LABORATORY OF ENERGY POLICY

Agora Energiewende

Breaking free from fossil gas

A new path to a climate-neutral Slovenia

Presentation overview

Project background

Project scope

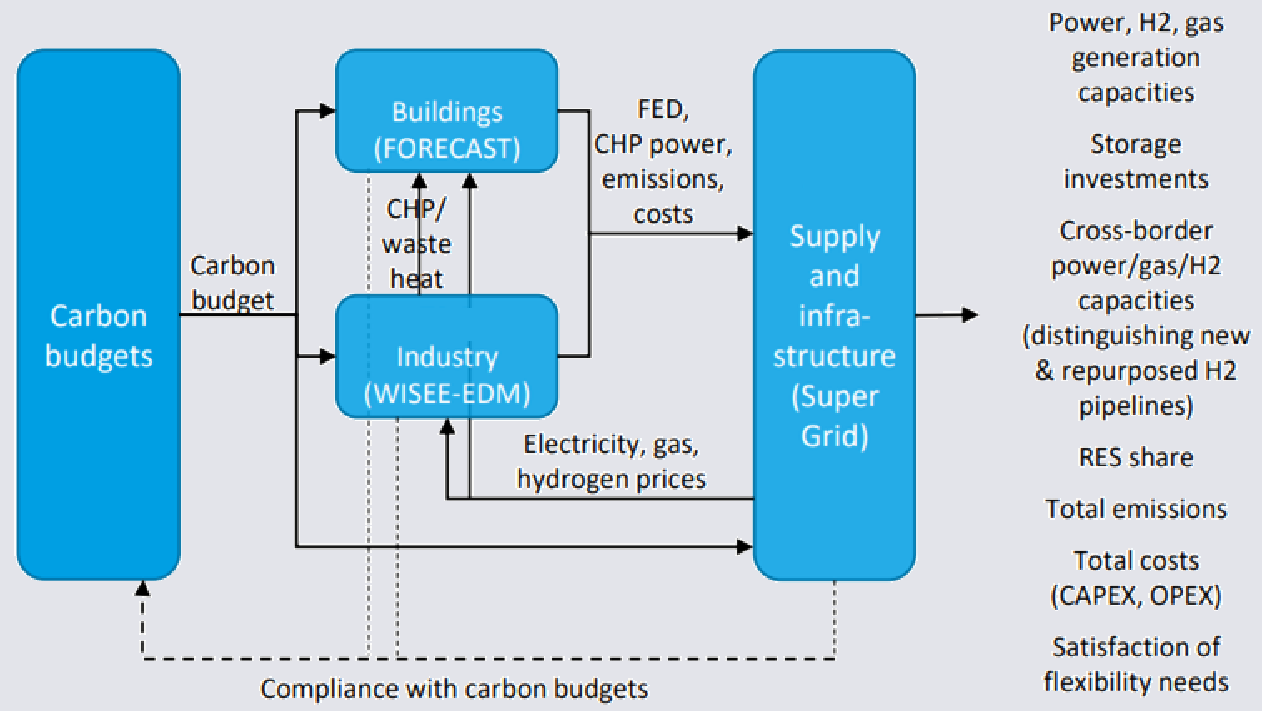
Project setting	Scope
→ Cooperation project between Ecco Climate and Agora Energiewende for Italy, within a consortium of 9 countries to develop national pathways and an EU-wide pathway: • **Bulgaria:** Center for the Study of Democracy (CSD) • **Czechia:** Nano Energies • **Greece:** FACETS S.A. • **Croatia:** 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 Ljubljana – Laboratory of Energy Policy (LEST)	→ Decarbonisation pathway until 2050, with fossil gas phase out by 2050 at the latest. 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). → Energy demand modelled bottom-up by TEP Energy (buildings) and Wuppertal Institute (industry); power sector by Artelys. Energy supply was modelled for the whole EU with an optimisation model by Artelys.

Disclaimer

→ As this project has started in 2021 and its main results were published in 2023, the main part of the work on this project was conducted in 2022. Therefore, the results of this project are highly influenced by the drastic effects of the Russian invasion in Ukraine on European energy markets (high prices, risk of a gas shortage) back then. Some of the results might thus be outdated as the economic and political context has changed.

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

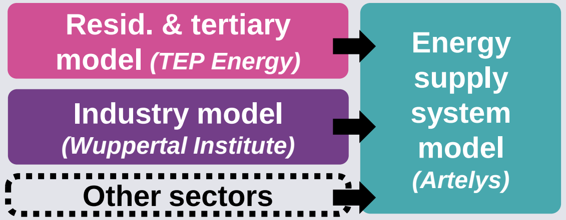
→ Supply and infrastructure model

- 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

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.

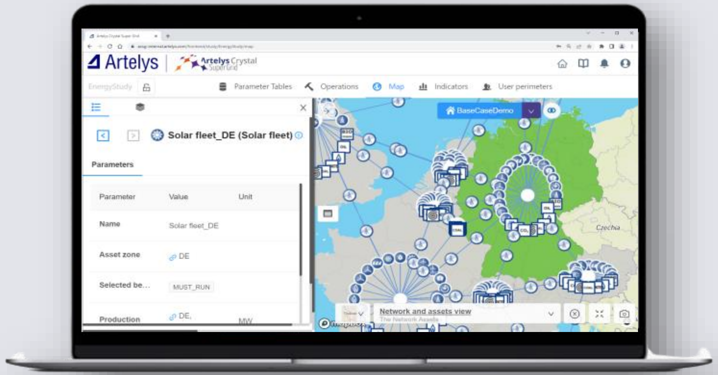
→ In concrete terms, the power sector is considered to be largely decarbonised by 2040.

Energy sector:

Methodology and assumptions

Energy system modelling in the EU-27

Artelys Crystal Super Grid model



A multi-energy modelling solution dedicated to interconnected systems

Bottom-up representation

Multi-energy approach

State-of-the-art optimisation techniques

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 generation 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).

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**

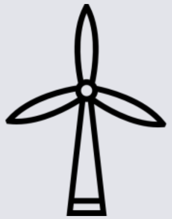
- Energy efficiency
- Circular economy
- Electric furnaces (EAF, induction, microwave etc.)
- Large scale (high temperature) heat pumps and waste heat integration
- Solar/geothermal
- Dry Biomass (+ onsite gasification, BECCS option)
- Green gases (hydrogen, e-gas, biomethane)
- Relocation of basic industry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

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)

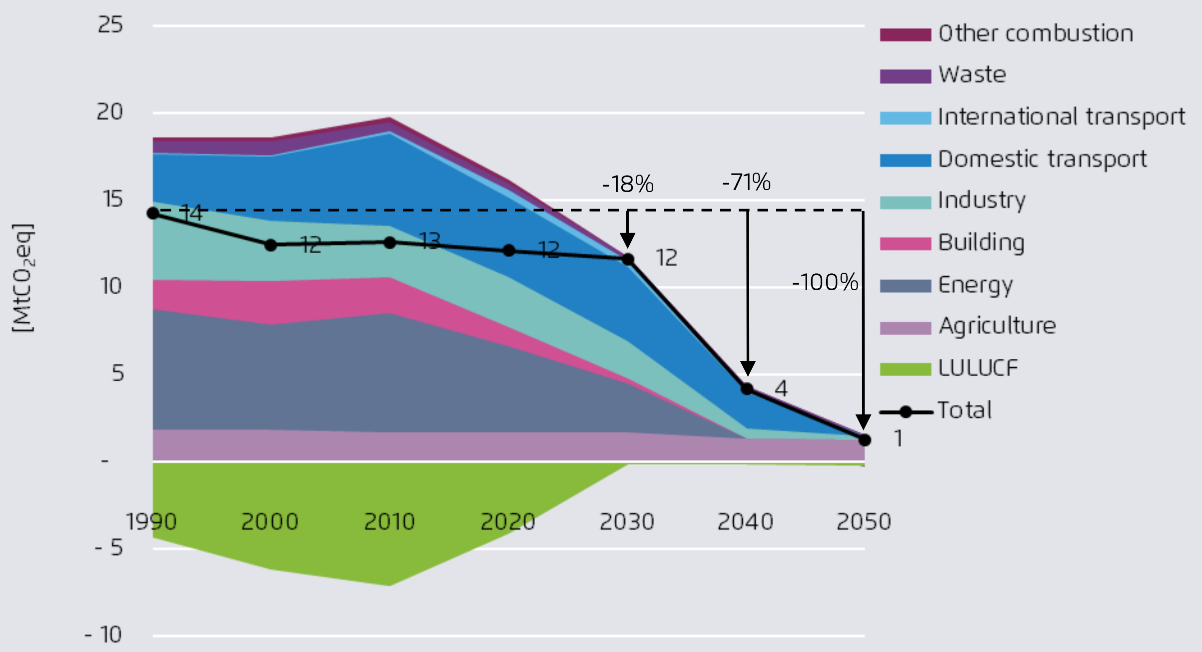
Biogas and biomethane
- Biogas and biomethane considered to be interchangeable with fossil gas
- Conservative approach concerning their availability due to sustainability concerns of biomass overall.
- Total biomass consumption (excluding material use in the study) assumed to remain at today's levels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

Energy sector:

Results –
Overall pathway and energy supply

Accelerated GHG reductions can be achieved with the right investments starting today: net-GHG emissions reductions of -59% by 2030, -88% by 2040 and -102% by 2050

GHG emissions by sector in Slovenia

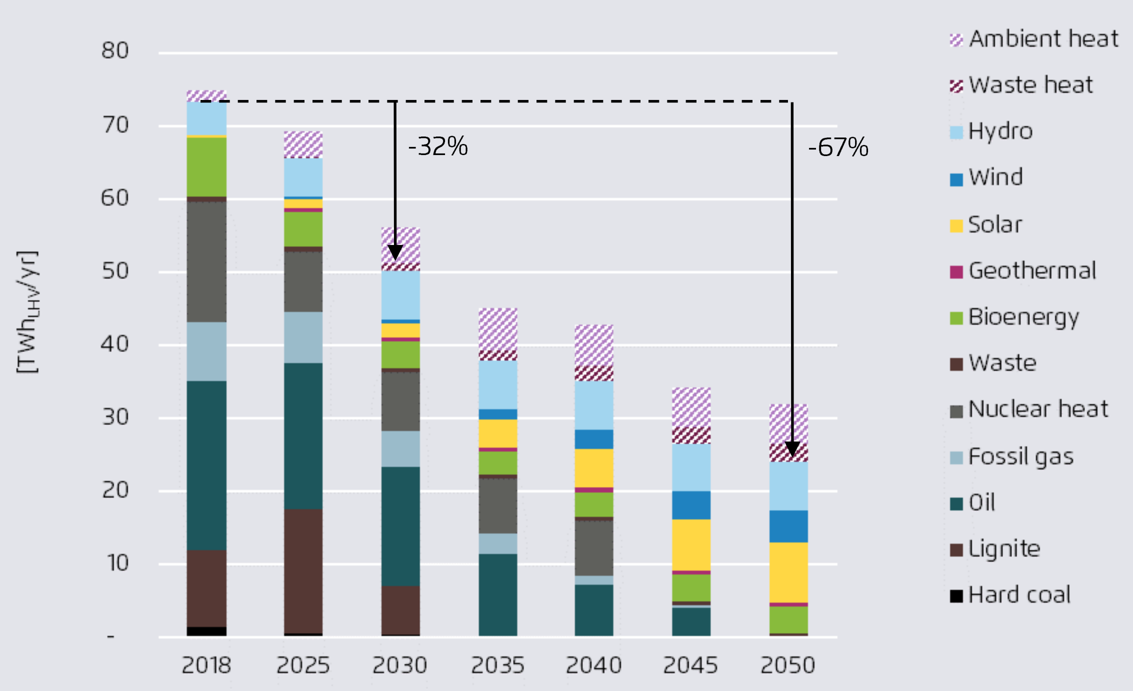


Eurostat; Artelys, TEP Energy, Wuppertal Institute modelling (2023)
* Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste)
** Based on the LULUCF+ scenario from the EC Climate Target Plan impact assessment (assumes a 5-year delay)

- A target of -90% for the EU by 2040 would avoid 3.3 Gt more GHG emissions than projected in the EU's 2020 Climate Target Plan. For Slovenia, that would amount to about -71% emissions.
- Transport, agriculture, waste and LULUCF covered by existing studies by Transport & Environment and the European Commision: Additional efforts in these sectors, especially e.g. in the LULUCF sector, could achieve further reductions quicker.
- Broadly speaking, the last 10% of residual emissions will be the hardest to mitigate.

Primary energy demand* declines by 32% by 2030 and 67% by 2050, not taking into account ambient and waste heat in the buildings and industry sectors

Primary energy demand* by energy source, Slovenia



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

* Data includes fossil gas and biomass/bioenergy non-energy consumption, but not oil non-energy consumption or hydrogen and synfuel imports. Hydrogen derivatives for non-energy use (ammonia, methanol etc.) are also excluded.

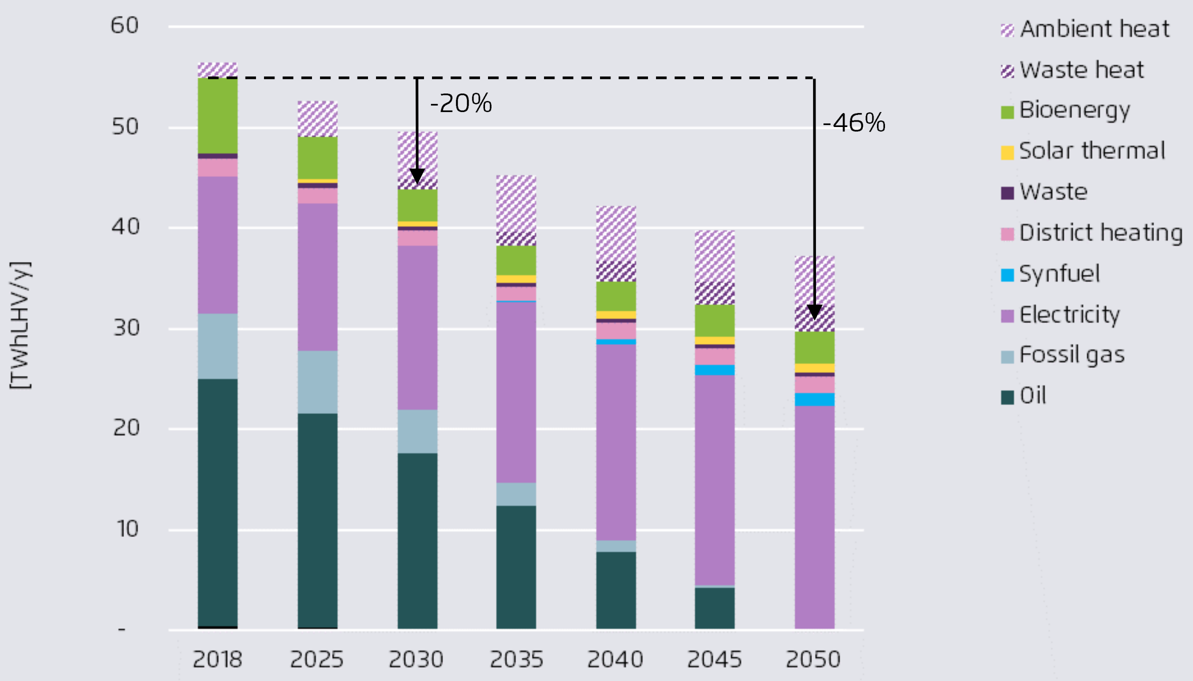
→ Decline primarily thanks to electrification and efficiency increases, in particular the use of heat pumps in buildings and industry making use of ambient heat, as well as waste heat integration.

→ Hard coal and lignite are entirely phased-out by 2030. Oil mostly remains in the transport sector after 2025.

→ Renewables, especially wind and solar, massively increase from 18% of PED* in 2018 to 98% in 2050.

Final energy demand declines by 46% between 2018 and 2050. It can already decline by 20% by 2030.

Final energy demand by energy carrier, Slovenia



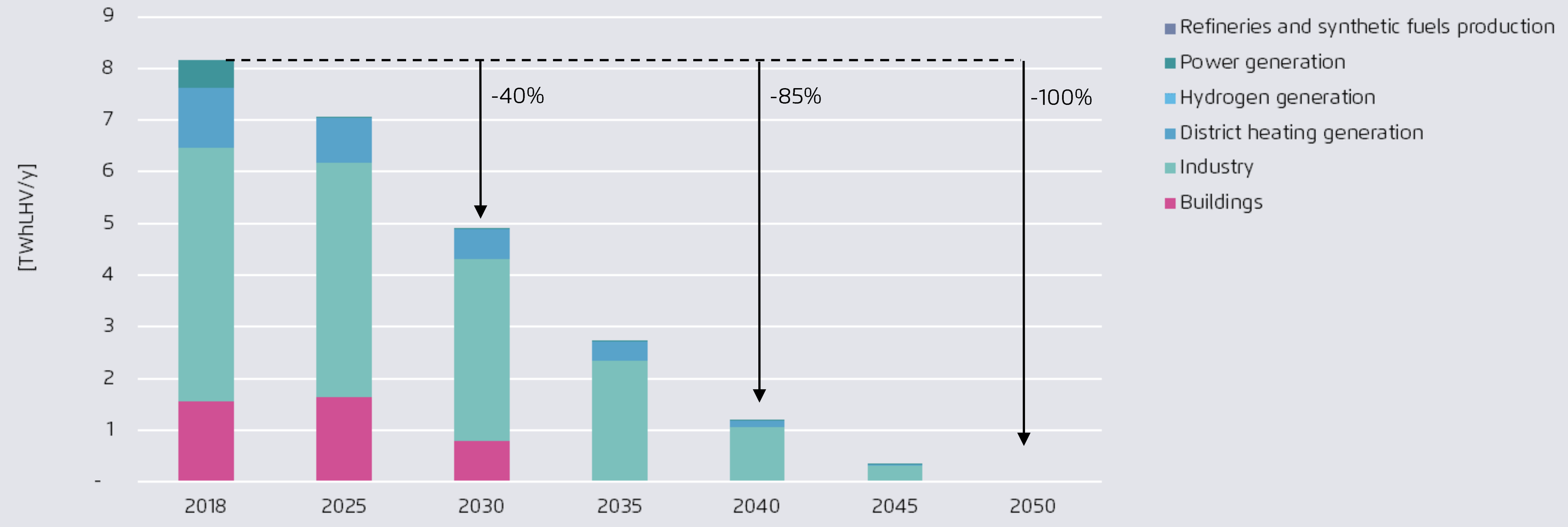
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

→ 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 25% in 2018 to 37% in 2030 and to 75% in 2050. On the contrary, fossil fuels representing 57% of FED in 2018 are phased out by 2050, oil in transport being the longest in the energy system.

Fossil gas use in Slovenia, a focus of this study, can be reduced by 40% by 2030 and completely be phased out by 2050 with structural demand reduction measures only.

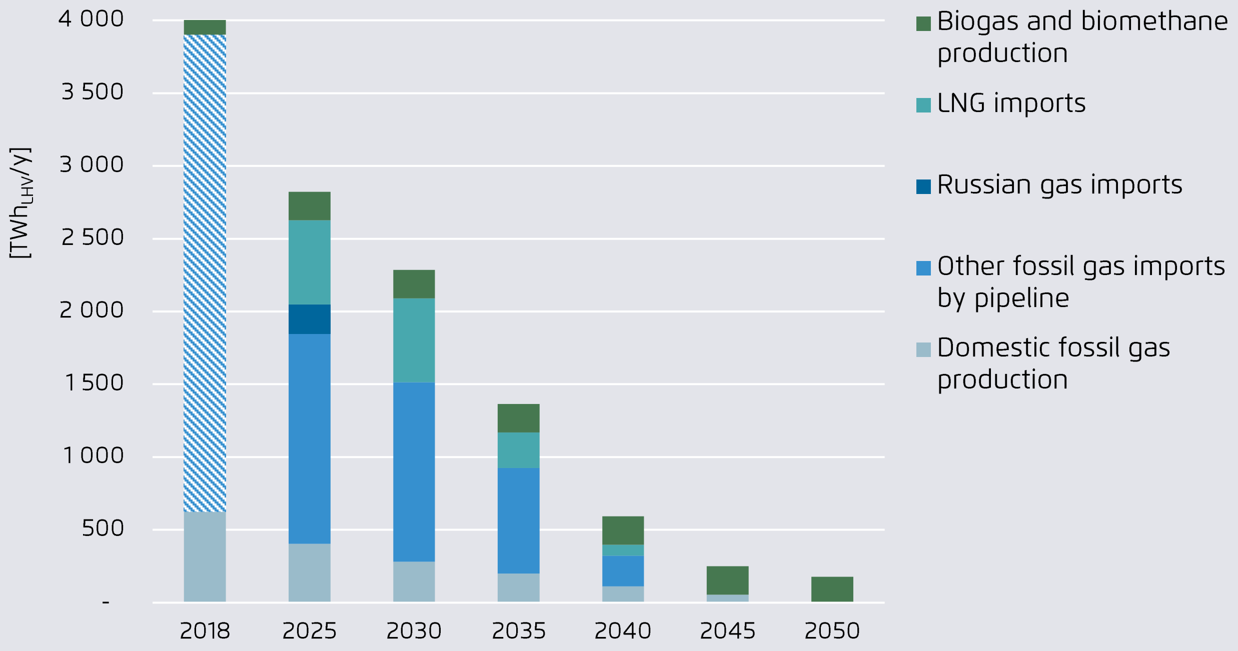
Evolution of total fossil gas consumption in Slovenia, 2018-2050 (in TWh_{LHV})



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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

Methane supply, EU-27

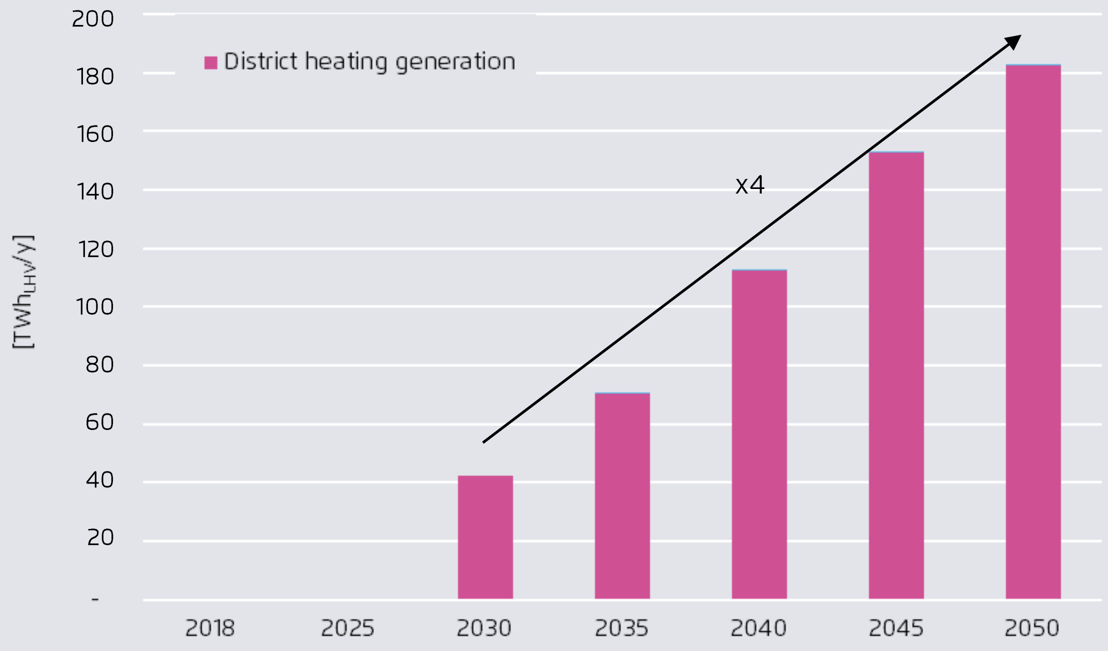


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → 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 European biogas and biomethane can almost completely supply the remaining methane demand by 2045.

Hydrogen demand will reach about 40 GWh by 2030 and is expected to quadruple after that until 2050

Hydrogen consumption by sector for Slovenia

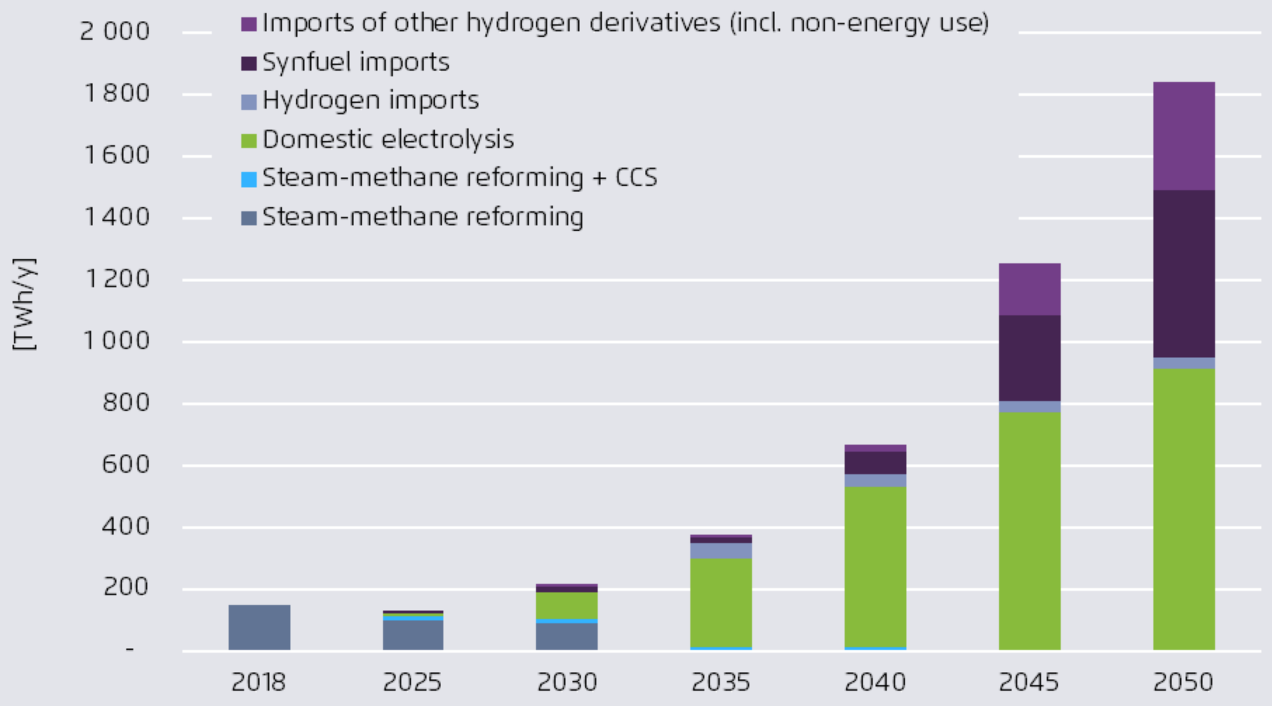


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- By 2050, hydrogen demand will reach 180 GWh 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.
- Slovenia does not consume hydrogen currently. Some hydrogen will 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.

Hydrogen can be mostly supplied domestically within Europe, while its derivatives are largely imported. Slovenia will most likely be importing the limited amount of H2 from other Member States.

Hydrogen and hydrogen derivatives supply mix, EU-27

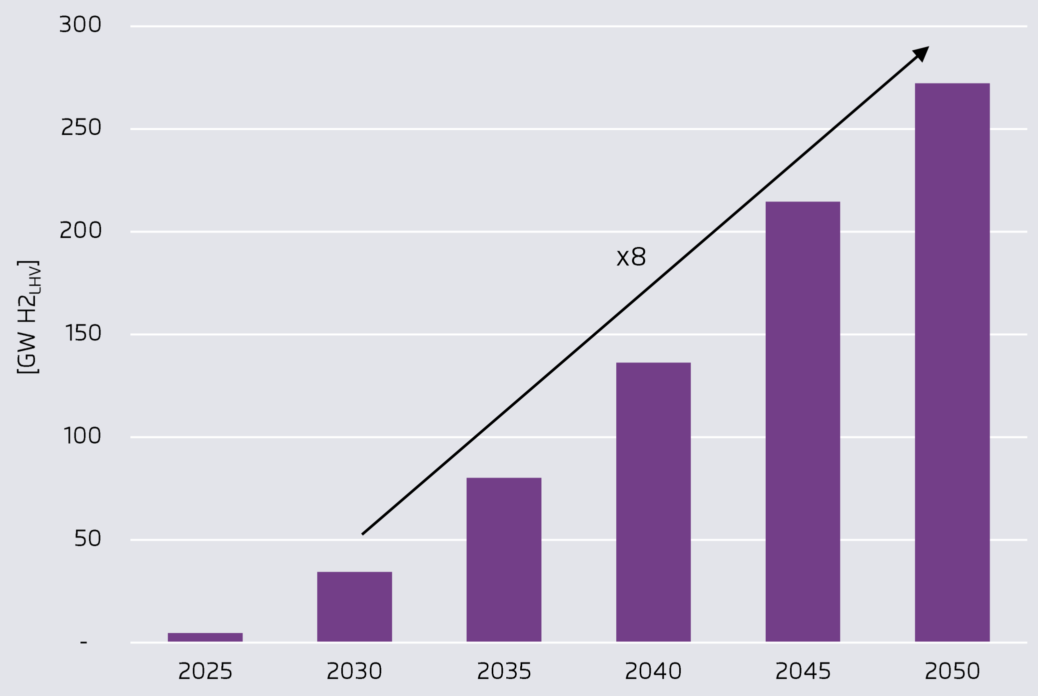


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → 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).

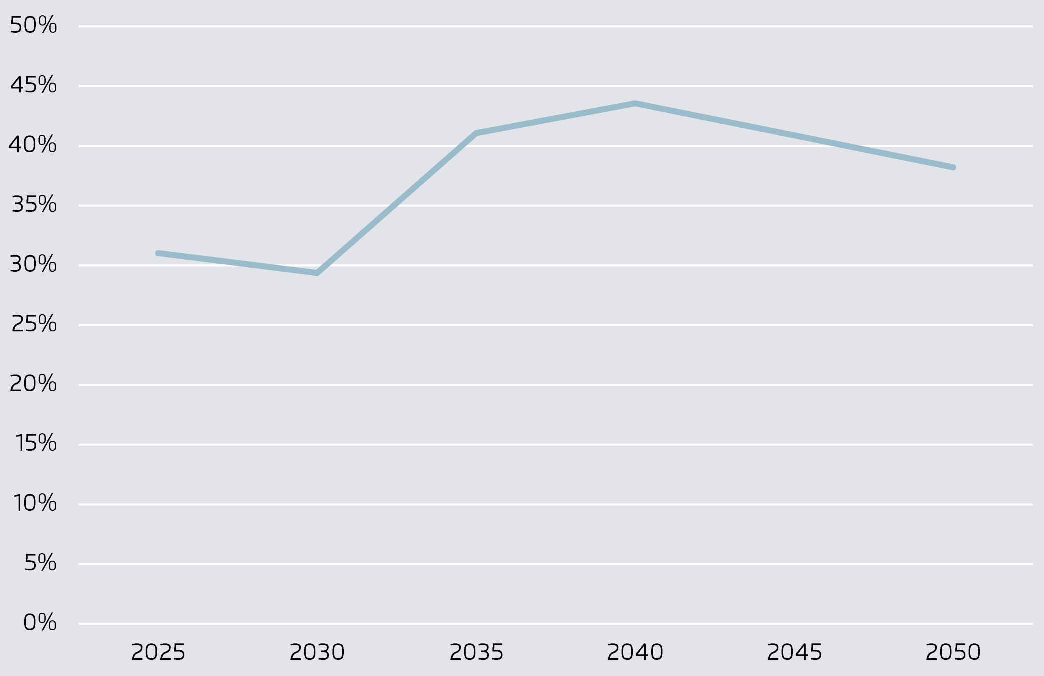
Electrolyser capacity reaches 34 GW in 2030 and is multiplied by 8 until 2050. Slovenia won’t need an own production for the limited amount of H2 demand.

Installed electrolyser capacity, EU-27



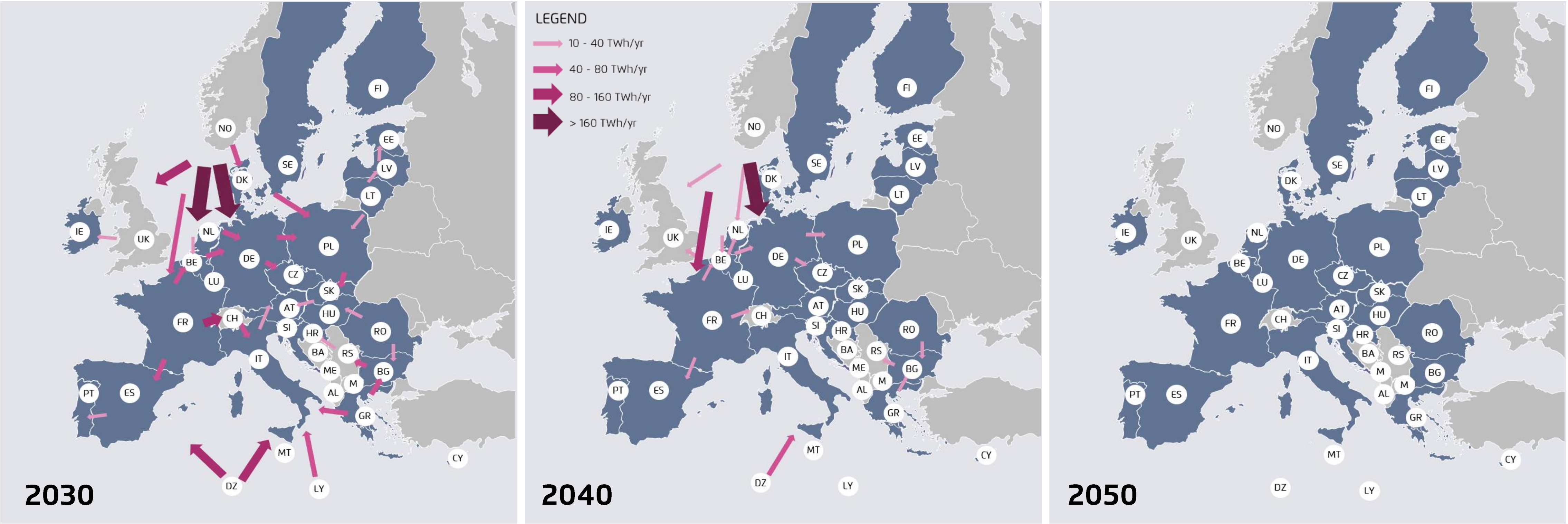
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Load factor of electrolysers



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

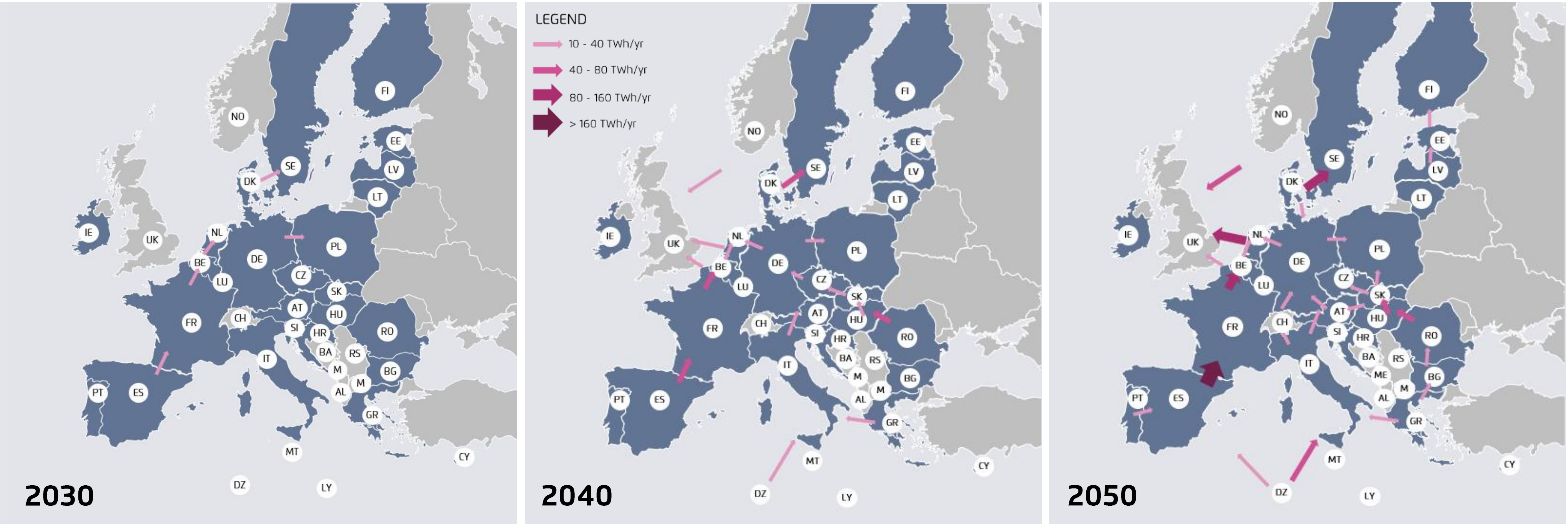
Methane flow through pipelines in Europe in 2030, 2040 and 2050



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

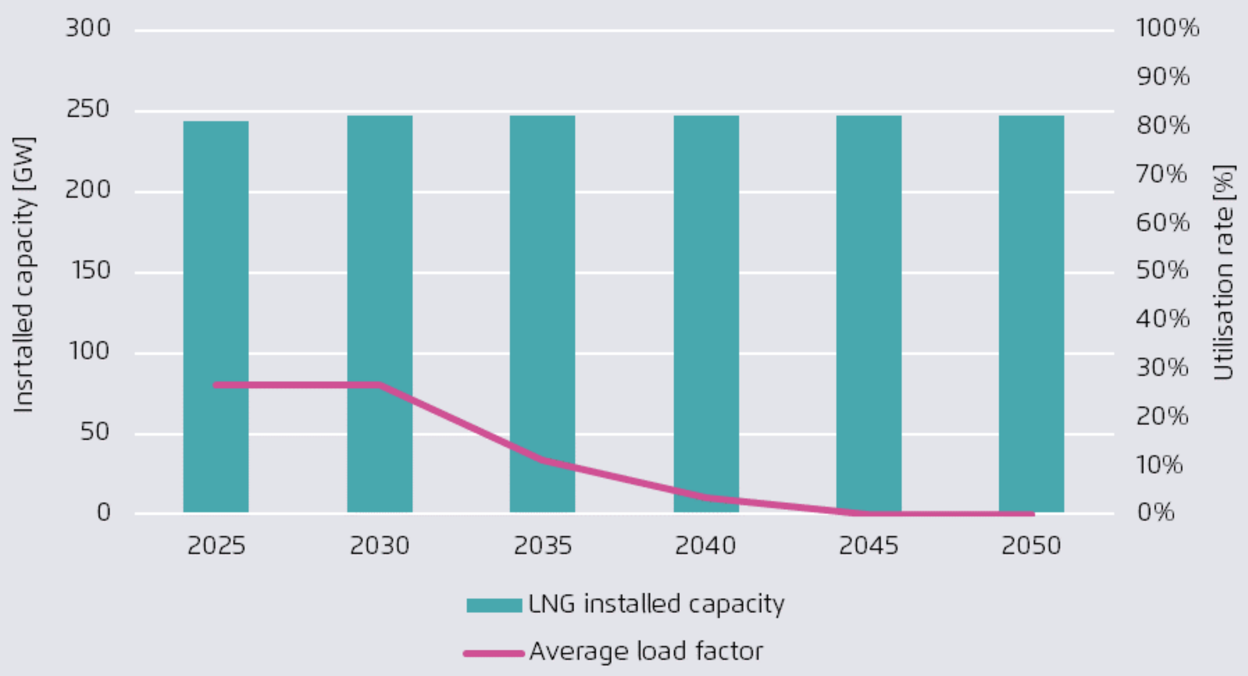
Hydrogen flow through pipelines in Europe in 2030, 2040 and 2050



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Current investments in new LNG terminals in Europe are over-dimensioned and risk becoming stranded assets quickly as fossil gas demand declines

LNG terminal capacity and utilisation rate, EU-27

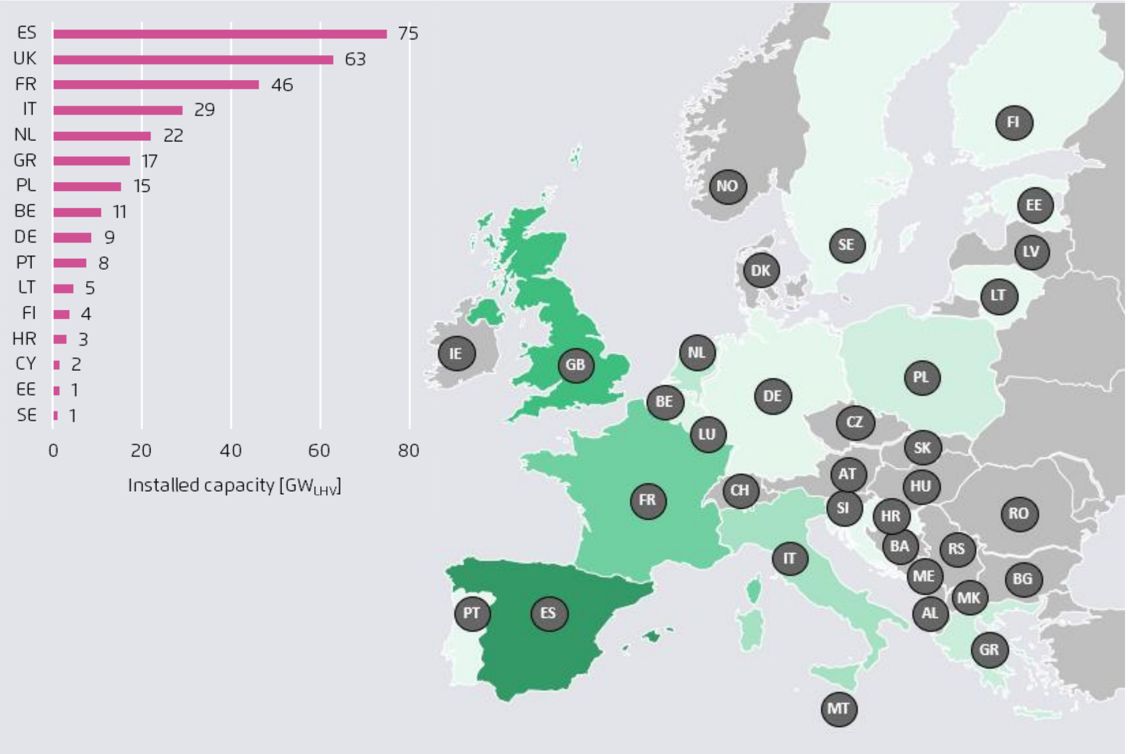


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

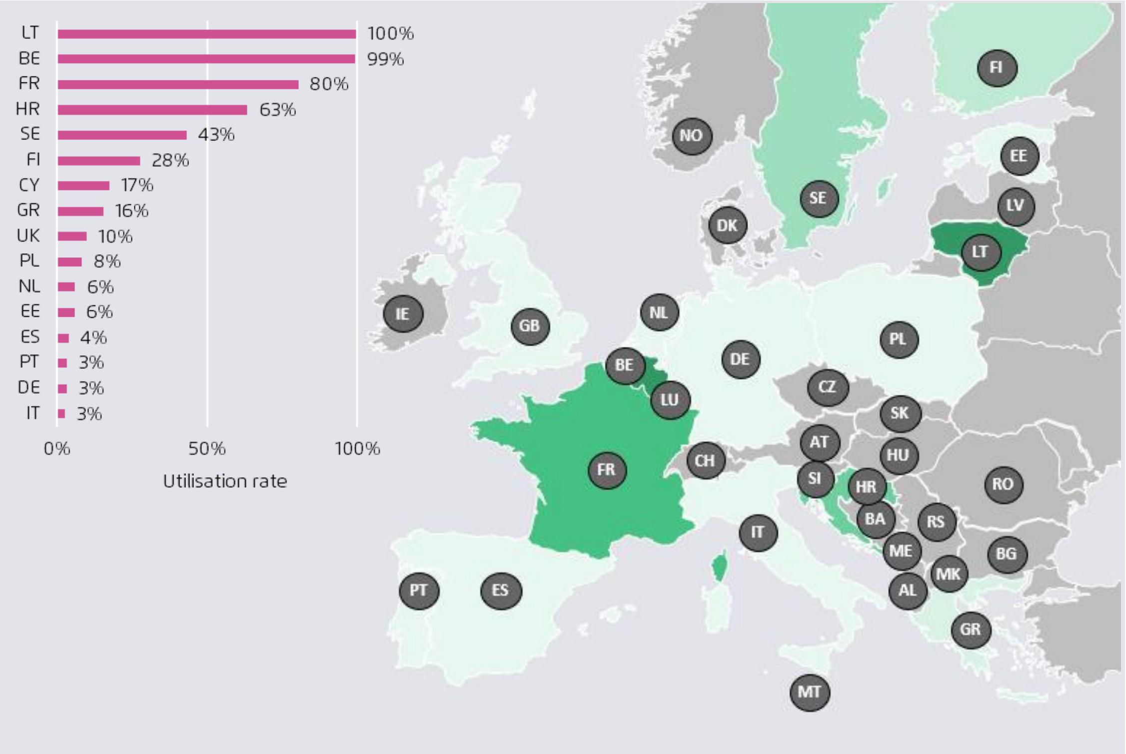
- As a response to the fossil gas supply crisis, LNG import capacity in the EU-27 will expand by 21%, or 53 GW compared with 2021.
- If demand declines as it should in order to ensure energy sovereignty and for Europe to achieve its climate targets, those investments will be used very little (average utilisation rate of the terminals will peak at about 27% in 2025-2030 from about 40% on average between 2018 and 2020) and become stranded assets by 2040 at the latest.

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)



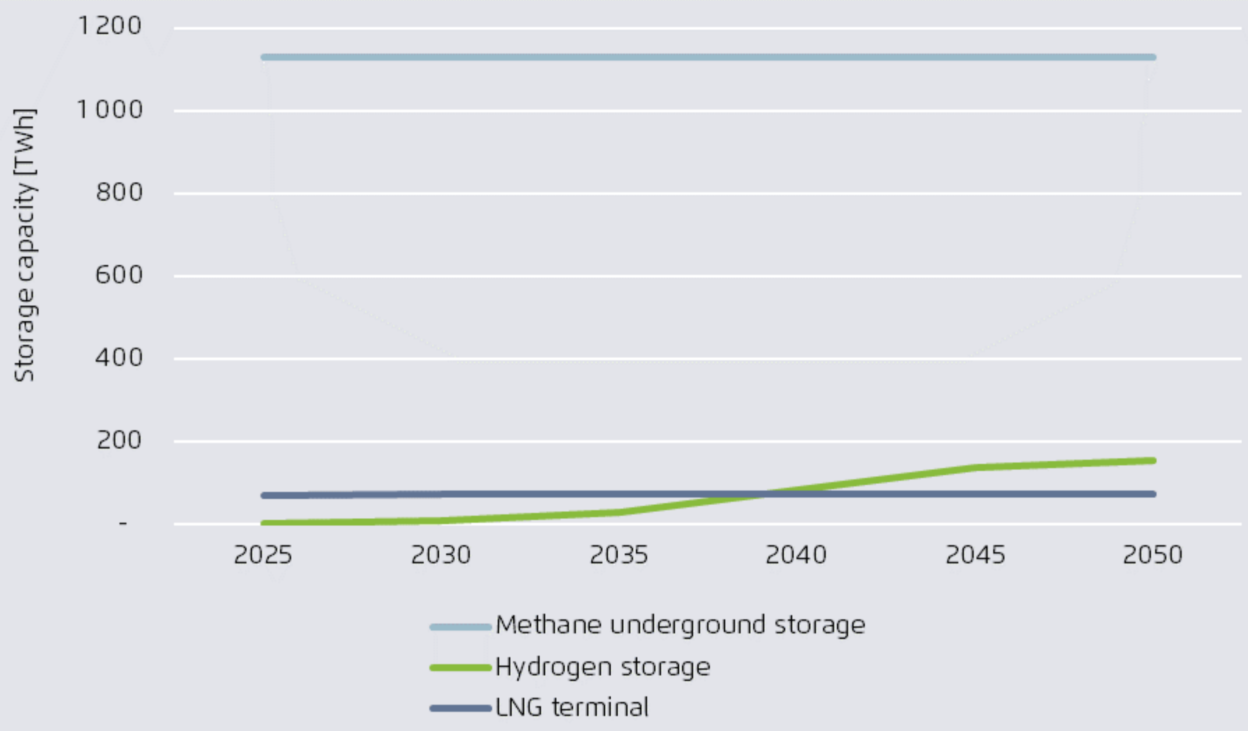
LNG terminal utilisation rate by country in 2030 (GW)



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Hydrogen storage increases with demand, but remains much lower than current methane storage

Storage capacity by type, EU-27

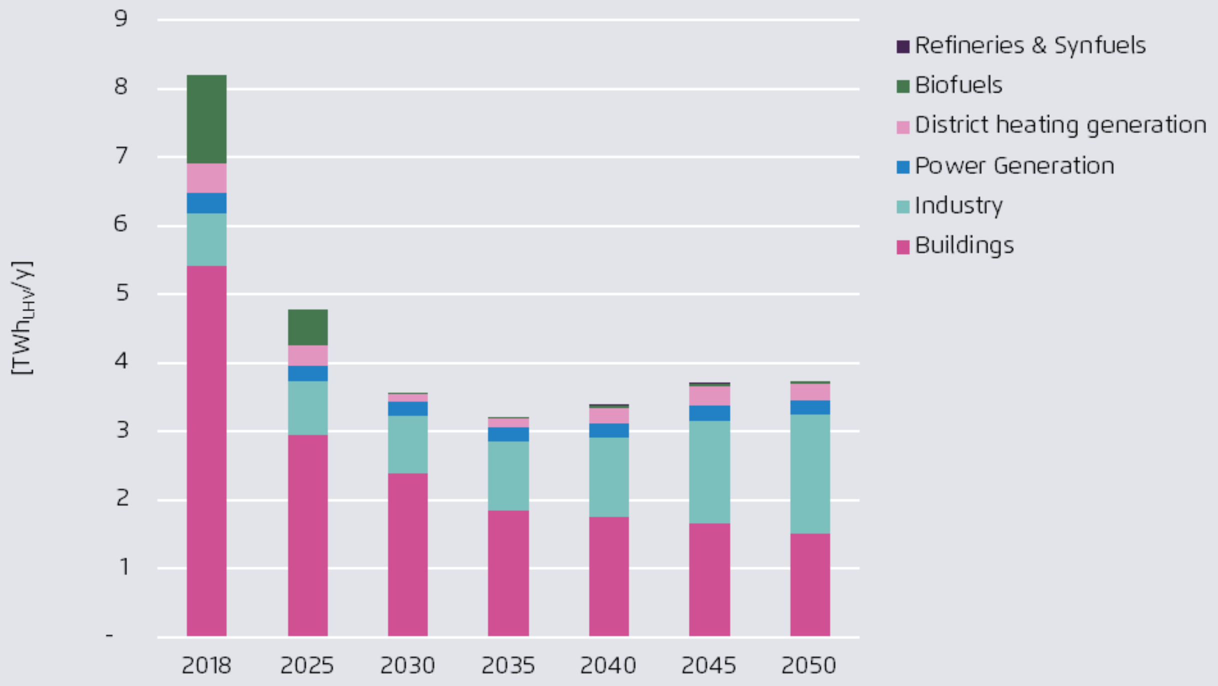


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → Hydrogen storage reach 154 TWh_{LHV} in the EU-27 (16% of demand by 2050).
- → This is more than twice the storage capacity in LNG terminals (73 TWh), but only about 15% of the current methane underground storage capacity.
- → Methane storage capacity is not optimised in the model and considered constant over the years.

The use of biomass for bioenergy and non-energy feedstock purposes declines in buildings and biofuels production

Energy and non-energy consumption of biomass by sector in Slovenia

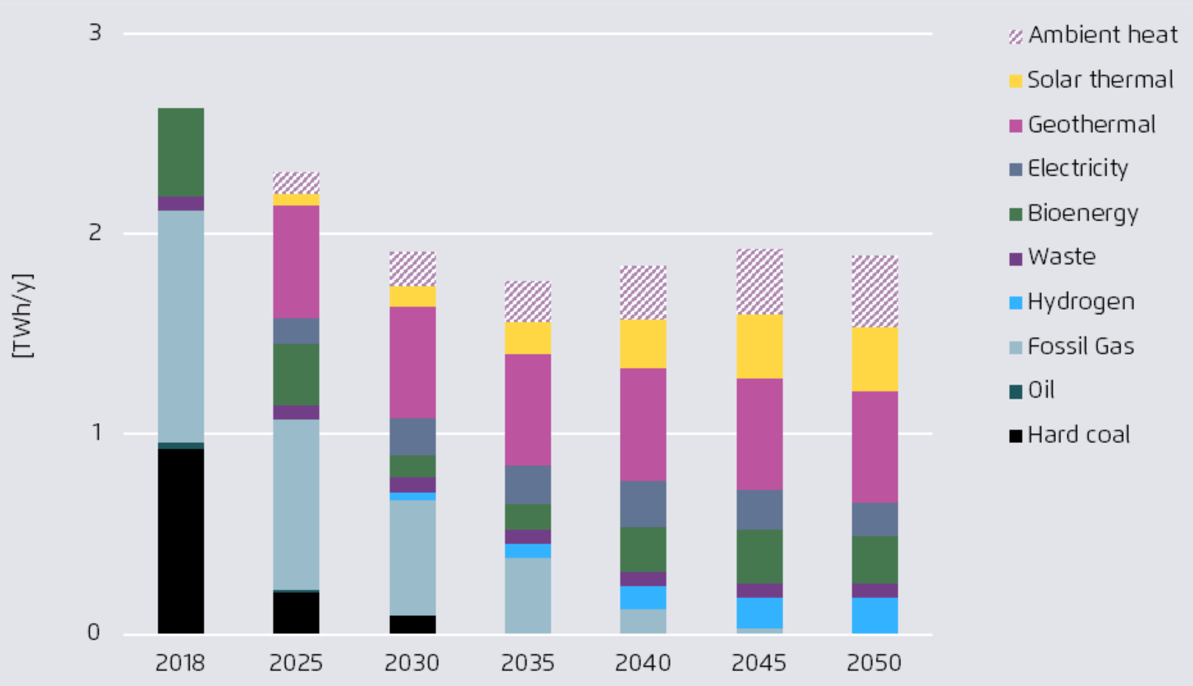


Artelys, TEP Energy, Wuppertal Institute modelling (2023)
Note: Including non-energy consumption of biomass feedstocks in chemicals and refineries, but excluding material uses

- In the Gas Exit Pathway, the use of biomass for bioenergy and non-energy feedstock purposes remains below today's levels as biomass consumption declines in buildings and energy and is prioritised for higher value applications over time.
- Bioenergy is mainly consumed in the buildings and industry sectors, including for district heating generation.
- Consumption halved from about 8 TWh in 2018 to 4 TWh in 2050. It declines by 70% in the buildings sector and for DH generation until 2050 but almost triples in the industry.
- The role of biomass for power generation remains stable until 2050.
- The Gas Exit Pathway shows what a climate optimised bioenergy pathway could look like, given that demand for biomass for materials is set to increase.

District heat supply can become more efficient despite an increase in heated surface by 2050.

Energy input to district heating (including CHPs), Slovenia

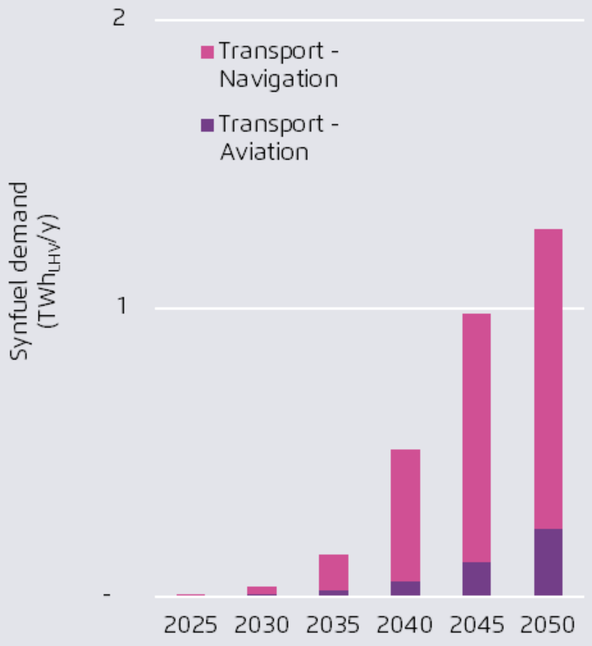


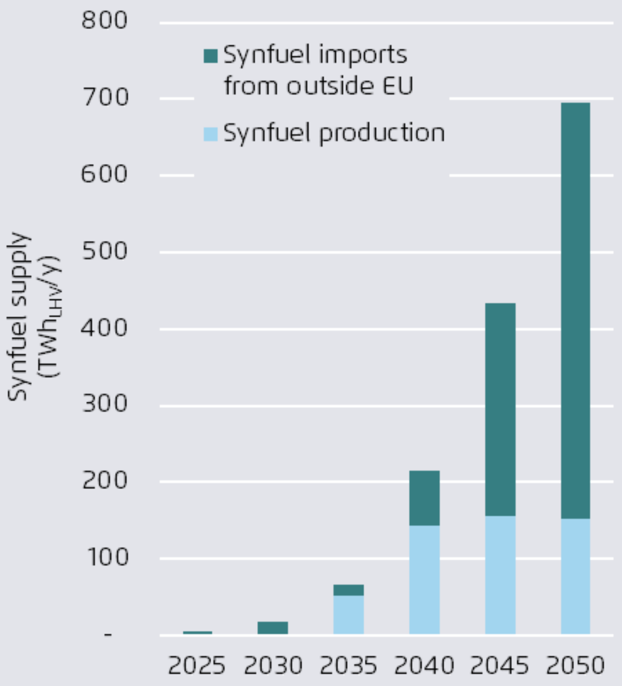
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- In 2018, the district heating supply mix is dominated by fossil gas (44% of the total), hard coal (35%) and biomass (17%).
- District heating sees a quick reduction in fossil-gas demand, declining by 50% from 2018 to 2030 to 600 GWh, and is almost phased out by 2040.
- Fossil gas is gradually replaced by heat-pumps, geothermal and solar thermal. These technologies account for roughly 75% of the energy consumption by 2050 if considering ambient heat.
- Hydrogen starts playing a role in 2030 to replace fossil gas, while biomass declines, from 450 GWh in 2018 to 240 GWh in 2050.

Synthetic fuels in the EU and Slovenian Gas Exit Pathway remain exclusively used in the transport sector, in particular aviation and navigation, after 2035.

Synthetic fuel demand in Slovenia, and supply mix at EU-27 level



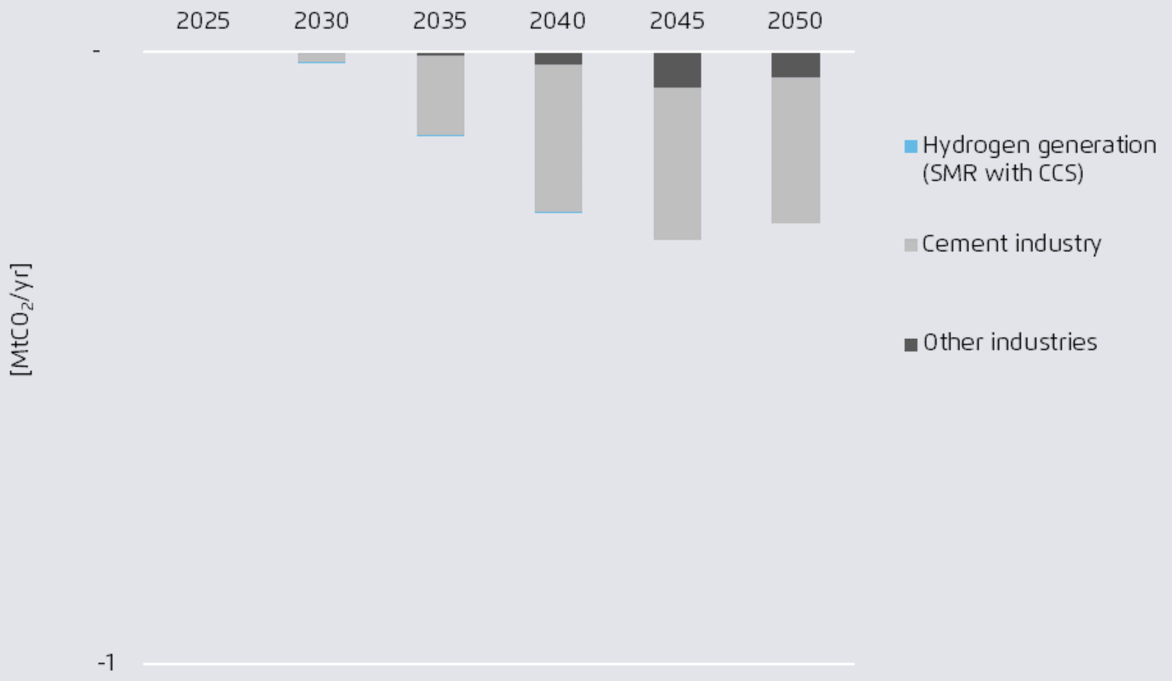


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- The T&E scenario included in this project foresees a very strong electrification of surface transport (both private and goods transport).
- Synthetic fuels are being used in particular in aviation and navigation, and imported starting 2025. Imports represent up to 78% of supply by 2050 for production efficiency/cost reasons.
- Production in Europe starts as refineries are being closed down around 2035 due to strong electrification of the transport sector.

CCS will play an important part in decarbonising the industry sector, though it could be limited to about 0.3 $MtCO_2$ per year by 2050.

CCS balance in Slovenia's Gas Exit Pathway



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

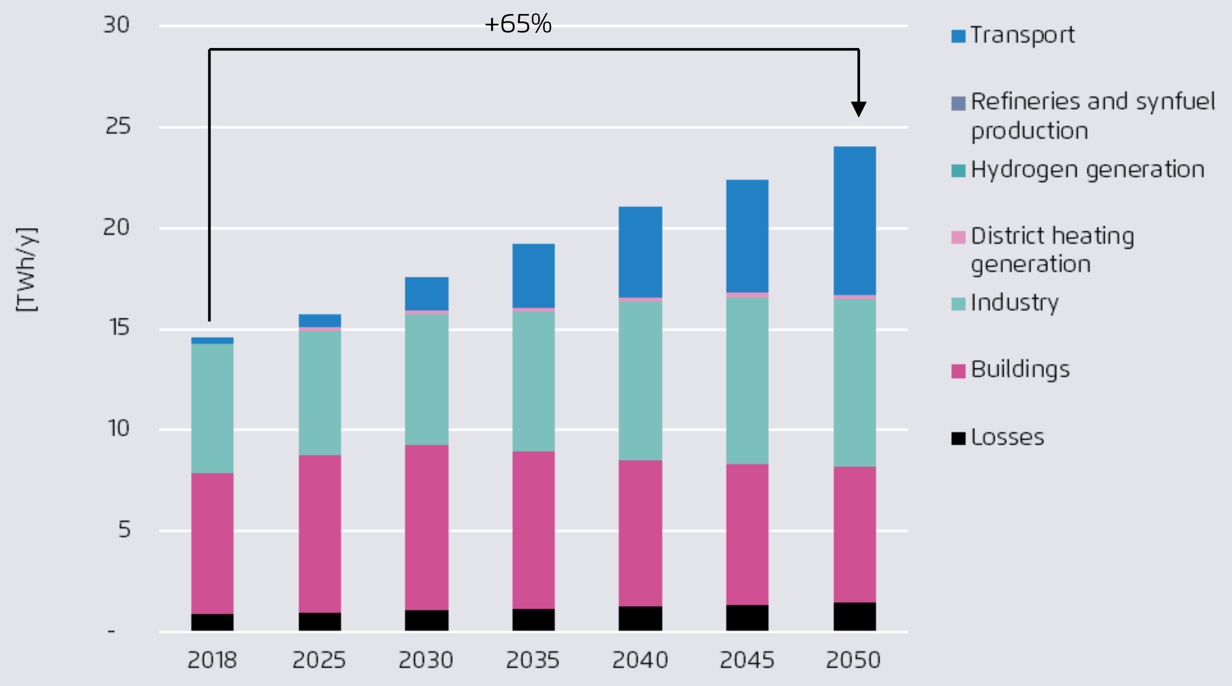
- The use of CCS can be economical for some applications by 2030 already: in the cement industry.
- It really takes off after 2030, the lion's share of the used CCS capacity during the whole transition going into the cement industry (>80%).
- The use of CCS in the power sector has not been considered in this study.

Energy sector:

Results –
Power sector

Electricity demand

Power consumption by sector for Slovenia

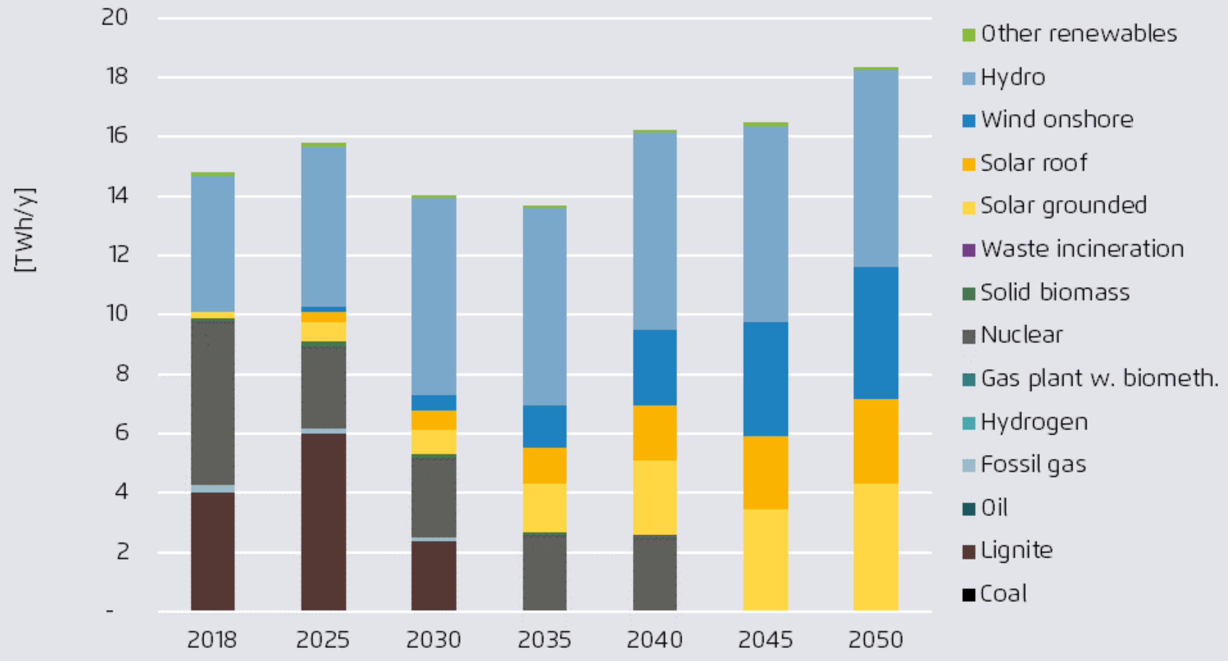


Artelys modelling (2023)

- Total electricity consumption increases by 65% between 2018 and 2050.
- The increase is mainly due to the electrification of transport (+7 TWh).
- 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 buildings and industry sector remain relatively stable between 2018 and 2050.

Power generation

Power generation in Slovenia

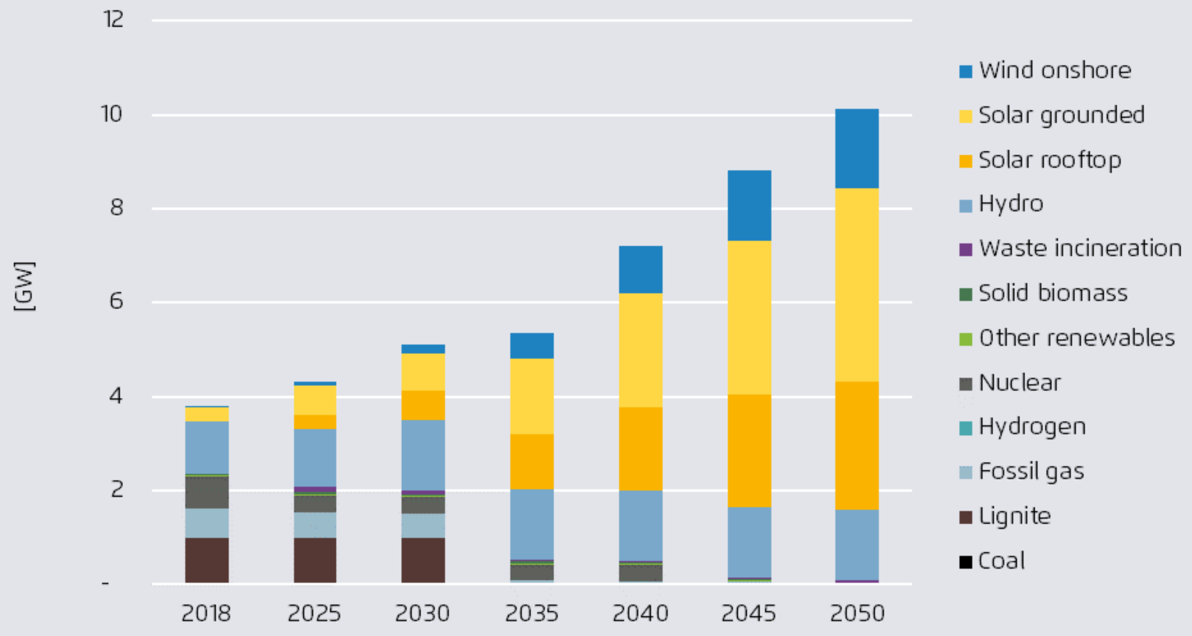


Artelys modelling (2023)

- → Coal and lignite is to be phased out by 2033 as per the governmental plan.
- → 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 is phased out by 2030. Fossil power generation is replaced by renewables.
- → Renewables (solar + wind + hydro + biomass + renewable hydrogen) account for 62% of total power supply by 2030 and 100% by 2045, up from 33% in 2018 (mostly hydro power).
- → Hydro power generation replaces fossil gas as dispatchable power generation technology by 2045 and represents about 36% of total generation by 2050.
- → In the cost optimised Pathway, nuclear power is being phased out after 2040.

Installed capacity

Power generation capacity, Slovenia

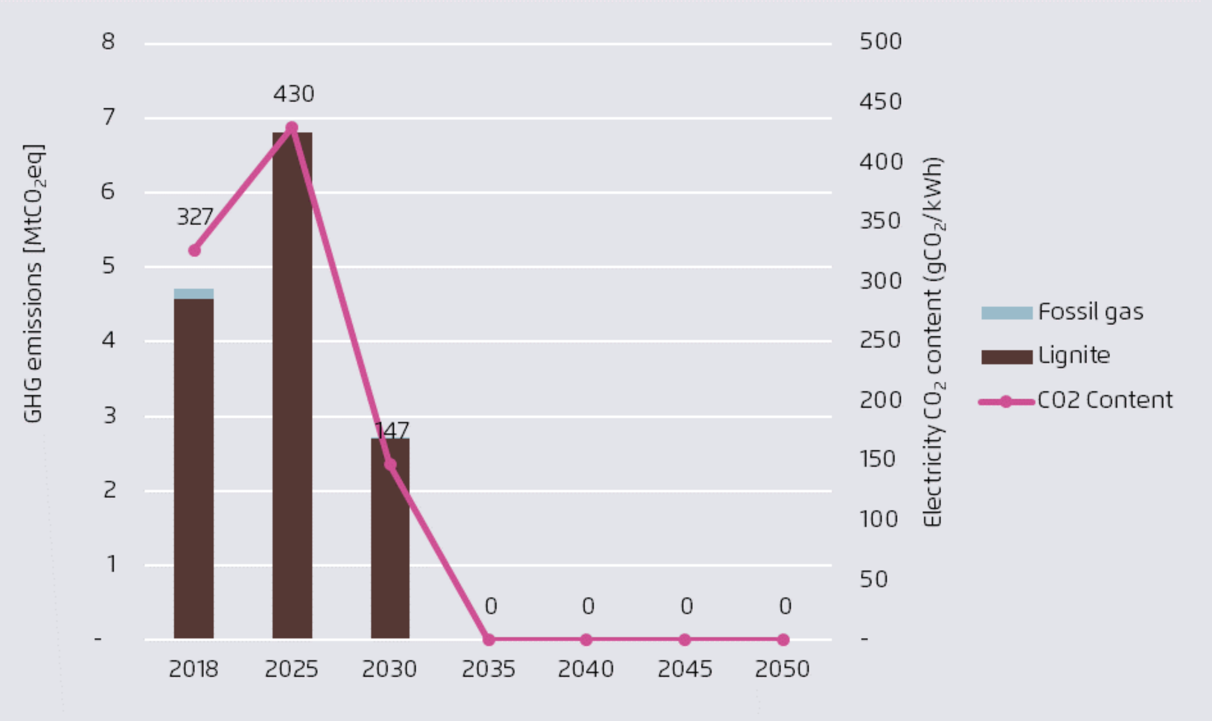


Artelys modelling (2023)

- The power generation mix is dominated by solar and wind power. By 2050, solar accounts for 68% of installed capacity and wind for 17% for a total of 85% of capacity).
- Wind reaches 200 MW by 2030 and 1.7 GW in 2050.
- Solar reaches 1.5 GW by 2030 and 7 GW by 2050.
- Dispatchable capacities are almost all decommissioned by 2050.
- From 2030 onwards, gas powered capacities are gradually phase-out and replaced by waste incineration and solid biomass capacities.

CO_2 content Power sector

Evolution of electricity CO_2 content, Slovenia

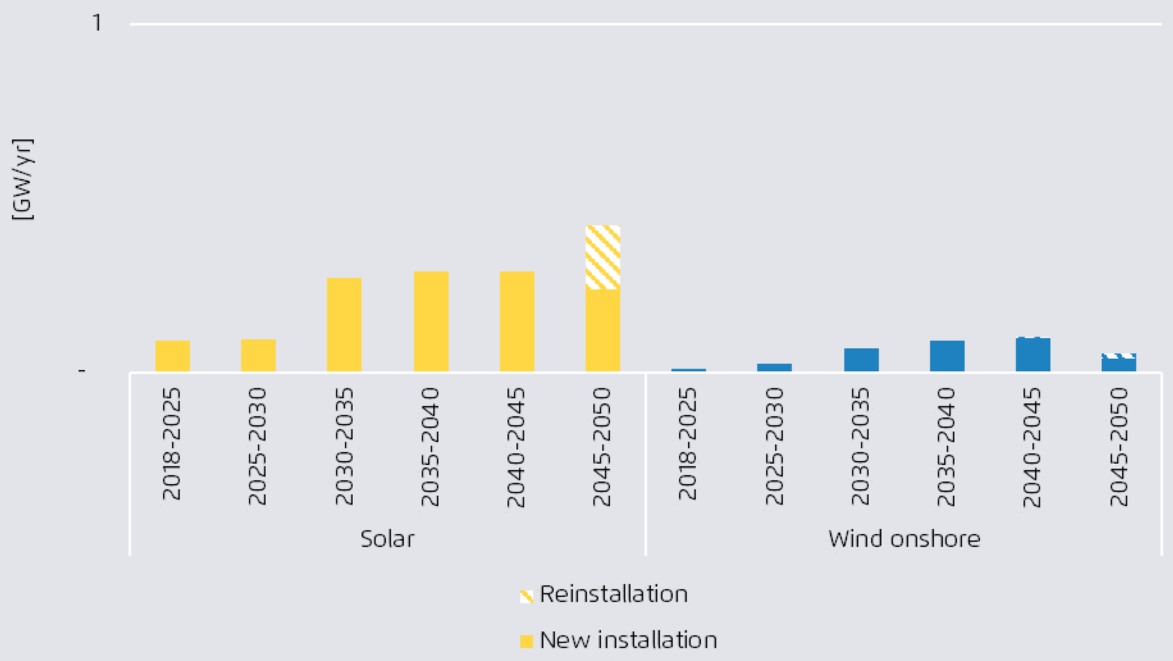


Artelys modelling (2023)

→ The power sector will be emissions free by 2035 after the phase-out of coal and fossil gas.

Capacity installation rate – renewables

Power generation capacity installation rate per year in Slovenia

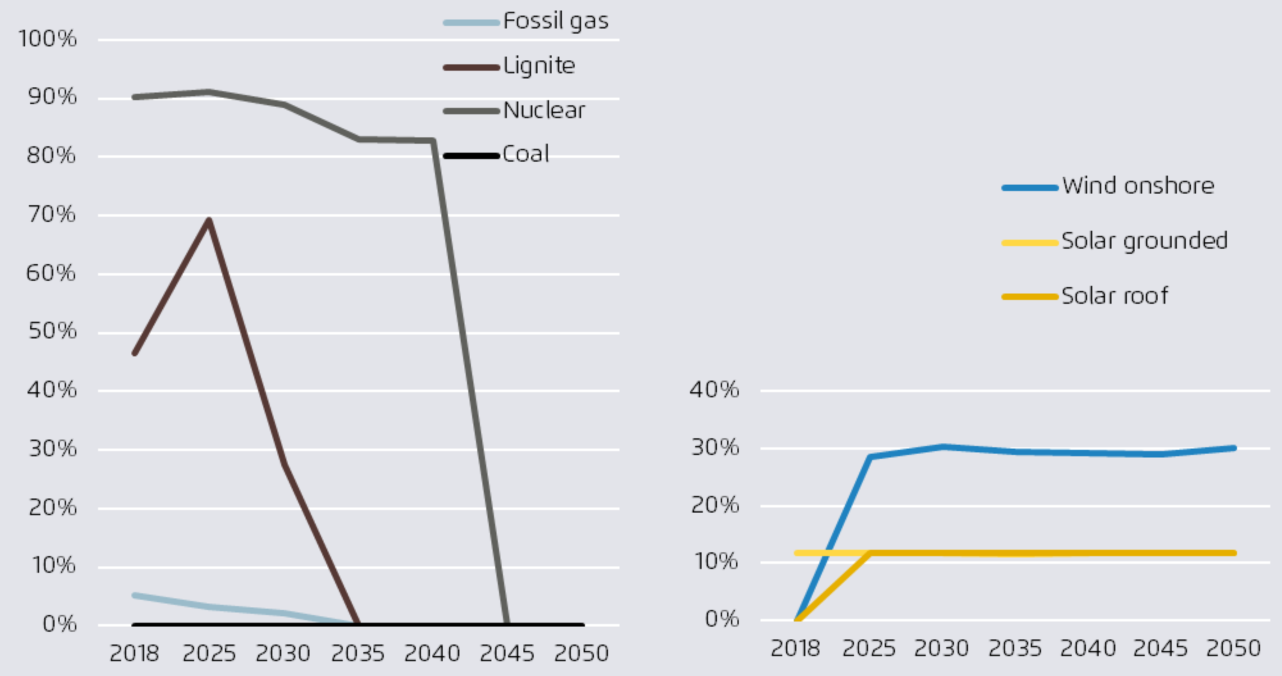


Artelys modelling (2023)

- 240 MW of solar and 60 MW of onshore wind need to be installed on average per year in the period 2018-2050.
- The pace of investment needs to be accelerated until 2030 to not push back the investments and realistically develop the local industry.
- Gross installation rates remain more or less constant from 2030, with some reinstallation necessary after 2040 (decommissioning of capacities at the end of their lifetime, replaced with new capacities).

Capacity factor of different technologies

Capacity factor per technology (%)

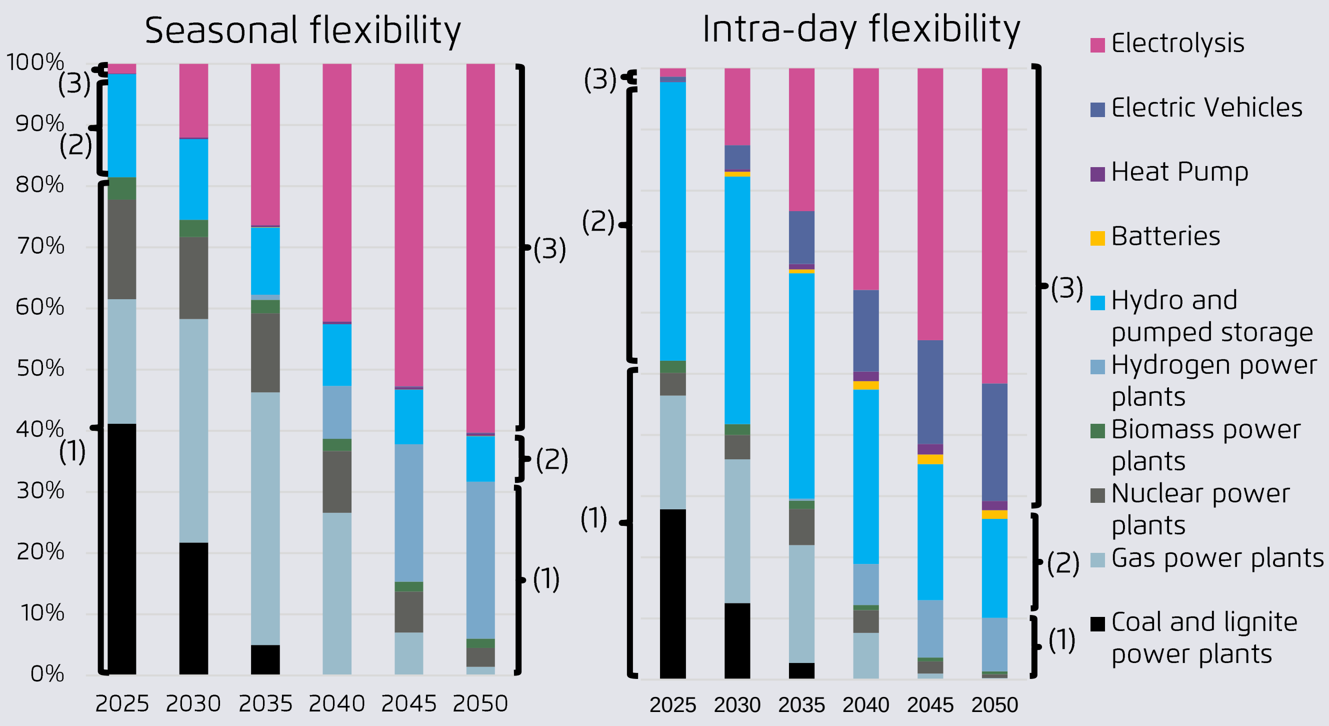


Artelys modelling (2023)

- → The average capacity factor of carbon-intensive dispatchable technologies strongly decreases during the transition and until their phase-out.
- → Gas power generation never had an important role in the power sector in Slovenia. Their role declines quickly given the current context.

Flexibility provision

Evolution of the provision of flexibility in EU-27

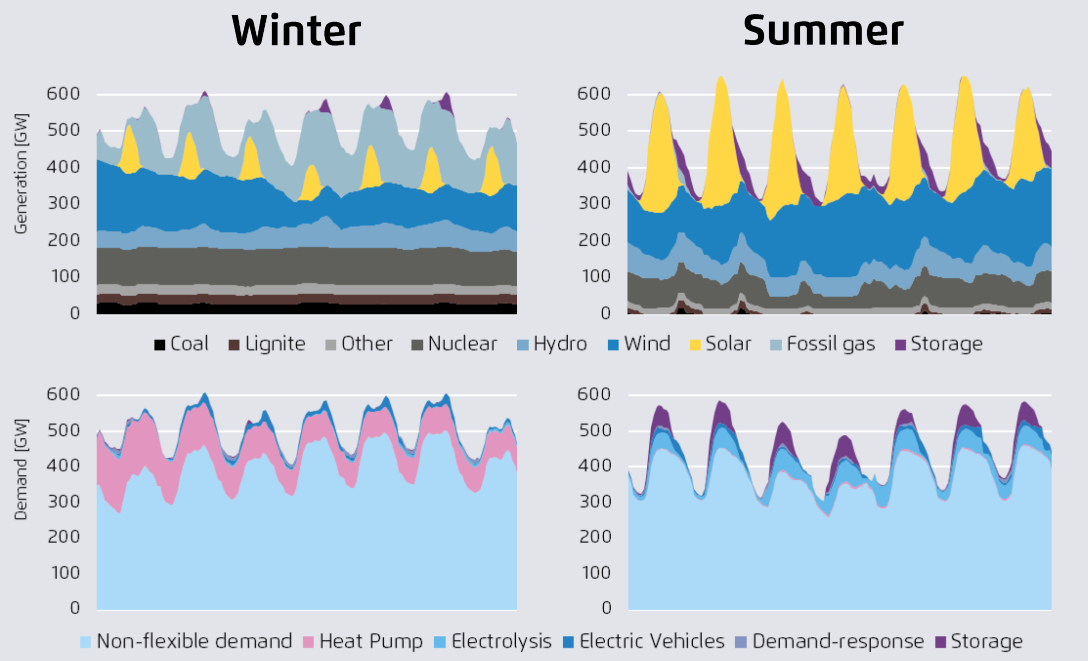


Artelys modelling (2023)

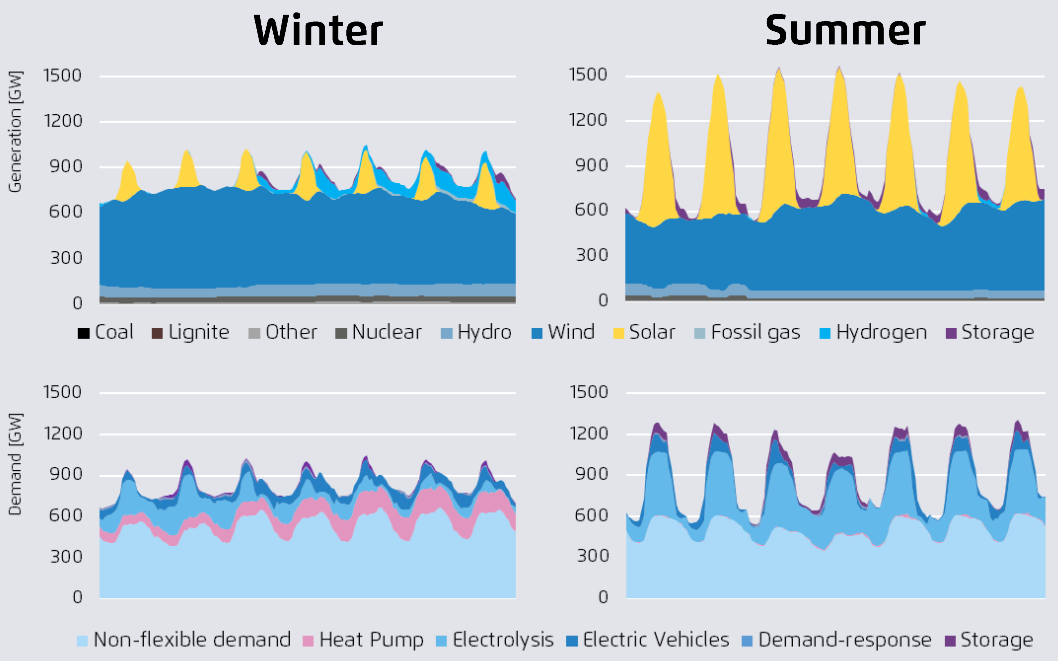
- Currently, system flexibility needs are mainly met by conventional power plants (1) and storage technologies (2) for both seasonal and short-term flexibility.
- In future, demand side flexibility (3) will play a predominant role, especially electric vehicles will provide short-term flexibility with about 20% of the intra-day flexibility needs in Slovenia.
- Hydro power and pumped storage will play a significant role in offering flexibility over the transition in Slovenia after the phase-out of the dispatchable capacities.
- Batteries play an increasing role over time for short-term flexibility, which however will remain very limited considering total flexibility needs (<5%)

Flexibility requirements will significantly increase until 2050

Demand-supply balance during a typical week in 2030 in the EU



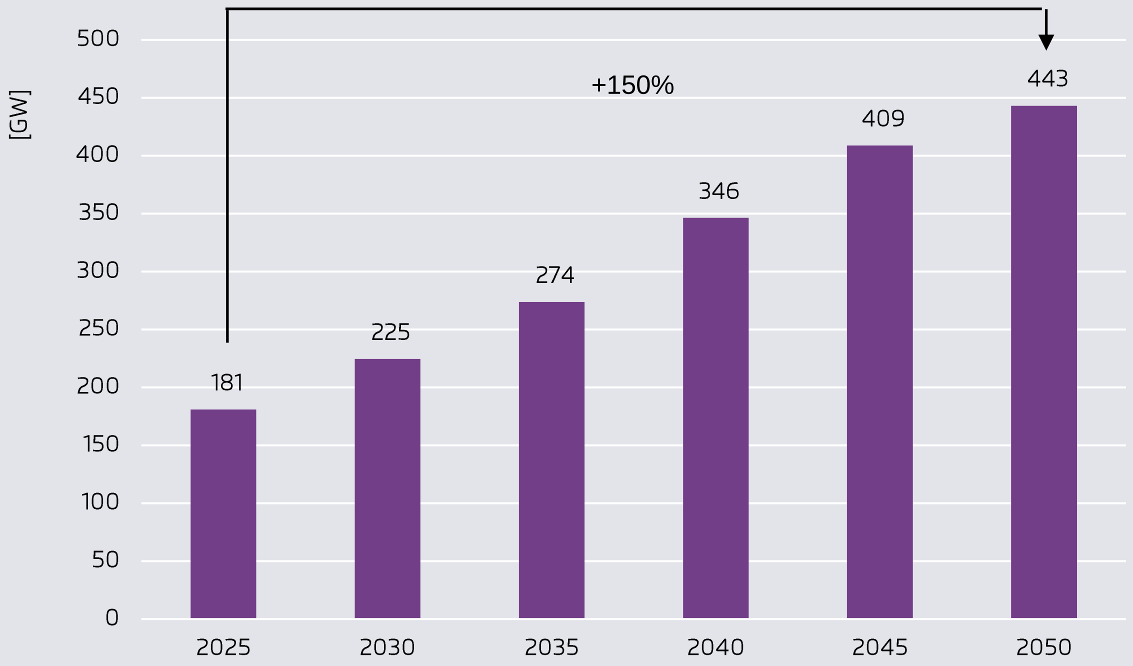
Demand-supply balance during a typical week in 2050 in the EU



Artelys modelling (2023)

Evolution of power transmission infrastructure

Power transmission cross-border capacities in the EU-27



Artelys modelling (2023)

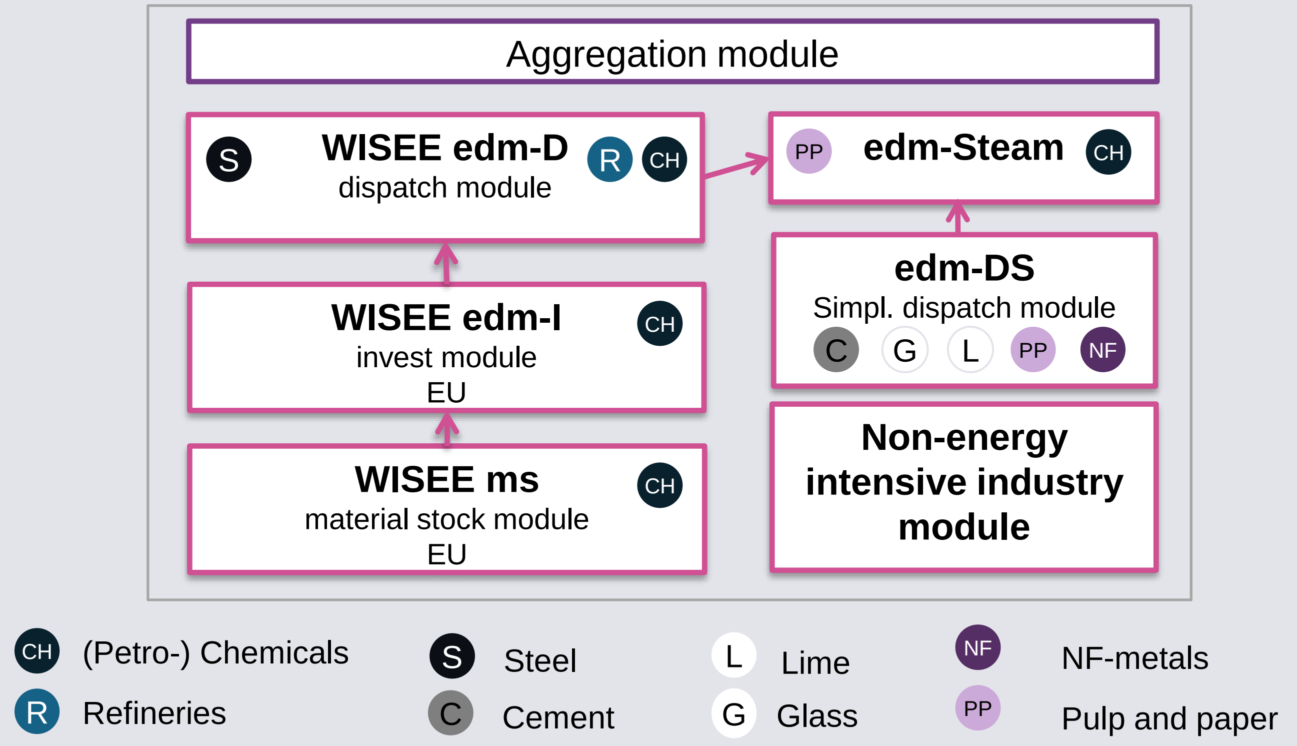
- Electricity interconnections are multiplied by 2.5 between 2025 and 2050.
- Interconnections are found to be very efficient flexibility solutions to foster variable renewable generation. Their development may nevertheless be constrained by social acceptance issues which need to be tackled.

Industry & refineries:

Methodology and assumptions

Industry modelling: country and technology specific

Overview of the WISEE-EDM modelling system



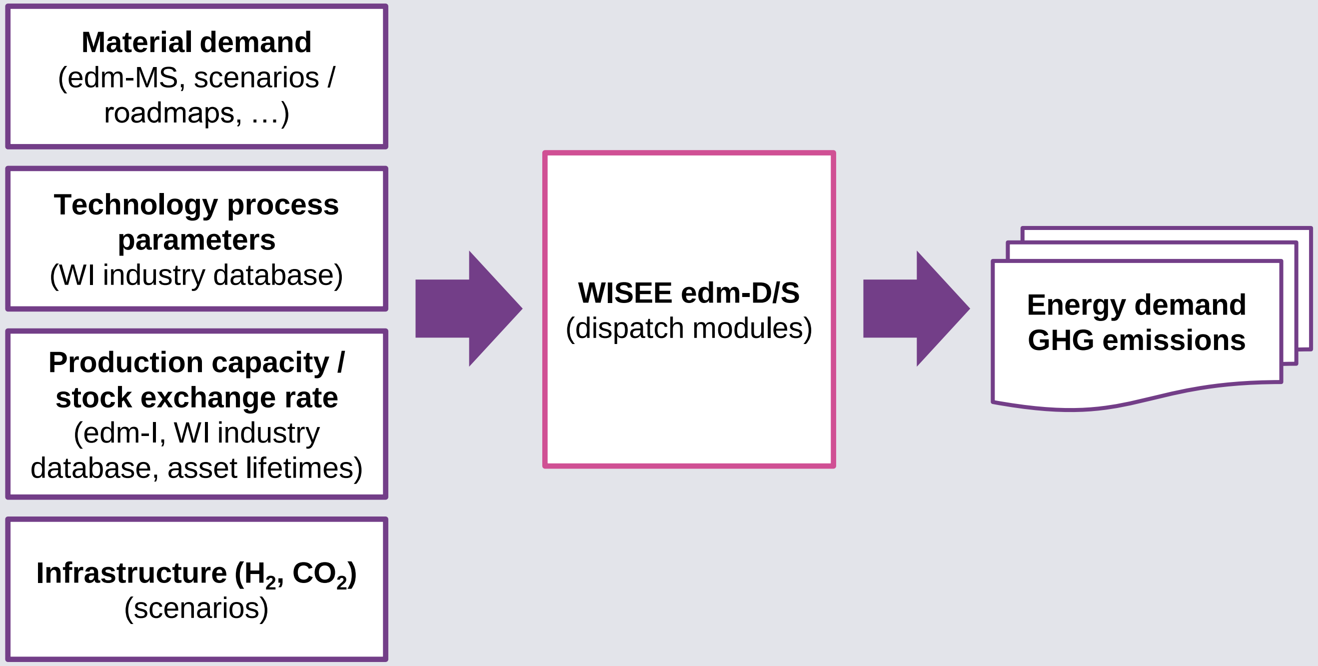
Wuppertal Institute

Graduated modelling approach:

- → Full site-specific European value chains are modelled for the petrochemical sector.
- → Other chemicals, iron & steel as well as refineries are modelled technology- and site-specific
- → Non-metallic minerals, non-ferrous metals and the paper industry are modelled technology specific.
- → Other industry branches are modelled in an econometric manner, with real gross value added (GVA) as a driver and assumptions about temperature level distribution of heat demand.

Industry modelling: A glimpse at the edm-Dispatch model

Main drivers and outputs of the edm-D



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- Energy demand modelled based on physical production and technology parameters
- CO_2 emissions derived from energy carrier use and process emissions (considering CO_2-capture)

Selected model features:

- Bottom-up model WISEE-EDM covers >100 different industrial process types
- Site / network balances for steam, steel gases and hydrogen (industrial symbiosis)
- Feedstock balances for petro-chemicals (use of residual products for steam generation)

Industry modelling: A detailed analysis of assumptions and results was carried out in five of the national deep dive countries together with national partners

Five deep dive countries for industry	Key parameters
→ **Bulgaria:** Center for the Study of Democracy (CSD) → **Hungary:** Regional Centre for Energy Policy Research (REKK) → **Italy:** ECCO Climate → **Poland:** Forum Energii → **Romania:** Energy Policy Group (EPG)	Industrial production: consistent at EU-27 level → GVA of industry and its branches → Evolution of production volumes for energy intensive products (and market shares within the EU) → Assumptions / simulation results for core (re-)invests such as Fischer-Tropsch refineries, iron reduction or steam crackers Industrial sites & infrastructure: → Evolution of the H_2 backbone in the country and connection dates for important sites (chemicals, refineries, steel) → Evolution of the CO_2 grid in the country and connection dates for important sites

Key parameters and assumptions on the industry sector

Industrial production

- Gross Value-Added of industry and its branches
- Evolution of production volumes for energy intensive products and market shares within the EU
- Assumptions / simulation results for core (re-)investments such as Fischer-Tropsch refineries, iron reduction or steam crackers
- Substitution rates for fossil gas boilers
- Market shares in the substitution in the branches and at different levels of temperature of:
  - Heat pumps
  - Electric heaters (electrode boilers)
  - Hydrogen boilers
  - Concentrated solar power (CSP)
- Evolution of industrial CHP per country:
  - MWth and MWel
  - Energy carrier use
  - Electricity shares
  - Full load hours

Industrial sites & infrastructure

- Evolution of the H_2 backbone in the country and connection dates for important sites (chemicals, refineries, steel)
- Evolution of the CO_2 grid in the country and connection dates for important sites

Assumptions on the industry sector

- Only slight relocation of production:
  - The industrial structures and value chains in the EU countries are stable.
  - Some extra-EU ammonia imports (compared to 2021 and earlier) and relocation of ammonia production within the EU
- Fast electrification via heat pumps and electric boilers to displace fossil gas
- Industrial ovens are replaced by electric devices after 2030
- Use of fossil gas as a bridge in the transformation of integrated steel mills only in locations without supply bottlenecks.
- No distribution grid for hydrogen, only chemical parks and steel sites are supplied via backbone
- The role of hydrogen as an energy carrier is limited to the use in hybrid steam supply systems (chemical parks)
- Biogas and biomethane are considered interchangeable with fossil gas.

Assumptions: Technology costs

Overnight Investment costs*)

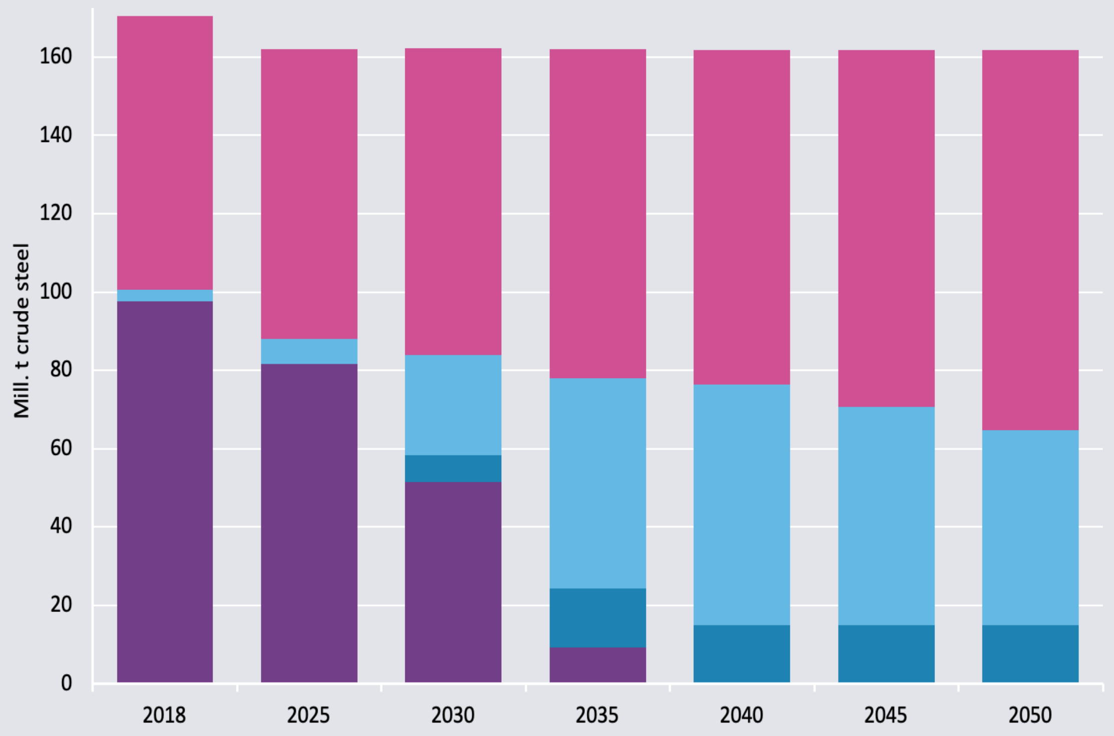
Technology	new/retrofit	overnight invest [€/kW] (useful]	Source
LT Natural Gas boiler (condensing)	new built	179	PRIMES
LT heat pump	new built	637	PRIMES
HT heat pump	new built	549	IFSME**) Study
Natural Gas heater	new built	256	IFSME Study
Hydrogen heater	converted NG	66	IFSME Study
Hydrogen heater	new built	308	IFSME Study
Plasma heater	new built	1017	IFSME Study
Natural Gas boiler	new built	220	IFSME Study
Hydrogen boiler	converted NG	66	IFSME Study
Hydrogen boiler	new built	264	IFSME Study
Electrode boiler	new built	146	IFSME Study

*) Technical lifetimes are assumed to be 25 years
**) Industrial Fuel Switching Market Engagement Study

Compilation Wuppertal Institut (2023)

EU steel industry
Characterization of the general development

Crude steel production per process in the EU-27



Wuppertal Institute (2023)

- → Blast furnaces are quickly phased-out avoiding additional relinings.
- → Electric arc furnaces become the standard steel production units throughout Europe, basic oxygen furnaces remain a little share to ensure the availability of all steel qualities.
- → Scrap becomes the main iron input in steel making and reaches 67% in 2050 (compared to ca. 50% today).
- → The second iron input is DRI, which is mainly produced in Europe.
- → The EU is a frontrunner in DRI production, but imports are accepted, starting with 8% in 2030 and reaching a peak in 2040 at 27% (8% in 2050).

Chemicals in the EU
Characterization of the general development

- In the mid-term (until 2030) ammonia production in the EU-27 is concentrated at sites with good fossil gas access and partly substituted by imports.
- Fossil refineries are closed throughout the EU, starting in the 2020s (not converted to feedstock refineries).
- Petrochemical sites come thus under pressure to search for new sources. In the mid-term shale gas and Extra-EU naphtha imports increase, but chemical recycling as well.
- Until 2040 new Fischer-Tropsch refineries are opened-up at selected sites in Europe (ES, NL, RO, SE, UK).
- CCU-methanol is produced in Spain and the UK.
- In 2040 green methanol can be imported from the world market, afterwards also synthetic feedstock (naphtha) comes available.

Non-metallic minerals in the EU
Characterization of the general development

- → The challenge in these branches is the transformation of high-temperature heat supply.
- → Electrification is a challenge as the respective ovens are in most cases not market ready at scale and efficiency gains are often relatively low, compared to lower temperatures.
- → Electrification does not adress process-related emissions.
- → Focus in therefore on:
  - Efficiency gains and waste firing (in the short term)
  - Biomass firing, (partial) electrification and CCS in the mid- and long-term

EU refineries
Characterization of the general development

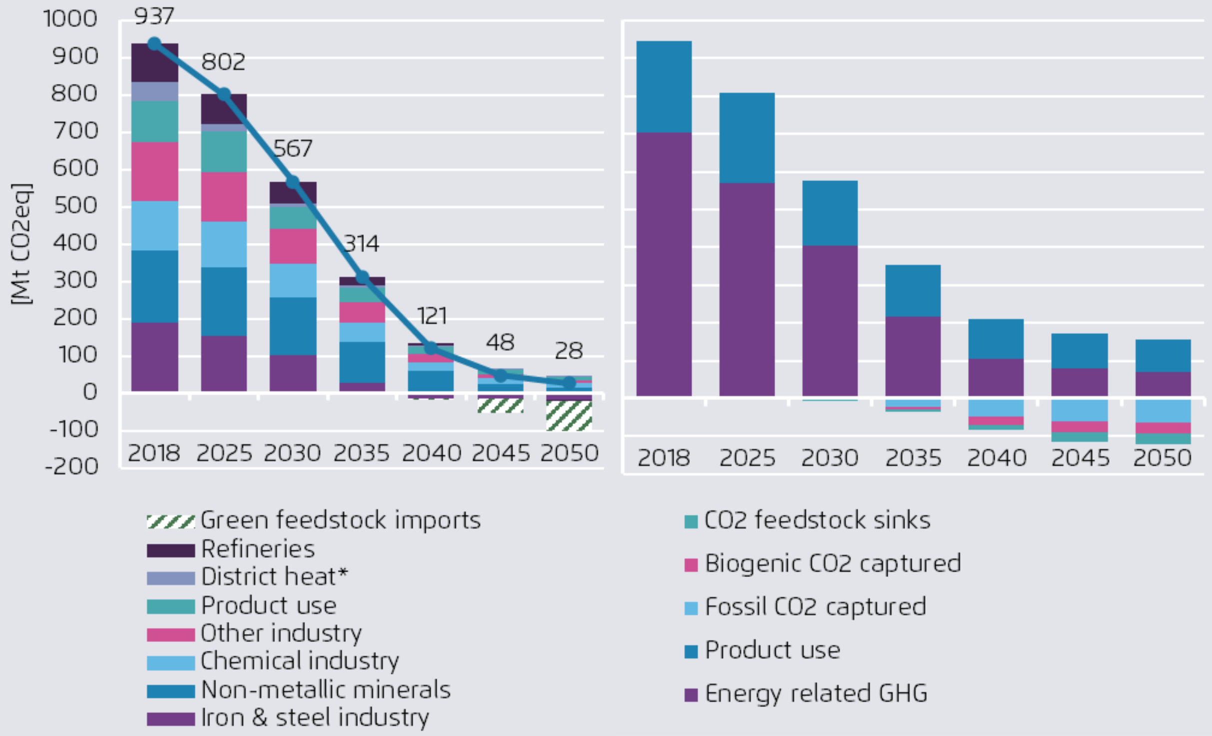
- Due to electrification of the transport sector, fuel demand will decline quickly throughout the EU.
- Processing of crude oil is completely phased-out in Europe until 2050.
- Refineries are assumed to be closed according to their age (typical lifetime of 60 years)
  → need for refinement to account for regional supply security within the EU

Industry & refineries:

EU-27 *Results*

Greenhouse gas emissions

GHG emissions from industry & refineries in the EU-27



Wuppertal Institute (2023)
* District heat = external heat supply in sectors other than chemicals and refineries

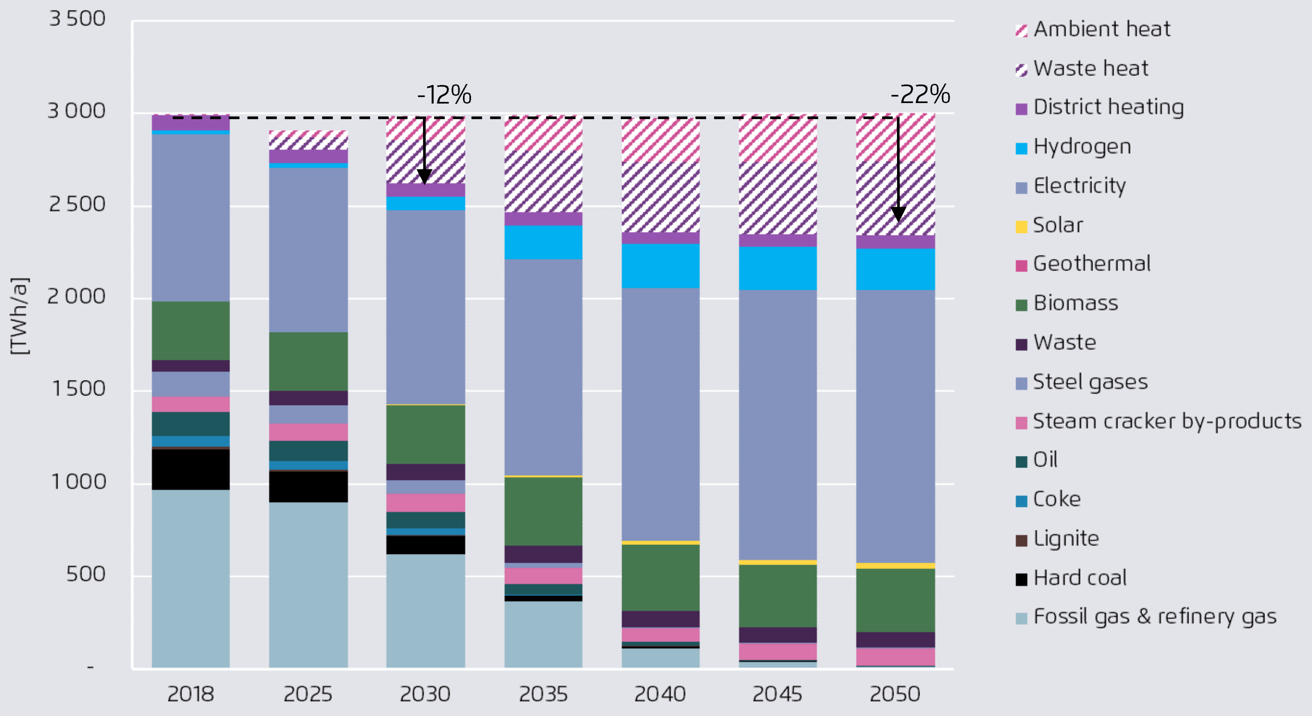
- The trajectory for GHG emissions of the industry and the crude oil refining sectors shows a steep decline between today and 2040.
- In 2040, the defossilisation of energy supply is almost accomplished. The main remaining emissions are process-related and are increasingly captured.
- After 2040, negative emission contributions are added via green feedstock and BECCS.

Until 2030, …

- ...the bulk of emission reductions are achieved in the iron & steel industry (89 Mt CO_{2eq} or 47%).
- … the non-GHG intensive industries achieve a reduction by 61%, mainly by phasing out fossil gas.
- … the chemical industry and refineries reduce their GHG emissions by 45 and 46 million tons (33% / 45%).

Final energy demand declines mostly due to electrification and the use of waste heat

Final energy demand in industry in the EU-27

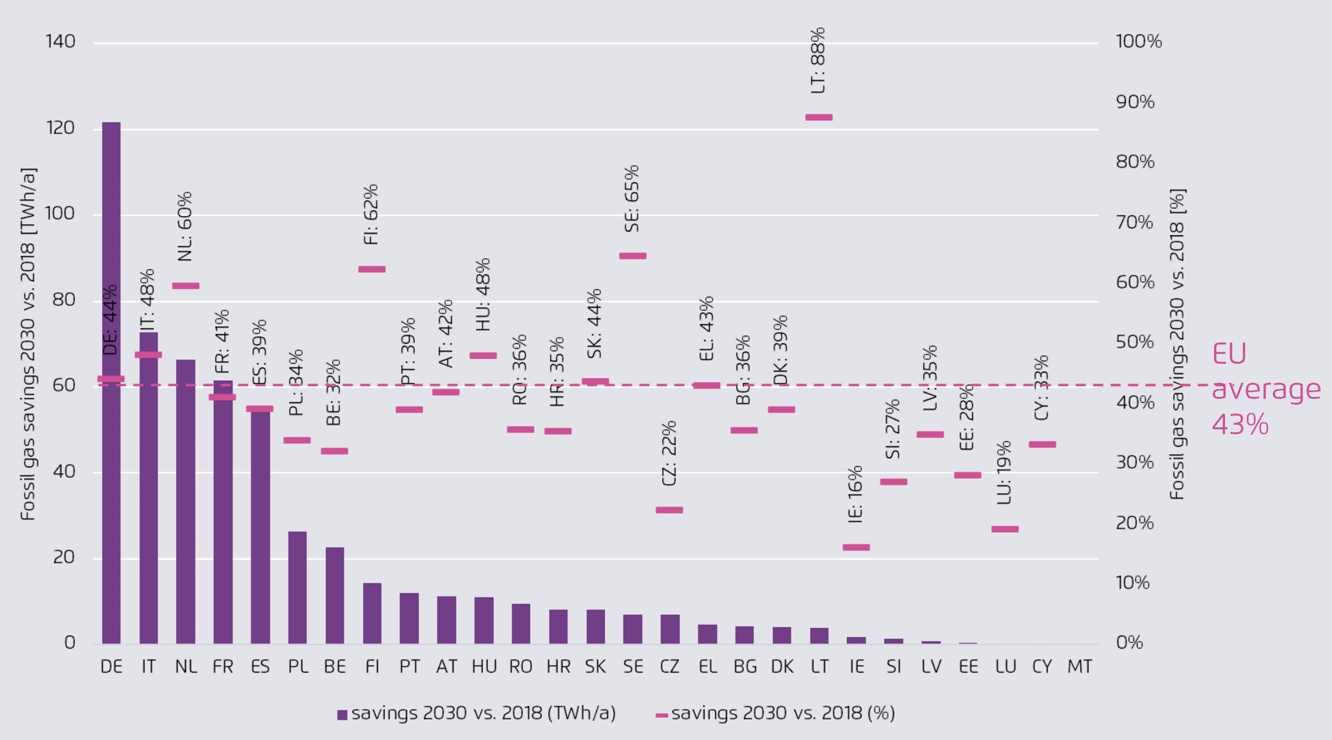


Wuppertal Institute (2023)

- Final energy demand in the sector declines by 12% by 2030 and by 22% 2050 (not including ambient and waste heat).
- Fossil fuels decline from 53% in 2018 to 38% in 2030 (direct use in industry). It further declines to 9% in 2040 with a limited remainder of oil consumption by 2050 (1%, 6 TWh), which represents the energetic use of by-products in the chemical industry. Fossil gas can be almost phased out by 2045.
- Electrification as primary fuel switch strategy: from 30% of total in 2018, 40% by 2030 and about 60% by 2040 and beyond.
- Energetic biomass and waste are restricted to high temperature generation and are mainly used in plants with carbon capture.
- Solar thermal energy plays an important role in big chemical parks in the Mediterranean and Black Sea region where it is part of hybrid steam supply systems.

The industry and refinery sectors can save on average 43% of fossil gas by 2030

Savings in fossil gas use in industry and oil refining in the EU-27, 2030 vs. 2018

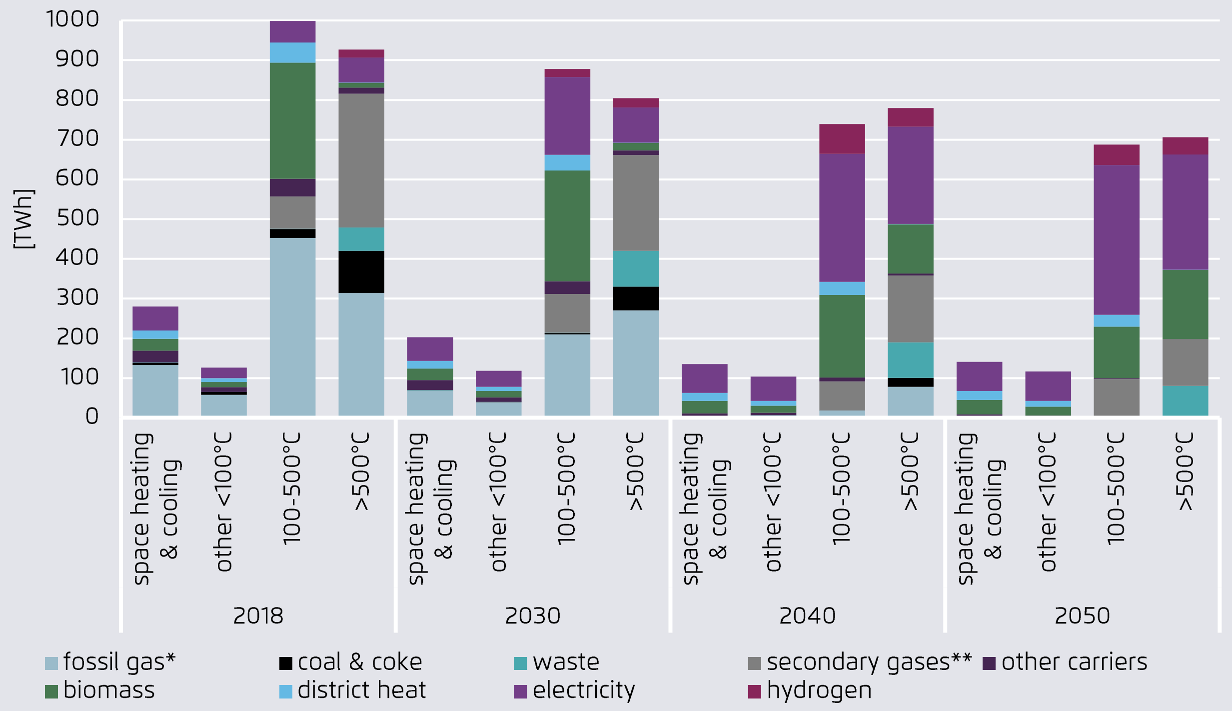


Wuppertal Institute (2023)

- Savings stretch from 16 to 88% according to the Member State.
- The largest savings are achieved in Germany, Italy, the Netherlands, France and Spain, together representing 70% of the industrial savings in volume.

Fossil gas can be displaced by direct electrification at all temperature levels, complemented by biomass, hydrogen, waste and district heat

Final energy use for heat in the industry sector per temperature level, EU-27

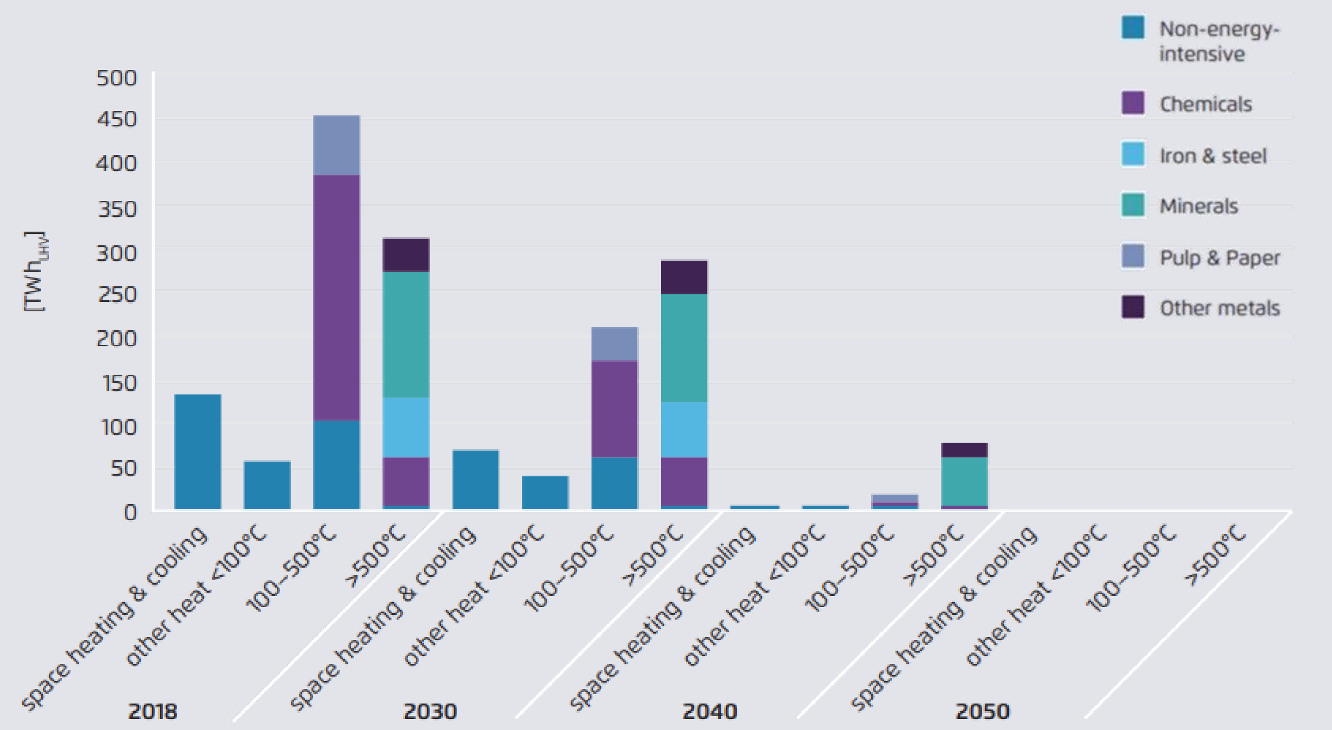


Wuppertal Institute (2023) * "fossil gas" includes fossil gas, refinery gas and LPG; **"secondary gases" include coke oven gas, blast furnace gas, basic oxygen furnace gas and steam cracker by-products

- → Rapid gas demand reduction until 2030 in the low- to mid-temperature segments including steam production. Further decline in all segments after 2030, the remainder in 2040 being mostly in high temperature processes.
- → Electrification plays a significant role in all temperature levels.
- → Biomass gain in importance starting in 2030, especially in higher temperature segments.
- → Hydrogen is used in a limited manner starting in 2040 in high temperature segments. Hydrogen remains mostly used as a feedstock at any time.
- → The use of secondary gases as by-product of industrial processes declines with the transition of those production processes to cleaner alternatives.

The use of fossil gas differs according to the subsector, requiring a mix of technologies to displace

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

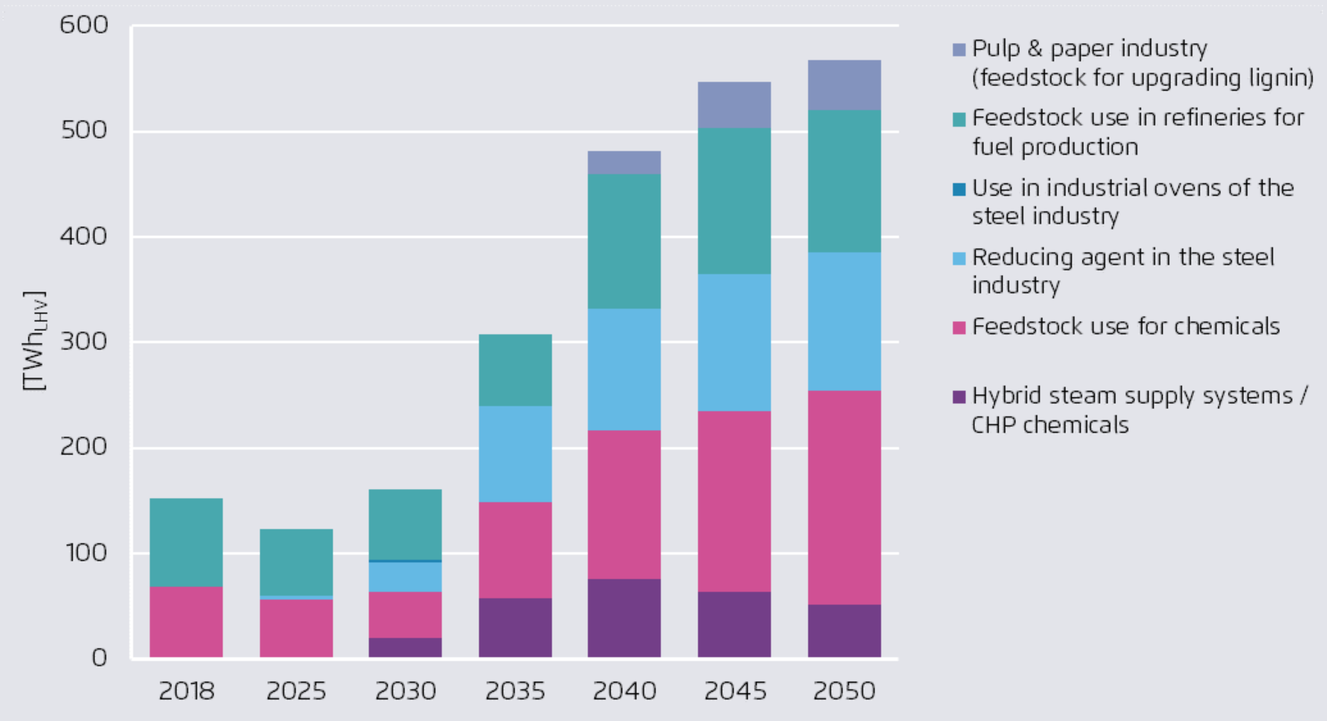


Wuppertal Institute (2023).
* Fossil gas includes fossil gas, refinery gas and LPG.

- → The non-energy-intensive sectors consume fossil gas to produce heat up to 500°C. The largest share goes into low-temperature heat up to 100°C, which can be easily electrified with heat pumps already today.
- → The chemical industry consumes most of its fossil gas to produce mid-temperature heat, as well as the pulp and paper industry.
- → High-temperature heat, last to phase out fossil gas, is spread between Minerals, Iron & steel, other metals and the chemical industries. Nearly half of the residual fossil gas consumption in 2040 is found in the non-metallic minerals sub-sectors such as glass, lime and cement.

Hydrogen demand will increase after 2030 to cover for new applications replacing fossil fuels

Net* hydrogen demand per sector and appliance in industry & refineries, EU-27

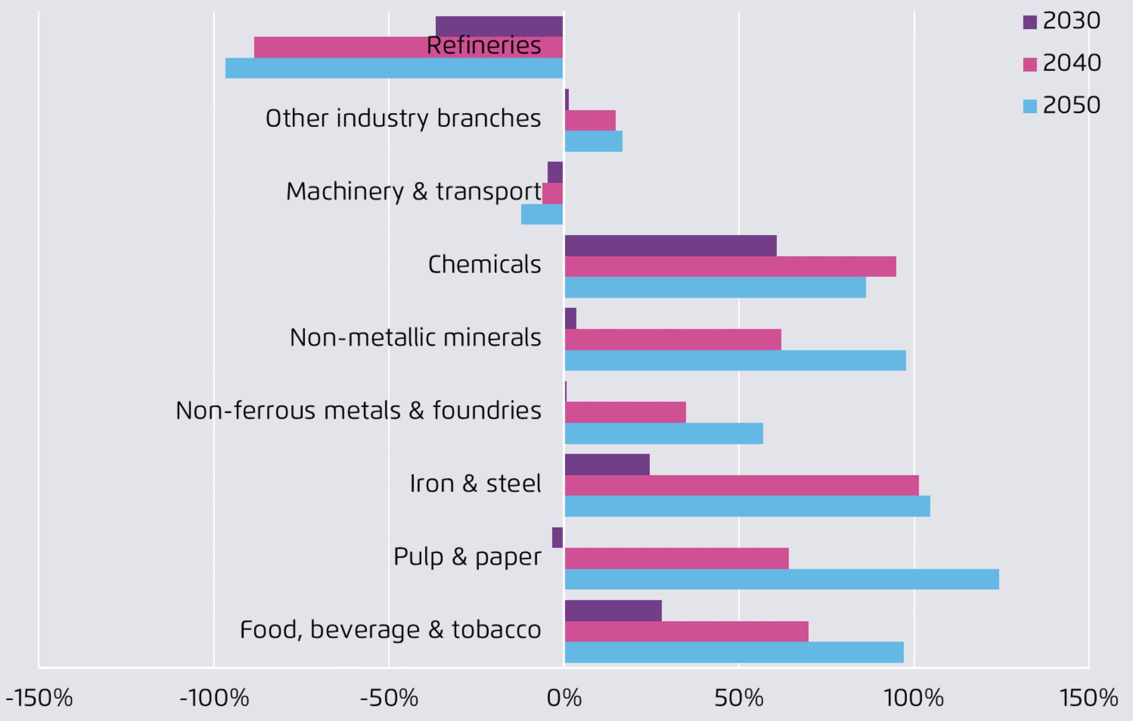


Wuppertal Institute (2023) * Gross hydrogen demand and gross by-production (e.g. by chlorine production) are balanced out, leaving only net demand to be covered by sources such as SMR or water electrolysis.

- → Despite some new applications in 2030, total H2 demand will remain stable as part of the ammonia demand will be imported, substituting the EU domestic production as already started in 2022.
- → Demand only increases after 2030 if direct electrification is prioritised as a more mature and efficient technology to displace fossil fuels.
- → Production in refineries will shift from the current oil-based products to Fischer-Tropsch fuels in the 2030s, H2 also shifting from fossil to renewable. Some refineries will start closing in the 2020s, reflecting a declining demand in conventional transport fuels.
- → Iron and steel production will partly shift to H2-based direct reduction starting after 2025.
- → Hybrid steam supply systems are introduced quickly in chemical parks with electric boilers using existing fired boilers as a back-up. The back-up carrier fossil gas is replaced over time by hydrogen and the utilisation rates of the electric boilers increase over time.

Power demand will almost double by 2050 in most of the sub-sectors of the industry

Gross power demand evolution compared to 2018 in EU-27 industry branches

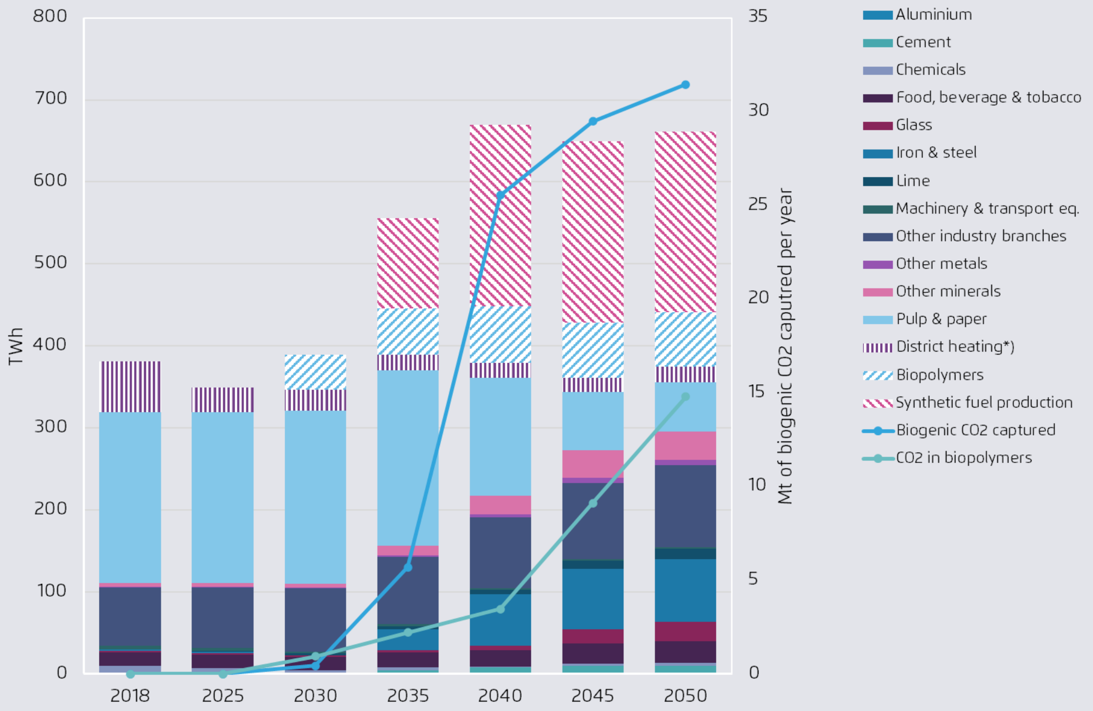


Wuppertal Institute (2023)

- → Electricity use increases in the energy-intensive branches by ca. 100% until 2050.
- → The non-ferrous metals & foundries branch is an exemption, but its electricity share is already high today.
- → The chemical industry is a frontrunner in electrification.
- → The actual increase in connected loads is even higher when companies switch from generating their own electricity to buying electricity from external sources (steel, chemicals, paper, food).

Biomass use in industry & refineries will increase through the transition as an efficient alternative to fossil fuels to decarbonise

Biomass use for final energy, district heating and synthetic hydrocarbons, EU-27

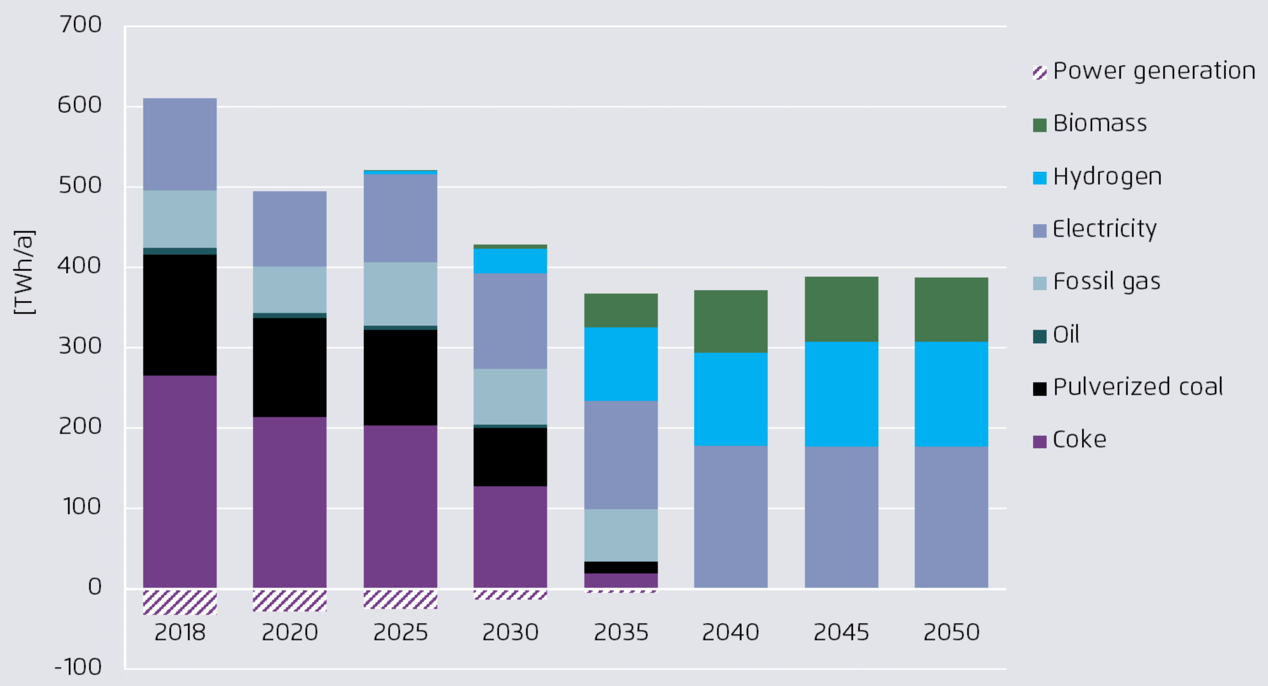


Wuppertal Institute (2023)

- Biomass demand will shift from pulp & paper production to the glass, iron & steel, minerals and other industry branches, mostly combined with CCS to achieve negative emissions.
- Starting 2030, the production of biopolymers replacing carbon-based polymers will create new demand, as well as the production of synthetic fuels, replacing the conventional transport fuels being phased out. This will require up to a third of total demand for biomass in the industry.
- This will allow to capture more than 30 Mt of biogenic CO_2 per year by 2050, compared with about 100 Mt through CCS in the industry.

Sub-sector transformation: Iron & steel

Primary energy use of the steel industry in the EU-27

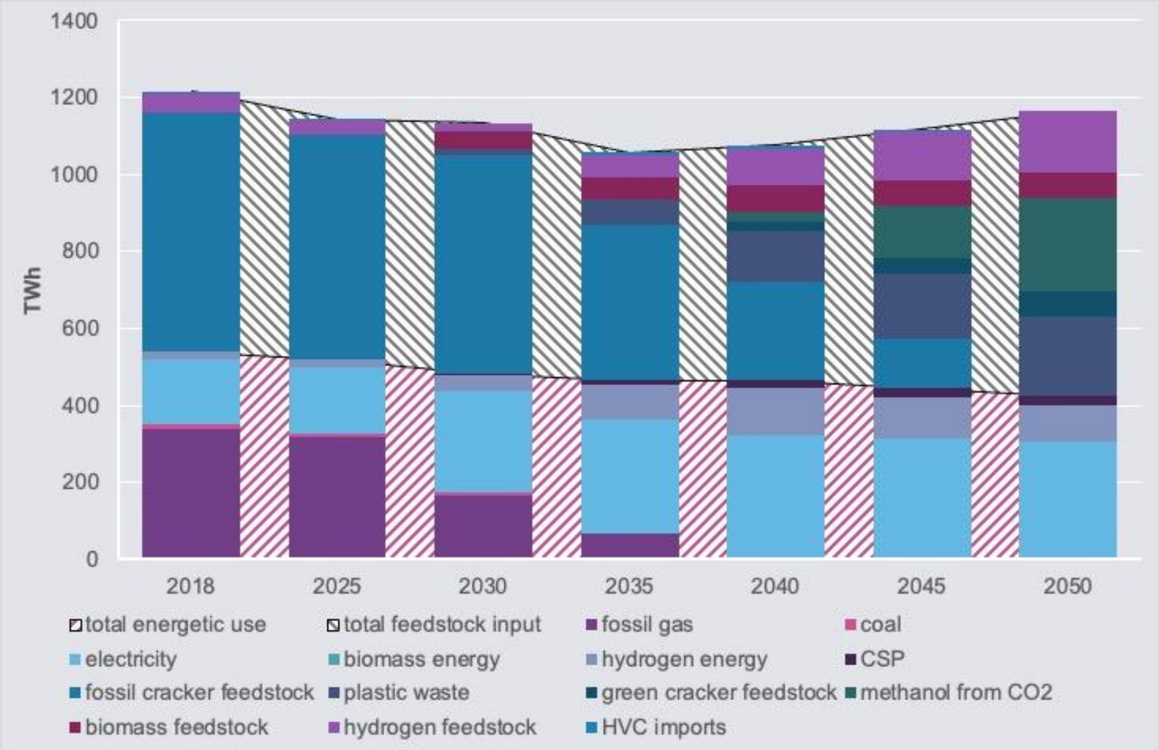


Wuppertal Institute (2023)

- Thanks to a (limited) shift to secondary steel and a process shift to direct reduction in primary steel production the primary energy demand declines by 28% by 2030 and ca. 35% by 2035.
- Only limited decline in gas demand until 2030, but the sector can be fossil-gas free by 2040.
- Coal and coke use may almost be phased-out until 2035.
- New reinvestment pathway for the European steel industry avoiding stranded “green” assets but resulting in a very concentrated additional H2 demand in Sweden and Spain.
- Biomass use in the steel industry only partly related to carbon requirements (carburation in the EAF and BOF process) but also due to the opportunity of achieving net negative emissions via BECCS (use of biomass in furnaces).

Sub-sector transformation: Chemicals

Final energy use and feedstock input in the chemical industry in the EU-27

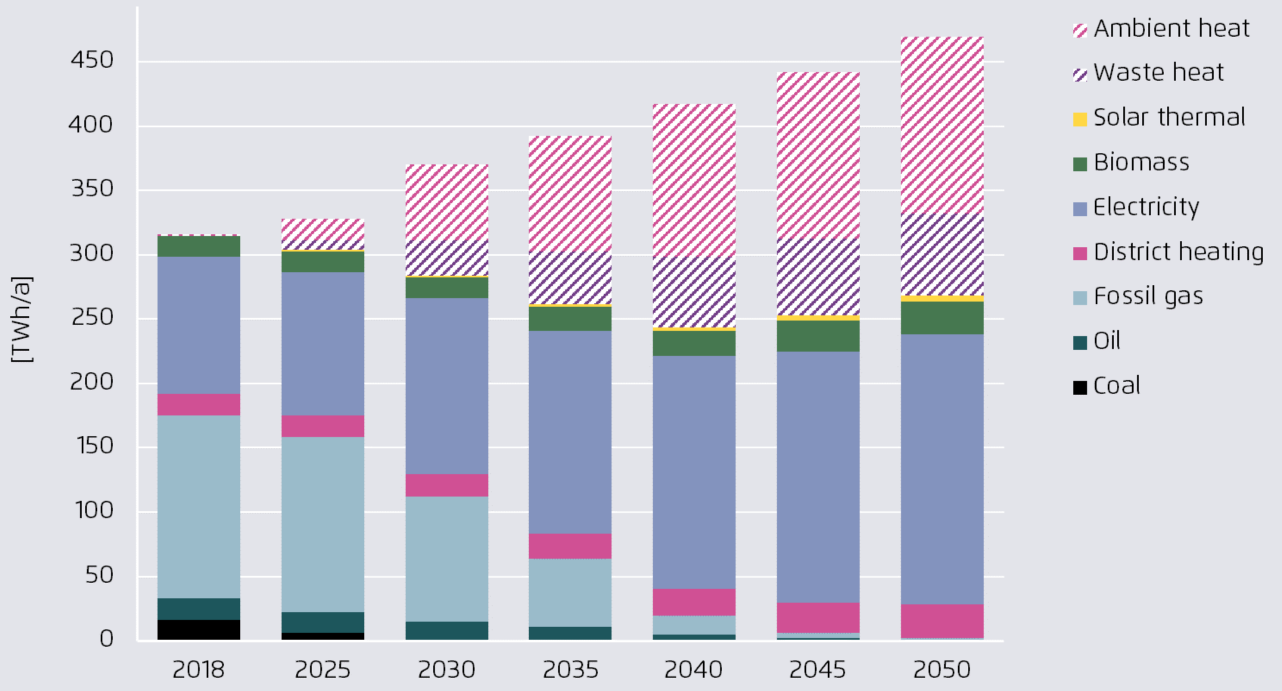


Wuppertal Institute (2023)

- Thanks to efficiency increases and electrification, final energy demand declines by 7% by 2030 and 16% by 2050 (excluding ambient and waste heat).
- The sub-sector is fossil-gas free in terms of energy use by 2040: it is being replaced mostly by electricity (about 80% of energy demand in the long run) and renewable hydrogen.
- Fossil steam cracker feedstock currently representing more than 90% of feedstock use next to fossil-based hydrogen is being replaced starting 2030, starting with biomass and renewable hydrogen. On the way towards a circular economy the complete feedstock supply is defossilized by 2050.
- The renewable feedstock (e.g. methanol from atmospheric CO_2 and hydrogen from water electrolysis) serves as a carbon sink delivering net negative emissions. Green refineries in Europe and CCU in Southern Europe (e.g. from cement plants) help to diversify the feedstock supply.
- Massive investments in waste treatment plants and in methanol-based production routes are required.

Sub-sector transformation: Food, Beverages & Tobacco

Final energy demand in the manufacturing of food, beverages & tobacco, EU-27

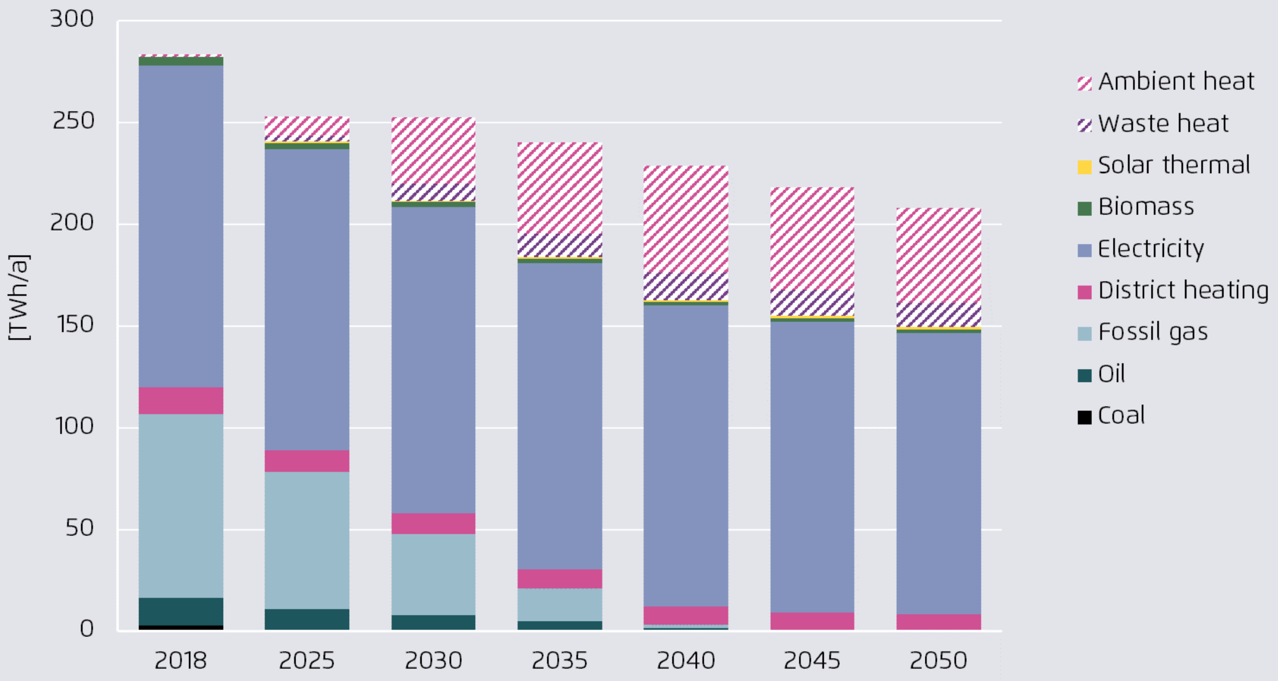


Wuppertal Institute (2023)

- → The strong efficiency increases in the sector are partly compensated by a strong economic growth, resulting in limited final energy demand decline: only 10% until 2030 and 15% by 2050 (excluding ambient and waste heat).
- → The sub-sector can be close to fossil-gas free by 2040, phasing out oil and coal as well at the same time.
- → Today, fossil gas is used mostly in low- and mid-temperature ranges (in heating and cooling, as well as the drying processes), especially in CHPs and steam production. Current technologies can be substituted by heat pumps making use of ambient heat and waste heat, the sub-sector having a large production of low temperature waste heat.
- → Consequently, power demand scales up from about 35% to represent up to 80% of final energy demand (excluding ambient and waste heat) by 2050.
- → Biomass and district heat use will increase slightly, though will remain a complementary technology in this sub-sector motivated by the local availability of these options.

Sub-sector transformation: Machinery & Transport equipment

Final energy demand in the manufacturing of machinery & transport equipment, EU-27

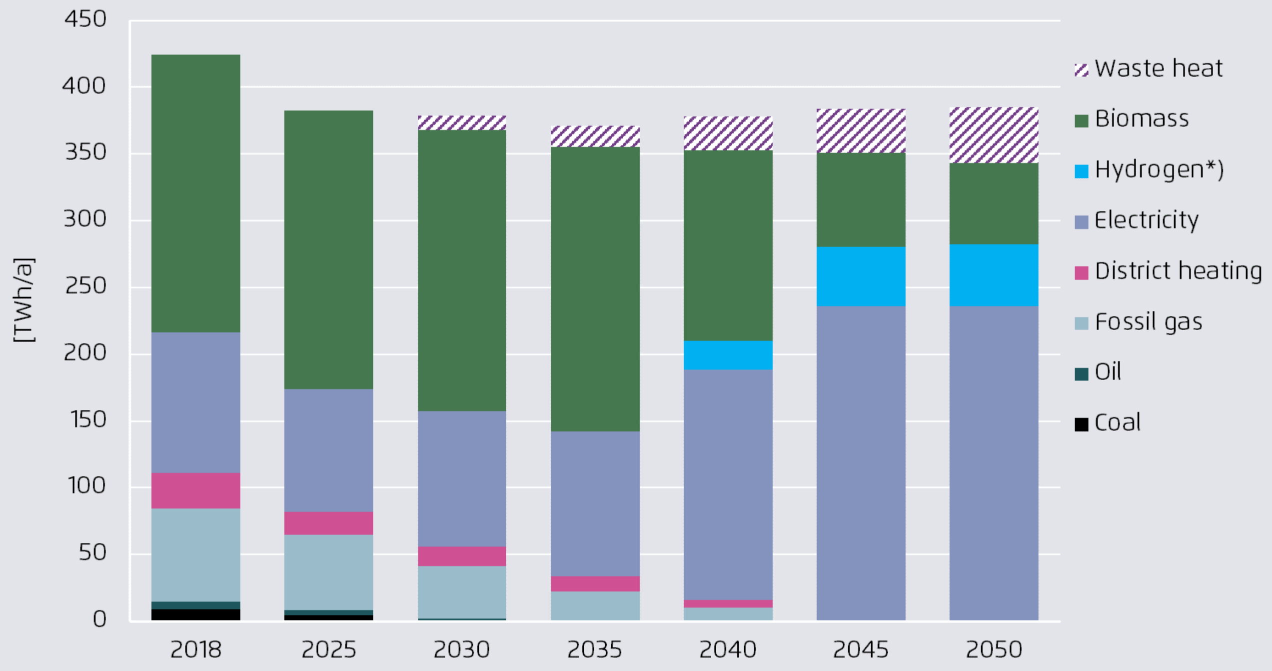


Wuppertal Institute (2023)

- The sub-sector already relies largely on power today (up to 56% of final energy demand). Thanks to efficiency increases and electrification, final energy demand declines by 25% by 2030 and 47% by 2050 (excluding ambient and waste heat).
- The sub-sector can be close to fossil-gas free by 2040, phasing out its relatively small share of oil and coal as well at the same time. Biomass and district heat use will also rather decline over the transition.
- Fossil gas is used mostly in low- and mid-temperature ranges, especially in space heating and low-pressure steam. Current technologies can be substituted by heat pumps making use of ambient heat and partially waste heat.
- Even with an increased electrification the use of heat pumps allows to reduce power demand overall by 12% between 2018 and 2050. Power demand represents up to 92% of final energy demand by 2050 (excluding ambient and waste heat). The remainder may be supplied by district heat.

Sub-sector transformation: Pulp & paper

Final energy demand in the manufacturing of pulp and paper, EU-27

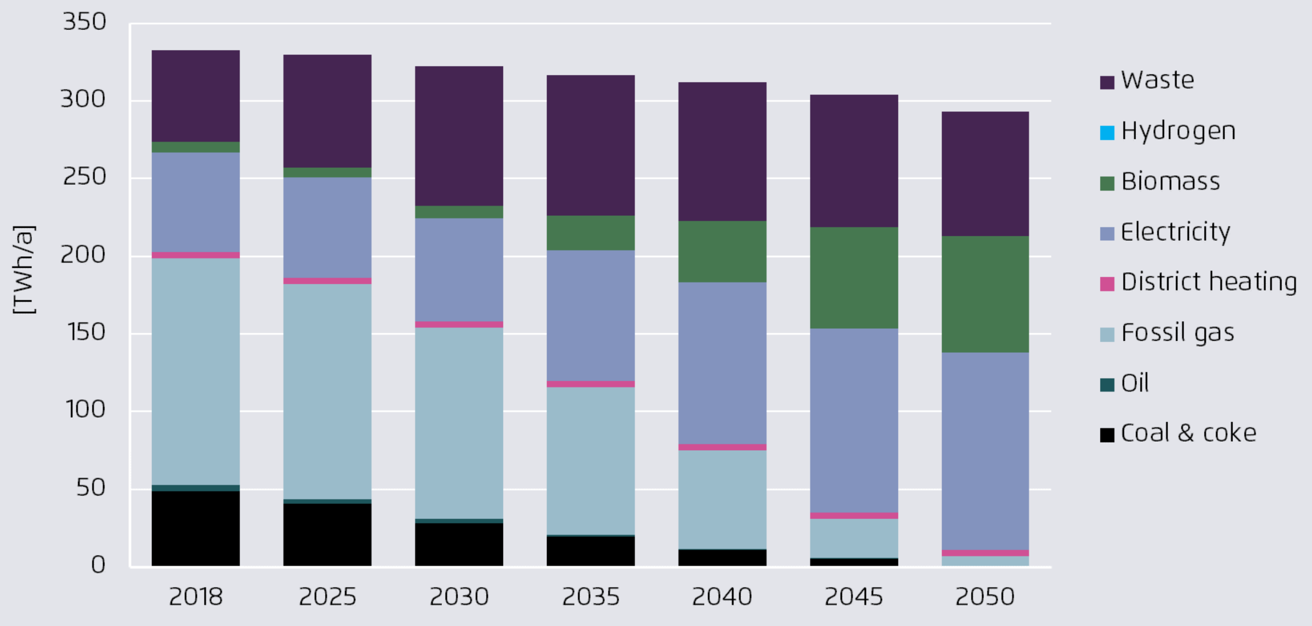


Wuppertal Institute (2023)
*) hydrogen is used for black liquor upgrading to methanol

- Thanks to efficiency increases and electrification, final energy demand declines by 13% by 2030 and 30% by 2050 (excluding waste heat).
- A relatively small fossil gas consumer compared to the other sub-sectors, it can be close to fossil-gas free by 2040, phasing out its relatively small share of oil and coal as well at the same time.
- Fossil gas is used mostly in mid-temperature ranges for steam production, especially in the paper production process.
- Biomass represents about half of FED in the sub-sector today. Biomass residues (bark, black liquor) are available in pulping plants, which are highly concentrated in Sweden and Finland. Biomass will be heavily substituted by electric heat, which allows a shift of biomass use towards more efficient uses.
- Power demand will scale up to represent up to 80% of final energy demand by 2050, up from 25% in 2018 (excluding waste heat). The remainder will be supplied by biomass residues.

Sub-sector transformation: Non-metallic minerals

Final energy demand in the processing of non-metallic minerals, EU-27

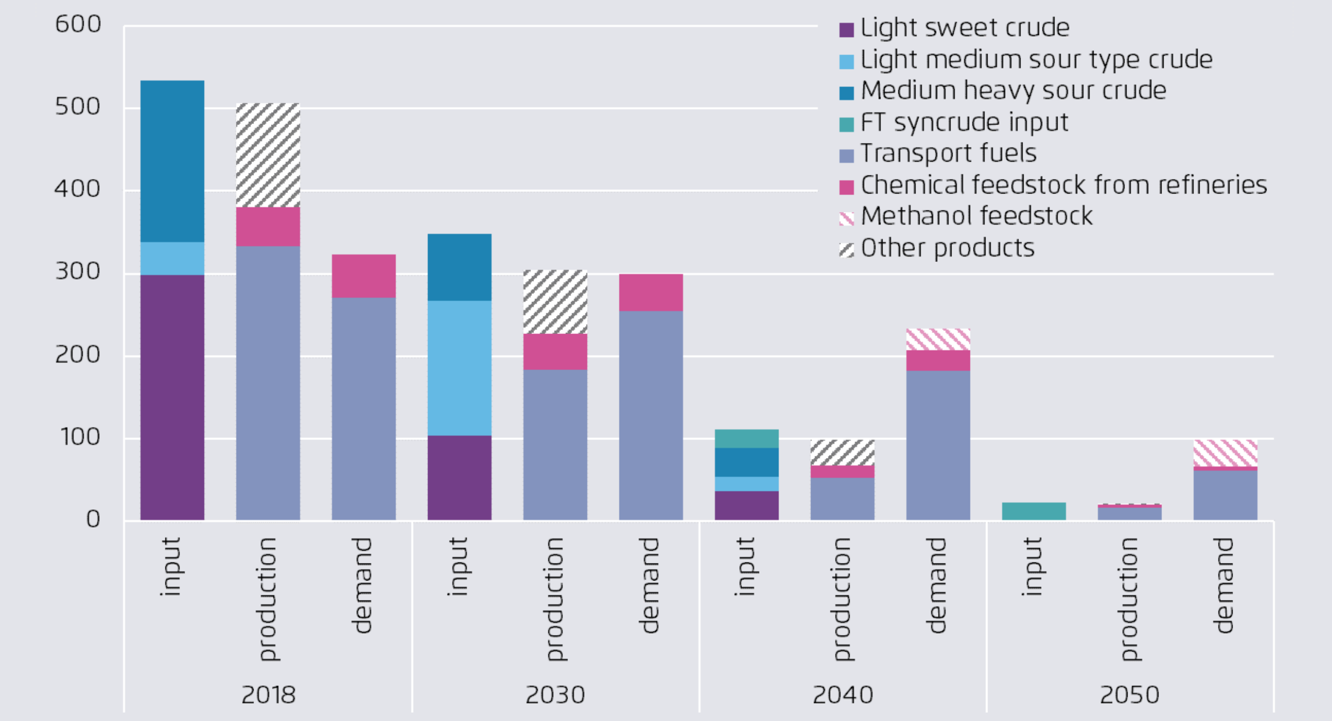


Wuppertal Institute (2023)

- Final energy demand will decline steadily in this sub-sector to reach 12% by 2050.
- Due to the high temperature heat demands and production locations near to raw materials rather than to energy infrastructures, the non-metallic industry branch is really a hard-to-abate sector.
- Fossil gas demand will decline by only 5% by 2030. The bulk of its demand reduction will take place between 2030 and 2045, making this sub-sector the last one to phase out fossil gas. Coal, coke and oil will be almost phased out in parallel until 2040. District heat and biomass use will also decline.
- Easy investments into technologies such as waste use are quickly made, but the further defossilisation of energy supply requires rather large investments into core technologies of the sector, i.e. in the ovens.
- Waste and biomass fired ovens are equipped with carbon capture wherever possible and (partial) electrification is fostered after 2030, especially in the glass or the cement industry (calcination).

Sub-sector transformation: Refineries

Refinery balance vs. fuel and feedstock demand in the EU-27

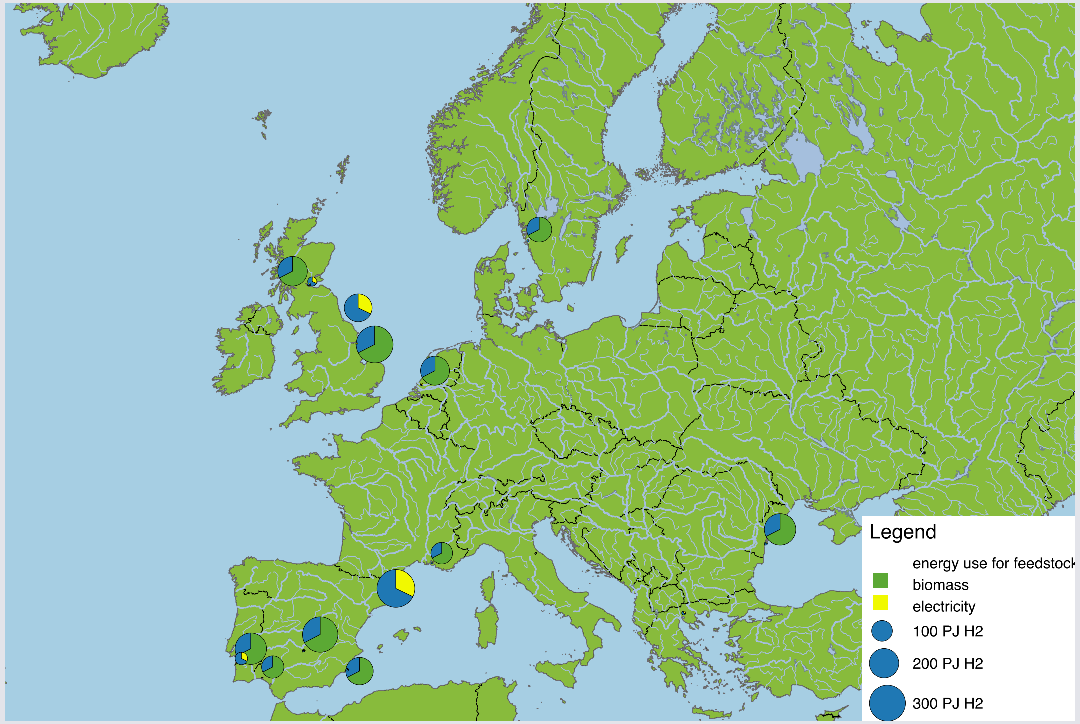


Wuppertal Institute (2023)

- → Europe has overcapacities in crude oil refining, but many refineries are old and not well integrated.
- → A decline in hydrocarbon transport fuel demand should thus result in refinery closings or massive scale-downs, starting around 2030.
- → Refinery closings together with a switch in crude oil supply to lighter feedstock improves the gas balance.
- → The future of the European refining sector is still very open, but we assume a partial coverage of European remaining demands in aviation and shipping by domestic Fischer-Tropsch fuel production (synthetic fuels) at sweet spots on the Iberian Peninsula and smaller units at the North, Baltic and Black Sea.

EU refineries
Fuels & feedstock in 2050

Site specific energy use



Wuppertal Institute (2023)

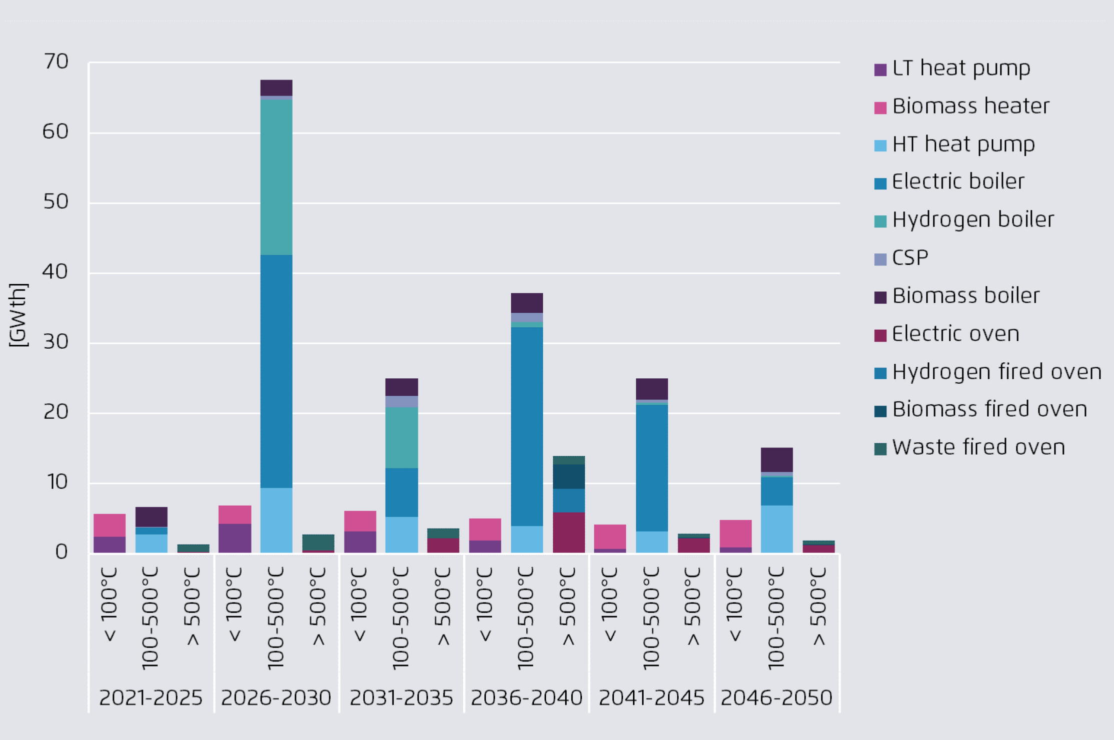
EU28 fuel and feedstock balance 2050 [Mt/a]

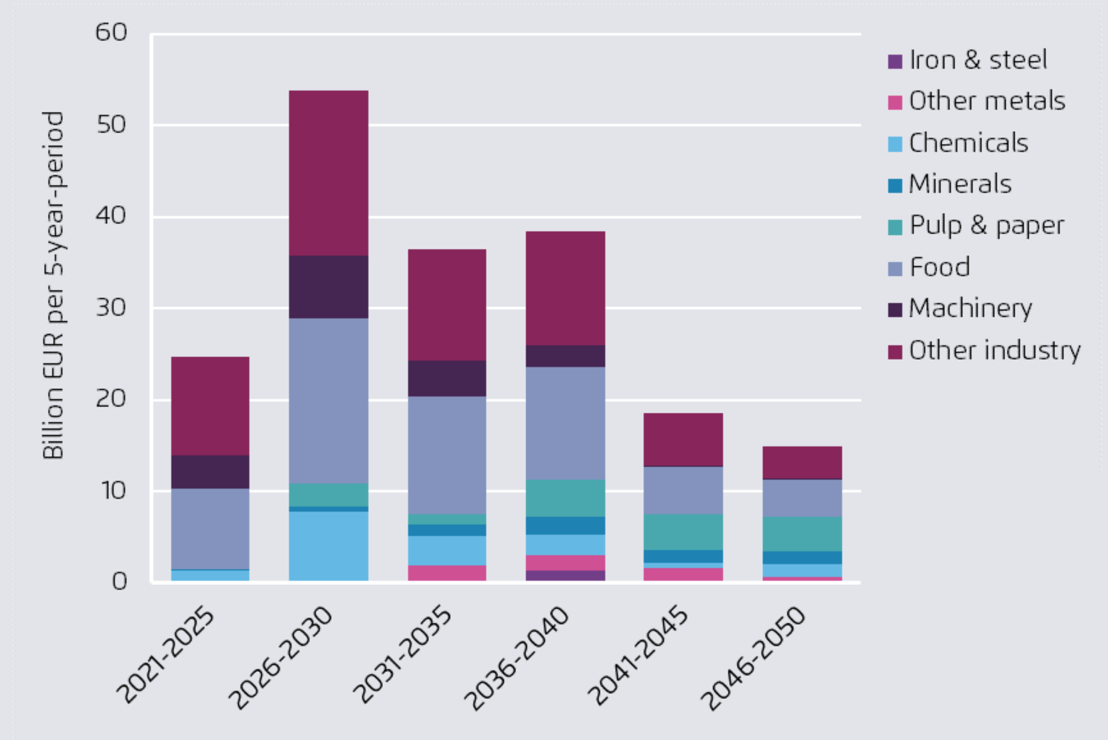
	production	consumption
kerosene	21.1	47.8
navigation fuel (gasoil)	14.2	24.5
cracker feedstock	12.6	22.1
chemicals from FT refineries (HVC)	1.3	NA
MeOH from CO_2	17.3	43.3

Wuppertal Institute based on T&E (2023)

Invest in fuel switch for heat supply

Invest in $GW_{thermal}$ (left) and billion Euros in EU-27 industry (right)*

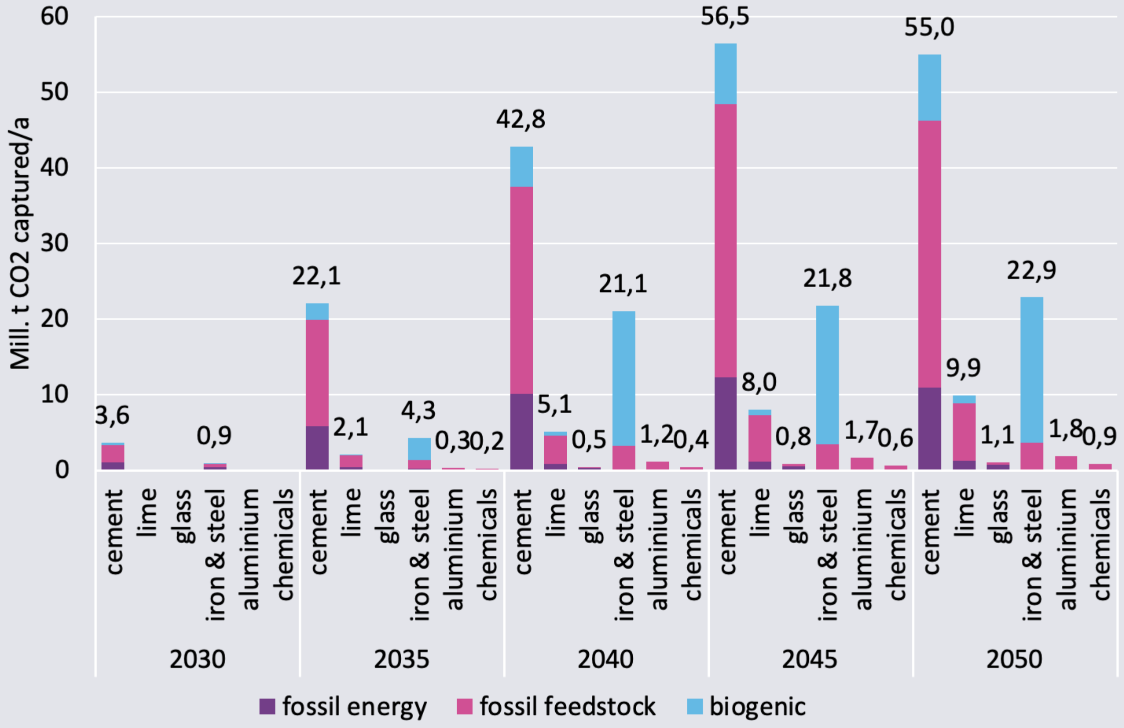




Wuppertal Institute (2023) - *excl. investments in new technologies such as DRI plants, new steam crackers or oxyfuel cement clinker ovens

The role of CCS in industry

CO_2 captured in industrial processes, EU-27



Wuppertal Institute (2023)

→ Carbon capture is exclusively used at industrial plants that have process related emissions and/or require high temperatures.

→ Most of the CO_2 captured is assumed to be stored in suitable geological formations, only little amounts are used to produce methanol at sweet spots with very low expected electricity prices (especially in Spain).

→ The bulk of captured CO_2 comes from the processing of limestone in combination with waste and biomass energetic use.

→ A particular case for BECCS is foreseen in the steel industry, where biomass could deliver parts of the reducing gas in shaft furnaces and energy for downstream operations (hot rolling plants).

Agora Energiewende

LABORATORY OF ENERGY POLICY

Buildings:

Methodology and assumptions

Buildings: Scope

- → Includes energy used inside the building, e.g. for heating, hot water, cooking, lighting, appliances
- → Final energy:
  - Delivered by the gas, electricity or district heating grid, by delivery of fuels.
  - Ambient Heat: tapped by heat pumps from air (air/air or air/water heat pumps), ground/geothermal (brine/water heat pumps) and water (water/water heat pumps). Thus, shallow geothermal heat pumps are included.
- → Electricity consumption for heat pumps is accounted separately from ambient heat.
- → Electricity:
  - Heat applications (e.g. heat pumps, direct electric heating) and other appliances (e.g. lighting)
  - Electric consumption of lighting decreasing due to further diffusion of LED and installation of day-light and occupancy controls in the residential and tertiary sectors.
  - Moderate reduction of electric consumption for household, ICT and other appliances as well as for building technologies.

FORECAST Model – Focus Buildings Sector

Main input parameters residential sector

	Residential sector
Main drivers	- No of households - Building area [m²] by type of building and by age class
Prices	- Energy prices - Taxes
Technology data	**Building related data:** - Insulation levels - Heating system efficiency - Heating system and envelop retrofit costs - Lifetime **Appliance data by efficiency class** - Market share - Specific energy consumption, Standby power and hours - Lifetime

Source: TEP Energy and Fraunhofer ISI

- → Energy consumption and emissions driven by
  - Structure and condition of the current building and heating systems stock
  - Future development of main drivers (employee, floor area demand), energy-efficiency improvement and changes of the heating systems structure
- → Energy-efficiency improvement through retrofits of envelop and building technologies
- → Heating systems choices of building owners: heat pumps, biomass, connection to district heating systems instead of fossil heating system renewals
- → Considered:
  - Re-investment cycles (e.g. time of the replacement due moment)
  - Relative cost-effectiveness
  - Codes and standards, energy-prices and taxes, subsidies, willingness to pay

FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

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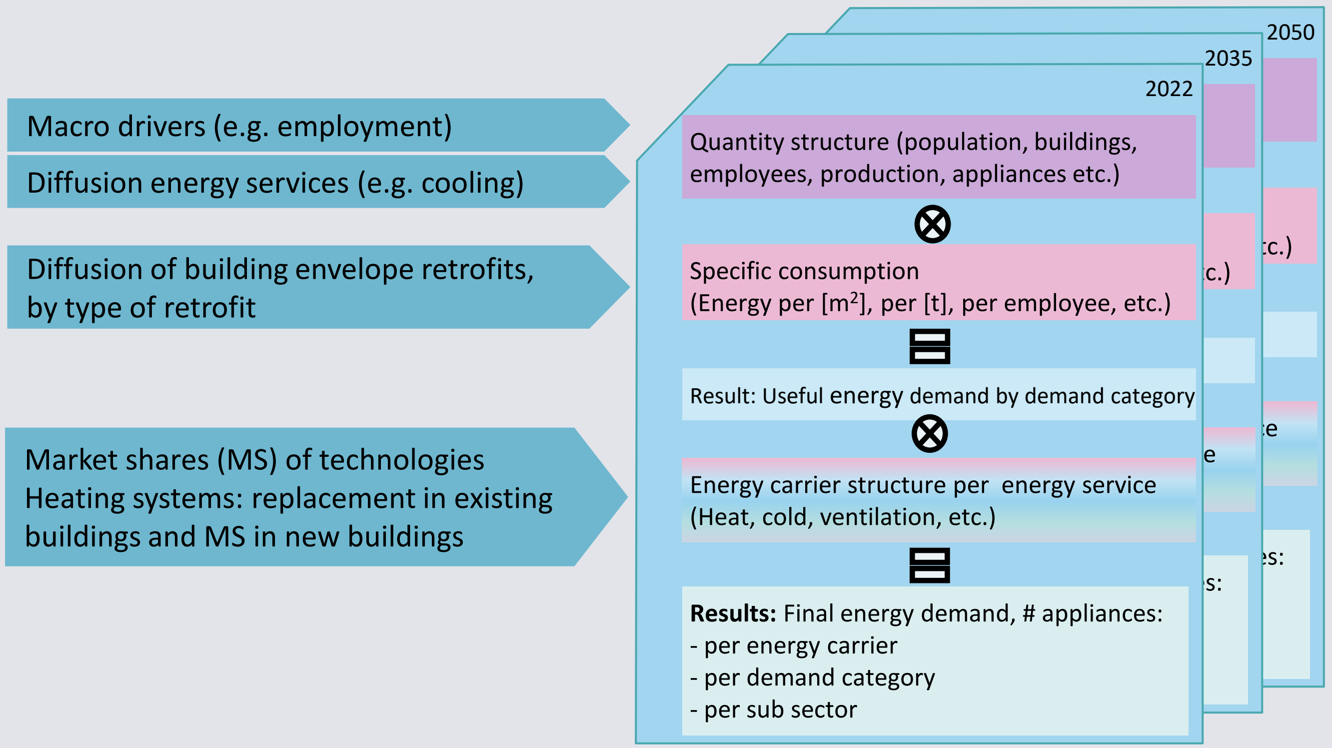
LABORATORY OF ENERGY POLICY

FORECAST Model – Focus Buildings Sector

Methodology: example services sector



TEP Energy and Fraunhofer ISI

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FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

Agora Energiewende

LABORATORY OF ENERGY POLICY

FORECAST Model – Focus Buildings Sector

Input	Output

• Population, number of employees
• Specific floor area per employee or person
• Detailed building stock data:
  ○ 2+8 building typologies, 5 age classes
  ○ 4 building elements: walls, windows, roof, basement
  ○ Building codes per building element
  ○ Investment & life-cycle costs of refurbishment measures
  ○ 12+ different heating technologies, incl. costs per technology and replacement type
• Energy carrier prices, carbon prices, energy taxes and other policy instruments (codes and standards, subsidies, tax incentives, bans/mandatory requirements)
• Potentials and limitations: decentralized (thermal) Renewable Energy Sources (RES) and central district heating, infrastructure (cost curve) based on fundamentals gained in other projects (including spatial and topological analysis)
• Calibrated to Eurostat final energy demand for residential and tertiary sector
	• Final energy demand per energy carrier (including district heating) and country, per year
	• Specific heat demand per m^2 energy reference area
	• Energy related CO_2 and greenhouse gas emissions
	• Investment costs for refurbishment measures, heating technologies and district heating infrastructure and heat generation
	• Installation rates for heating systems and envelope retrofit measures

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FORecasting Energy Consumption Analysis and Simulation Tool

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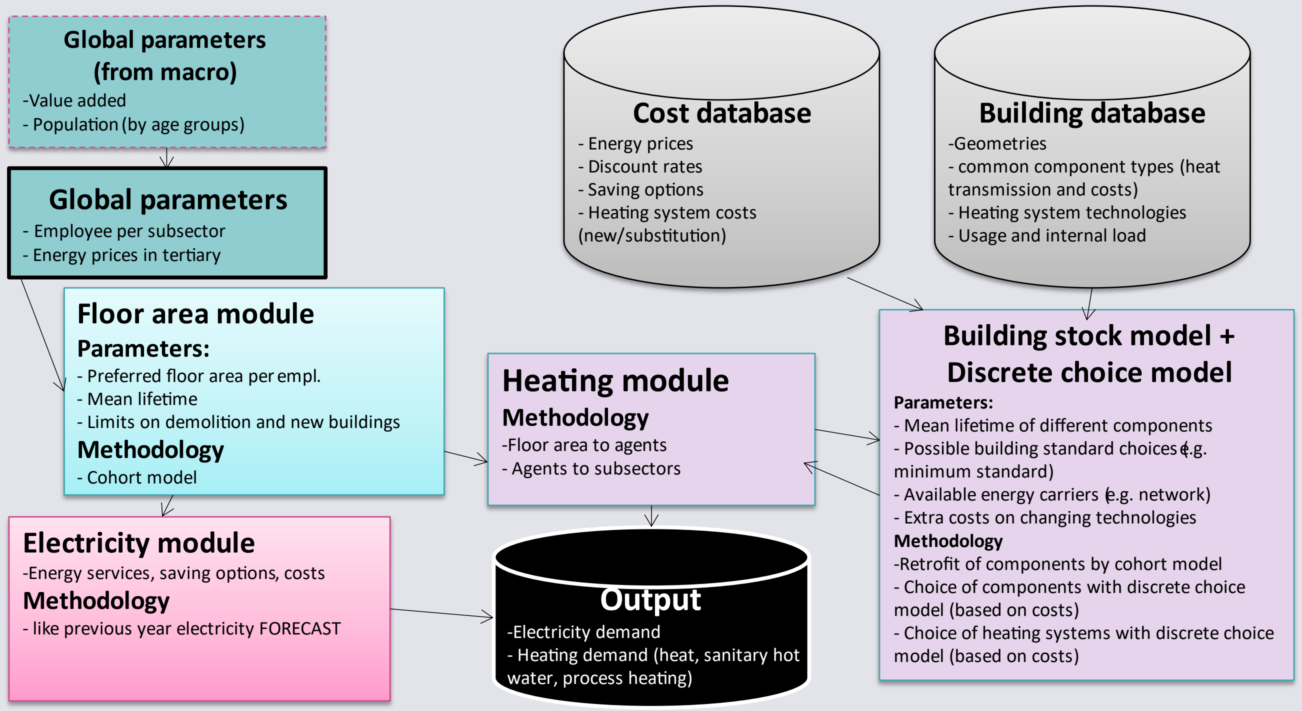
LABORATORY OF ENERGY POLICY

FORECAST Model – Focus Buildings Sector

Model and data base



TEP Energy and Fraunhofer ISI

Scope

- Residential, services (and industry) sector buildings final heating demand per fuel type, incl. district heating, electricity, fossil gas, hydrogen and biogas, fuel oil and renewable sources
- Development of the building stock in terms of specific heat energy demand differentiated for new and refurbished buildings
- Integration of remaining carbon budgets and emission reduction targets for all countries
- Focus on nine core countries with respect to assumptions (national policies, national targets)

FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

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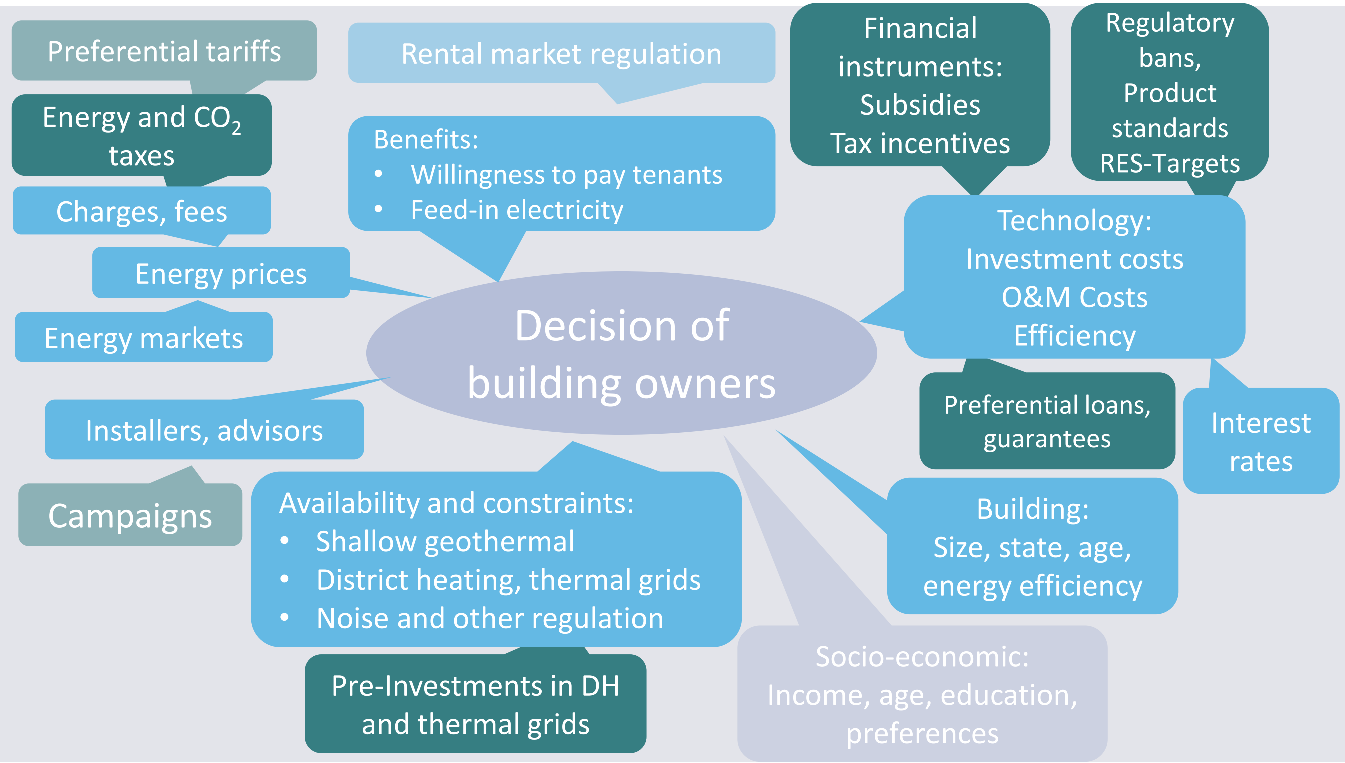
LABORATORY OF ENERGY POLICY

FORECAST Model – Decision modelling

Owners' decisions are influenced by exogenous drivers and policy measures



TEP Energy and Fraunhofer ISI

Development of final energy demand by energy carrier is driven building retrofit and heating system choices of owners. Choices depend on:

- → Exogenous drivers such as interest rates, energy prices, regulation, availability of local renewable energy sources, market supply, technical parameters
- → Preferences and socio-economic context
- → Policy measures that impact on both of the above:
  - ○ Energy taxes, CO_2-levy, preferential loans, subsides or other financial instruments to balance relative economic performance
  - ○ Provide energy infrastructure / clean energy
  - ○ Ban non-renewable energy use and set minimal performance standards

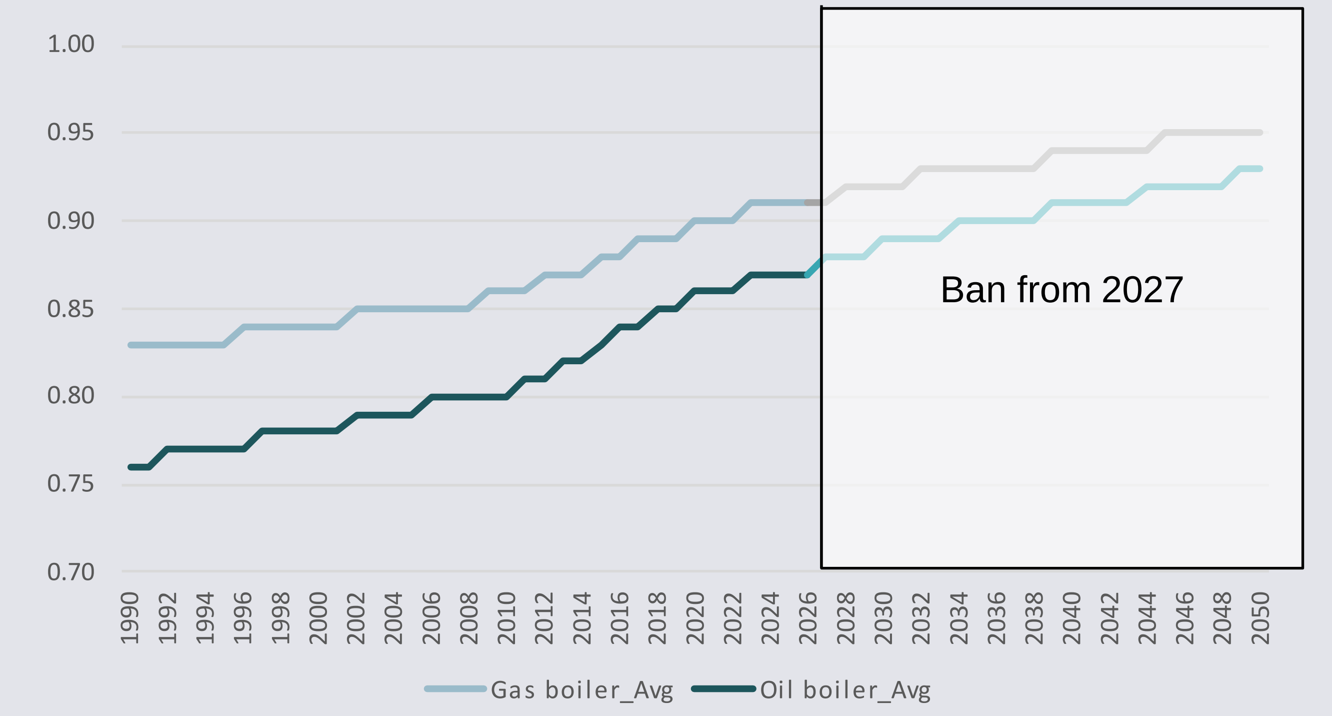
Legend: *Exogenous drivers* *Policy measures*

Key policy assumptions for buildings

- **Fossil fuel subsidies:** No explicit fossil fuel subsidies enabled in the modelling.
- **Carbon pricing:** CO_2 price of 39 €/tCO2 in 2027 rising to 49 €/tCO_2 in 2030 and 200 €/tCO_2 in 2040 to reflect an EU emissions trading system for building and transport fuels.
- **Efficiency in buildings:** High energy efficiency standards for the thermal envelope of new construction and existing buildings in line with reinvestment cycles for components. However, no explicit modelling of minimum energy performance standards.
- **Fossil fuels in new buildings:** No fossil fuels allowed in new buildings from 1 January 2027.
- **Fossil heating in existing buildings:** Modelling assumptions simulating ecodesign & energy labelling rules that restrict the installation of fossil heating appliances from 1 January 2027.
- **Coal heating phase-out:** Country specific coal phase-out dates in district heating and individual boilers before 2035.
- **Fossil cooking phase-out:** Phase out of fossil fuels in cooking appliances by 31 December 2030.

Key assumptions:
Phase out of stand-alone fossil fuel boilers

Efficiency of heating system

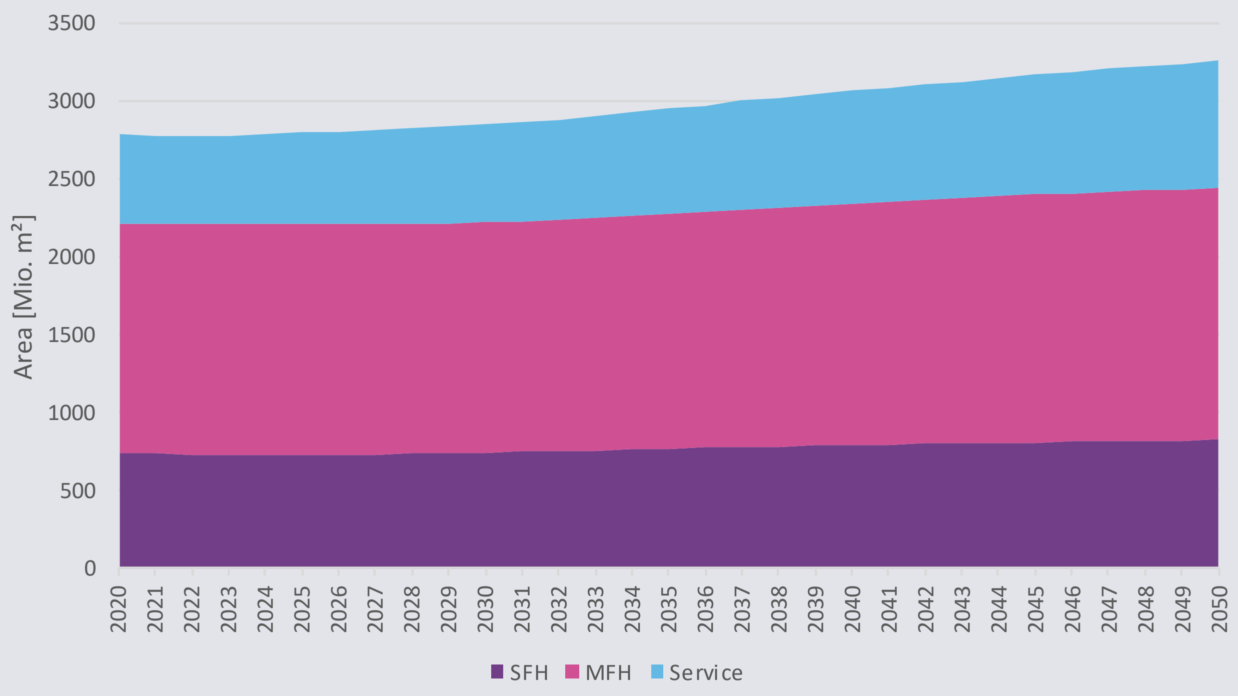


TEP Energy (2023)

- Ban of stand-alone fossil fuel boilers from 2027 based on boiler efficiency values, simulating a revision of Ecodesign rules for heating appliances currently under discussion.
- The rule is assumed to only apply to new installations, not existing ones.
- The efficiency values for heating appliances are based on lower calorific value and an average over all countries and includes distribution losses in the building.
- The modelling also assumes reduced *willingness to pay* for fossil fuel boilers before the ban to reflect the impact of the war in Ukraine.

Key assumptions:
Households and floor area

Floor area by building type in Italy

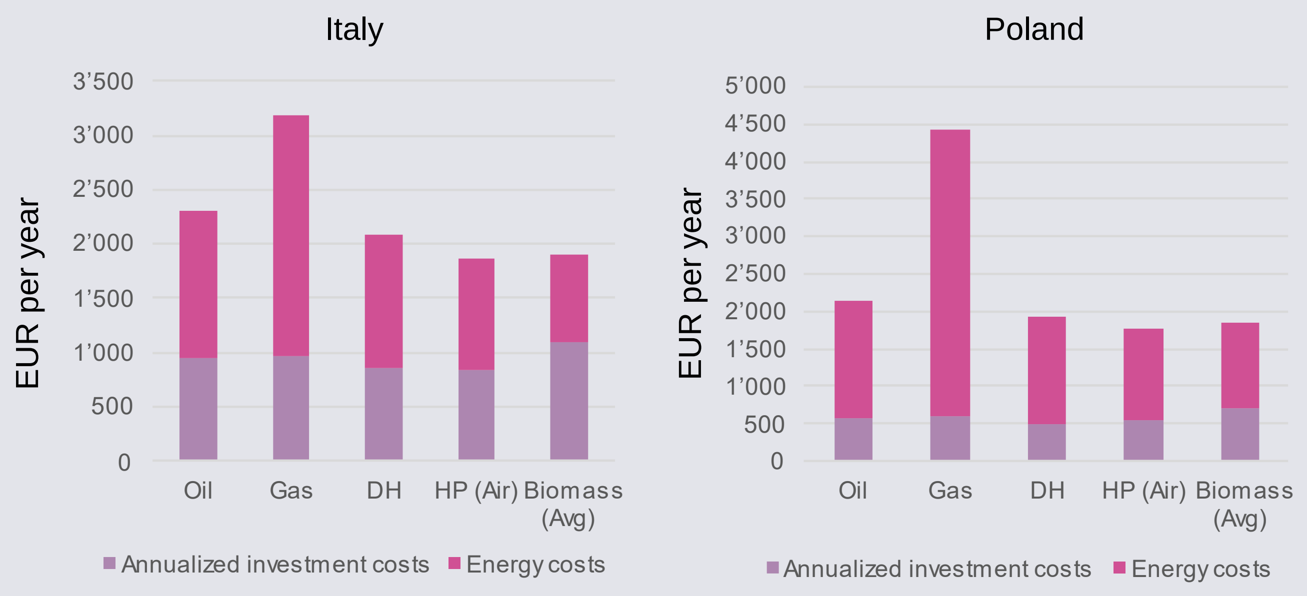


TEP Energy (2023)

- → Floor area is based on values per occupant (residential sector, single and multi-family homes) resp. per employee (service sector).
- → Development of population stems from demographic forecasts
- → Employment is based on macro-economic data that forms the basis of the simulation model.
- → Resulting total floor area increases by 17% between 2020 and 2050

Key assumptions:
Economics and policy of heating system changes

Annualized heat generation costs in single family house: heating system change 2025 – Example of Italy and Poland



TEP Energy modelling (2023)

Ranking of heat generation costs of individual heating systems depend on

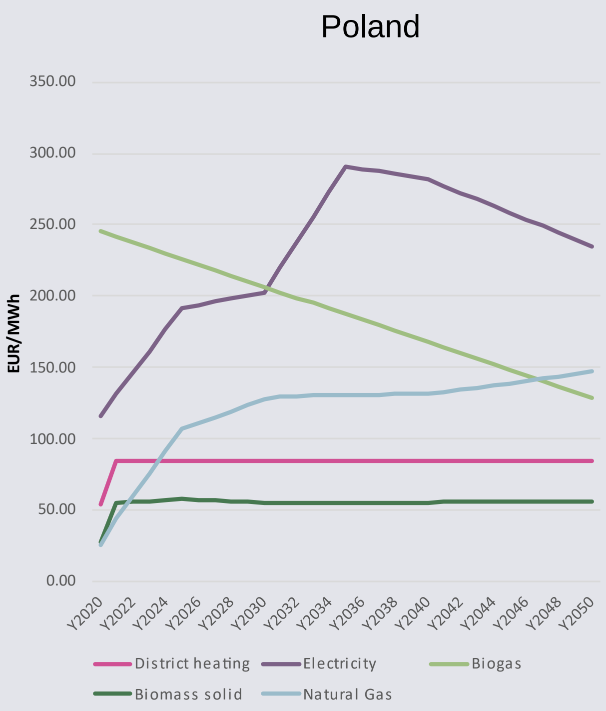
- → Investment costs of heating systems (by country)
- → Interest rate
- → Technical efficiency
- → Willingness to pay
- → Relative energy prices, including taxes, by country
  - Ratio of electricity price and fuel prices
  - Favourable for heat pumps: ratio <3

Policy measures to foster heat pump market take-up considered include:
Quality assurance (efficiency, noise, quality of installation), preferential tariffs, incorporate heat pump in building standards and labels

- Annualized costs are quite similar across systems using renewable energy sources (and less costly with high energy prices)

Key assumptions:
Energy prices and technology data

Exemplary energy prices from Italy and Poland, in the residential sector - with taxes, distribution, etc.



TEP Energy (2023)

Energy prices

- Consumer prices are derived from assumptions on energy commodity prices (whole-sale prices)
- Electricity: underlying energy commodity prices consistent with results from the simulation of the energy sector.

Technology data

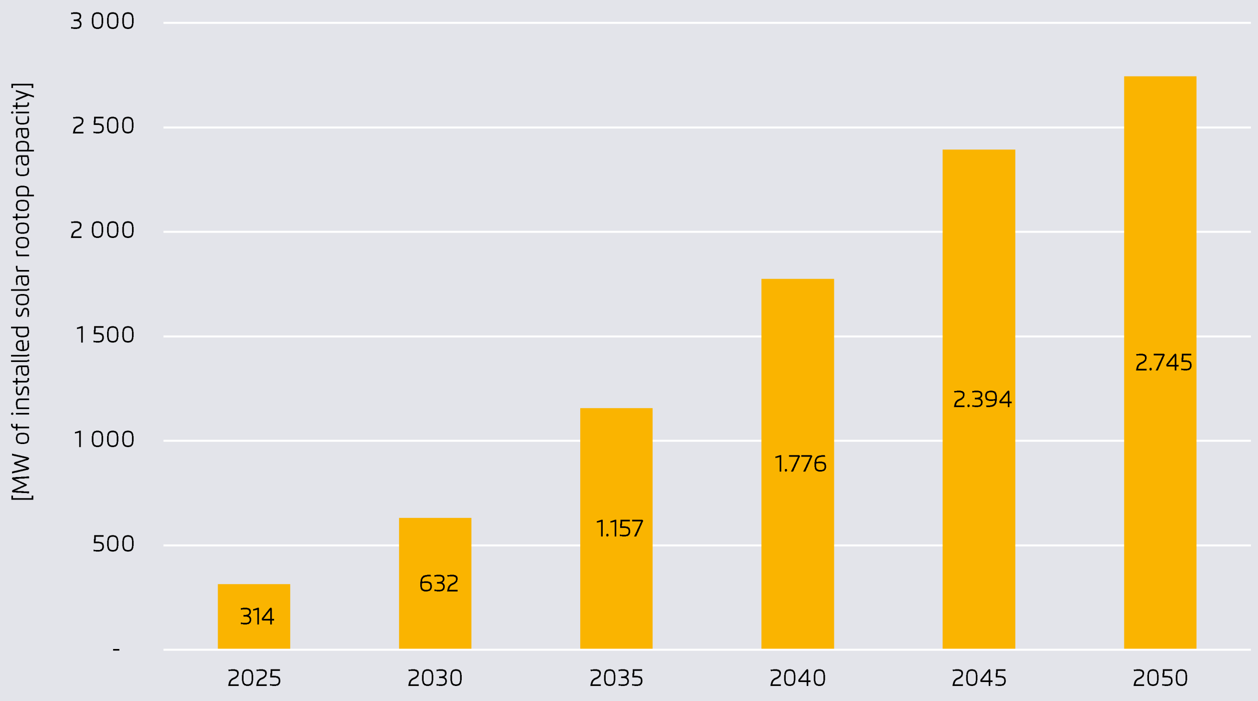
- Technical and economic parameters of the different heating systems are defined in the simulation framework of FORECAST.
- This data is used and updated in numerous European projects (e.g. sEEnergies, Building Market Briefs - BMB).

Buildings:

Results

Deep dive: Solar rooftop PV

Installed solar rooftop PV capacity (in MW) – Slovenia



Artelys

- Installed solar rooftop capacity and generation grows rapidly, especially after 2030:
  - 0.6 GW (2030); 1.7 GW (2040); 2.7 GW (2050)
  - 0.7 TWh (2030); 1.8 TWh (2040); 2.8 TWh (2050)
- Rooftop solar is expected to represent around 40-45% of total solar capacity and generation
- Rooftop PV generation is on an aggregate yearly balance able to cover a significant share of electricity consumption in buildings :
  - (%) total electricity demand in buildings (excl EVs): 8% (2030); 25% (2040); 42% (2050)
  - (%) of electricity for heating, cooling & ventilation: 18% (2030); 59% (2040); 102% (2050)

District Heating (DH): Methodology and assumptions

District heat: is it useful, is it needed and if yes, why?

Two types of motivation for the use & expansion of district heating	Two examples of constraints for decentralized heating systems

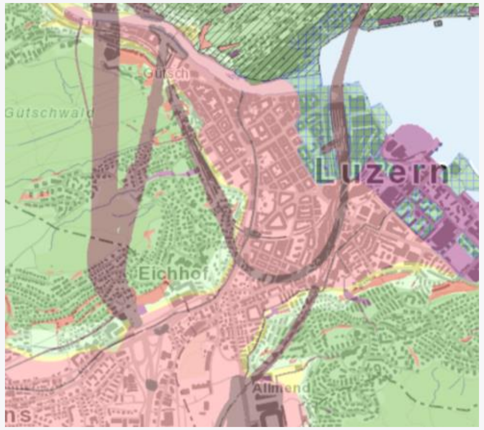
→ Positive motivation:

- Favourable energy density
- Low-cost solution for building owners (depending on the price model of utilities)
- Few actors to decarbonise building stock

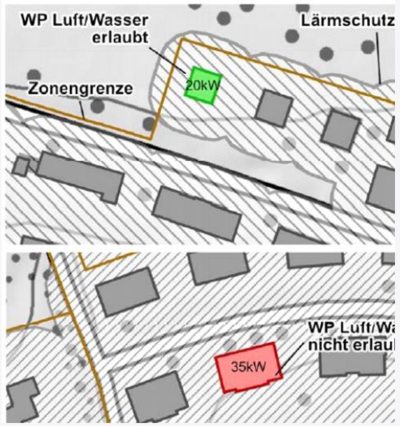
→ Decentralized systems

- Renewable energy potentials limited
- Constraints: space, noise
- Might be more costly
  (e.g. to thermally recover geothermal borehole heat exchanger, to implement noise protection measures)
- A lot of actors (building owners) to be convinced

Borehole HP not allowed in ground-water areas



Air/water HP emit noise in and need space



Topology resulting from spatial energy analysis

Example: Municipalities in Switzerland with more than 10’000 inhabitants

	Share of energy floor area
Only thermal grids (decentral solutions constraint)	23 %
Thermal grids & decentral solutions (geothermal, air)	63 %
Decentral solutions: geothermal and air	6 %
Decentral solutions: only air	2 %
Decentral solutions: only geothermal	4 %
None of them	2 %
Total	**100 %**

Source: TEP Energy modelling (2021), table adopted Prognos/Infras/TEP 2021 (Technical report about the Energy Perspectives 2050+ on behalf of the Swiss Federal Office of Energy)

Settlement structure (urban/rural topology, linear energy demand density), renewable energy source availability and legal/technical limitation determine feasible solutions.

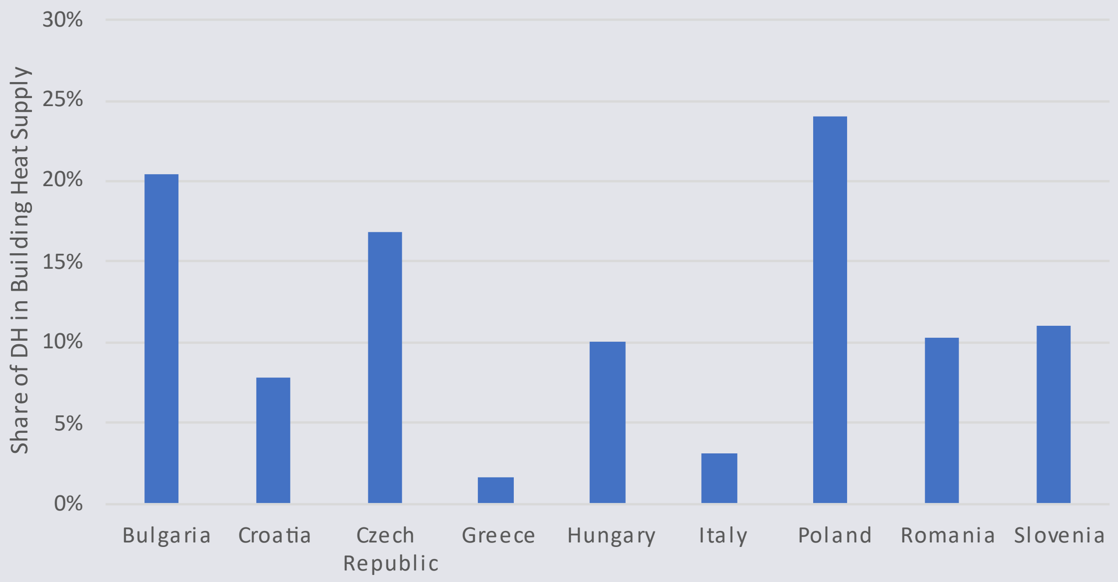
Spatial energy analysis: topology of centralized/non-centralized options.

Results (example Switzerland):

- → In about two thirds allow of the floor area several options (grid and non-grid) are feasible (at medium thermal grid distribution costs)
- → District heating almost exclusive approach to bring thermal energy in cities (if gas grids are phase-oud): about 20% to 25% of the building stock in municipalities > 10’000 inh.
- → About 10% only decentralized systems

District heating (DH): starting from very different sitations

Share of district heating at Building Heat Supply in 2020



TEP Energy and Wuppertal Institute (2023)

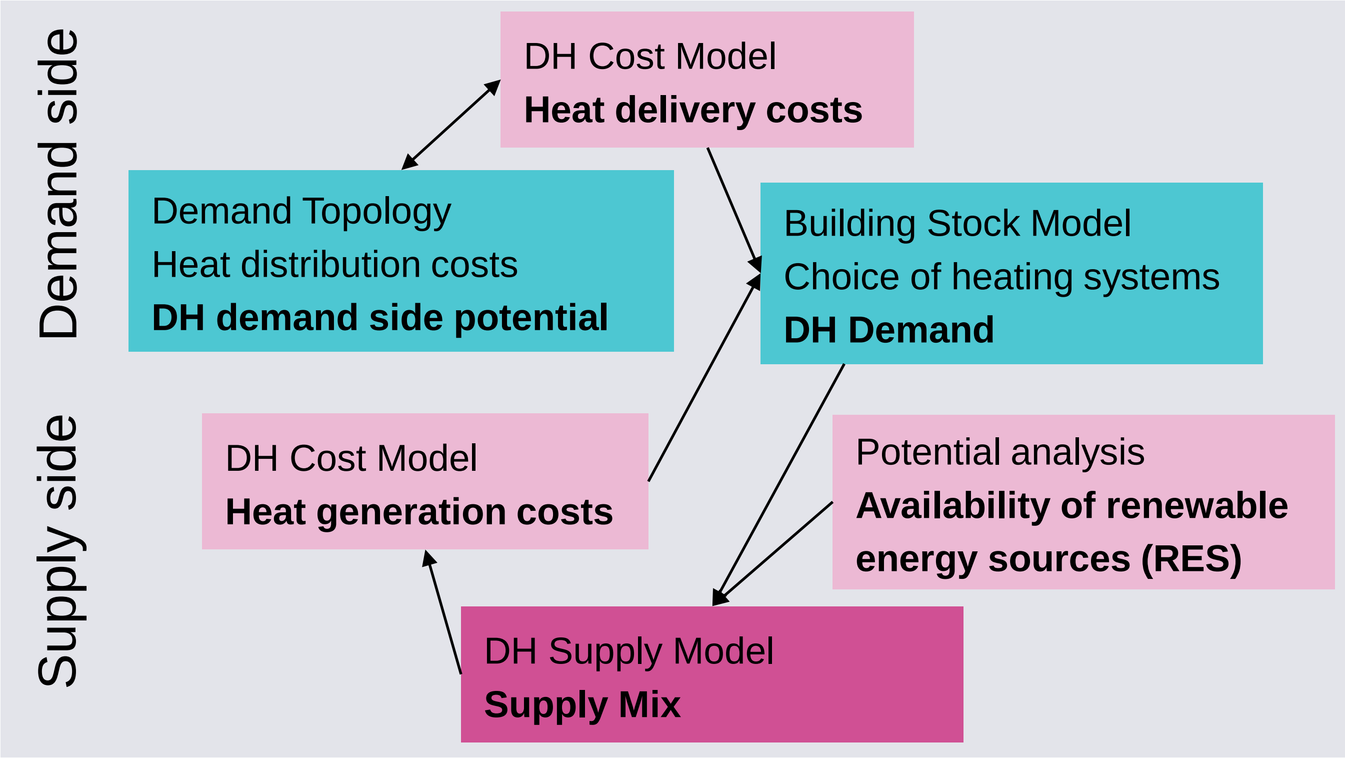
Two types of countries (focus on 9 national partners):

→ Historical experience countries (PL, CZ, BG) :
  - to lower district heating temperature to accommodate RES
  - to get DH provision more efficient
  - to keep and slightly increase district heating coverage

→ “Newcomer” counties with a current share of about 10% or less (IT, GR, HR, HU, RO, SI):
  - to increase district heating coverage
  - mainly in cities where decentralized renewable energy systems are a challenge (limited potentials, noise restriction, env. protection)

District heating modelling: demand and supply

Conceptual modelling approach district heating generation and provision



TEP Energy and Wuppertal Institute (2023)

Demand side :

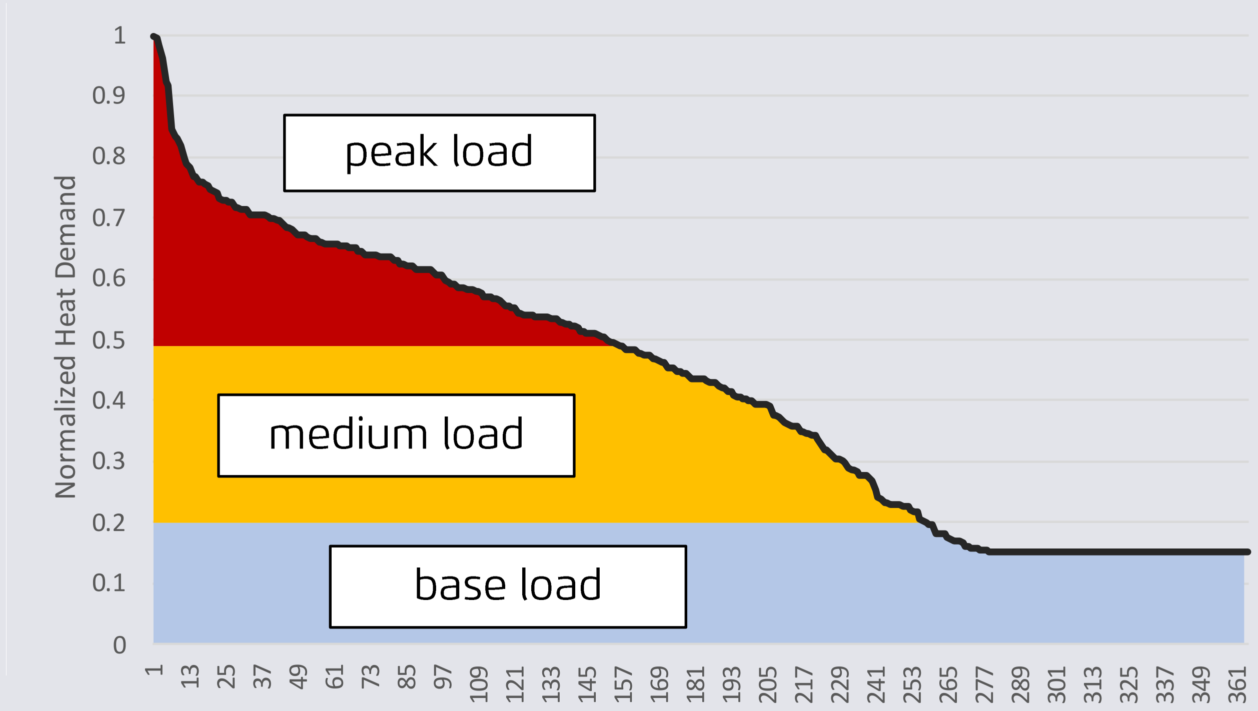
- → Heat distribution costs
- → Constraints (depending on topology of built environment)
- → Decision of owners to connect (also depending on competitiveness of decentral alternatives)

Supply side

- → Potentials
- → Heat distribution infrastructure
- → Heat generation costs
- → Actor to build up and operate district heating infrastructure

District heating modelling: conceptual approach

Illustration of assumed heat supply logic



TEP Energy (2023)

- The district heating supply modelling covers the full mix of technologies needed to cover the heat supply for base and peak load.
- Heat pumps, solar thermal, geothermal and waste are assumed to be covering the base load.
- Peak load is assumed to be provided by gaseous energy carriers and direct electric applications for a yearly energy share of 15-20%.
- Hydrogen and biogas/biomethane are assumed to be used in district heating as peak load technologies.
- Solid biomass is assumed to be covering a medium range of heat supply between base load and peak load.

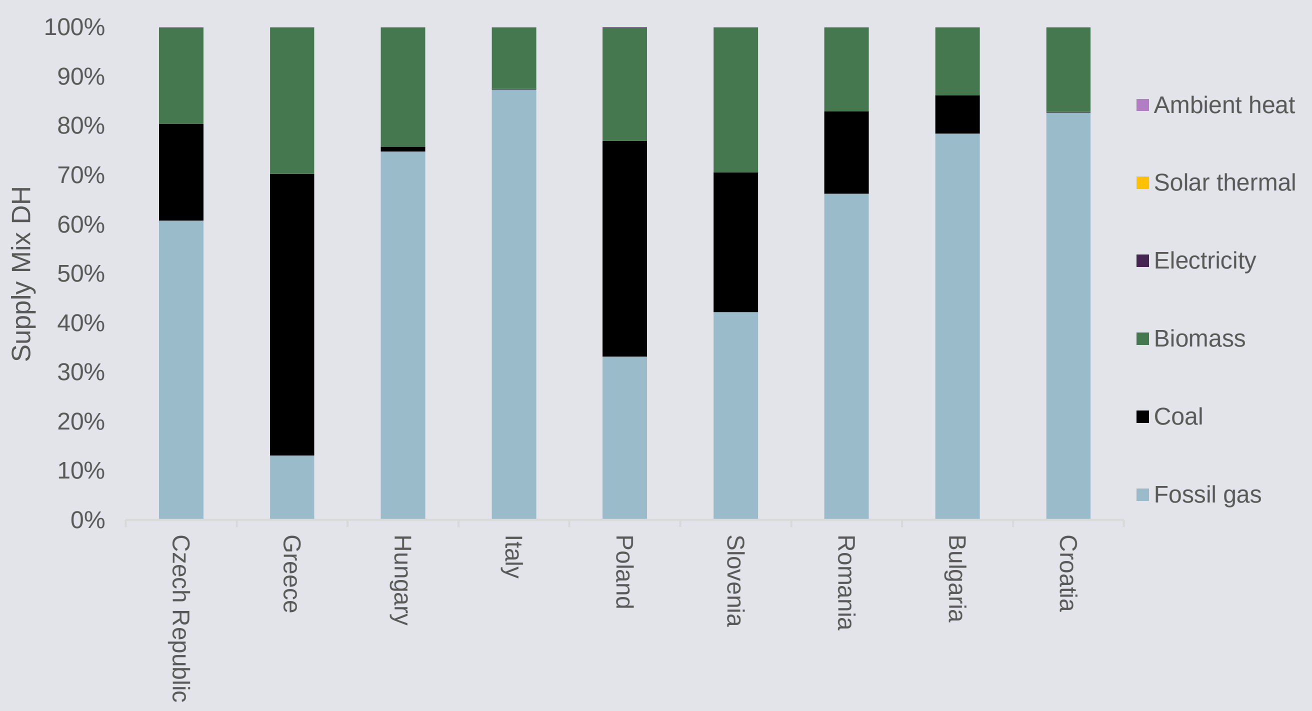
District heating: results

District heat: Background note for interpreting the results

- Includes energy that is used on site in heat generation for district heating. Grid losses are included.
- Includes heat generation from combined heat and power (CHP) and heat processes
- Ambient Heat in district heating is the source for heat pumps and can be from the air (air/air or air/water heat pumps) or from the ground or ground water (water/water heat pumps)
- Deep geothermal heat that can be used for district heating without the need of heat pumps is accounted separately.
- Electricity for heat applications is shown, whereas primary energy for producing electricity is balanced in the energy sector.
- In some cases, country specific restrictions (via limits to consumer *willingness to pay*) based on expert judgement were applied to avoid overshooting the deployment potentials for district heating. Without adjusting the model assumptions, district heating would not be competitive to other heating systems in some countries.

District heating generation: starting from very different situations

Share of district heating energy provision mix



TEP Energy and Wuppertal Institute (2023)

Starting from very different situations

- → In the starting year, fossil gas was dominant in most deep-dive countries, yet at quite different levels: mostly 30% to 90% (except for Greece)
- → Coal important in some countries (Poland, Slovakia, CZ varying from 20% to more than 40%) and very important in Greece
- → Biomass (mostly solid) account for 10% to 30%
- → Ambient heat / heat pumps and solar thermal are negligible in district heating generation