Breaking free from fossil gas

A new path to a climate-neutral Europe

Deep dive on the power sector and energy supply

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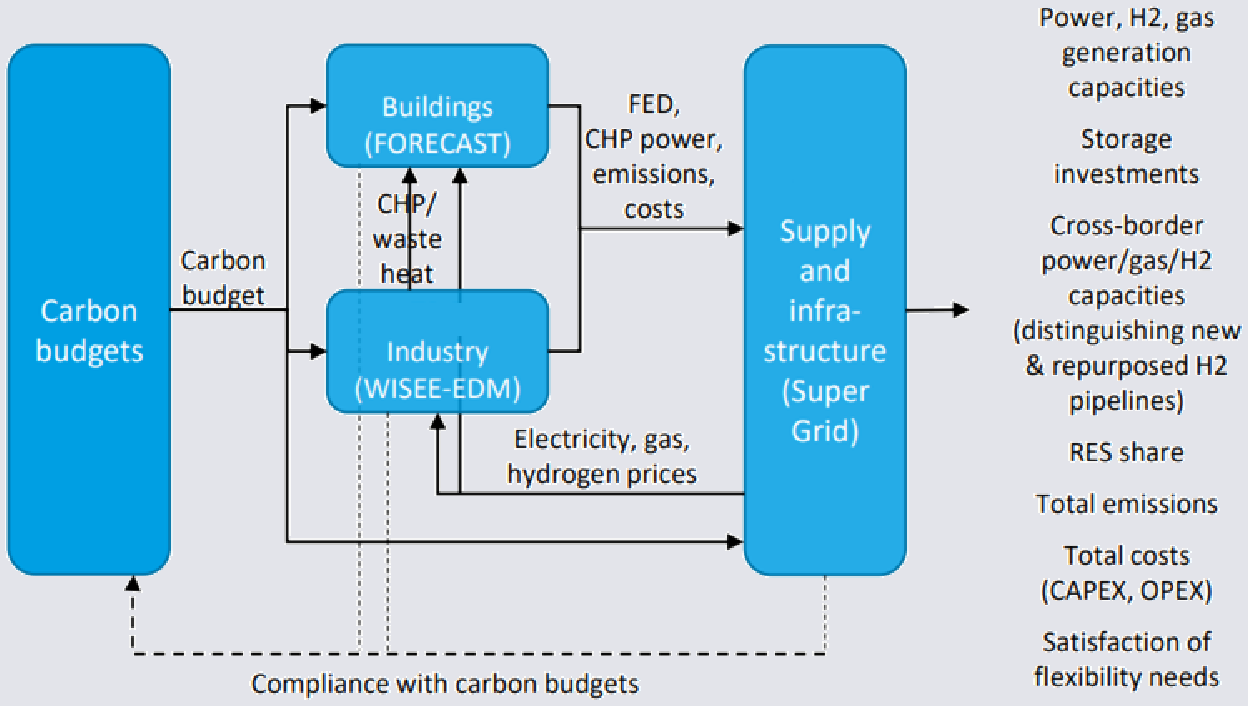
A short introduction to the study and key messages

Project scope

Scope and basic settings	“Deep dives”
→ Decarbonisation pathways until 2050, with Russian gas phase out as quickly as possible (by 2027). → Focus on long-lasting demand reductions, as opposed to short-term behavioural changes. → Cost-optimized balance between direct electrification and “no-regret” applications of hydrogen. → Modelled sectors in 5-year steps: power, buildings, industry + infrastructure including interconnectors and storage (transport and agriculture sectors covered by existing studies). → EU energy system is modelled country per country. Energy demand modelled bottom-up by TEP Energy (buildings) and Wuppertal Institute (industry); power sector and energy supply modelled for the whole EU with an optimisation model by Artelys.	The EU-27 modelling work was accompanied by “deep dives” in 9 focus countries with 1 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 Navel 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)

Overall modelling workflow

Data flow between the models



Artelys, TEP Energy, Wuppertal Institute

- Three separate models for building, industry and power and energy supply are soft-linked
  - Close coordination between the different models to select the least-cost options, making use of life-cycle costs, preferences and possibly cost abatement curves
  - Facilitates proper reflection of the “communicating vessels” logic between sectors
  - Feedback loop to carbon budgets allows to reallocate them between sectors or to identify the potential need for negative emissions
- Supply and infrastructure model
  - determines the optimal capacity mix to meet the final energy demand identified in the buildings and industry models (+ from other sectors according to integrated scenarios)
  - provides an educated guess of energy carrier prices to the demand models

Overview of technologies considered to move away from fossil gas

→ **Buildings**

- Energy efficiency
- Heat pumps (various RES)
- District heating (low/high temperature)
- Solar thermal
- Geothermal
- Biomass/pellets
- Green gases (hydrogen, e-gas, biomethane)

→ **Industry**

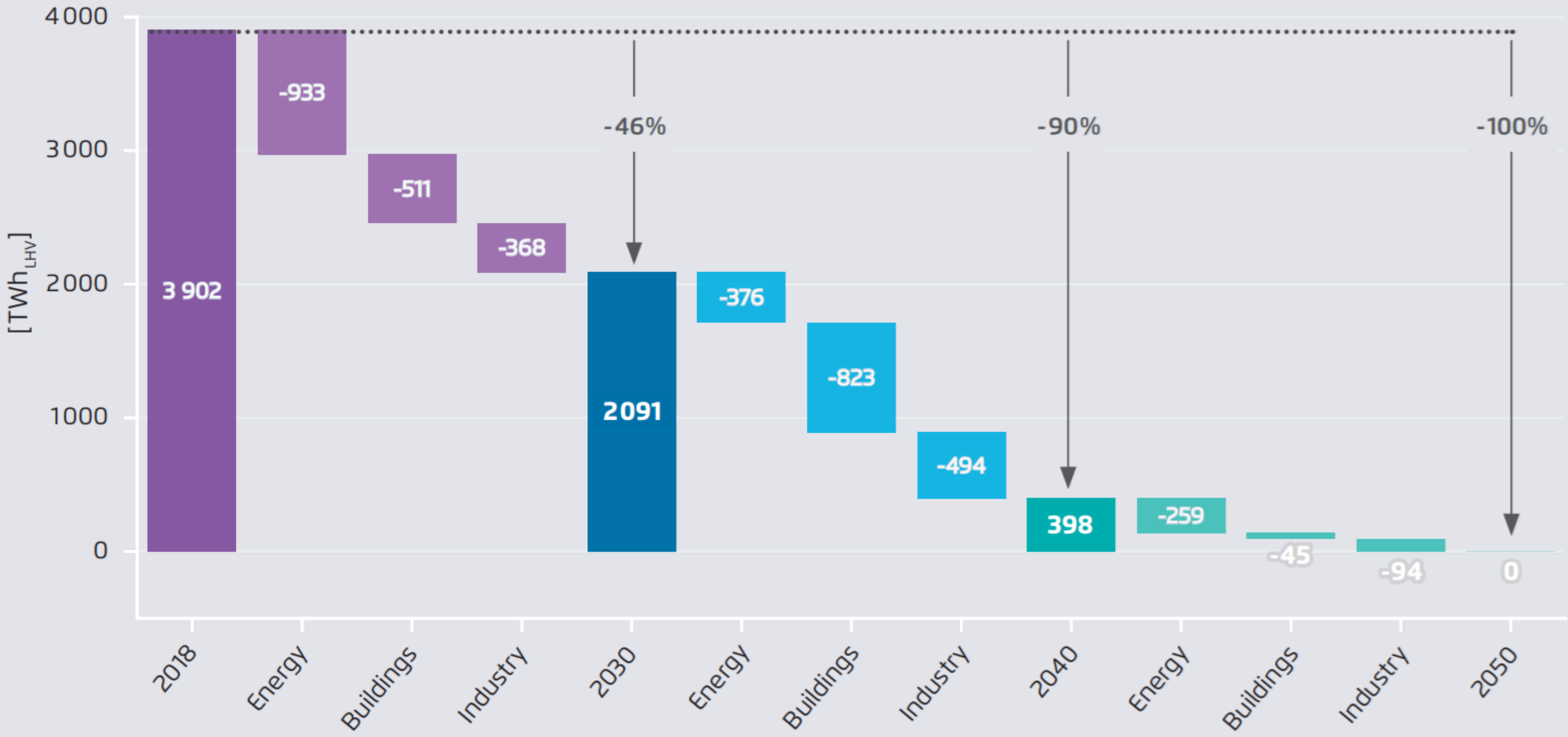
- Energy efficiency
- Circular economy
- Electric furnaces (EAF, induction, microwave etc.)
- Large scale (high temperature) heat pumps and waste heat integration
- Solar/geothermal
- Dry Biomass (+ onsite gasification, BECCS option)
- Green gases (hydrogen, e-gas, biomethane)
- Relocation of basic industry within Europe (only partial)

→ **Power and energy supply**

- Electricity generation technologies (RES, hydrogen turbines, nuclear)
- Green gases (hydrogen, e-gas, biomethane)
- Storage assets (power, fossil gas, H2)
- Conversion processes (electrolysers, methanation, power-to-liquids)
- Cross-border infrastructure (for power, fossil gas, H2)
- Demand side response (EVs, heat pumps)
- Sector-coupling (+ flexible operation)
- Hybrid assets (e.g. hybrid heat pumps)

Fossil gas use in Europe can be halved by 2030 and completely phased out of the EU energy system by 2050 without disruptive behavioral changes or short-term demand destruction in industry, while fully ensuring security of supply

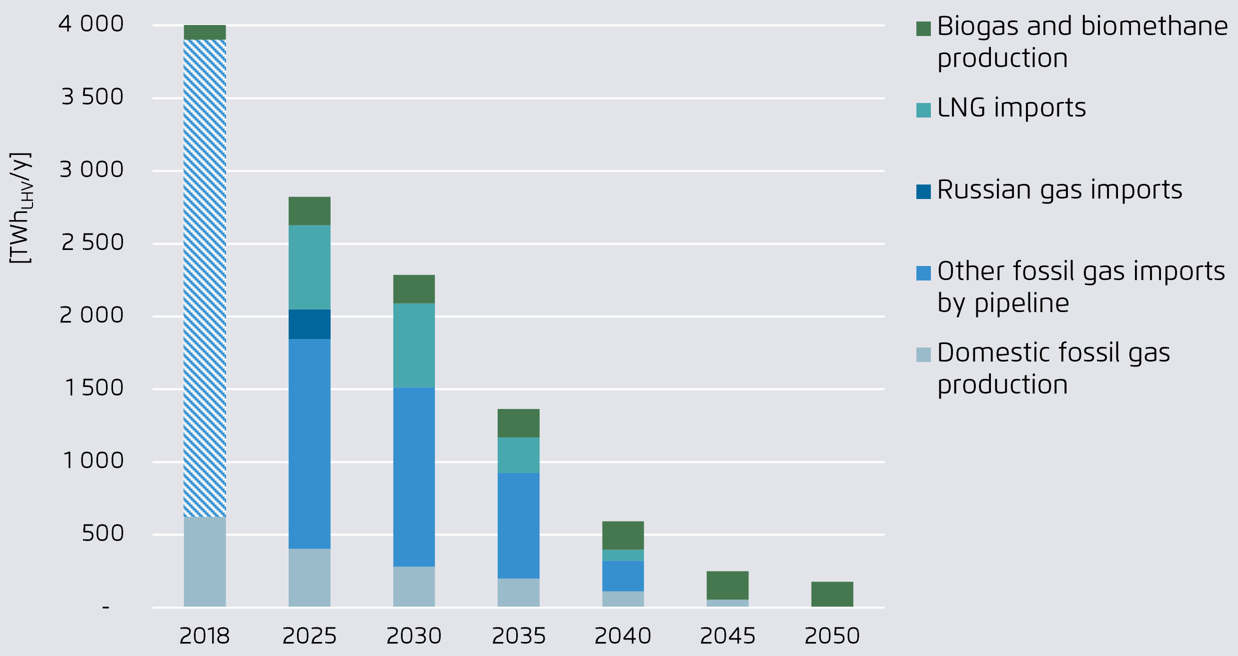
Evolution of total fossil gas consumption in the EU-27, 2018-2050 (in TWh_{LHV})



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

With well-planned and implemented measures, the EU can phase out Russian gas by 2027 at the latest and continue reducing its dependence on fossil gas.

Methane supply, EU-27

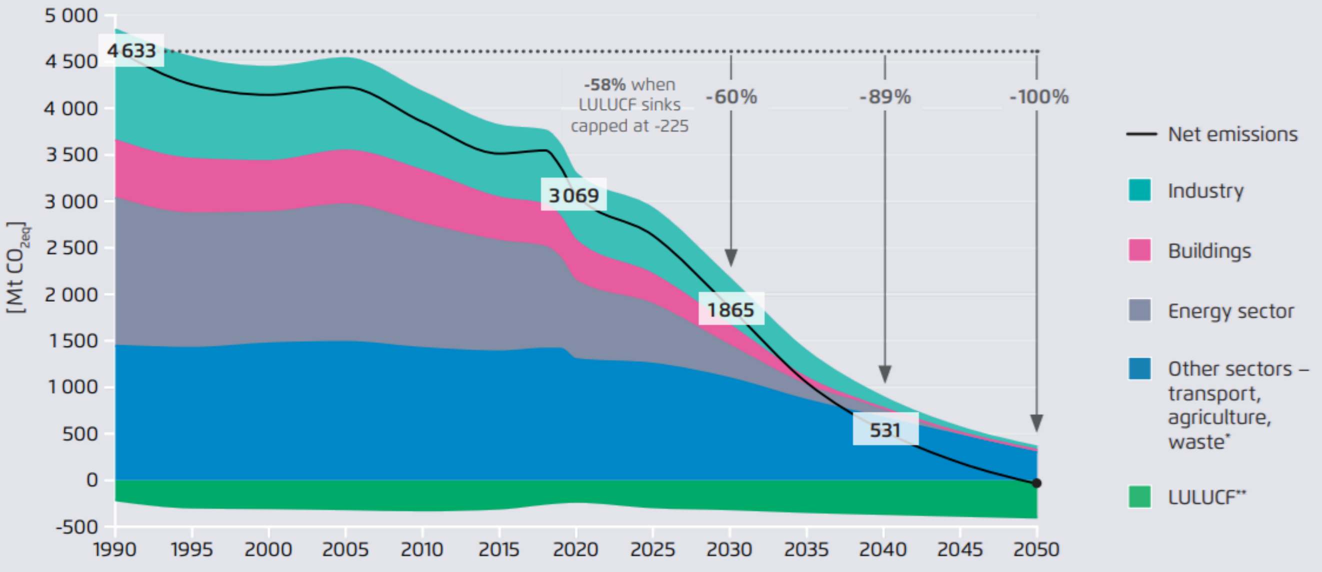


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- Russian gas: imports through Ukrainian and TurkStream transits are phased out by 2027 and considered to remain at very low levels until then (<10% of supply).
- Thanks to electrification, fossil gas needs only to be replaced partially by alternatives such as hydrogen and biomethane.
- Domestic biogas and biomethane can almost completely supply the remaining methane demand by 2045.

The EU's ambition for the 2040 greenhouse gas reduction target should be set at around -90%, based on 1990 levels.

GHG emissions by sector – EU27 in Mt CO2eq

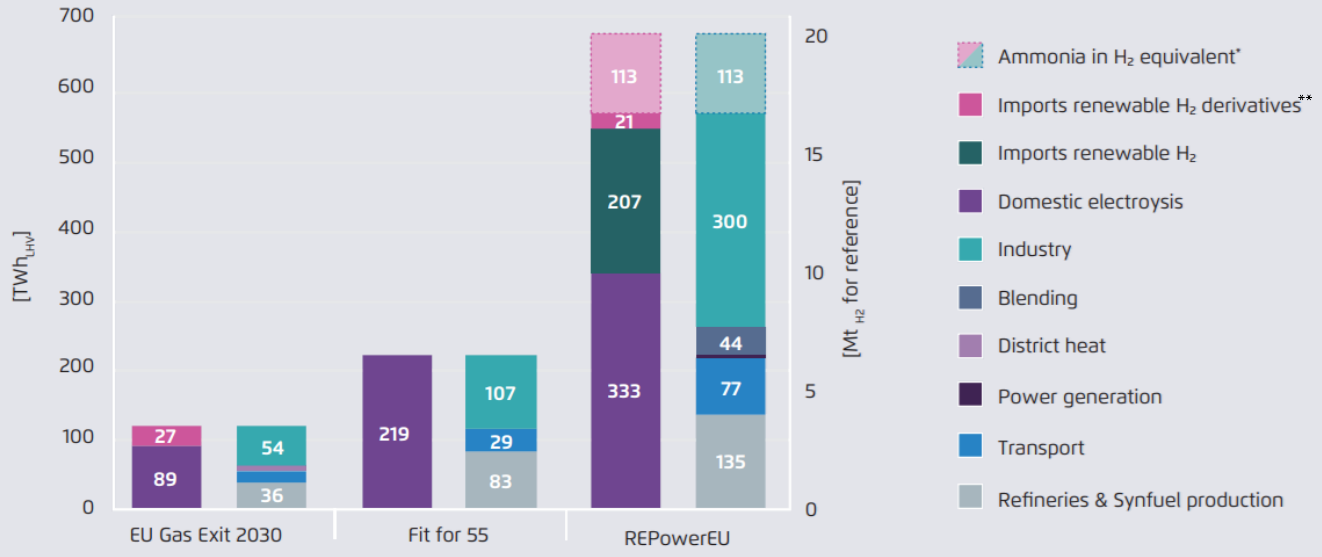


Eurostat; Artelys et al. modelling (2023)
* Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste)
** Based on the LULUCF+ scenario from the EC Climate Target Plan impact assessment (assumes a 5-year delay)

- → The Commission must propose an EU 2040 GHG-target latest 6 months after the first Global Stocktake under the Paris Agreement at COP28 in Dubai (30.11 - 12.12.2023).
- → Accelerated GHG reductions can be achieved with the right investments starting today: net-GHG emissions reductions of -60% by 2030, -89% by 2040 and -100% by 2050.
- → A target of -90% by 2040 would avoid 3.3 Gt more GHG emissions than projected in the EU's 2020 Climate Target Plan.
- → Transport, agriculture, waste and LULUCF covered by existing studies by Transport & Environment and the European Commision: Additional efforts in these sectors could achieve further reductions by 2040.
- → Broadly speaking the last 10% of residual emissions will be the hardest to mitigate.

Demand for renewable hydrogen and derivatives in the EU Gas Exit pathway is a fifth of the foreseen demand in REPowerEU in 2030.

Supply by source and sectoral demand for renewable hydrogen and derivatives



Artelys et al. modelling (2023). Commission staff working document accompanying the REPowerEU plan (2022). Assuming the 20 Mt hydrogen and derivatives in the REPowerEU plan are all renewable.

- When cost-optimised, hydrogen and its derivatives are first used in the historical sectors, i.e. industry and refineries to displace their fossil equivalent as it can be observed in the EU Gas Exit Pathway. Some synthetic fuels are also imported for the transport sector.
- The REPowerEU plan foresees a significant scale up of demand in industry, but also roughly half of the final hydrogen demand 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%), leading to a strong reliance on imports.
- 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.

* Ammonia has a lower calorific value than H2. The REPowerEU plan seems to have used the same conversion rate for ammonia as for H2 for its calculations in Mt.
** Derivatives include ammonia and synthetic fuels.

Key policy implications for the EU’s gas related policy initiatives

(1) The EU should set its 2040 climate target in the order of 90% GHG reductions compared to 1990 levels.

(2) The EU should fundamentally revisit the EU gas and methane package as well the REPowerEU targets on hydrogen and biomethane.

(3) Governments and regulators should prepare for an accelerated decline in gas demand and thoroughly evaluate its impact on gas supply and distribution infrastructure.

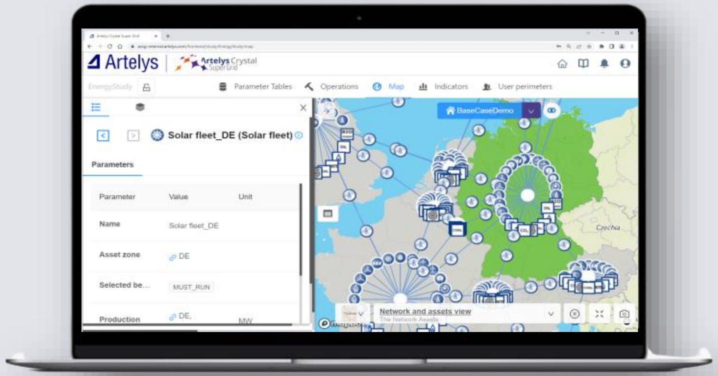
(4) The sale of new fossil gas-burning equipment in buildings should end quickly.

(5) Member States should reflect the rapid phasing down of fossil gas demand when updating their National Energy and Climate Plans in 2023-24.

Methodology

Energy system modelling in the EU-27

Artelys Crystal Super Grid model



A multi-energy modelling solution dedicated to interconnected systems		State-of-the-art optimisation techniques	
Bottom-up representation	**Multi-energy** approach	**Optimisation** models	Advanced **capacity expansion** features

Artelys

- The power, methane and hydrogen system in the EU-27 has been modelled in Artelys Crystal Super Grid.
- Bottom-up energy modelling solution: the different production and consumption technologies are explicitly represented and the supply-demand balance is simulated at an hourly granularity.
- The different energy carriers are modelled (electricity, hydrogen, methane, biomass), as well as CO_2 emissions and all sector couplings between energy carriers.
- Infrastructure such as electrolysers, interconnectors and storage are modelled, but not the national transmission and distribution grids (all energy carriers).
- CCS is explicitly considered with respect to the removal of carbon emissions, but CO_2 pipelines and storage are not explicitly modelled.
- Fossil gas imports from outside the EU are endogenously determined based on gas cost curves provided by ENTSOG’s TYNDP.

Energy system modelling

Overview of the power, methane and hydrogen sector modelling

Current energy system

- Historical capacities at the beginning of the pathway
- Final energy demand for electricity, CH4 and H2.

Investment options

- Capacity development potentials (maximum total installed capacity and maximum installation rates)
- Cost (CAPEX, O&M) of different technologies
- Other technical properties (yields, lifetime, availability)

Policy Options

- GHG emissions limit
- Minimum RES developments
- For some technologies, national phase-out plans (e.g. coal) or investment options (e.g. nuclear).

Artelys Crystal SuperGrid

Multi-Energy Capacity Expansion Pathway

Joint optimisation of :

Investment in new capacities

- *Power generation (RES, CCGT, OCGT, etc.)*
- *Electrolysis*
- *Storage (batteries, hydrogen)*
- *Transmission and pipeline capacity (interconnectors)*

and

Optimal dispatch

Within every modelled year, least cost hourly dispatch of the power, methane and hydrogen system

System KPIs

- Installed capacity of each technology in each node
- Energy annual supply mix
- Hourly energy dispatch
- Cross-border power, methane and hydrogen flows and imports
- Utilisation rate of the different generation, transmission and storage technologies
- LOL, ENS, Curtailment of Renewable Energy

Economic KPIs

- Investment cost (CAPEX)
- System operation cost
- Cost of fuel consumption

Policy KPIs

- CO_2 emissions
- Welfare calculations

→ In the present study, a capacity expansion pathway optimisation has been performed in Artelys Crystal Super Grid: joint optimisation of investments in new capacities (generation plants, transmission, storage) and of the energy dispatch.

→ The capacity expansion optimisation is performed on the entire pathway, with 5-year periods from 2025 to 2050. Within each of these years, the energy dispatch is optimized on an hourly basis.

→ Capacity expansion optimisation is constrained by GHG emission limits.

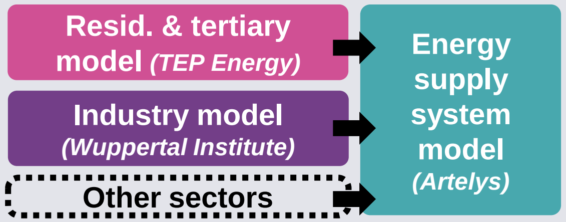
→ The model used for this study covers around 40 nodes (EU-27 + neighboring countries).

Key assumptions

Assumptions on final energy demand and CO_2 emissions

Approach

Evolution of final energy demand:
- Buildings: TEP Energy (1)
- Industry : Wuppertal Institut (1)
- Transport: Transport & Environment, Road2Zero scenario (2)



Carbon budget approach:
- Overall carbon budget over the pathway split into yearly carbon budgets
- Greenhouse gas emissions of non-modelled sectors based on exogenous sources
  - Transport: Transport & Environment (2)
  - Agriculture and Waste: European Environment Agency (3)
  - LULUCF: European Commission (4)
- CO_2 price not an exogenous assumption for the modelling work

(1) Agora - Breaking free from fossil gas (this study)
(2) Road2Zero scenario of the T&E study "Advanced renewable fuels in EU Transport"
(3) Scenario "With Additional Measures" of the European Environment Agency
(4) European Commission Climate Target Plan impact assessment (assumes a five-year delay)

→ The two most dimensioning constraints in the optimisation of the energy supply system are the evolution of the final energy demand and constraints on GHG emissions.

→ The evolution of final energy demand, computed by TEP Energy for the residential, tertiary and by Wuppertal Institute for the industry were used as inputs for the optimisation of the upstream energy supply system.

→ Yearly carbon budgets available for the upstream energy sector have been determined at the European level, based on the European climate ambition and the emissions foreseen in all other sectors.

→ In concrete terms, the power sector is considered to be largely decarbonised by 2040.

Assumptions on the power sector

Assumptions on available technologies and investment options

Renewables:
- Total potential per technology and deployment rates per 5-year period based on ENSPRESO (1)
- Amendments for some countries based on expert consultations

Fossils:
- Existing capacities decommissioning plans
- Coal and lignite forced out before 2035
- Investment options in new capacities of methane and hydrogen OCGT and CCGT (no CCS)

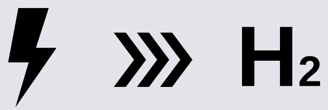
Nuclear:
- Existing capacities decommissioning plans
- Life extension reinvestment options (2)
- Investment options in new capacities in relevant countries (3)

Flexibility:
- Existing capacities
- Investment options in cross-border transmission lines, batteries

(1) ENSPRESO - ENS_Med_ForestBaU scenario
(2) In all the countries expect the countries with nuclear phase-out plans, namely DE, CH and HR
(3) CZ, HU, PL, SI, BG, RO, FR, GB, SK, FI

Assumptions on hydrogen and biogas/biomethane

Assumptions on available technologies and investment options



Domestic production:
- Existing SMR capacities forced out after 2030
- Investment options in new capacities of electrolyser and SMR with CCS in Europe including Norway
- In 2030, constraint on the minimum development of electrolysers (policy targets)

Pipelines and import infrastructure:

Investment options from 2030:
- New intra-European pipelines
- Imports pipelines from Algeria, Ukraine & Norway (import costs from Gas for Climate study)
- Repurposing of existing methane pipelines
- Maritime import infrastructure

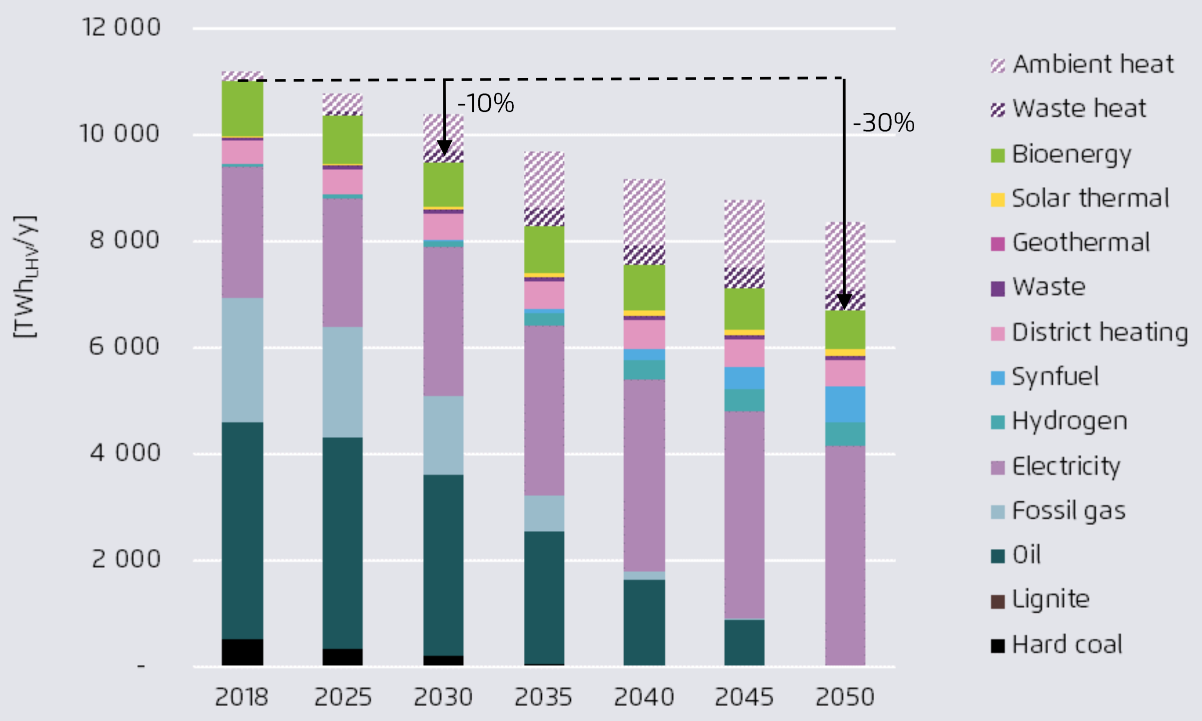
Storages:
- Investment options in new hydrogen underground storages (salt caverns) in some countries (1)

Biogas and biomethane
- Biogas and biomethane considered to be interchangeable with fossil gas
- Conservative approach concerning their availability due to sustainability concerns of biomass overall.
- Total biomass consumption (excluding material use in the study) assumed to remain at today’s levels at maximum.

Energy balance in the EU Gas Exit Pathway

Final energy demand declines by 30% between 2018 and 2050. It can already decline by 10% by 2030.

Final energy demand by energy carrier, EU-27

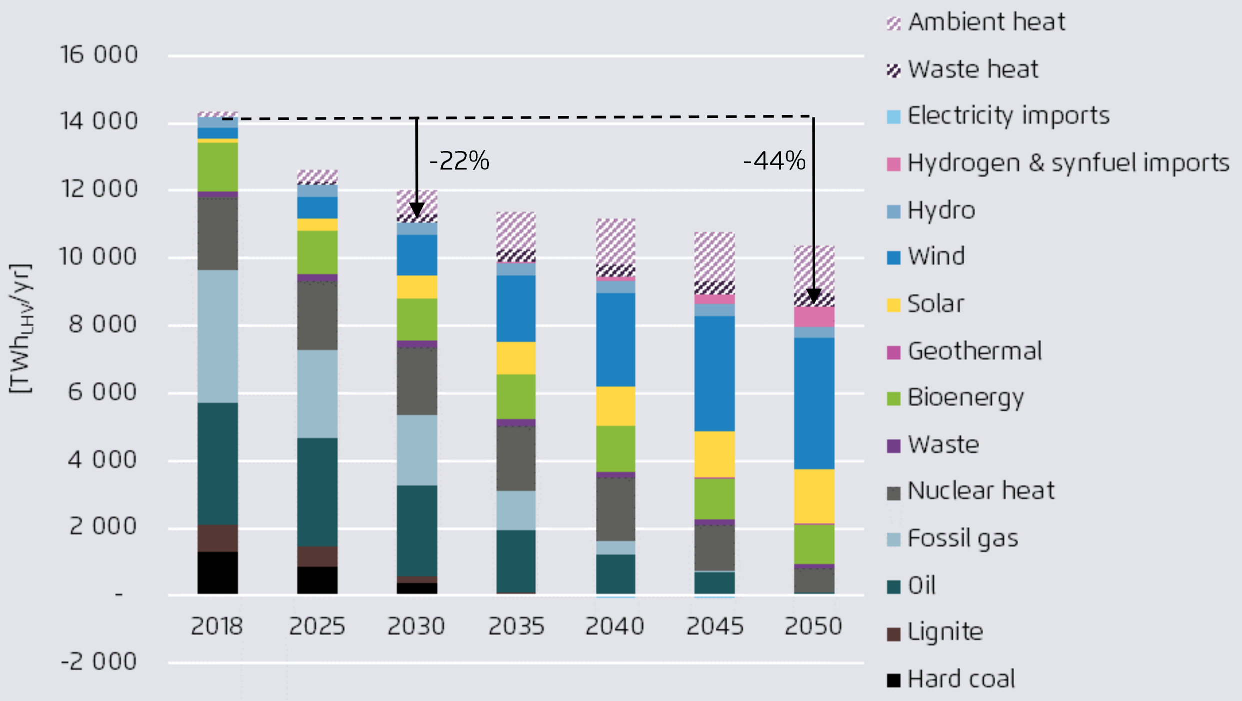


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → Direct electrification is the key decarbonisation route, playing a major role in buildings, industry and mobility. Same as for PED, the use of heat pumps in buildings and industry making use of ambient and waste heat integration significantly reduce energy demand.
- → The share of power in final energy demand (FED) increases from 22% in 2018 to 30% in 2030 and to 62% in 2050. On the contrary, fossil fuels representing 63% of FED in 2018 are phased out by 2045, oil being in transport being the longest in the energy system.

Primary energy demand* declines by 22% by 2030 and 44% by 2050, not taking into account ambient and waste heat in the buildings and industry sectors

Primary energy demand* by energy source, EU-27



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

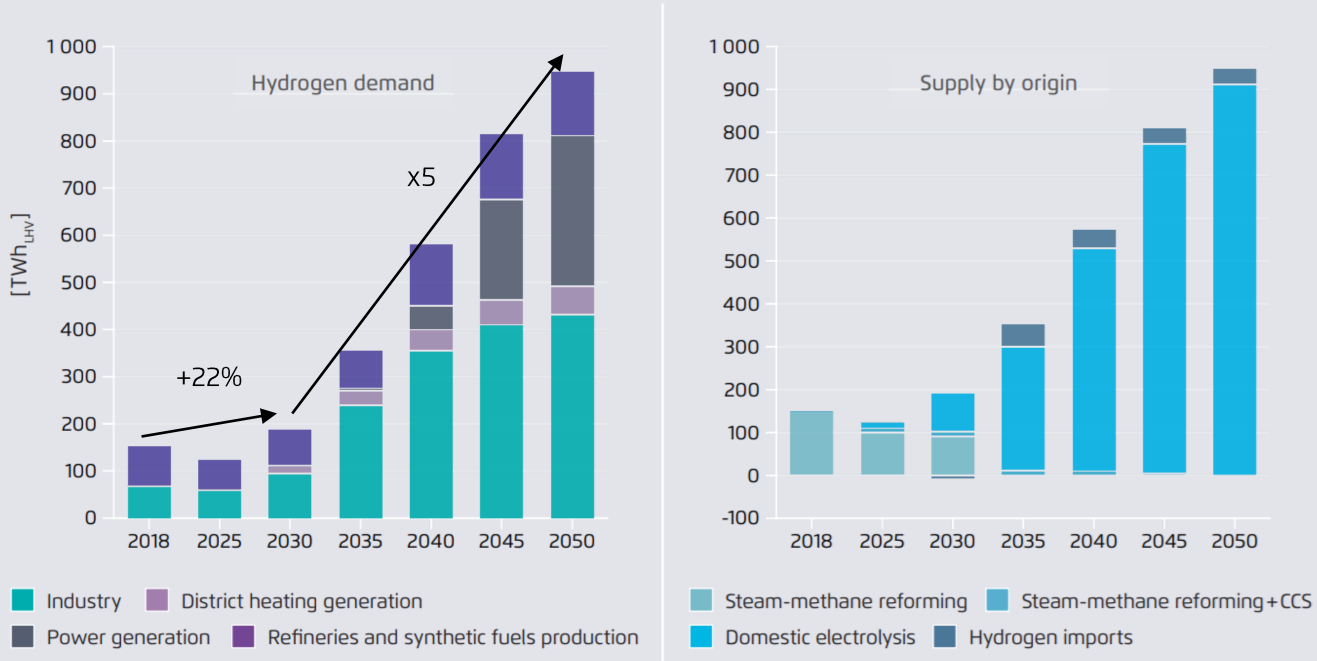
* Data includes fossil gas and biomass/bioenergy non-energy consumption, but not oil non-energy consumption. Hydrogen and synfuel imports include hydrogen imports by pipelines (intra and extra-European) and hydrogen derivatives for energy use (synfuels etc.). Hydrogen derivatives for non-energy use (ammonia, methanol etc.) are excluded.

- → Decline primarily thanks to electrification and efficiency increases, in particular the use of heat pumps in buildings and industry making use of ambient heat, as well as waste heat integration.
- → Including ambient and waste heat, primary energy demand* (PED) declines by 16% by 2030 and 32% by 2050.
- → Hard coal and lignite are almost entirely phased-out by 2035. Oil mostly remains in the transport sector after 2025.
- → Renewables, especially wind and solar, massively increase from 16% of PED* in 2018 to 88% in 2050.
- → Nuclear represents between 15 to 20% from 2018 to 2045, to decline to 9% of PED*.

Fossil gas and hydrogen

Hydrogen demand will only grow by 22% until 2030, but is expected to almost quintuple between 2030 and 2050

Hydrogen consumption by sector and supply by origin for EU-27

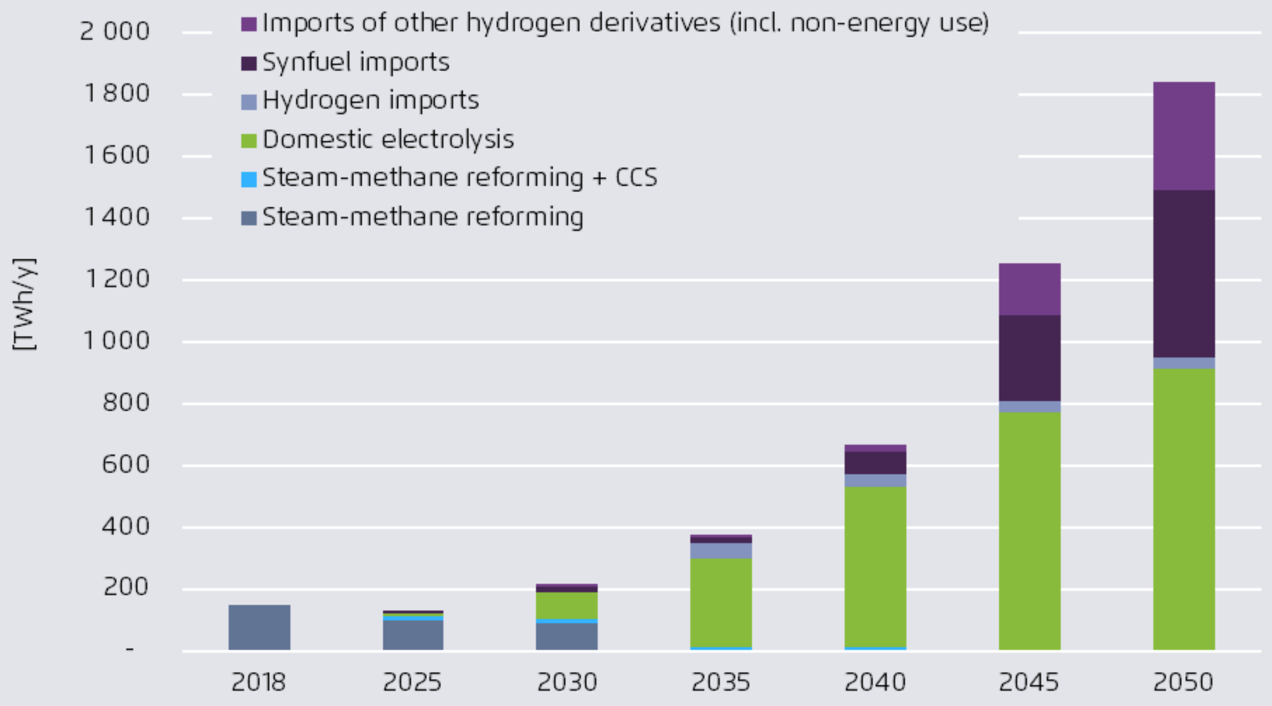


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- By 2050, hydrogen demand will reach 950 TWh, about 24% of current fossil gas demand if prioritised effectively. Hydrogen and its derivatives should indeed be prioritised for hard-to-abate sectors, as it will remain more costly and less efficient than direct electrification where available.
- In industry, hydrogen used as feedstock currently produced via carbon-emitting processes such as Steam Methane Reforming (SMR) is replaced by renewable hydrogen. Some processes requiring high temperature heat can also be based on hydrogen in future, e.g. in steel-making.
- Some hydrogen will also be needed to provide heat for district heating starting 2030. Hydrogen will remain too costly to be used in individual boilers to produce low temperature heat for the buildings sector.
- From 2040 onwards, hydrogen turbines emerge to provide flexibility services to the power system, requiring hydrogen storage assets to handle part of the seasonality of hydrogen demand.

Hydrogen can be mostly supplied domestically, also supplying flexibility to the power system, while its derivatives are largely imported

Hydrogen and hydrogen derivatives supply mix, EU-27

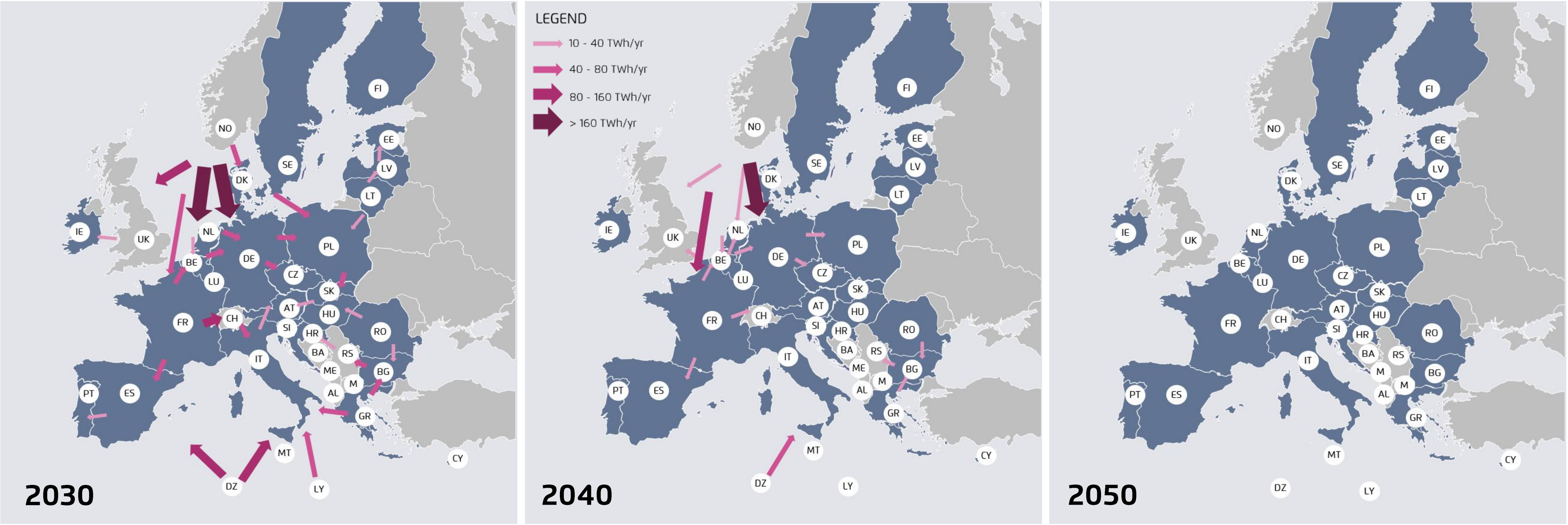


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- Renewable hydrogen produced in Europe reaches 90 TWh (2.7 Mt) by 2030 to first replace fossil-based hydrogen. It scales significantly until 2050 to reach 910 TWh (27 Mt).
- Imports of renewable hydrogen only start in 2035 with 52 TWh/y (about 15% of supply) and remain low until 2050. SMR hydrogen with CCS is found to play a minor role in the transition pathway.
- Imports of hydrogen derivatives (ammonia, methanol, synthetic cracker feedstock as well as synthetic fuels for transport) starts in 2030 with 28 TWh (0.9 Mt). By 2050, most of the hydrogen derivatives (incl. non-energy use) will be imported – about 895 TWh (27 Mt in H2 equivalent).

As demand declines, transmission pipelines will be partly converted to hydrogen, the rest decommissioned.

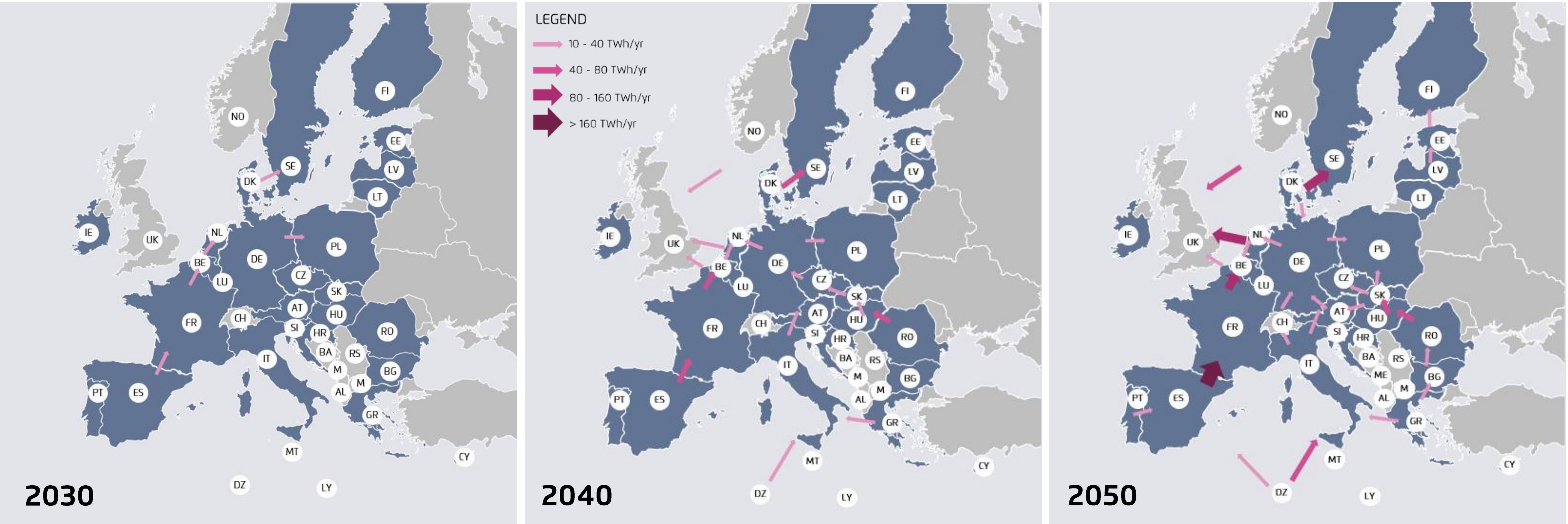
Methane flow through pipelines in Europe in 2030, 2040 and 2050



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

A hydrogen pipeline infrastructure will emerge after 2030 to supply Europe with mostly domestically produced renewable hydrogen from South to North

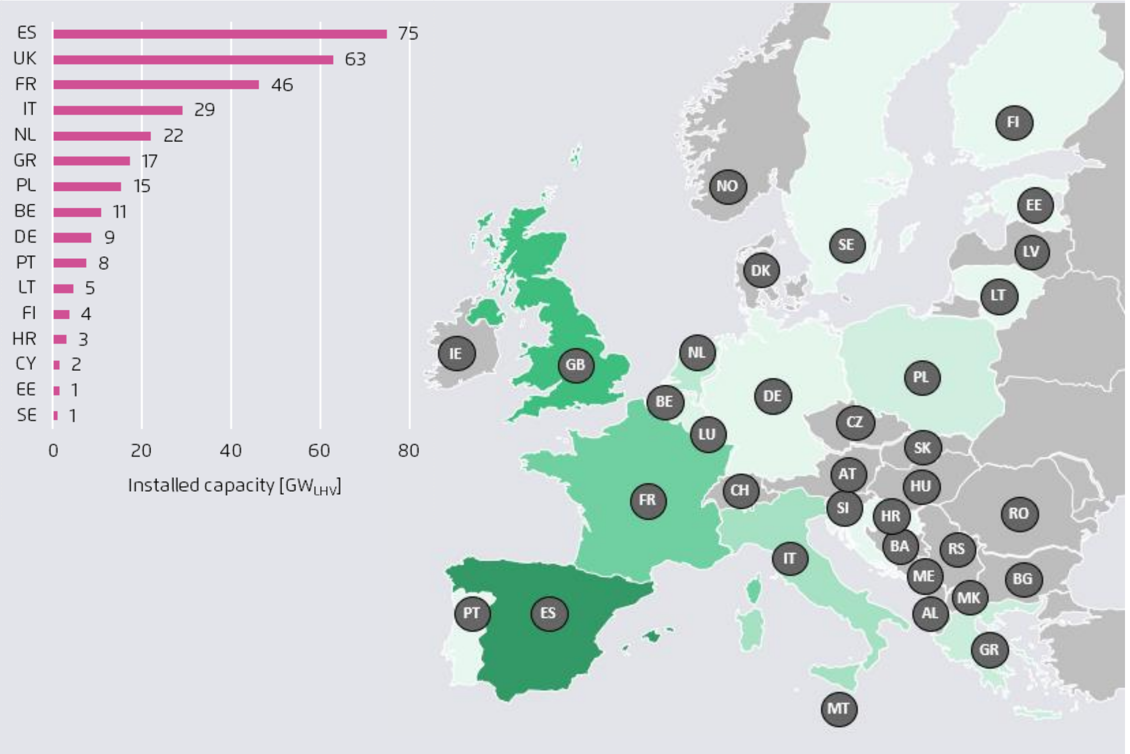
Hydrogen flow through pipelines in Europe in 2030, 2040 and 2050



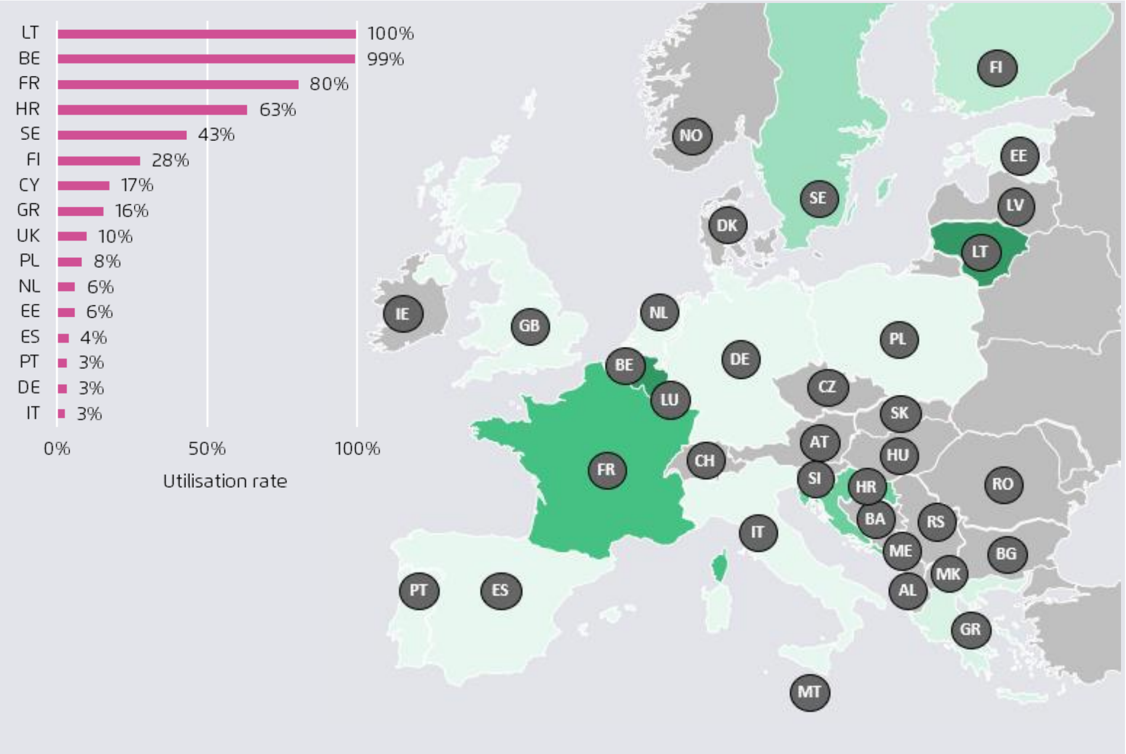
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

LNG terminals currently being built in several European Member States risk becoming stranded assets by 2030 already

LNG terminal installed capacity by country in 2030 (GW)



LNG terminal utilisation rate by country in 2030 (GW)

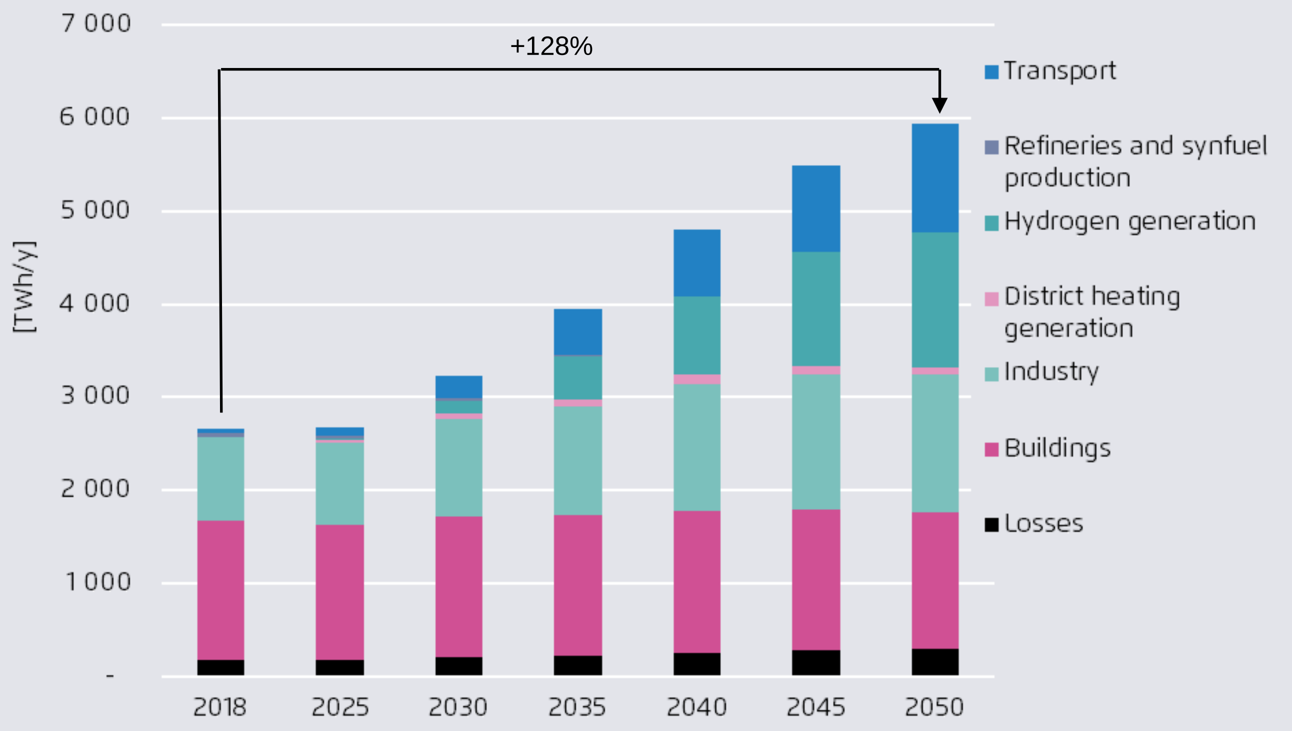


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Power sector

Electricity demand

Power consumption by sector for EU-27

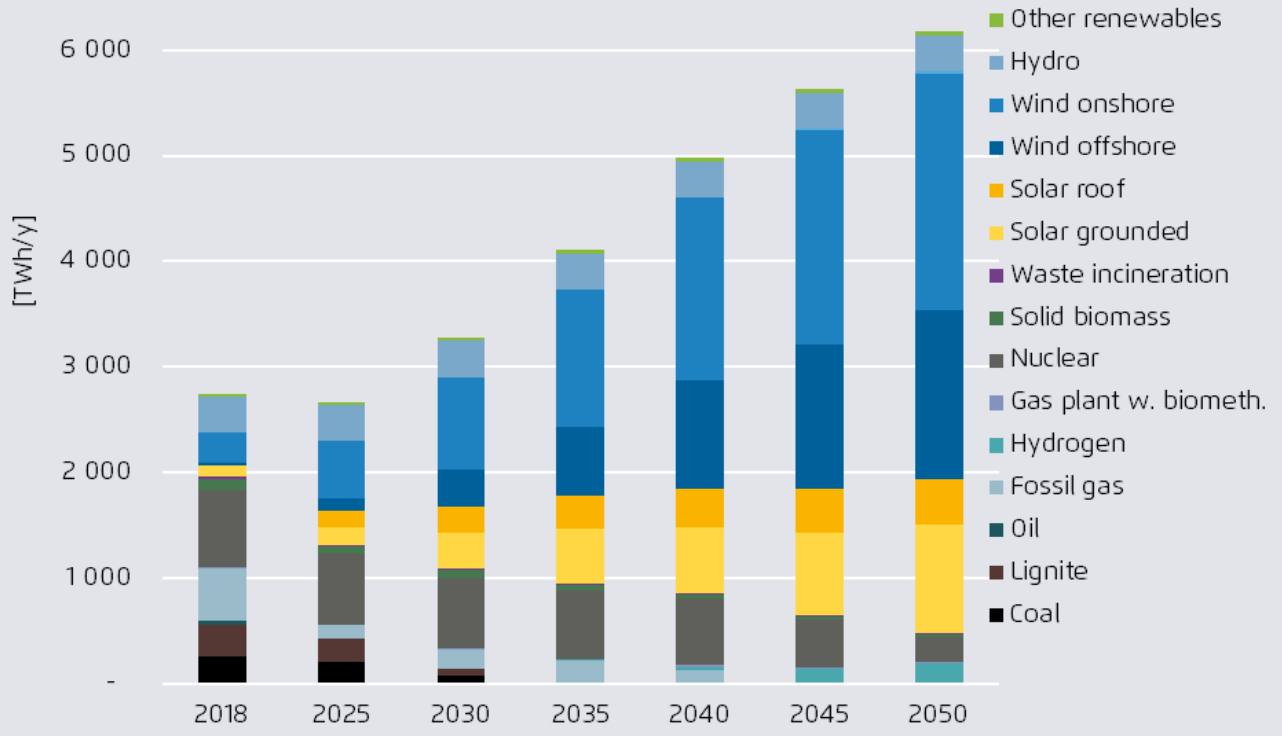


Artelys modelling (2023)

- → Total electricity consumption **more than doubles between 2018 and 2050**;
- → The increase is mainly due to **electrolysis** (+1456 TWh), **e-mobility** (+1230 TWh) and electrification of processes in **industry** (+536 TWh, +57%);
- → Due to the combined effect of **energy efficiency** measures (incl. building renovations) and **electrification** of heating devices (mainly through heat-pumps), **power demand in the building sector remains stable** between 2018 and 2050.

Power generation

Power generation in EU-27

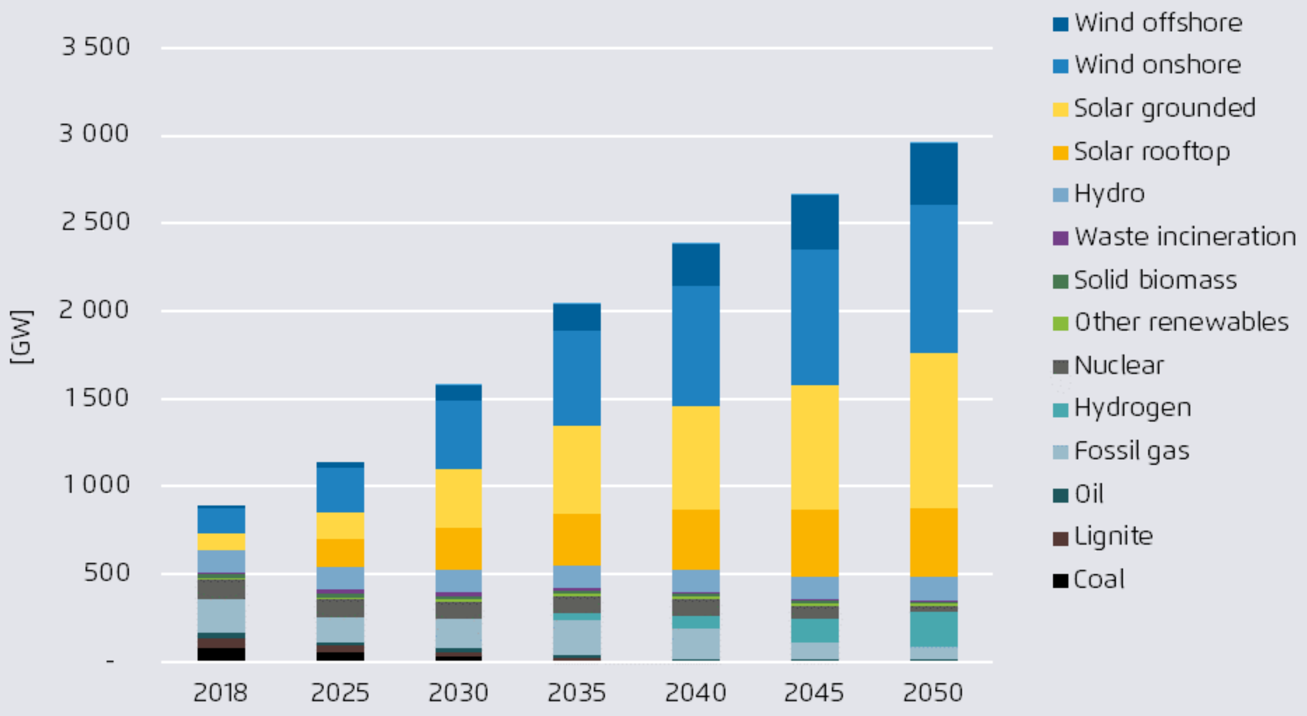


Artelys modelling (2023)

- The output of coal & lignite technologies is divided by 4 between 2018 and 2030. These technologies are phased out by 2035.
- Due to the current context and the gas prices which are expected to remain higher than they used to be in the past ten years, electricity generation with fossil gas decreases strongly between 2018 and 2025 (-75%).
- Renewables (solar + wind + hydro + biomass) account for 69% of total power supply by 2030 and more than 93% by 2050.

Installed capacity

Power generation capacity, EU-27

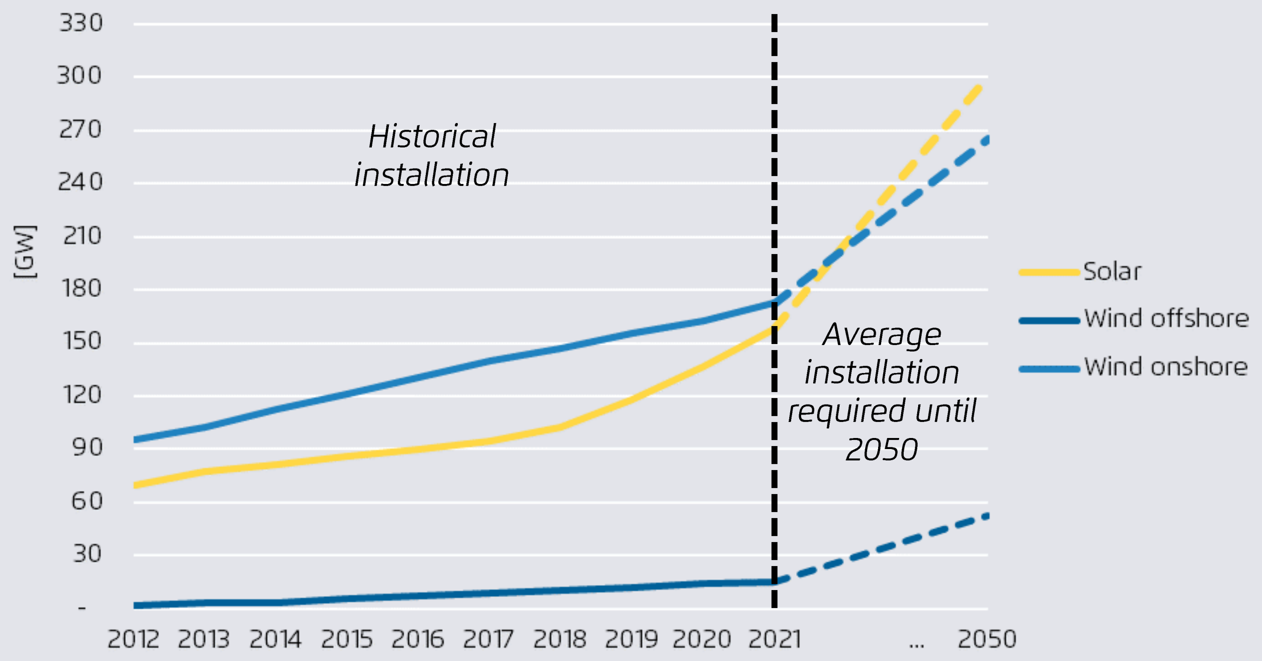


Artelys modelling (2023)

- The power generation mix is dominated by solar and wind power (by 2050, solar accounts for 43% of installed capacity and wind for 40%).
- Wind reaches 480 GW by 2030 (390 GW onshore and 90 GW offshore) and 1200 GW in 2050.
- Solar reaches 570 GW by 2030 and 1280 GW by 2050.
- Dispatchable capacities decrease by 25%, from 630 GW in 2018 to 470 GW in 2050.
- From 2035 onwards, gas powered capacities are gradually phase-out and replaced by hydrogen powered capacities.

Capacity installation rate – renewables

Comparison of historical installation rates with average installation rates required until 2050

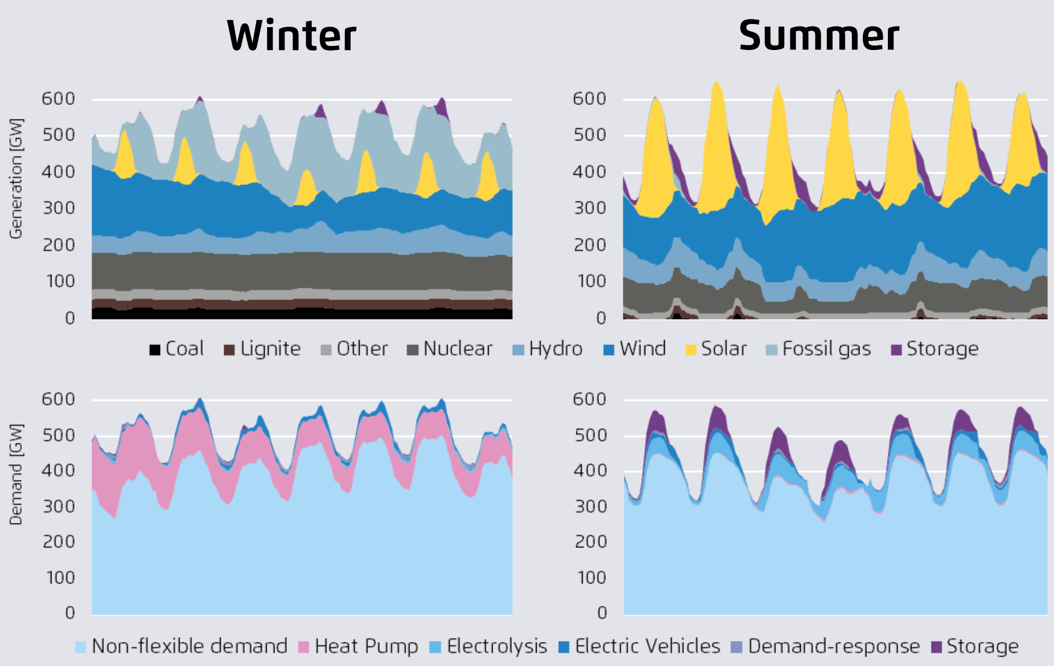


Artelys modelling (2023)

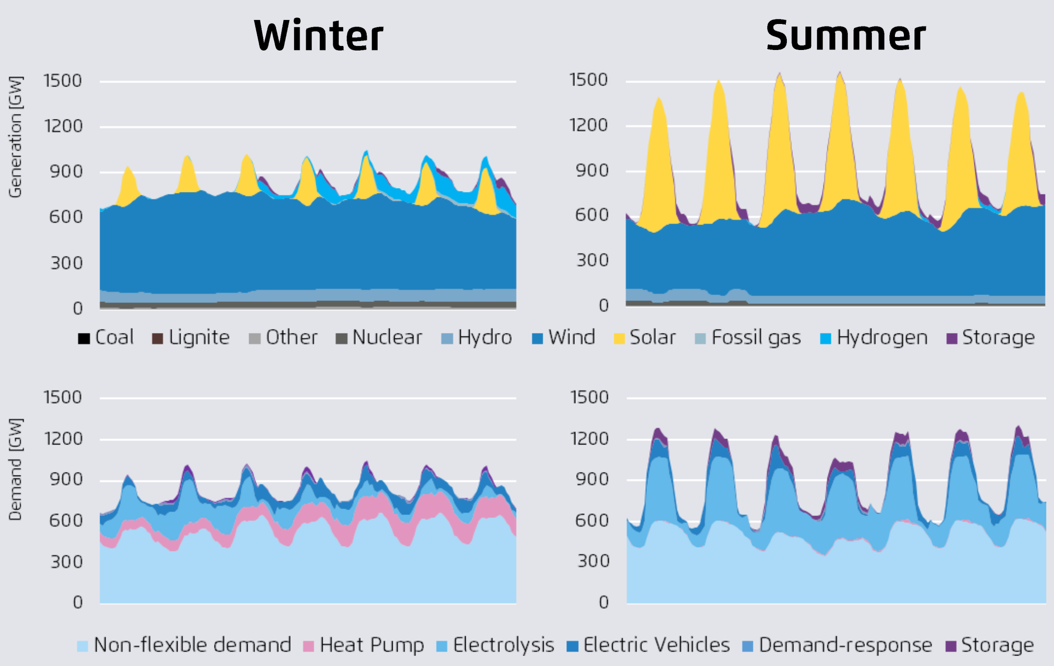
- In order to reach the target of this study, average yearly installation rate need to be multiplied by 2.7 compared to the highest historical installation rate over the past 10 years
  - x1.3 for solar
  - x2.2 for onshore wind
- 2022 already saw a significant increase in installation rates in the EU-27, especially solar with +41 GW, almost 50% more than in 2021, reaching 209 GW at the end of 2022.
- Continuing with this trend will allow to reach the targets. Offshore wind installations will also need to take off.

Flexibility requirements will significantly increase until 2050

Demand-supply balance during a typical week in 2030



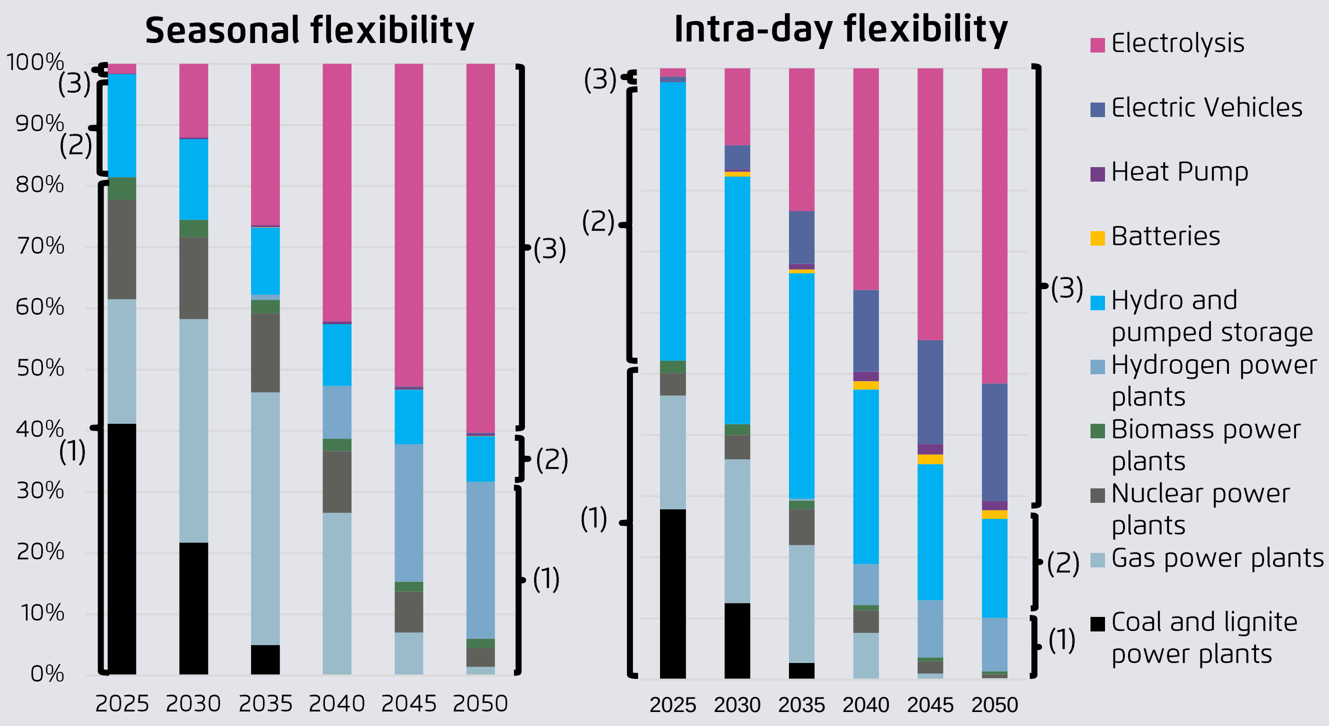
Demand-supply balance during a typical week in 2050



Artelys modelling (2023)

Flexibility provision

Evolution of the provision of flexibility in EU-27



Artelys modelling (2023)

- Currently, system flexibility needs are mainly met by conventional power plants (1) and storage technologies (2) for both seasonal and short-term flexibility
- In future, demand side flexibility (3) will play a predominant role
  - Electrolysis alone will provide 60% of the seasonal flexibility needs and 50% of intra-day flexibility needs by 2050.
  - Electric vehicles will provide short-term flexibility with about 20% of the intra-day flexibility needs.
- Hydrogen power plants will gradually replace gas and nuclear power plants starting 2040 for both seasonal and short-term flexibility. They will play an important role especially for seasonal flexibility, representing about 25% by 2050.
- Hydro and pumped storage continue offering the same level of flexibility over the transition, though its share in overall flexibility services declines
- Batteries play an increasing role over time for short-term flexibility, which however will remain very limited considering total flexibility needs (<5%)

Key points from the power sector

→ Power system increasingly dominated by renewables in future

- Deployment challenge: permitting, land availability, materials… as well as public acceptance
- Change in role of dispatchable units from baseload generation to provision of capacity services
- Importance of demand flexibility

Q&A

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Questions or Comments? Feel free to contact me:

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