades. It increases by 80% every 5 years afterwards until 2045, with a steady increase in the industry sector. Hydrogen demand for power generation and district heating also begins to phase in after 2035 and gains in importance from 2040 to reach about a third of hydrogen demand by 2050. As regards the transport sector, hydrogen is assumed to be consumed almost exclusively in the form of hydrogen-derivative synthetic fuels for no-regret applications in aviation and shipping.

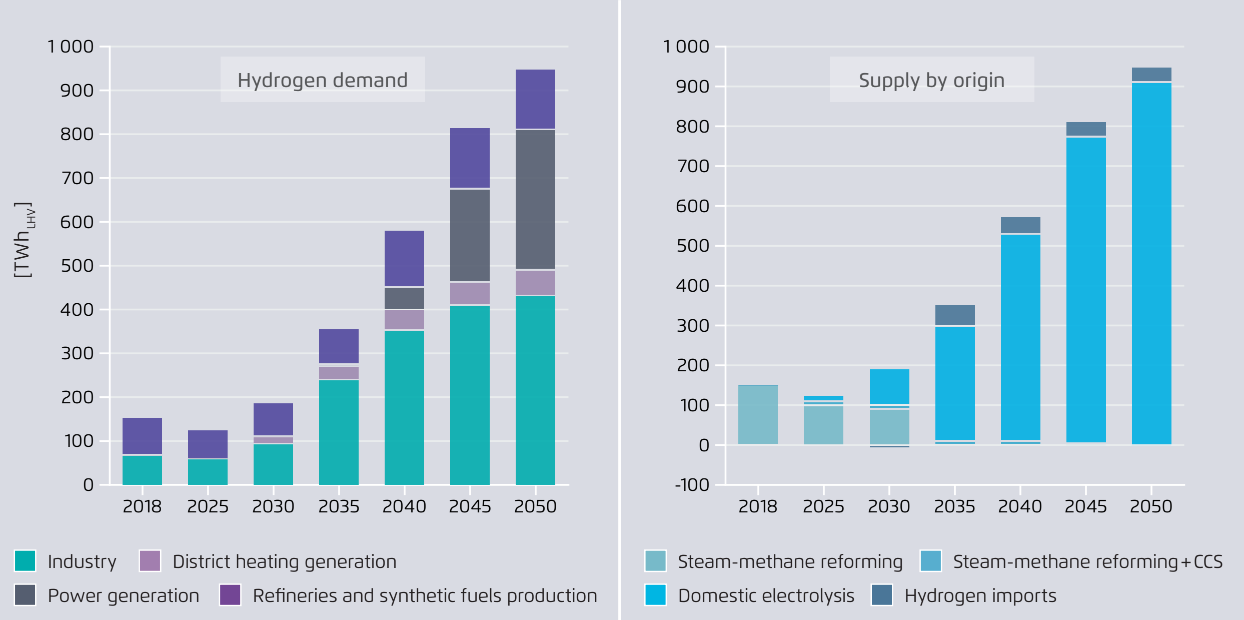
Regarding hydrogen supply, domestic hydrogen production in the EU Gas Exit Pathway is expected to continue initially to include a significant share of fossil gas-based hydrogen production from SMR for use in existing applications until 2030, with fossil-based hydrogen declining by only 48 TWh between 2018 and 2030 (roughly a third). However, this fossil gas-based hydrogen is nearly eliminated by 2035, as renewable-hydrogen production rapidly picks up in the following years. Only a limited amount of infrastructure for SMR hydrogen with CCS built before 2030 is expected to remain in operation until 2050 (less than 3% of hydrogen demand until 2045) and no new SMR with CCS is expected to be built after 2030 due to lack of competitiveness relative to renewable hydrogen produced using electrolysers. By contrast, dedicated domestic renewable hydrogen production increases rapidly in the EU Gas Exit Pathway, already reaching 89 TWh between now and 2030 before rising to 289 TWh in 2035, 520 TWh in 2040, 769 TWh in 2045 and 911 TWh in 2050. This scaling is accompanied by a parallel increase in electrolyser deployment and electricity demand; installed electrolyser capacity reaches 34 GW in 2030, 136 GW in 2040 and 272 GW in 2050, while the additional electricity consumption reaches 142 TWh in 2030, 832 TWh in 2040 and 1456 TWh in 2050. This implies that by 2050, the equivalent of roughly half of today's EU-27 electricity production could be used just for the production of hydrogen.

Despite the significant investment needed to scale up domestic renewable-hydrogen production, net imports of renewable hydrogen from outside the EU by pipeline or ship are expected to remain marginal in 2030, before rising to 81 TWh in 2040 and 155 TWh in 2050. This low volume of imports relative to domestic production is a result of the cost optimisation emerging from the modelling and reflects a lower cost of domestic hydrogen production in Europe compared to non-pipeline hydrogen imports, especially in the short to medium term. By contrast, the cost-competitiveness of renewables-based hydrogen-derivative imports, especially ammonia and methanol, is expected to improve significantly in later decades due to the easier handleability and lower conversion losses associated with these energy carriers. As a result, hydrogen-derivative imports rise sharply in later years to reach 447 TWh in 2045 and 894 TWh in 2050, up from just 28 TWh in 2030. Hydrogen-derivative imports are expected to play a particularly important role as fuels in international shipping and aviation, as well as for supplying feedstocks to industry.

However, it should also be noted that the amount of domestically produced and imported hydrogen and hydrogen derivatives could be further reduced by importing intermediate goods produced with renewable hydrogen instead of the renewable hydrogen itself, for example through the direct importation of green iron for steel production. This "embodied hydrogen" has the benefit of being much easier and more cost-efficient to transport to and within Europe with existing infrastructure, as well as reducing the environmental, security and economic risk of hydrogen leakage over the supply chain.

Hydrogen demand by sector and supply by origin

Figure 28



Artelys, TEP energy and Wuppertal Institute modelling (2023).

CCS in the EU Gas Exit Pathway

CCS made a strong comeback in energy policy debates in recent years with the net zero commitments. The technology will indeed be necessary over the course of the transition to a net zero energy system globally but in amounts that strongly depend on the transition pathway considered. According to the IEA,[30] for the energy sector to achieve net zero emissions by 2050, the global scale of carbon *storage* in 2030 and 2050 must respectively be ten times and fifty times greater than the current *capture* volume, 40 Mt per year as of 2020.

However, there are significant controversies around the availability, location and potential for long-term geological storage, as well as on the capacity to transport and store the gases underground without leakage. As of today, operating such energy-intensive equipment also comes with very high costs, which makes it only reasonable for specific large-scale applications without more efficient alternatives, such as in the cement sector. Most of the CCS projects so far have been rather small-scale research projects, and progress towards larger-scale commercial application has been slow.

In the EU Gas Exit Pathway, the cost-optimised use of CCS leads it to specific applications that have no alternatives or where significant added value can be achieved through net negative emissions, for example in the case of a combined use with sustainable biomass in industry (BECCS). CCS is expected to initially be introduced to capture CO_2 emissions from fossil-based hydrogen production from 2025 (3 Mt per year until this technology phases out after 2040), before being introduced in other industry sector applications from 2030. As a result, CCS volumes increase from 8 Mt per year in 2030 to 106 Mt per year in 2050, with cement, iron and steel representing roughly 75% of the CCS capacity. This is well below the older, technology-focused scenarios from the EU Commission's EU Long-Term Strategy (293.5 Mt and 258.4 Mt) but above levels in scenarios focused more on increasing the EU's natural sinks, such as the 1.5LIFE scenario (53.4 Mt) and its 1.5LIFE-LB sensitivity (81.7 Mt). A comparison of negative emissions in the EU Gas Exit Pathway with these scenarios can be found in Annex 2.

30 International Energy Agency (2021)

Biogas and biomethane

The role of domestic biogas and biomethane production in providing energy security for the EU has not been fully explored in the EU Gas Exit Pathway, given the exogenous assumption that biogas and biomethane production remain constant until 2045 before declining by 2050. However, we estimate that the following amounts of domestic biogas and biomethane would be needed to achieve several important energy benchmarks:

- → 586 TWh in 2040 (+390 TWh vs today's levels) and 249 TWh in 2045 (+53 TWh) would be needed to phase out fossil methane by 2040 and 2045, respectively;
- → 474 TWh (+278 TWh) would be needed in 2040 to reduce the EU's fossil methane import dependence to zero;
- → 331 TWh (+135 TWh, and less than the proposed 35 bcm biomethane target) would be needed in 2050 to avoid the direct import of hydrogen (excluding hydrogen derivatives) and avoid an increase in total gas import dependency.

These numbers highlight the potentially important role that domestically produced biogas and biomethane can play in both accelerating the decarbonisation of the EU's energy system and reducing the EU's import dependency on both fossil and decarbonised gases. However, the potential energy security benefits of this approach would need to be carefully weighed against the multiple economic, environmental and social factors mentioned in the previous section; the changing land-use practices needed for a net zero economy; and the growing competition for bioenergy feedstocks. For example, biomass inputs for advanced biofuels and the production of synthetic fuels are expected to grow from close to zero today to more than 270 TWh over the same period.

6 What does an accelerated fossil gas phase-out mean for EU financing needs?

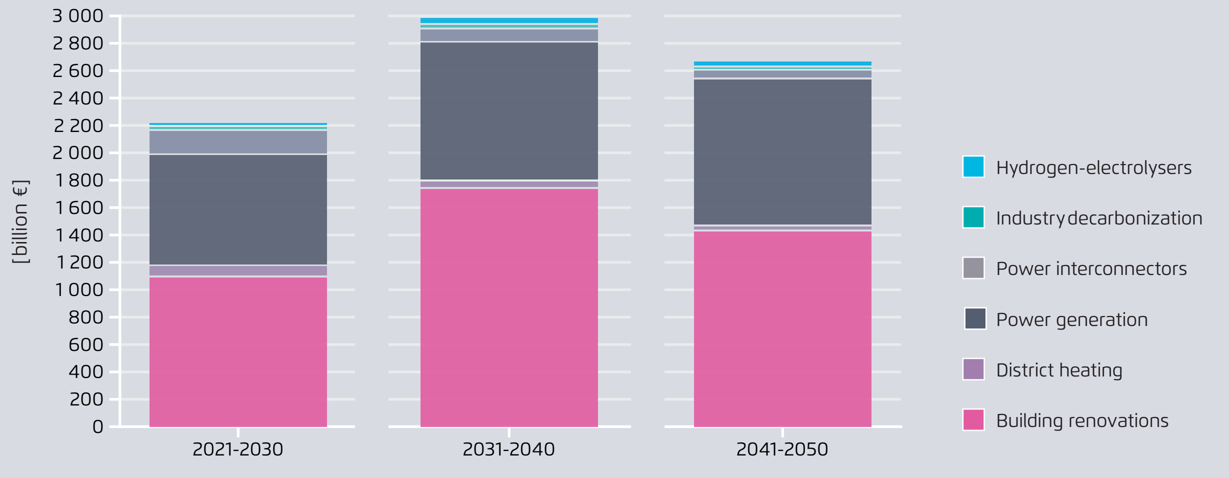
The investment needs across the sectors covered by the modelling – buildings, industry and energy supply – are around 225 billion euros per year in the current decade, increasing to 285 billion euros per year between 2031 and 2050 (see figure 29). The increase after 2030 mostly comes from a higher building renovation rate and, to a lesser extent, higher investment in renewable power generation. These capital expenditures (capex) would represent around 1.6% of the EU GDP through 2050. Investments in power transmission and distribution within countries, as well as in gas and hydrogen infrastructures, have not been quantified and are therefore not included in the figures.

Based on a differentiated assessment of the appropriate share of public support in each of the sectors, we calculate that up until 2030 roughly 29.5% of the total EU investment needs in industry, buildings and energy supply (or 669 billion euros) should be covered by the public sector either as direct public investment or grants. As the public-funding needs differ across sectors, differences in the private sector's estimated contribution across countries largely reflect the composition of the respective investment needs. For example, a large weight of renewable power generation in the total capital expenditures reduces the average burden on public funding, as new large-scale solar- and wind-power plants are expected to be profitable with few or no public subsidies.[31]

EU funds available for the green transition before 2030 offer a solid base for closing the investment gaps implied by the EU Gas Exit Pathway. Depending on the realised carbon price over the next years, a cumulative 295 to 360 billion euros for green invest-

31 Opex support is included in the calculation of the sectoral public sector's shares. The shares used in the analysis are based on Claudio Baccianti (2022).

Cumulative investment per ten-year period | Figure 29



Artelys, TEP energy and Wuppertal Institute modelling (2023)

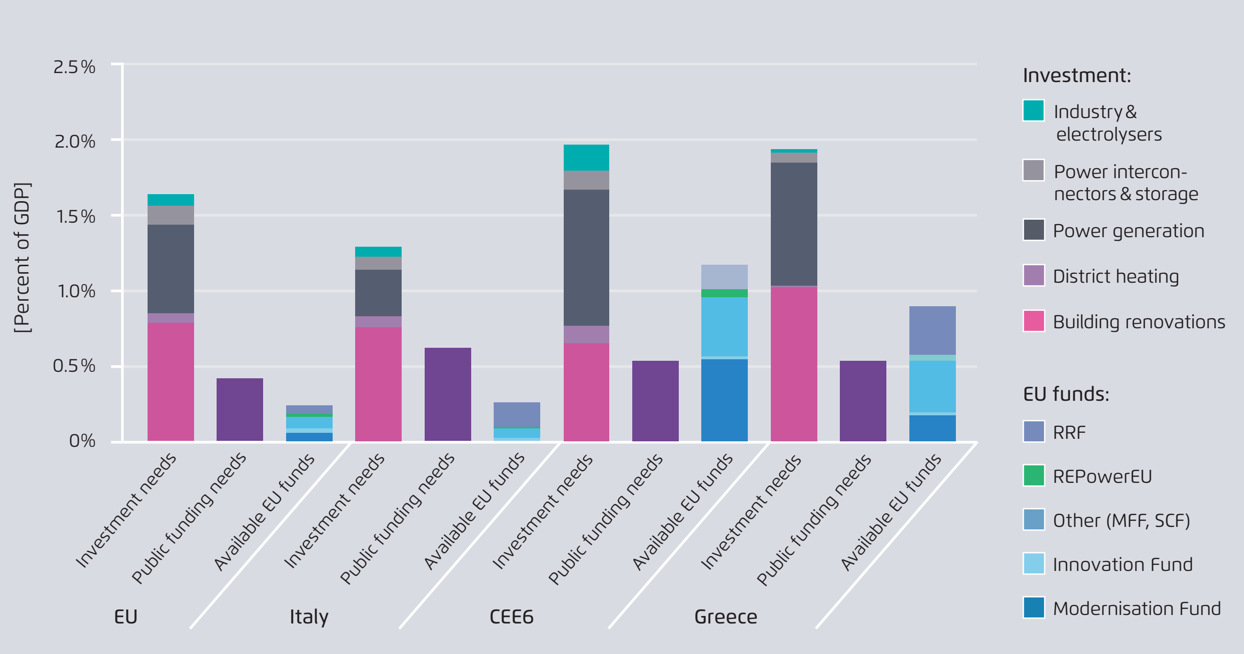
ment in the power, industry and buildings sectors up to 2030 should become available through the EU's Multiannual Financial Framework (MFF); the Recovery and Resilience Facility (RRF) established by the Next Generation EU economic recovery budget; funding foreseen under the REPowerEU plan; and revenues from the EU Emissions Trading System (i.a. Modernisation Fund, Innovation Fund and Social Climate Fund). EU resources would then cover a large share of EU-wide public funding needs, which we estimate at 669 billion euros for the buildings, industry and power generation sectors in that period (see figure 30).

As the distribution of EU funds favours Member States with incomes below the EU average, Central and Eastern Europe are especially well covered. Countries such as Bulgaria, Czechia, Poland and Romania receive support not only from the Recovery and Resilience Facility, the Cohesion Policy and the Just Transition Mechanism under the MFF, but also from the Modernisation Fund. The Modernisation Fund could provide up to 80 billion euros until 2030 if the ETS price averages 85 EUR/tCO_2 over the period.[32] Out of this amount, as much as 61.5 billion euros would go to six Member States (Bulgaria, Czechia, Croatia, Poland, Romania and Slovenia).[33]

32 The ETS price averaged 80 EUR/tCO_2 in 2022 and is at 90 EUR/tCO_2 at the time of writing.

33 CEE6 countries are Bulgaria, Croatia, Czechia, Poland, Romania and Slovenia. The funding of the Innovation Fund is allocated to countries based on their share of EU GDP. All funding in the 20 billion euros REPowerEU plan and Modernisation Fund is accounted for. Recovery spending includes the relevant items. It is assumed that only one third of the Social Climate Fund will be used to support the decarbonisation of buildings, therefore excluding transport investment and income support. For the MFF (incl. NGEU contributions), only the Cohesion Policy, Connecting Europe Facility (CEF) and Just Transition Fund are included, and the target climate mainstreaming share is allocated to sectors based on fixed coefficients (33% buildings, 10% industry, 10% power). For CEF, all funding for energy is allocated to the power sector.

Annual average investment needs and EU fundings in 2021-2030 in different regions — Figure 30



Agora Energiewende based on Artelys et al. (2023) and European Commission EU funding programmes and REPowerEU plan

The Innovation Fund alone could make a significant contribution to closing the energy investment gap for the industry transition and for ramping up renewable-hydrogen supply until 2030. If the ETS price again averages 85 EUR/tCO_2 over the period, the Innovation Fund will have around 30 billion euros to support the 54 billion euros of investment that we calculate are needed for industry and electrolysers by 2030. This would be on top of funding allocated in national recovery and resilience plans, as well as funding from the Modernisation Fund that can also be used for the same purposes.

However, the Innovation Fund will also finance part of the EU's effort to scale up the domestic manufacturing of clean technologies, as outlined in the European Commission's Green Deal Industrial Plan. The investment and public support needs of clean-tech manufacturing are not included in our assessment of investment needs, which focuses on the capital expenditures needed to decarbonise industrial processes. The European Commission estimates that 16 to 18 billion euros of capex funding support will be needed to meet the manufacturing capacity targets set in the Net Zero Industry Act, coming alongside opex subsidies that have not yet been quantified.[34]

Our assessment of the investment needed to kickstart the transition in the buildings, power and industry sectors away from fossil fuels suggests that pursuing this avenue is feasible for two reasons. First, the spending gaps have already started to decline. The deployment of heat pumps and renewable power has already accelerated since 2021 across the EU.[35] Second, several EU Member States will receive enough EU funding over the next years to scale up climate investments. This is the case for the Central and Eastern European Member States, as well as for countries such as Greece. The EU funding available to these Member States seems sufficient to narrow the investment gap by 2030, even taking into account power grid investments that are not part of our figures. According to existing studies for the CEE6 region, investment needs for the power grid by 2030 are 0.5% GDP annually in Poland (EY-PKEE 2022, McKinsey 2020b) and 0.1% GDP in Czechia (McKinsey 2020a).

The medium-term outlook, after 2026, is less positive. RRF funding and REPowerEU will end in 2026 under current agreements, largely shifting the financing burden to national governments. As shown in figure 30, these two sources alone provide around one third of the EU funding for climate investment on average, with a much larger contribution in countries such as Italy and Greece. Italy will not benefit from the Modernisation Fund and receives relatively small transfers from the Cohesion Policy as a percentage of its national income. Moreover, fiscal constraints limit the ability of high-debt countries such as Italy to scale up their climate investment programmes, as the spending needs become sizable once the transport sector and national-level energy-supply infrastructure are also considered.

34 European Commission (2023)

35 See the following review on the development of heat pump sales in 2022 https://twitter.com/janrosenow/status/1621438423297933315

7 Implications for EU policy-making

The EU Gas Exit Pathways study yields several insights for EU policy-development, specifically for:

- → the EU 2040 climate target debate;
- → ongoing legislative work on future EU rules on gas and hydrogen;
- → ongoing legislative work on the EU regulatory framework applying to buildings;
- → actions by governments and regulators to anticipate the impact of declining gas demand on gas supply and distribution infrastructure;
- → efforts of national governments to adequately reflect the future roles of fossil gas, renewable hydrogen and biomethane in national transition pathways for industry, buildings and energy supply when updating their national energy and climate plans over the course of 2023/2024.

Policy consequence #1:
The EU should set its 2040 climate target in the order of 90% greenhouse gas reductions compared to 1990 levels

The European Climate Law obliges the European Commission to propose a greenhouse gas reduction target for 2040 at the latest within six months of the first global stocktake under the Paris Agreement at COP28 in Dubai (30.11.2023–12.12.2023); this means around the time when EU citizens will elect a new European Parliament in May 2024. When presenting its proposal for a 2040 climate target, the European Commission must also publish a projected indicative EU greenhouse gas budget for the period 2030–2050.

The EU Gas Exit Pathway shows that the EU should feel confident in setting its 2040 climate target at around 90% domestic GHG emissions reductions compared to 1990 levels. The EU Gas Exit Pathway achieves net domestic greenhouse gas emissions reductions of 60% by 2030, 77% by 2035, 89% by 2040, 96% by 2045 and 101% by 2050 (compared to 1990 levels) with a resulting indicative EU greenhouse gas budget for the period 2030–2050 of 14.3 Gt.

Politically, it seems beneficial to initiate the debate on the 2040 target well ahead of the elections to the new European Parliament, as it would ease political adoption of an ambitious 2040 climate target if citizens are able to cast their vote for political parties that specifically commit to accelerated climate action. Political tailwind from the European elections in May 2024 would also enable the new European Commission to formally propose an ambitious 2040 climate target as one of its first actions after taking office in November 2024. Setting an ambitious trajectory for EU climate action beyond 2030 as early as possible will also provide industry in Europe with the clarity needed to invest in the transition to climate neutrality.

Policy consequence #2:
The EU should fundamentally revisit the EU gas and methane package as well the REPowerEU targets on hydrogen and biomethane

The hydrogen and gas markets decarbonisation package was published by the European Commission in December 2021, just weeks before Russia escalated its war of aggression against Ukraine. The war triggered a fossil fuel supply and fossil fuel price crisis in Europe and fundamentally changed the outlook on the availability and costs of fossil gas in Europe's transition to climate neutrality. By contrast, the EU Gas Exit Pathway shows not only that the transition away from fossil gas can be achieved but also that it can be done with significantly less deployment of hydrogen, hydrogen derivatives and, in particular, biomethane than is the case in either the REPowerEU plan or other prominent EU-level scenarios on the future of gas infrastructure.

Given the slow uptake of renewable- and fossil-based hydrogen with CCS, as well as significant lingering concerns over the existing sustainability framework for the production of hydrogen and biomethane, this is good news. It gives us a vision for how we can design a strategy for the future of the gas sector built on potentially more realistic and sustainable near-term deployment targets, while helping to avoid lock-in to environmentally and economically unsustainable investments.

On the other hand, it also suggests that a fundamental re-evaluation of the gas package and several targets proposed in the REPowerEU plan (particularly hydrogen and biomethane deployment) is urgently needed. Instead of rushing the gas package through the legislative process during the Swedish Council presidency, the EU institutions should take the time to reassess the fundamentals of the market they are trying to regulate and ask the European Commission to carry out a new impact assessment. It is particularly regrettable that the 20-Mt hydrogen target and the 35-bcm biomethane target proposed in the REPowerEU plan are currently being used as a basis for regulation without any serious impact assessment.

This re-evaluation is also important given that the EU legislator is discussing the Net Zero Industry Act Regulation that could result in legally binding, quantitive targets for hydrogen and biomethane production in Europe in direct reference to the REPowerEU plan. It would directly run against the objectives of the Green Deal Industrial Strategy to lock in in structurally higher energy costs than necessary for European industry.

If deemed necessary, additional environmental safeguards should also be put in place via new legislation or the EU state-aid framework.

As a result, the proposed European Commission review of the climate and economic impacts of the delegated act framework by 2028 should be done sufficiently early to assess the impacts of the rules on emissions reductions and, if necessary, lead to additional safeguards being put in place, e.g. a continuation of the criteria in the temporary state-aid framework.

Similarly, without appropriate safeguards, a political biomethane target in the EU Gas Regulation could drive unsustainable exploitation of biomass and lead to perverse environmental and economic outcomes. In this context, any biomethane target – 35 bcm or otherwise – must be limited to biomethane produced from feedstocks on Annex IX A. Furthermore, any target for biomethane, indicative or otherwise, should be based on a thorough assessment by the European Commission of the sustainable biomethane potential until 2030, taking into account competing uses. If necessary, the target should be left to be defined in a delegated act.

Finally, recent research has shown that biomethane is potentially associated with greater methane emissions in the supply chain than is fossil gas. These estimates highlight the need to put in place a strict regulatory framework for the monitoring, reporting and verification of methane emissions from biogas and biomethane installations to avoid the worst impacts from the biomethane supply chain, especially super-emitters. However, as proposed by the European Commission, the Methane Regulation currently being negotiated features no regulatory safeguards on biogas and biomethane. While these energy sources are included in the scope of the regulation, no chapter is included that explicitly regulates their activity. This is an oversight that must quickly be remedied, ideally during the ongoing negotiations.

Policy implication #3:
Governments and regulators should prepare for an accelerated decline in gas demand and thoroughly evaluate its impact on gas supply and distribution infrastructure

The EU Gas Exit Pathway highlights the very real prospect of an accelerated near-term decline in the demand for fossil gas in the EU, combined with lower uptake of hydrogen and biomethane, especially at the gas distribution level. Furthermore, fossil gas imports via pipelines and LNG terminals are expected to decline sharply by 2040 and phase out entirely by 2045, while only being partially replaced by imports of hydrogen derivatives that could allow for a repurposing of LNG supply infrastructure.

This pathway stands in stark contrast to many scenarios used by gas grid operators, including the TYNDP 2022 scenarios developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) and European Network of Transmission System Operators for Gas (ENTSOG), which foresee a much larger role for hydrogen, power-to-methane and biomethane in meeting the EU's goal of climate neutrality, as well as a significant role for LNG supply infrastructure into the future.

These large differences between the scenarios draw attention to the urgent need to stress test the analytical basis, as well as the assumptions, underlying the EU's current electricity- and gas-network planning. A failure to do so could pose a serious risk of developing stranded assets, especially with regards to distribution grid and LNG supply infrastructure.

In this context, there is an urgent need for policymakers to develop a regulatory and planning framework for an accelerated decommissioning of existing gas assets. Furthermore, it will be important for EU and national regulators to thoroughly assess the sufficiency of existing and planned LNG supply infrastructure, as well as their associated supply contracts, in view of meeting the EU's climate and security of supply objectives and avoiding long-term lock-ins.

The amendment to the Gas Directive on the development of "distribution network development plans" proposed by the European Parliament (Article 52b) could play an important role in preparing policymakers and stakeholders for these fundamental changes and aligning local infrastructure planning with local and national heating and cooling plans.

By contrast, no equivalent safeguards have been adopted or proposed to shield against the risk of overbuilding LNG supply infrastructure, and a proposed measure to limit long-term contracts for fossil gas until 2049 risks being too little, too late. The co-legislators should thus consider moving forward this date to at least 2045 in the gas-package negotiations, as well as assigning an additional regulatory role to ACER to help safeguard against the development of LNG supply infrastructure and contracts that would undermine both the EU's climate and security of supply objectives.

Policy implication #4:
The sale of new fossil gas-burning equipment in buildings should end quickly

In line with the IEA's Net Zero by 2050 scenario for the world as a whole, the EU Gas Exit Pathway shows that the building sector is the first major gas-consuming sector to phase out fossil gas and that unabated fossil gas use in buildings must largely come to an end by 2040. Nearly all existing fossil gas heating systems and cooking appliances must be replaced by this point in time, and the vast majority of buildings will have undergone some form of energy renovation.

Many investments made in 2020–2030 will still be in use in 2040, and some beyond 2050. Houses last 80–100 years; grids 50–60 years; gas boilers 15–25 years. Climate and energy policies must take these investment cycles into account to avoid stranded assets and expensive retrofits.

The EU Gas Exit Pathway shows that such lock-ins can be avoided. But as with the IEA Net Zero scenario, it also requires a significant improvement in the energy performance of buildings and for the sale of new fossil fuel-fired boilers to be phased out this decade. EU legislation started addressing CO_2 emissions from cars, vans and parts of industry more than 15 years ago, progressively tightening standards. But it is simply too late to apply such a gradual approach to household heating systems. The sale of new fossil gas-burning equipment must be stopped quickly.

Policymakers in the European Parliament and in the Council should therefore look beyond the EU's headline targets for renewables and energy efficiency to adopt robust regulatory policies that tangibly spur and deliver green investments in the building sector and prevent the lock-in of fossil fuel boilers and stoves. These include:

- → adopting an ambitious Minimum Energy Performance Standards in the Energy Performance of Buildings Directive (EPBD);
- → tightening Ecodesign standards for space and water heating appliances from 2027 to restrict the placement of stand-alone fossil fuel boilers in the EU single market;
- → rescaling energy labels for space and water heating appliances from 2024/2025 in such a way that stand-alone fossil fuel boilers are placed at the bottom of the A-G rating;
- → prohibiting all direct subsidies for fossil fuel heating appliances from 2024/2025 in the EPBD.

Furthermore, Member States should use the National Building Renovation Plans foreseen in the revision of the EPBD to explore in greater detail with which policies and measures they plan to "phase out fossil fuels in heating and cooling with a view to a complete phase-out by 2040 at the latest".[36]

36 See European Commission (2021a)

Policy consequence #5:
Member States should quickly update their National Energy and Climate Plans to align them with the Fit for 55 package

Member States are subject to numerous climate-related planning and reporting requirements at the EU level. Chief among these are the National Energy and Climate Plans (NECPs) that Member States must develop in accordance with the EU Governance Regulation. The first round of NECPs for 2021–2030 were submitted primarily in2019–2020, well before the invasion of Ukraine and the adoption of the REPowerEU plan, and many still gave a significant role to fossil gas, including an expansion of gas infrastructure.[37] The vast majority of these strategic documents are thus fundamentally outdated and must be aligned with the new energy and climate targets emerging from the Fit for 55 package.[38]

As these strategic documents were conceived as products of an iterative policy-making process, a formal update is already scheduled, with final updates to the existing NECPs for 2021–2030 to be submitted by 30 June 2024. Furthermore, each of these documents is to be updated for the 2031–2040 period by 1 January 2029. It will be critical for Member States to use these strategic policy processes to align their policies and measures with the Fit for 55 package and prepare for the phase-out of fossil gas across all key sectors (energy, industry and buildings).

37 E3G (2019)

38 See Agora Energiewende (2021)

Annex 1 Summary of key scenario data

Summary of key scenario data — Table 1

GHG emissions (Mt CO_2eq)	2018	2030	2040	2050	2030/1990 % change	2040/1990 % change	2050/1990 % change
Total	**3 509**	**1 865**	**548**	**-39**	**-60%**	**-88%**	**-101%**
Energy conversion	1 096	352	93	26	-78%	-94%	-98%
Industry	797	502	117	36	-58%	-90%	-97%
Buildings	453	191	6	0	-65%	-98%	-100%
Other (transport, agriculture, waste)	1 414	1 105	687	299	-24%	-52%	-79%
LULUCF	-251	-310	361	400	+46%	+69%	+88%
Primary energy consumption (TWh)	**2018**	**2030**	**2040**	**2050**	**2030/2018 % change**	**2040/2018 % change**	**2050/2018 % change**
Total	**14 157**	**12 275**	**10 732**	**9 000**	**-14%**	**-25%**	**-37%**
Total excl. ambient heat	**13 217**	**11 342**	**9 006**	**7 228**	**-20%**	**-36%**	**-49%**
Coal	2 108	579	16	4	-73%	-99%	-100%
Oil	3 799	3 144	1 509	-	-17%	-60%	-100%
Fossil gas	3 704	1 957	386	-	-47%	-90%	-100%
Fossil gas incl. feedstock	3 902	2 091	398	-	-46%	-90%	-100%
Nuclear	2 172	2 019	1 877	706	-7%	-14%	-67%
Renewables (excluding bioenergy)	937	3 179	6 009	7 644	+239%	541%	+716%
Bioenergy & waste	1 604	1 398	935	615	-13%	-42%	-62%
Electricity							
Gross electricity consumption (TWh_{el})	2 657	3 239	4 807	5 949	+22%	+81%	+124%
Gross electricity generation (TWh_{el})	2 740	3 276	4 979	6 177	+20%	-82%	+125%
Renewable share in generation (%)	34	70	85	96			
Onshore wind capacity (GW)	145	391	688	845	+170%	+374%	+483%
Offshore wind capacity (GW)	10	87	235	359	+770%	+2 250%	+3490%
Solar PV capacity (GW)	99	572	929	1 277	+478%	+838%	+1 190%
Number of heat pumps (Buildings) (million of units)	12	40	80	82	+233%	+567%	+583%
Average specific energy demand (residential buildings, in kWh/m²)	228.4	184	147.9	131.2	-19.4%	-35.2%	-43%
Synthetic fuels demand (TWh_{th})							
Total	153	204	819	1 994	+33%	+435%	+1203%
Hydrogen (TWh_{th})	153	186	580	947	+22%	+279%	+519%
Share of import (%)	-	-	7.4	38			
Synthetic fuels (TWh_{th})	-	18	215	695			
Share of import (%)	-	100	45	82			
Import of other renewable H_2 derivatives (TWh_{th})	-	9	24	352			
Domestic electrolyser capacity (GW_{el})	-	34	136	272			
Power input for renewable H_2 production (share of power generation) (%)	-	4	17	24			
Carbon capture and storage (gross volume, Mt CO_2)	-	-8	-77	-106			

Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Annex 2 Scenario data on GHG emissions

Overview of GHG emissions reductions (vs 1990 levels) for the EU-27 across different scenarios — Table 2

	GHG emissions scope	2030	2035	2040	2045	2050	Carbon budget 2030–2050 (in $GtCO_{2e}$)
European Commission Long-Term Strategy (1.5 TECH Scenario)	Domestic EU-28 (incl UK)	-41%	-62%	-82%	-93%	-99%	23.2
European Commission Long-Term Strategy (1.5 LIFE Scenario)	Domestic EU-28 (incl UK)	-42%	-65%	-84%	-94%	-99%	21.6
European Commission Climate Target Plan	Domestic EU-27	-55%	-69%	-86%	-95%	-101%	17.6
Agora Energiewende EU Gas Exit Pathway (MS Projections)	Domestic EU-27	-58%	-72%	-80%	N/A	N/A	N/A
Agora Energiewende EU Gas Exit Pathway (Central Scenario)	Domestic EU-27	-60%	-77%	-89%	-96%	-101%	14.3
Agora Energiewende EU Gas Exit Pathway (Central Scenario)	Domestic + International Shipping and Aviation EU-27	-57%	-75%	-86%	-95%	-101%	16.6

Artelys et al. (2023). EU Commission EU Long-Term Strategy (2018) & Policy scenarios for delivering the European Green Deal (2020)

Overview of annual and cumulative negative emissions for the EU-27 across different scenarios — Table 3

	GHG emissions scope	2030	2035	2040	2045	2050	Total negative emissions 2030–2050 (in $GtCO_{2e}$)
European Commission Long-Term Strategy (1.5 TECH Scenario)	CCS	0	-2	-52	-163	-258	-8.7
	LULUCF	-312	-327	-336	-327	-317	
European Commission Long-Term Strategy (1.5 LIFE Scenario)	CCS	0	-2	-17	-41	-53	-9.1
	LULUCF	-351	-385	-416	-438	-464	
Agora Energiewende EU Gas Exit Pathway (MS Projections)	CCS	-8	-34	-77	N/A	N/A	N/A
	LULUCF	-209	-201	-210	N/A	N/A	
Agora Energiewende EU Gas Exit Pathway (Central Scenario)	CCS	-8	-34	-77	-100	-106	-8.9
	LULUCF	-310	-340	-361	-381	-400	

Artelys et al. (2023). EU Commission EU Long-Term Strategy (2018) & Policy scenarios for delivering the European Green Deal (2020)

Annex 3 Renewable energy and energy efficiency target estimates

Energy efficiency
In the EU Gas Exit Pathway, primary energy demand declines to 11 342 TWh (975 Mtoe) and final energy demand to 9 023 TWh (776 Mtoe) by 2030 in line with the methodology under the Energy Efficiency Directive. Relative to other comparable scenarios, this means that primary energy consumption is significantly lower than in modelling performed for the Fit for 55 package and REPowerEU plan, and slightly higher than the REPowerEU scenario with regards to final energy consumption (see table 4).

Consequently, the EU Gas Exit Pathway is also well aligned with the final outcome of the Energy Efficiency Directive negotiations for primary energy consumption (993 Mtoe) and only slightly above the ambitious final energy consumption target (763 Mtoe).

Compared to the modelling for the REPowerEU plan, the EU Gas Exit Pathway has lower primary energy consumption and higher final energy consumption. Key factors that could explain the greater primary energy reductions in the EU Gas Exit Pathway include lower conversion losses due to the prioritisation of direct electrification, a higher share of heat pumps and a faster phase-out of fossil fuels in the power sector. By contrast, the final energy demand levels are more similar between the two scenarios, but with differences across sectors. Based on available data, we estimate that final energy consumption in the EU Gas Exit Pathway is only slightly higher than the REPowerEU scenario in transport (+18 TWh)

Comparison of primary and final energy demand across legislative proposals and scenarios (in million tonnes of oil equivalent - Mtoe)

Table 4

	Legislative proposals and positions for the EED	
	Primary Energy Consumption	**Final Energy Consumption**
COM (Original proposal)	1 023	787
COM (REPowerEU)	980	750
European Parliament	960	740
Council of the EU	1 023	787
Final EED compromise	993	763
	Scenarios	
	Primary Energy Consumption	**Final Energy Consumption**
Fit for 55	1 033	787
REPowerEU	1 006	751
EU Gas Exit	975	776

Agora Energiewende based on on the REPowerEU Impact Assessment and modelling by Artelys et al. (2023)
Note: Both Primary and Final Energy Consumption exclude ambient heat, international aviation fuels and non-energy use of energy carriers (e.g. natural gas used as feedstock for producing chemicals) in line with their EED definitions.

and buildings (+16 TWh), while the difference in energy consumption in industry is larger (+220 TWh).

Renewable energy

With regards to the renewable energy targets, the difference between the pathways is more notable. While the modelling for the REPowerEU plan achieves a 45% share of renewables in gross final energy consumption, the EU Gas Exit Pathway achieves only close to a 43% share, a level slightly higher than in the modelling done for the EU's Climate Target Plan and the Fit for 55 packages and in line with the final negotiated outcome for the Renewable Energy Directive.

When comparing results at a sectoral level, the share of renewables in heating and cooling is significantly higher in the EU Gas Exit Pathway (+3%), while the share of renewables is the same in the electricity sector and significantly lower in the transport sector (-14%, see table 5).

Key differences between the scenarios include:

- → The REPowerEU scenario foresees a higher final renewable hydrogen and hydrogen derivatives consumption of 16.2 Mt (539 TWh) by 2030, compared to just 3.5 Mt (116 TWh) in the EU Gas Exit Pathway.
- → The REPowerEU scenario foresees a doubling of biomethane production by 2030 in line with political targets set in the REPowerEU plan, while the contribution of biomethane remains constant at today's levels in the EU Gas Exit Pathway.
- → The REPowerEU scenario foresees roughly double the level of biomass use in power generation compared to the EU Gas Exit Pathway.
- → The EU Gas Exit Pathway foresees a phase-out of conventional biofuels and a limited increase in advanced sustainable biofuels in the transport sector by 2030, while the REPowerEU scenario sees a more constant contribution by conventional biofuels and a more significant increase in the production of advanced biofuels.
- → The EU Gas Exit Pathway foresees a higher amount of ambient heat from heat pumps.

Comparison of renewable energy targets across legislative proposals and scenarios (in % of gross final energy consumption) — Table 5

	Total share (%)	RES-E (%)	RES-H&C (%)	RES-T (%)
Legislative proposals and positions for the RED				
COM (Original proposal)	40%	N/A	+1.1%	N/A
COM (REPowerEU)	45%	N/A	+2.3% p.a.	N/A
European Parliament	45%	N/A	+2.3% p.a.	N/A
Council of the EU	40%	N/A	+0.8–1.1%	29%
Scenarios				
EC MIX	38%	65%	40%	24%
Fit for 55	40%	66%	38%	29%
REPowerEU	45%	69%	47%	32%
EU Gas Exit	43%	69%	50%	18%

Calculations by Agora Energiewende based on the REPowerEU Impact Assessment and modelling by Artelys et al. (2023)
Note: Calculation in line with the methodology laid out in the Renewable Energy Directive

Annex 4 Methodology and scenario assumptions

This annex provides further information on the modelling assumptions for the EU Gas Exit Pathway.

Basic modelling framework

In this study, energy consumption in the three key fossil gas-consuming sectors (buildings, industry and energy sectors) has been modelled for the EU-27 in five-year increments from 2025 to 2050 in an integrated approach using three separate modelling tools. The modelling for the study was carried out by Artelys (power sector), TEP Energy (buildings and district heating) and Wuppertal Institute (industry and refining). In addition, the study draws on existing analysis by Transport & Environment (transport) and the European Commission (agriculture, waste, LULUCF) for key assumptions on sectors outside of the core focus of this study.

The following core constraints were set as part of the modelling of the EU Gas Exit Pathway:

- → At least 55% emissions reduction is achieved by 2030 and net zero emissions by 2050.
- → The EU-27 has phased out Russian gas by 2027 at the latest (about 40% less fossil gas demand relative to 2018) and fossil gas consumption is phased out by 2050.
- → Only structural gas demand reduction is considered – no behavioural change or temporary fuel switch to other fossil fuels or bioenergies.
- → There is no demand destruction in industry, nor reduction in industrial output in total until 2050. In other words, while some industrial sub-sectors move from one Member State to another due to changing resource conditions or experience declines reflecting market conditions already observed today (e.g. displacement of ammonia production since 2021), industry output is assumed to broadly remain stable in aggregate until 2050.
- → Limited sustainable hydrogen and bioenergy resources are prioritised for sectors for which there are no more efficient alternatives, in particular industry and international shipping and aviation.
- → The power sector is close to decarbonised by 2040, with coal- and oil-based power generation being phased out by the end of 2035 in the EU-27 as a whole.
- → Stand-alone fossil fuel boilers are no longer installed for heating in buildings from 2027.

On this basis, final energy demand in the three sectors was modelled for the EU-27 in an iterative modelling process to ensure that the climate targets for 2030 and 2050 are achieved in a cost-optimal way. An additional energy supply modelling was also performed to identify a cost-optimal energy supply and the corresponding cross-border infrastructure needed for its delivery.

External validation by partner organisations

The EU-27 modelling work was accompanied by "deep dives" in nine focus countries with one think tank or research partner per country, serving to validate the key input assumptions for each country:

- → Bulgaria: Center for the Study of Democracy (CSD)
- → Czechia: Nano Energies
- → Greece: FACETS S.A.
- → Croatia: University of Zagreb – Faculty of Mechanical Engineering and Naval Architecture
- → Hungary: Regional Centre for Energy Policy Research (REKK)
- → Italy: ECCO Climate
- → Poland: Forum Energii
- → Romania: Energy Policy Group (EPG)
- → Slovenia: University of Ljubjana – Laboratory of Energy Policy (LEST)

Power sector

Existing national objectives for the deployment of power generation capacity are assumed to be achieved by the Member States, as were the planned interconnectors between the Member States and non-EU neighbouring countries with which the EU trades electricity: Switzerland, Norway, the United Kingdom and the Western Balkans. At the same time, a maximum technical potential limit was placed on the total amount of renewables that can be installed in each Member State, as well as the maximum capacity that can be installed in every five-year period, in order to reflect resource potentials but also technological and political constraints in scaling the deployment of renewables, especially until 2030. The data for solar and onshore wind potentials stem from the ENSPRESO database - an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials,[39] while the data for offshore wind comes from the Global Offshore Wind Technical Potential dataset of the World Bank.[40] This data was adjusted after consultation with the project partners in the in nine focus countries when deemed necessary. Overall, the installed capacity for renewables proposed in the REPowerEU plan was cross-checked through literature review and in consultation with several stakeholders and deemed feasible, so that total deployment at the EU level was not capped.

Buildings sector

The buildings sector is modelled so as to reflect the technical (e.g. number and age of equipment) and social characteristics (e.g. surface area per inhabitant today and until 2050) of the existing and new buildings stock specific to each individual Member State. Instead of defining a renovation rate as an external assumption, renovation activity in the buildings stock is determined as an outcome of the FORECAST model[41] according to the ageing of its components (e.g. roof, wall, windows, basement, heating appliance). Each buildings component is assumed to have an average lifetime (technical lifetime). When the lifetime has passed, the model decides on a replacement or an add-on investment such as insulation considering existing national policies on renovation and expected technological improvements according to "reference" values for each component and appliance option. As such, the building stock is renovated according to a cost optimisation in which the equipment is being replaced by more efficient or renewable-based options at the end of their economic lifetime. For the choice of the individual component, the life-cycle costs based on the economic lifetime and a standard discount rate are considered, as are opportunity costs. Besides these strict economic parameters, the model also considers a defined willingness to pay per component and measure based on expert judgement, e.g. people are more prone to invest in windows because of better noise protection and lower air infiltration.

In addition, key EU policies currently being negotiated at EU level in the context of the Fit for 55 package were also taken into account in the modelling. For example, the model assumes a phase-out of all fossil fuel subsidies in line with provisions in the Energy Performance of Buildings Directive, as well as a rising carbon price (38.5 €/tCO_2 in 2027 increasing to 49 €/tCO_2 in 2030 and 200 €/tCO_2 in 2040) to reflect the introduction of an EU Emissions Trading Scheme for buildings and road transport from 2027.

Last but not least, a ban on the sale of stand-alone fossil fuel boilers was implemented from 2027, based on efficiency values of heating appliances, simulating a strict revision of Ecodesign and Energy Labelling rules for space and water heating appliances currently being discussed at EU level. This rule is assumed to

39 https://doi.org/10.1016/j.esr.2019.100379

40 https://datacatalog.worldbank.org/dataset/global-offshore-wind-technical-potential

41 See https://www.forecast-model.eu/ for more details

apply to all new installations of heating appliances at the end of a boiler's economic lifetime, not to existing boilers. The modelling also assumes reduced willingness to pay for fossil fuel boilers before the ban to reflect the impact of the war in Ukraine.

Conversely, a higher willingness to pay for heating systems based on renewable energy sources, e.g. heat pumps, was assumed. Also, an expansion of district heating and thermal grids to provide renewable energy to buildings in inner cities and densely-built urban areas was investigated and taken into account depending on national and local spatial, economic and regulatory contexts.

As energy consumption in agriculture mostly relates to electricity and low-temperature heat production in agricultural buildings, especially greenhouses, agriculture-related energy demand and emissions are included in the buildings sector and have been assumed to follow the same trend as in the buildings sector.

Industry

The economic development of the industry branches was modelled to reflect a trajectory for Gross Value Added in line with the EU Reference Scenario 2020[42] for each of the Member States.

The production volumes of steel and cement were based on Material Economics' "Industrial Transformation 2050" study ("New Processes" Scenario), while the production volumes of petrochemicals were the result of Wuppertal Institute's own modelling, with growing demand in engineering plastics but no further growth in packaging. Production volumes of ammonia were considered to only slightly decline due to modifications in agricultural practices, which does not reflect the most recent developments for the sector in Europe, which has been in quick decline since 2021 due to the increase in fossil gas prices. Material (and carbon) circularity plays an important role in the modification of the structure of produced materials, especially in the steel, chemicals and pulp industry. In the steel industry, for example, secondary steel production increases from today's approximately 50% to around 60%. Furthermore, in the chemical industry, mechanical and chemical recycling of plastic waste increases significantly, in particular during the 2030s.

Heat pumps are considered to be the major pillar for the supply of low temperature process heat to industry, and the major lever in decarbonising the less energy-intensive industries, which in most cases are not integrated into heavy industry clusters. This implies that the additional electricity demand of these industries will have investment implications for the development of the distribution grid, which was not explicitly modelled as part of this study or considered as a constraint.

Heat demand for industry was calculated at the temperature, sub-sector, and EU Member state level. The use of heat pumps in the modelling is restricted to the temperature ranges below 100 °C for ordinary heat pumps as available to the market today, as well as temperatures up to 160–180 °C, for which high-temperature heat pumps can be applied. At the same time, no constraints were considered with regards to the scaling of production capacity to deliver these industrial heat pump investments. The modelling therefore implicitly assumes that current bottlenecks in heat pump production and engineering capacities can be resolved during the 2020s and that electrification can be fostered throughout the EU and allows for a higher speed of deployment in countries that already have high electricity shares or high renewable shares in their electricity mix.

Sustainable hydrogen and bioenergy potentials are considered to be limited and therefore prioritised for sectors for which more efficient alternatives do not

42 https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

exist, in particular feedstock use and high-temperature heat supply in industry, as well as international shipping and aviation. As a result, the energetic use of biomass in industry (and BECCS) was restricted to a limited number of applications where the use of carbon is very beneficial and where CO_2 grids are expected to be available (i.e., the cement and steel industry), as well as for feedstocks for plastics and fuel production.

Finally, additional constraints were also placed on certain fossil-fuel applications. Notably, the use of fossil feedstock for hydrogen production and the use of industrial CHP is assumed to be completely phased out by 2045.

Cost assumptions on industrial heating applications stem from the PRIMES Energy System Model, the Industrial Fuel Switching Market Engagement Study[43] as well as Agora Energiewende's study *Klimaschutzverträge für die Industrietransformation*.[44]

Transport

Assumptions for the transport sector are based on the Road2Zero scenario from the Transport & Environment study "Advanced renewable fuels in EU Transport"[45] featuring the following key developments:

- → An achievement of zero GHG emissions in the transport sector by mid-century.
- → A rapid electrification in road transport.
- → The phase-out of combustion engines in light-duty vehicles and two-wheelers by 2035, and most trucks by the same time, broadly in line with the EU's recently adopted reform of the CO_2-standards for cars and vans and newly proposed CO_2-standards for trucks.
- → Conventional crop-based biofuels are completely phased-out in road transport by 2030, while a limited amount of advanced biofuels (based on waste and residue) is phased into aviation and road transport thereafter.
- → Synthetic fuels are assumed to be used exclusively in priority applications in aviation and navigation, where limited viable alternatives exist, with a slow uptake starting in 2030.

These assumptions were also the basis for an integrated modelling of refinery operations for the production of transport fuels and petrochemical products for the industry sector performed by Wuppertal Institute.

Agriculture, waste and LULUCF

Emissions developments in the agriculture, waste and LULUCF targets were not explicitly modelled for this study and draw on existing analysis by the European Commission for the Climate Target Plan and the EU Long-Term Strategy scenarios. In line with this analysis and the new EU LULUCF target for 2030, land-use sinks are assumed to reach 310 $MtCO_2eq$ in 2030 and gradually increase to reach 400 $MtCO_2eq$ in 2050.

The use of biomass (including solid biomass) for energy and non-energy purposes was prioritised for applications for which more efficient alternatives do not exist, in particular industry and international shipping and aviation, under the assumption that the sustainable potential of these energy carriers is limited, and its exploitation stands in competition with the EU's new biodiversity and LULUCF targets. However, neither the supply of biomass nor the interaction of the demand for bioenergy with the land-use sector was explicitly modelled as part of the assessment.

43 https://www.theccc.org.uk/publication/extension-to-fuel-switching-engagement-study-deep-decarbonisation-of-uk-industries-assumptions-log/

44 https://www.agora-energiewende.de/veroeffentlichungen/klimaschutzvertraege-fuer-die-industrietransformation-gesamtstudie/

45 Transport & Environment (2021)

Energy supply

All investments into electricity generation, fossil gas supply, hydrogen production (fossil with CCS and electrolytic) and cross-border grid infrastructure (including repurposing) are optimised by Artelys's energy supply model, taking into account geographic locations, existing infrastructure and existing import options. With regards to grid investments, only transmission infrastructure between Member states and storage is taken into account, not transmission and distribution grid investments within the national borders. With regards to LNG investments, all terminals announced by the Member States until summer 2022 were assumed to be built.

Technical and cost assumptions for power supply technologies' stem from the report "Technology pathways in decarbonisation scenarios" from the European Commission.[46] The following cost assumptions have been used for fossil fuels other than fossil gas:

Commodity price assumptions — Table 6

Commodity [€/MWh]	2025	2030	2035	2040	2045	2050
Oil	67.68	73.84	76.79	79.74	82.69	85.64
Lignite	3.96	3.96	3.96	3.96	3.96	3.96
Coal	13.64	15.48	20.18	24.88	29.57	34.27

TYNDP (2020)

A cost-optimal gas supply to meet EU demand is modelled taking into account fossil gas pipeline supplies from Russia, Norway or North Africa, as well as global fossil LNG markets for fossil gas supplies by ship. The supply of fossil gas from Russia is assumed to decline to zero before 2027 by design to reflect the REPowerEU plan. Furthermore, fossil gas is considered to be interchangeable with domestic biomethane and also displaceable by hydrogen depending on the application.

With regards to cost assumptions for fossil gas and LNG, the assessment used cost curves derived from the ENTSOG analysis for TYNDP 2020,[47] to which entry tariff cost (pipelines) and shipment cost (LNG terminals) were added until 2030. The curve was then prolonged to have fossil gas market prices converge towards 40€/MWh by 2050. The 2025 cost curves were also shifted upward for the next years to account for fossil gas prices average evolution (+7% between 2025 and 2030 – then +3% per five-year period according to the commodity prices evolution for natural gas given by the TYNDP 2020 scenario).

Hydrogen import costs are assumed to vary according to their origin and the shipping method used and include the cost of liquefaction or shipping through pipelines. The study uses cost assumptions drawn from the European Hydrogen Backbone study from June 2021, with slight upward adjustments to reflect additional constraints for hydrogen supplied from Ukraine (see table below). In addition, fossil-based hydrogen with CCS was allowed to be imported from Norway and produced in the Netherlands based on cost assumptions from the TYNDP 2022.

The role of domestic biogas and biomethane production in replacing fossil gas and providing energy security for the EU has not been fully explored in the EU Gas Exit Pathway, given the exogenous assumption that biogas and biomethane production remain at most constant until 2050. This is due to uncertainties around sustainable and affordable biomethane potentials in the EU, a subject of heated intellectual debate over the last several years (see box "Estimating the sustainable and affordable biomethane potentials in the EU" of the report), a well as a modelling outcome revealing a limited need for biogas and biomethane in 2050 to fully decarbonise the EU's gas supply. How-

46 https://data.europa.eu/doi/10.2833/994817

47 https://www.entsog.eu/sites/default/files/2020-12/entsog_TYNDP2020_Annex_D_Methodology_201221.pdf

Cost curve for fossil gas and LNG - 2025 Table 7

Type	Supply source	Minimum supply price [€/MWh GCV]	Maximum supply price [€/MWh GCV]	Maximum annual quantity for EU-27 [TWh GCV]
LNG	North Africa	48.29	62.25	787
	Australia	52.97	62.61	1
	Middle East	45.95	55.72	1 445
	Norway	47.80	57.54	169
	Peru	50.30	59.99	1
	Sub-Sahara	48.96	58.68	1 360
	Trinidad and Tobago	47.96	57.69	1
	United States	51.22	60.90	1 459
Pipeline	Libya	50.95	60.63	217
	Norway	47.80	57.54	3 486
	Russia	48.84	58.56	6 092
	Turkmenistan	59.47	69.01	874
	Azerbaijan	48.71	58.43	446
	Algeria	50.77	60.46	1 098

Calculations by Artelys based on TYNDP (2020) and expected TTF gas prices for 2025 at 50–60€/MWh according to https://www.theice.com/products/27996665/Dutch-TTF-Gas-Futures/data?marketId=5887232&span=2

ever, the outcomes of the EU Gas Exit Pathway for biomethane should not be interpreted as a representation of the technical or sustainability limits to the deployment of this energy source, but rather as a reflection of a more cautious approach to integrated energy system modelling for the reasons given.

Cost curve for fossil gas and LNG - 2030 — Table 8

Type	Supply source	Minimum supply price [€/MWh GCV]	Maximum supply price [€/MWh GCV]	Maximum annual quantity for EU-27 [TWh GCV]
LNG	North Africa	33.80	46.69	787
	Australia	37.08	46.96	1
	Middle East	32.17	41.79	1 445
	Norway	33.46	43.15	169
	Peru	35.21	44.99	1
	Sub-Sahara	34.27	44.01	1 360
	Trinidad and Tobago	33.57	43.27	1
	United States	35.86	45.68	1 459
Pipeline	Libya	35.66	45.47	217
	Norway	33.46	43.15	3 486
	Turkmenistan	41.63	51.75	874
	Azerbaijan	34.09	43.82	446
	Algeria	35.54	45.34	1 098

Calculations by Artelys based on TYNDP (2020) and expected TTF gas prices for 2030 according to https://www.theice.com/products/27996665/Dutch-TTF-Gas-Futures/data?marketId=5887232&span=2

Hydrogen import cost assumptions and maximum volumes — Table 9

Type	Supply source	Year	Minimum supply price [€/MWh GCV]	Maximum supply price [€/MWh GCV]	Maximum annual quantity for EU [TWh GCV]
Hydrogen via pipeline	North Africa	2030	93.801	93.801	45
		2035	84.059	84.059	187.5
		2040	73.597	73.597	330
		2045	68.088	68.088	665
		2050	62.169	62.169	1 000
Hydrogen via pipeline	Ukraine	2030	93.801	93.801	15
		2035	84.059	84.059	92.5
		2040	73.597	73.597	170
		2045	68.088	68.088	435
		2050	62.169	62.169	700
Hydrogen via liquefaction	Middle East	2030	119.191	119.191	45
		2035	109.449	109.449	187.5
		2040	98.987	98.987	330
		2045	93.479	93.479	665
		2050	87.559	87.559	1 000

Calculations by Artelys based on European Hydrogen Backbone – Analysing future demand, supply, and transport of hydrogen, June 2021 – https://ehb.eu/files/downloads/EHB-Analysing-the-future-demand-supply-and-transport-of-hydrogen-June-2021-v3.pdf

Annex 5 Status quo of fossil gas supply and demand in the EU in 2020

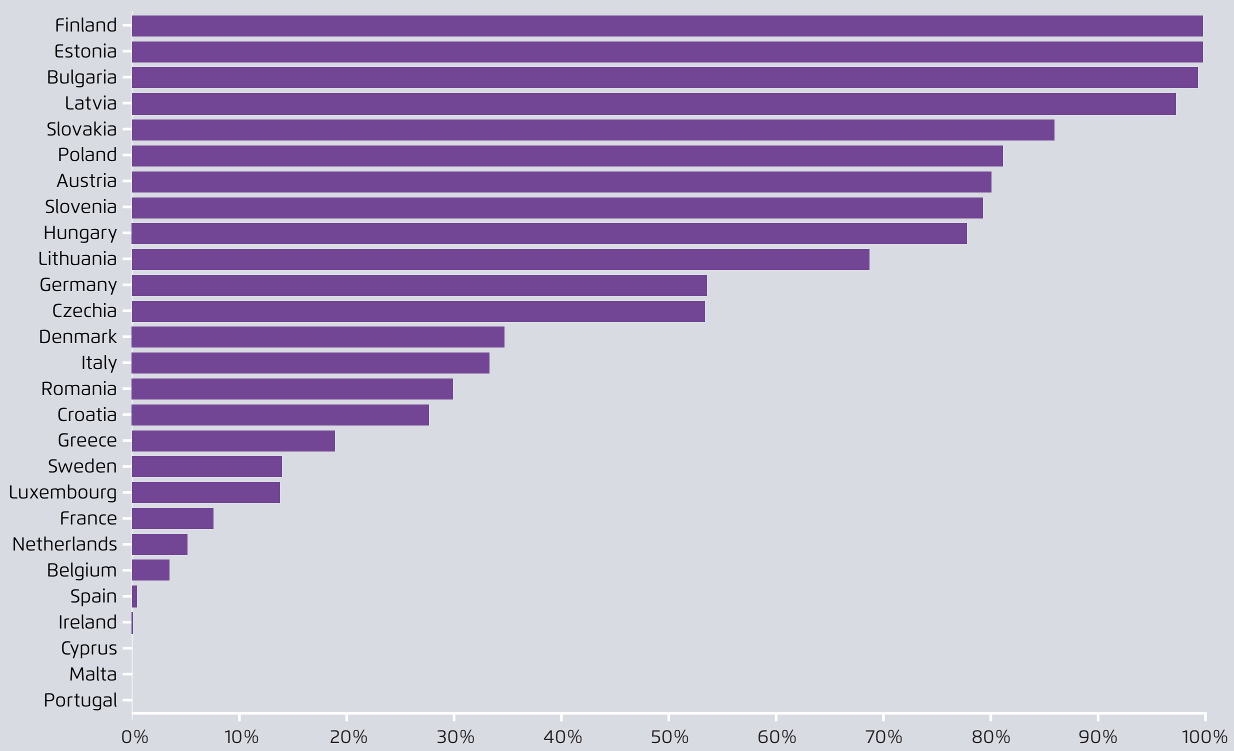
In 2020, 83.6% of fossil gas consumption in the EU-27 was covered by imports. The largest share of imports came by far from Russia (43%), followed by Norway (21%), Algeria (8%) and Qatar (5%).[48] However, the relative dependence of Member States on Russia as a fossil gas supplier varied significantly, ranging from >90% in parts of Central and Eastern Europe (Estonia, Finland, Bulgaria and Latvia) to <10% in parts of Western Europe (France, the Netherlands, Belgium, Spain, Ireland and Portugal)[49] (see figure A 1).

EU-27 fossil gas imports from Russia have also changed significantly over time in both absolute and relative terms. While Russia exported 1 091 TWh of fossil gas to the EU (58% of total imports) in 1990, exports increased to 1 514 TWh by 2020 – an increase of 423 TWh. At the same time, its relative share of EU-27 imports was significantly lower by

48 Eurostat (2022a)

49 Import shares from Russia based on 2021 numbers. Bruegel (2022)

Relative dependence on Russia as a fossil gas supplier (in %) Figure A 1



Agora Energiewende based on Eurostat (2022)

2020 due to greater supply diversification. Over the same period, total imports from other suppliers have increased from 790 TWh in 1990 to 2 399 TWh in 2020 – an increase of 1 609 TWh.

Part of the increase in supply diversification is explained by greater LNG imports. In 2020, the EU imported roughly 20% of its total fossil gas imports in the form of LNG, an increase of more than 600 TWh compared to 1990 levels. The EU's main suppliers of LNG in 2020 were Qatar (21%), the United States (20%), Russia (17%), Nigeria (15%) and Algeria (10%).

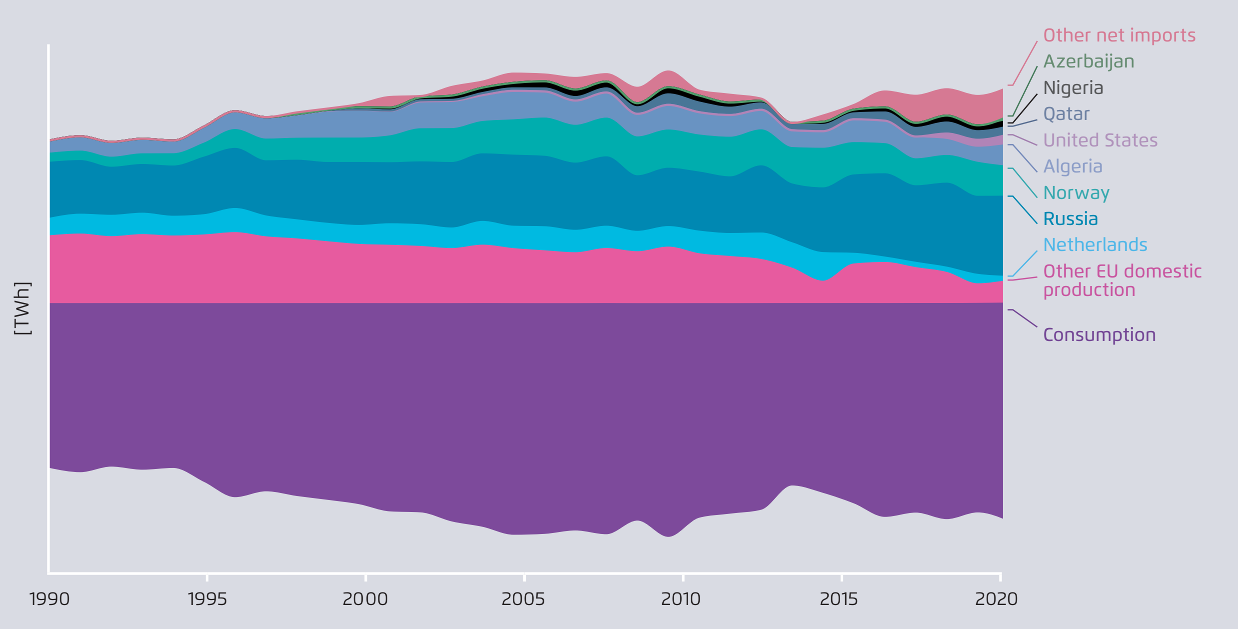
Domestic production of fossil gas accounted for only 12.6% of gross inland gas consumption in 2020, to which the largest contributors were the Netherlands (42%), Romania (18%), Germany (10%), Poland (8%) and Italy (8%). Domestic fossil gas production has also been on a downward trend over the last decade, falling by nearly two-thirds (62%) from 2010 to 2020.

While no EU Member State was self-sufficient, Romania (76.3%), Denmark (56.4%), the Netherlands (54.9%), Ireland (36.3%) and Croatia (27.9%) covered a significant share of their fossil gas consumption from domestic production.

In 2020, the EU-27 consumed approximately 3 800 TWh of fossil gas, representing roughly a quarter of the total energy mix. At the same time, European countries diverged considerably in their reliance on fossil gas as an energy source. Germany, Italy, France, the Netherlands and Spain were the five largest consumers of fossil gas in absolute terms, representing nearly 70% of total gas consumption. By contrast, Italy, the Netherlands, Hungary, Ireland and Croatia had the highest relative shares of fossil gas in their gross primary energy demand (see figure A 2).[50]

50 Eurostat (2022b)

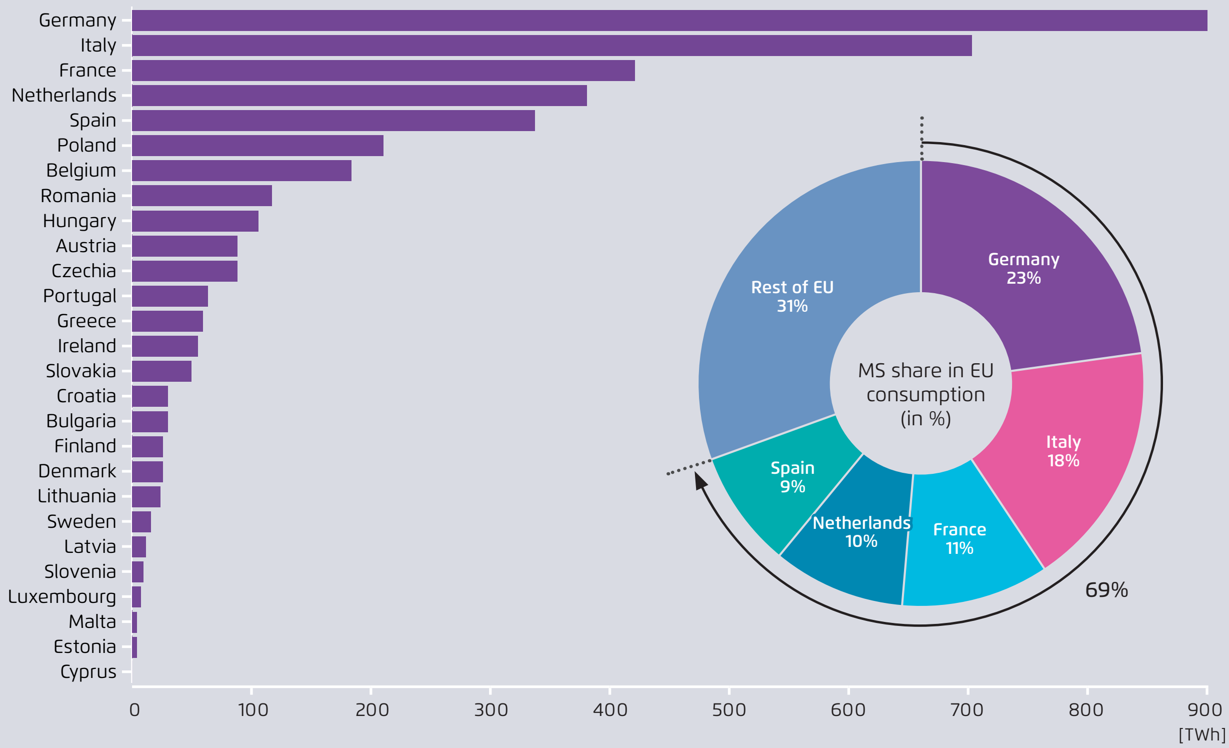
Fossil gas demand and supply by source, EU-27 — Figure A 2



Agora Energiewende (2023) based on Eurostat

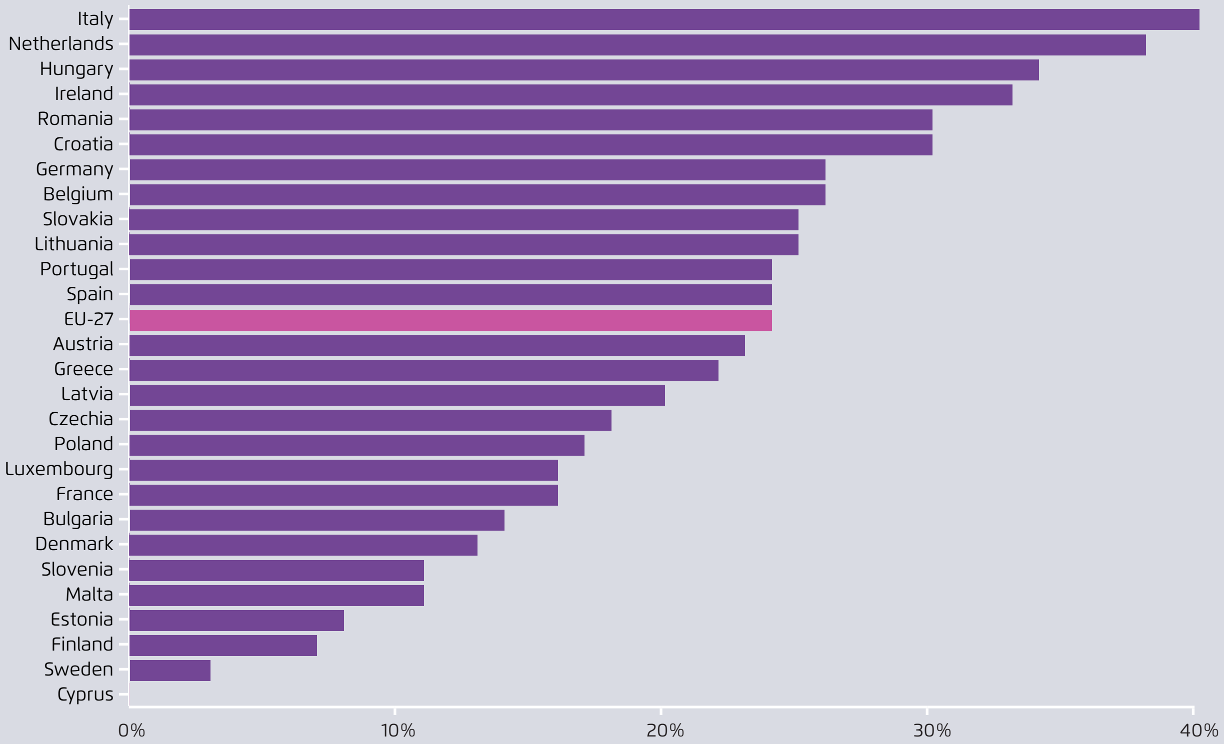
Fossil gas consumption in 2020 and MS share in EU consumption

Figure A 3



Agora Energiewende based on Eurostat (2022)

Relative share of gas consuption in gross primary energy demand in 2020 | Figure A 4



Agora Energiewende based on Eurostat (2022)

List of abbreviations

Bcm	billion cubic meters
BECCS	bioenergy and carbon capture and storage
Capex	capital expenditures
CCS	carbon capture and storage
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
CSP	concentrated solar power
DAC	CO_2 direct air capture
DHC	district heating and cooling
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
EU ETS	EU Emissions Trading Scheme
FED	final energy demand
Ff55	Fit for 55 package
FSRU	floating storage and regasification unit
GDP	gross domestic product
GHG	greenhouse gas
GVA	gross value added
H_2	hydrogen
IRA	Inflation Reduction Act
LCOE	levelized cost of electricity
LHV	low heating value
LNG	liquefied natural gas
LTS	Long-Term Strategies
LULUCF	Land-Use, Land-Use Change and Forestry
MFF	Multiannual Financial Framework
NDC	Nationally Determined Contribution
NGEU	Next Generation EU
Opex	operational expenditures
PED	primary energy demand
PV	photovoltaic
RE	renewable energy
RRF	Recovery and Resilience Facility
SCF	Social Climate Fund
SMR	steam methane reforming
TWh	terawatt hours
TYNDP	Ten-Year Network Development Plan

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Analyse zur Zementbranche

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Wie Europa den Übergang zu einer fossilfreien, energieeffizienten und energieunabhängigen industriellen Produktion vollziehen kann

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Agora Energiewende develops scientifically sound, politically feasible ways to ensure the success of the energy transition – in Germany, Europe and the rest of the world. The organization works independently of economic and partisan interests. Its only commitment is to climate action.

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