

facets

Agora
Energiewende



Breaking free from fossil gas

A new path to a climate-neutral Greece



Presentation overview

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Project background



Project scope

Project setting

- Cooperation project between FACETS S.A. and Agora Energiewende for Greece, 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)

Scope

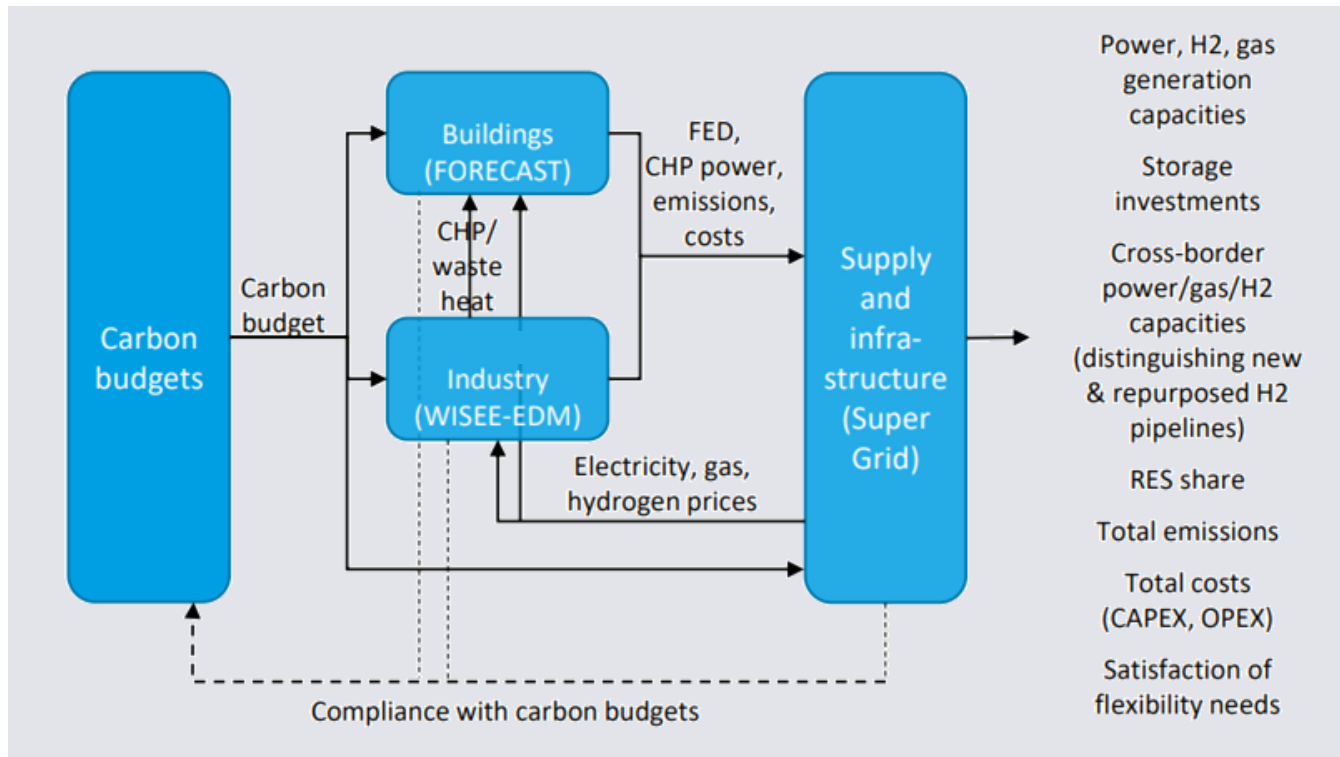
- Decarbonisation pathway until 2050, with fossil gas phase out by 2050 at the latest. Russian gas phase out as quickly as possible (by 2027).
- Focus on long-lasting demand reductions, as opposed to short-term behavioural changes.
- Cost-optimized balance between direct electrification and “no-regret” 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 Some of the results might thus be outdated as the economic and political context has changed.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



- 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

Artelys, TEP Energy, Wuppertal Institute

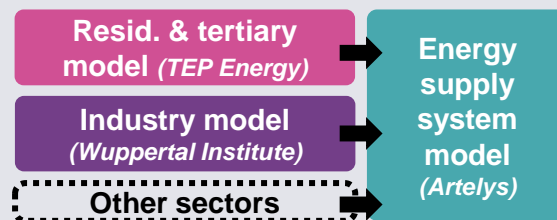
Assumptions on final energy demand and CO₂ emissions

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)
- CO₂ price not an exogenous assumption for the modelling work

- 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.

(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)

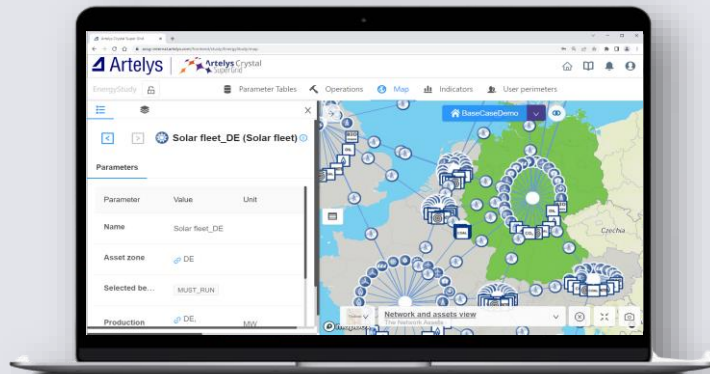
Energy sector:

***Methodology and
assumptions***

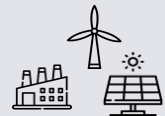


Energy system modelling in the EU-27

Artelys Crystal Super Grid model



A multi-energy modelling solution dedicated to interconnected systems



Bottom-up
representation

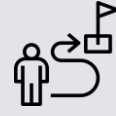


Multi-energy
approach

State-of-the-art optimisation techniques



Optimisation
models



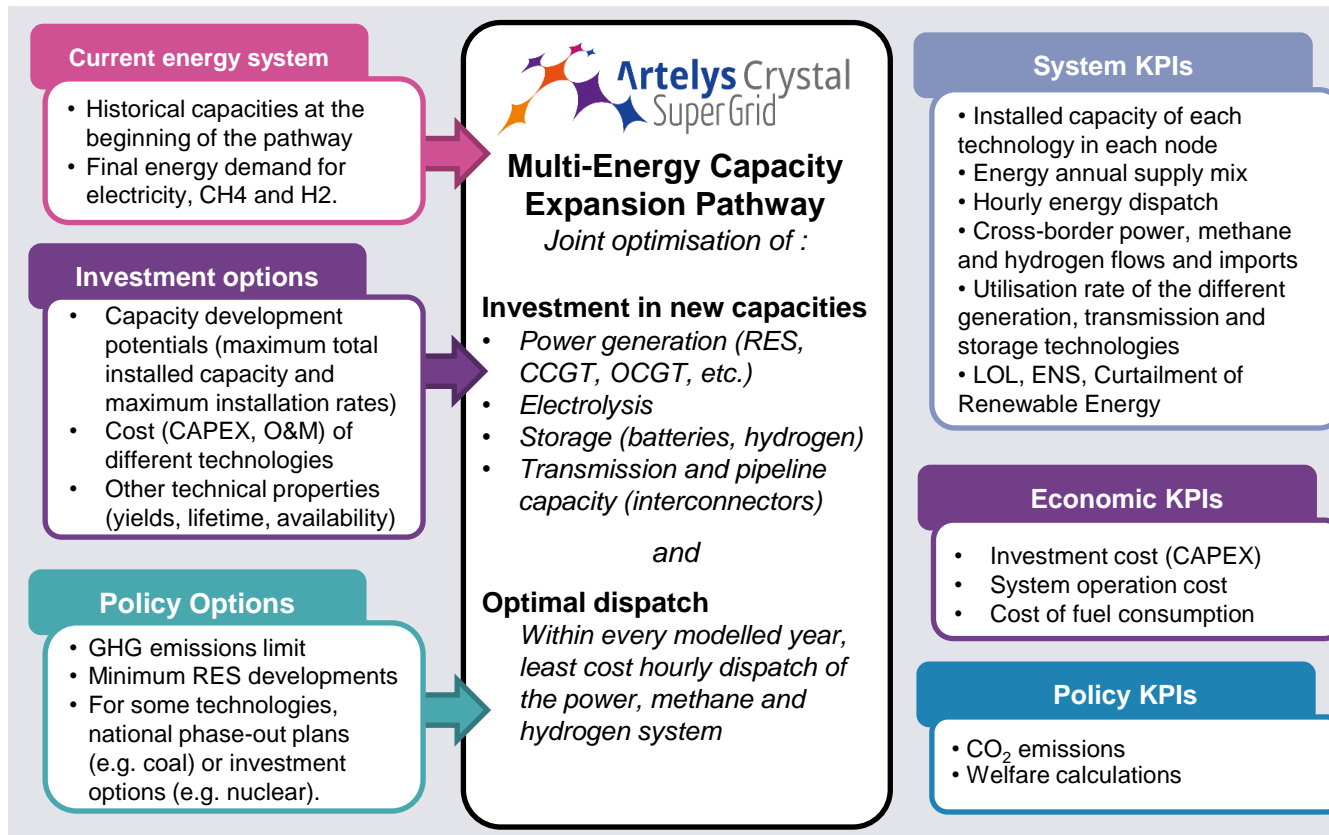
Advanced capacity
expansion features

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 CO₂ emissions and all sector couplings between energy carriers.
- Infrastructure such as electrolyzers, 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 CO₂ 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



- 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

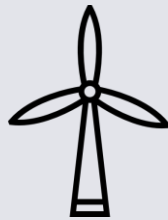
- Energy efficiency
- Circular economy
- Electric furnaces (EAF, induction, microwave etc.)
- Large scale (high temperature) heat pumps and waste heat integration
- Solar/geothermal
- Dry Biomass (+ onsite gasification, BECCS option)
- Green gases (hydrogen, e-gas, biomethane)
- Relocation of basic industry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



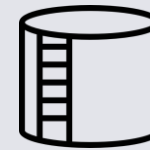
Domestic production:

- 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.

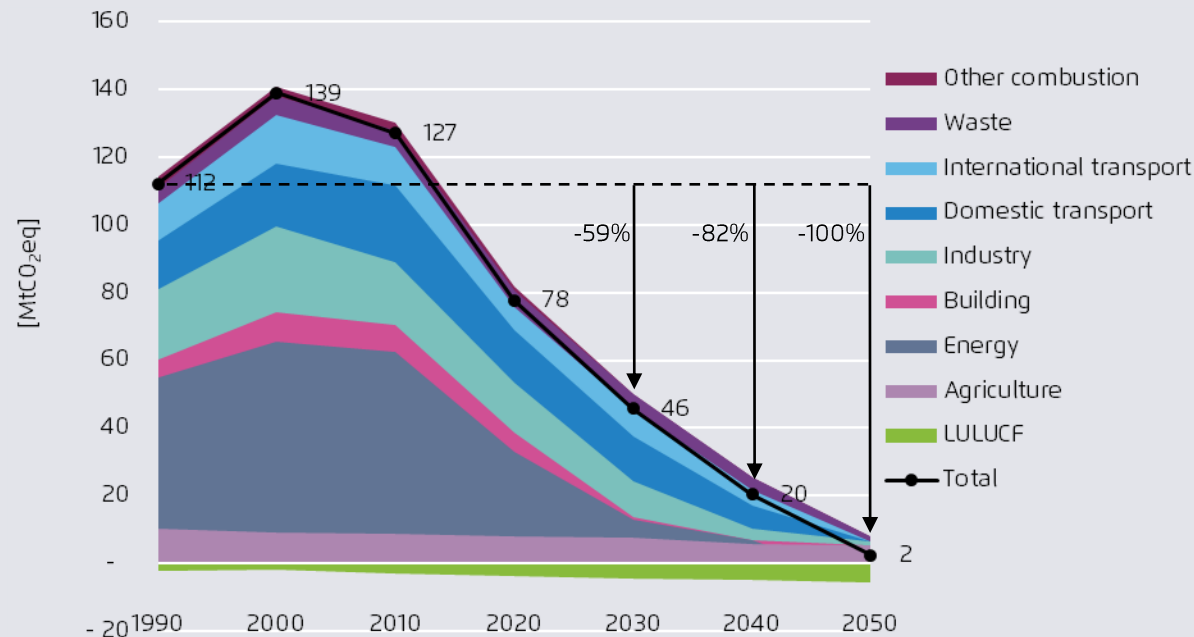
Energy sector:

***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, -82% by 2040 and -100% by 2050

GHG emissions by sector in Greece



Eurostat; Artelys, TEP Energy, Wuppertal Institute modelling (2023)

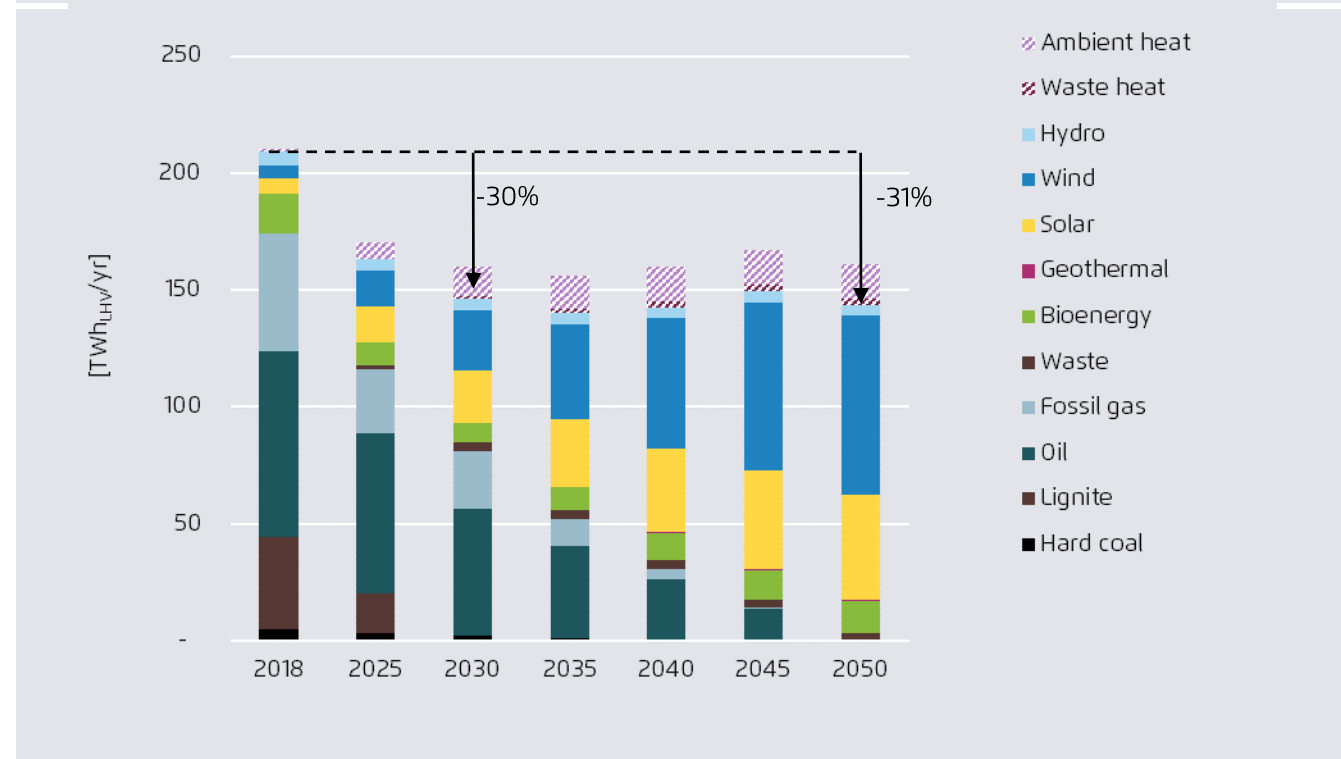
* Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste)

** 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 Greece, that would amount to about -82% emissions.
- Transport, agriculture, waste and LULUCF covered by existing studies by Transport & Environment and the European Commission: 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.

Primary energy demand* declines by 30% by 2030 and remains stable until 2050, not taking into account ambient and waste heat in the buildings and industry sectors

Primary energy demand* by energy source, Greece



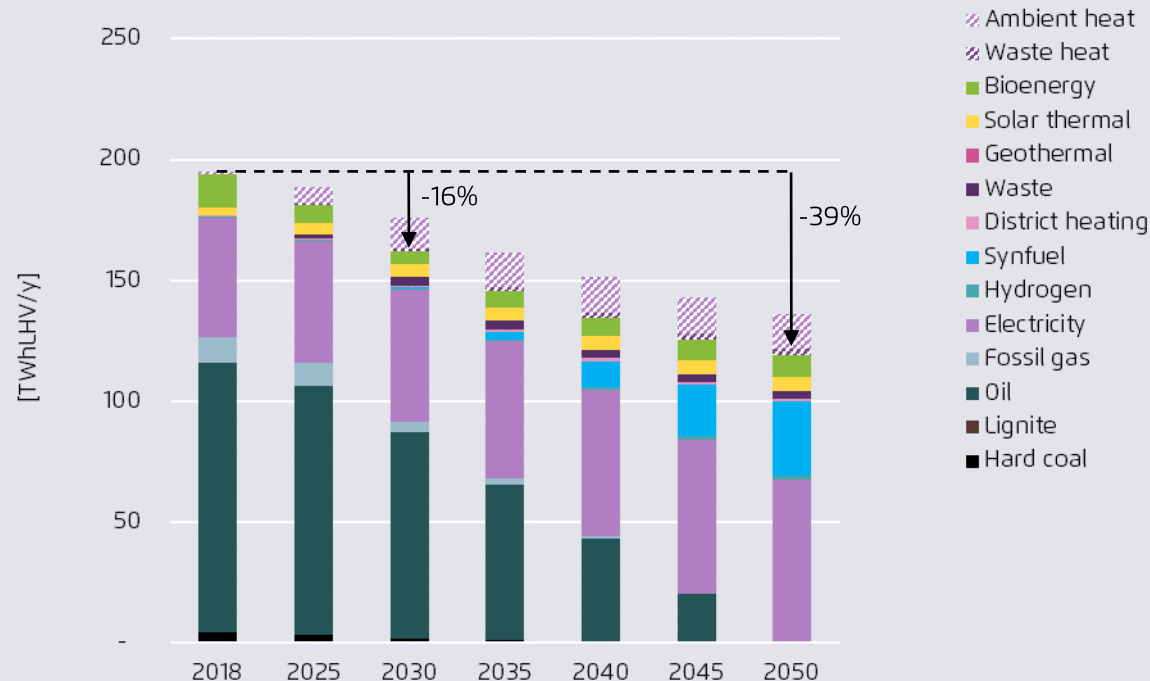
- Decline primarily thanks to electrification and efficiency increases, in particular the use of heat pumps in buildings and industry making use of ambient heat, as well as waste heat integration.
- Hard coal and lignite is entirely phased-out by 2030. Oil mostly remains in the transport sector after 2025.
- Renewables, especially wind and solar, massively increase from 17% of PED* in 2018 to 98% in 2050.

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.

Final energy demand declines by 45% between 2018 and 2050. It can already decline by 18% by 2030.

Final energy demand by energy carrier, Greece

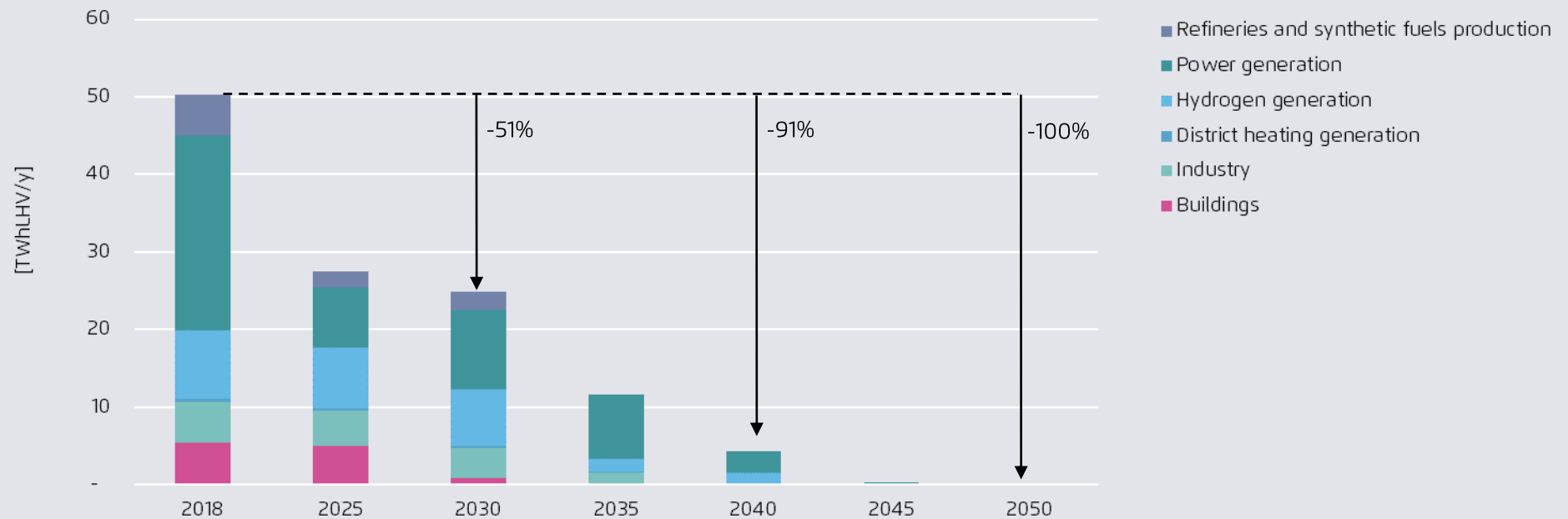


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- 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 34% in 2030 and to 57% in 2050. On the contrary, fossil fuels representing 65% of FED in 2018 are phased out by 2050, oil in transport being the longest in the energy system.

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

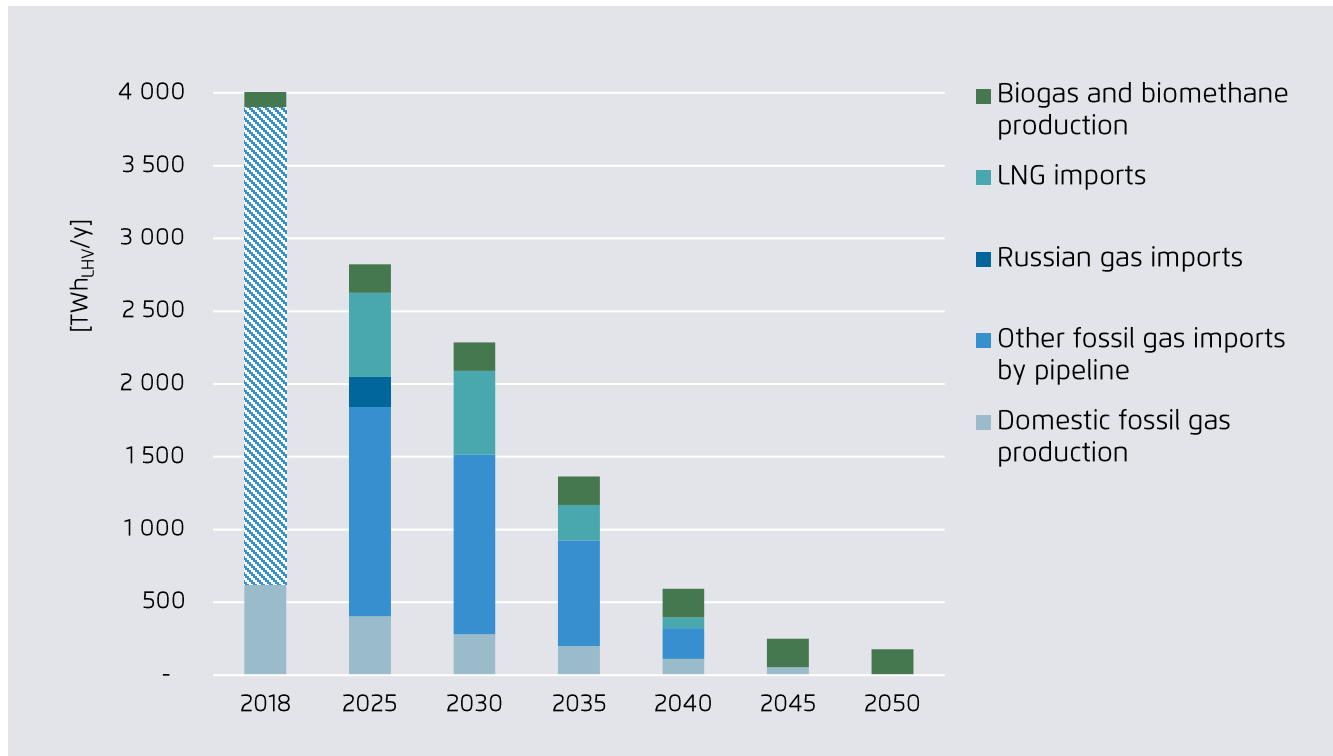
Evolution of total fossil gas consumption in Greece, 2018-2050 (in TWh_{LHV})



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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

Methane supply, EU-27

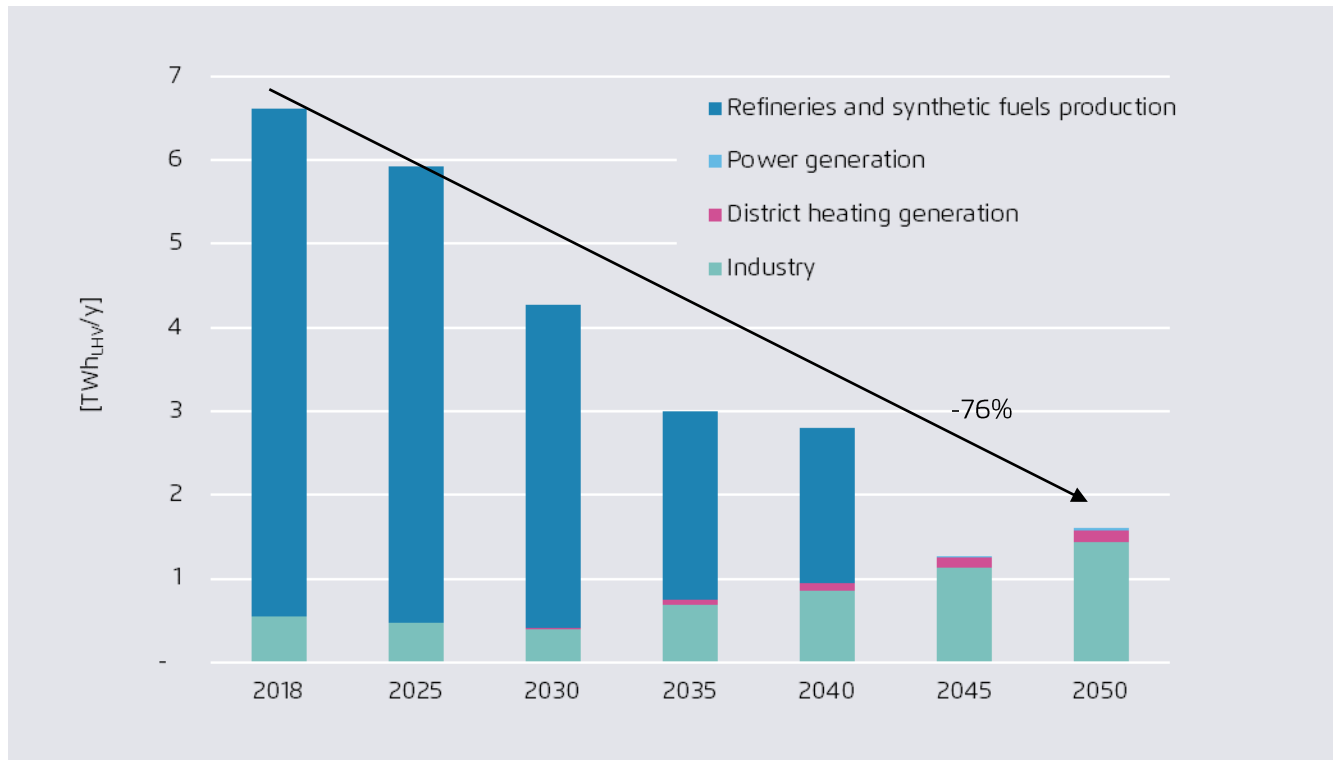


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- 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 could decline by 76% by 2050 due to large demand from refineries not being substituted

Hydrogen consumption by sector for Greece

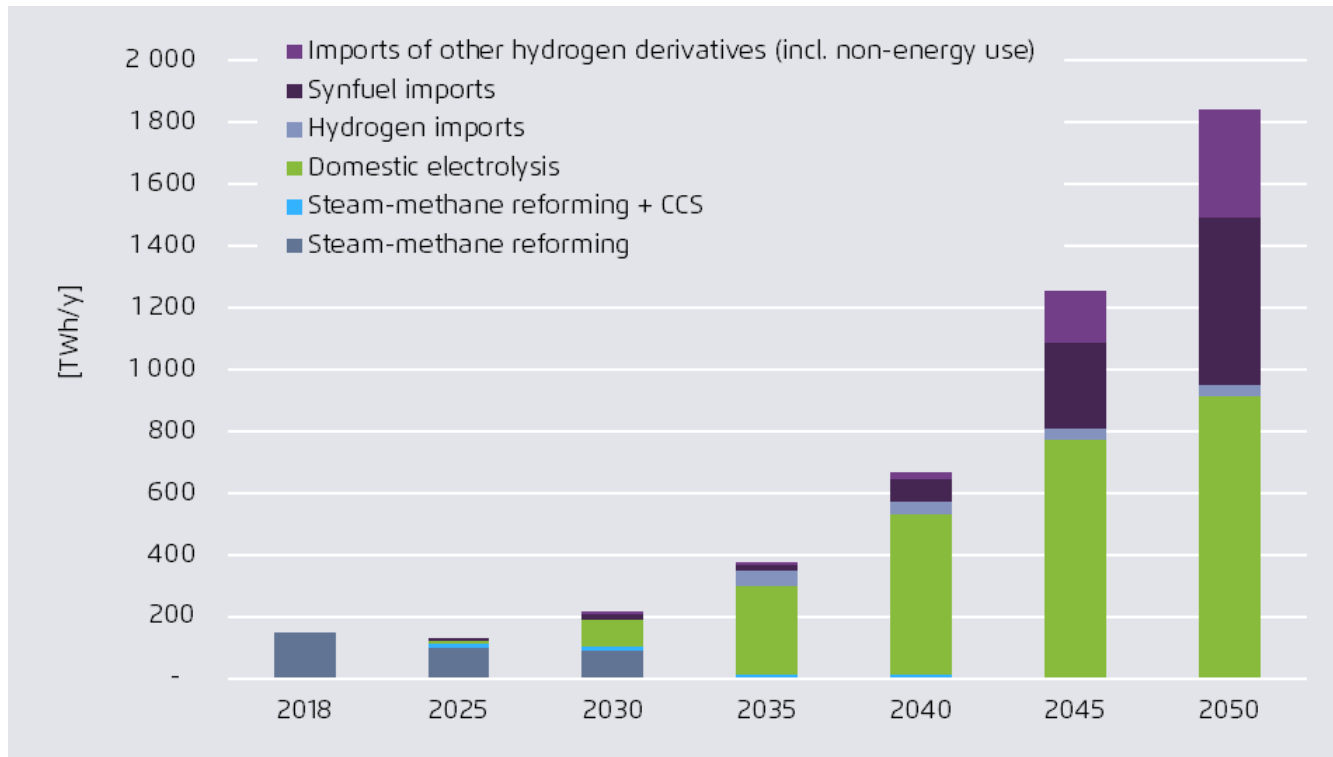


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- By 2050, hydrogen demand will reach 1.6 TWh, about 3% 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 Greece, most of the current hydrogen is used in refineries. This will decline with the transition of the transport sector, with the electrification of surface transport. Instead, demand in industry will increase starting 2035, to produce high temperature heat for processes and in hydrogen boilers, 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, some hydrogen turbines emerge to provide flexibility services to the power system, however to a very limited extent.

Hydrogen can be mostly supplied domestically within Europe, while its derivatives are largely imported. Greece can cover its demand and export its significant surplus to other Member States.

Hydrogen and hydrogen derivatives supply mix, EU-27

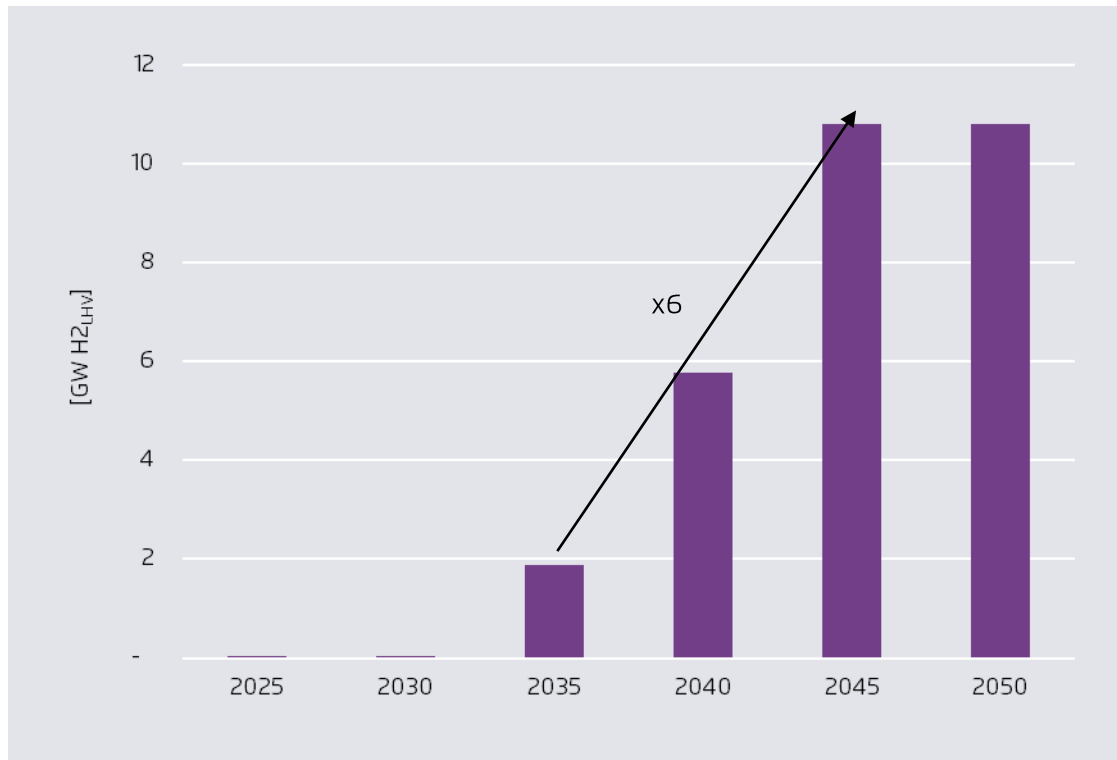


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

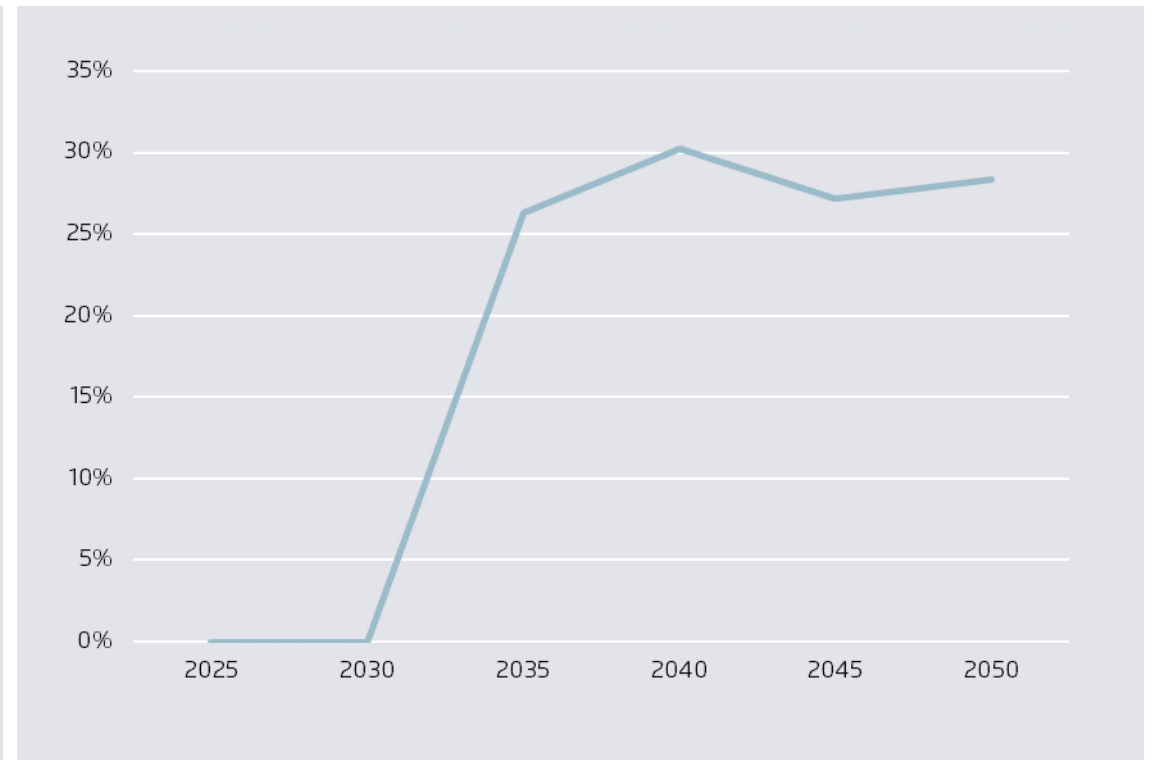
- Renewable hydrogen produced in Europe reaches 90 TWh (2.7 Mt) by 2030 to first replace fossil-based hydrogen. It scales significantly until 2050 to reach 910 TWh (27 Mt).
- Imports of renewable hydrogen only start in 2035 with 52 TWh/y (about 15% of supply) and remain low until 2050. SMR hydrogen with 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 2 GW in 2035 and is multiplied by 6 by 2045 to make use of the abundant renewable power.

Installed electrolyser capacity, Greece



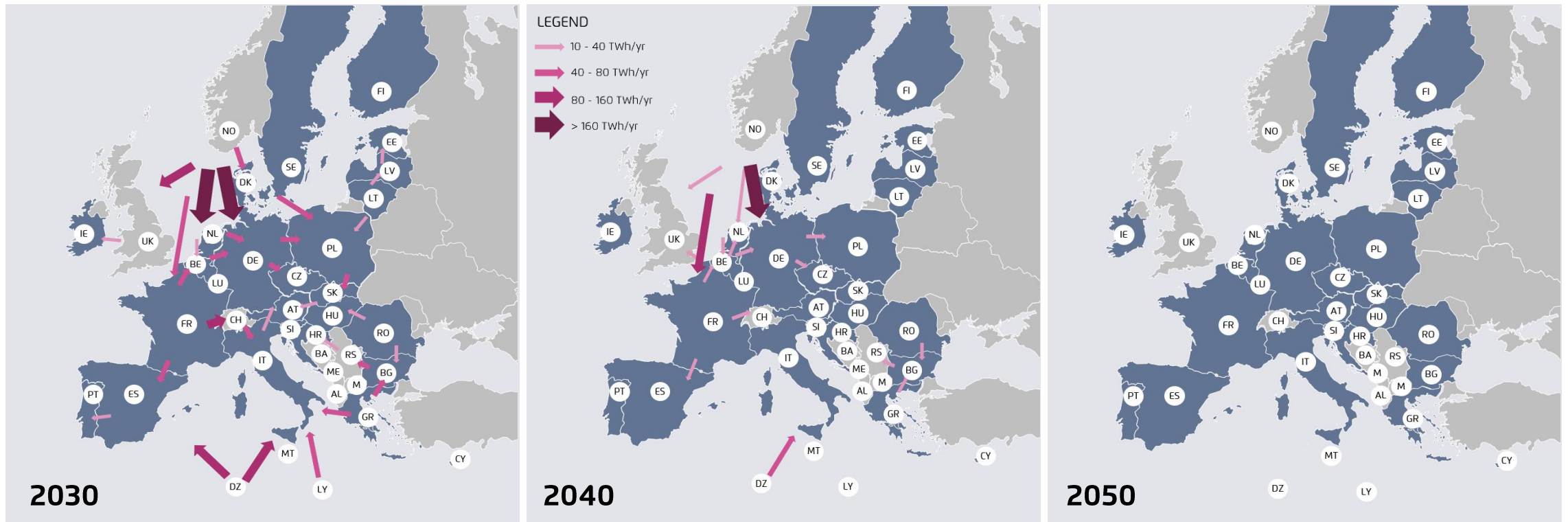
Load factor of electrolyzers



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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

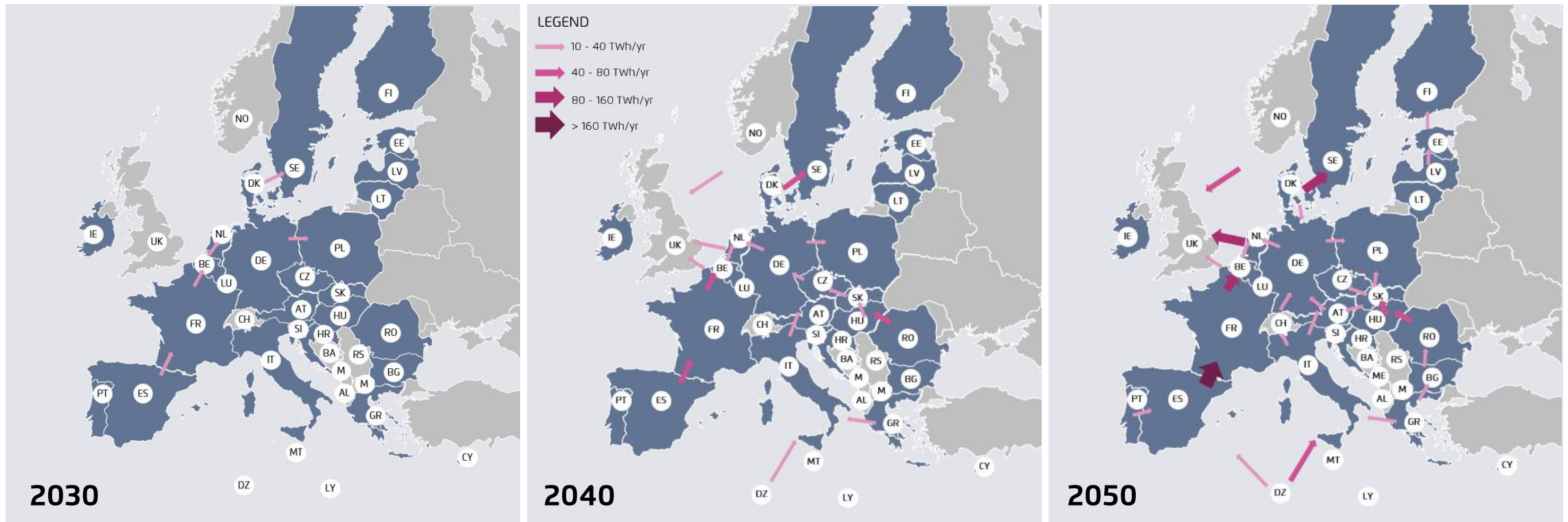
Methane flow through pipelines in Europe in 2030, 2040 and 2050



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

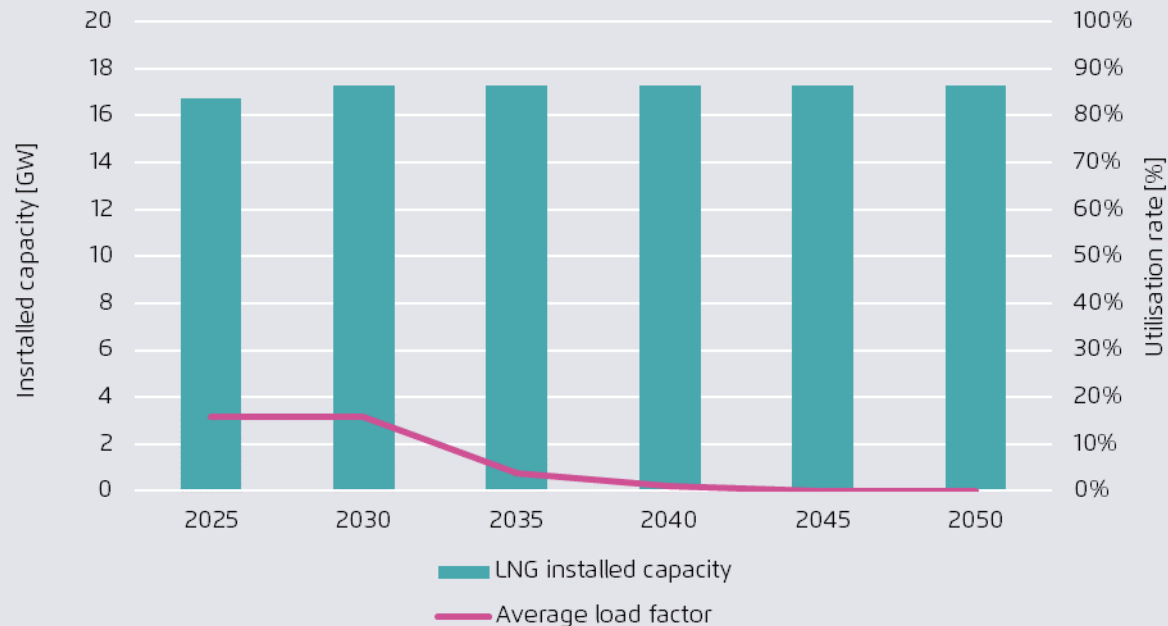
Hydrogen flow through pipelines in Europe in 2030, 2040 and 2050



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, Greece

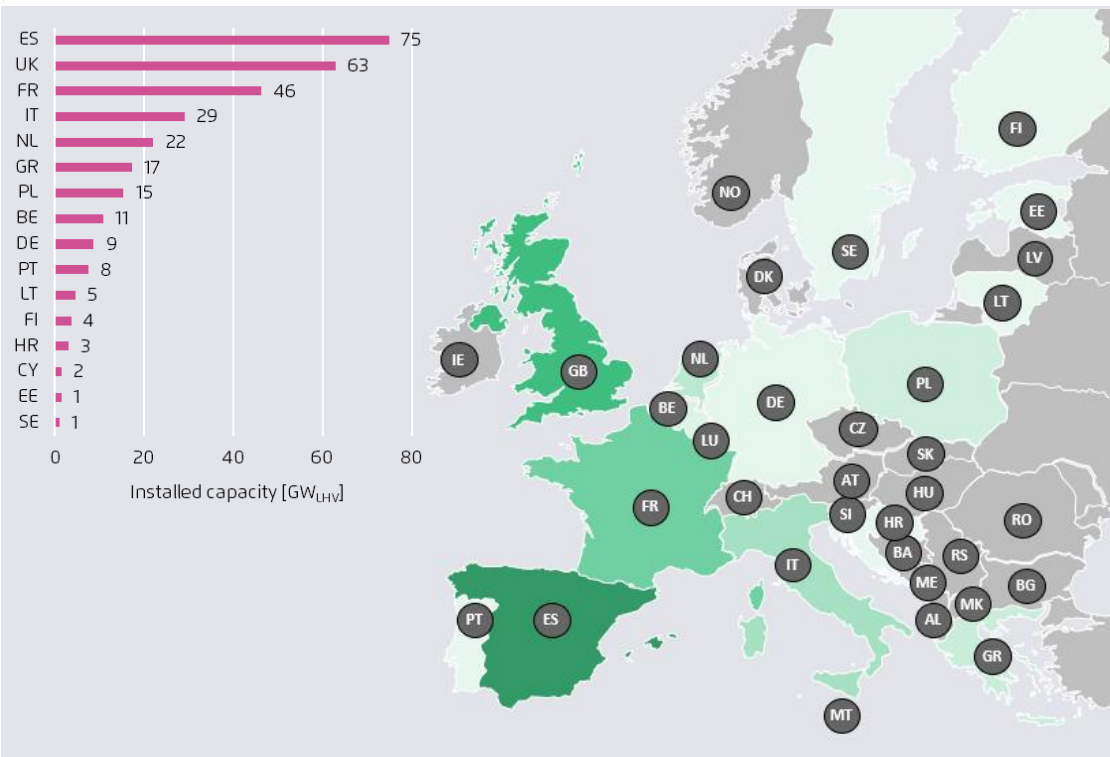


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

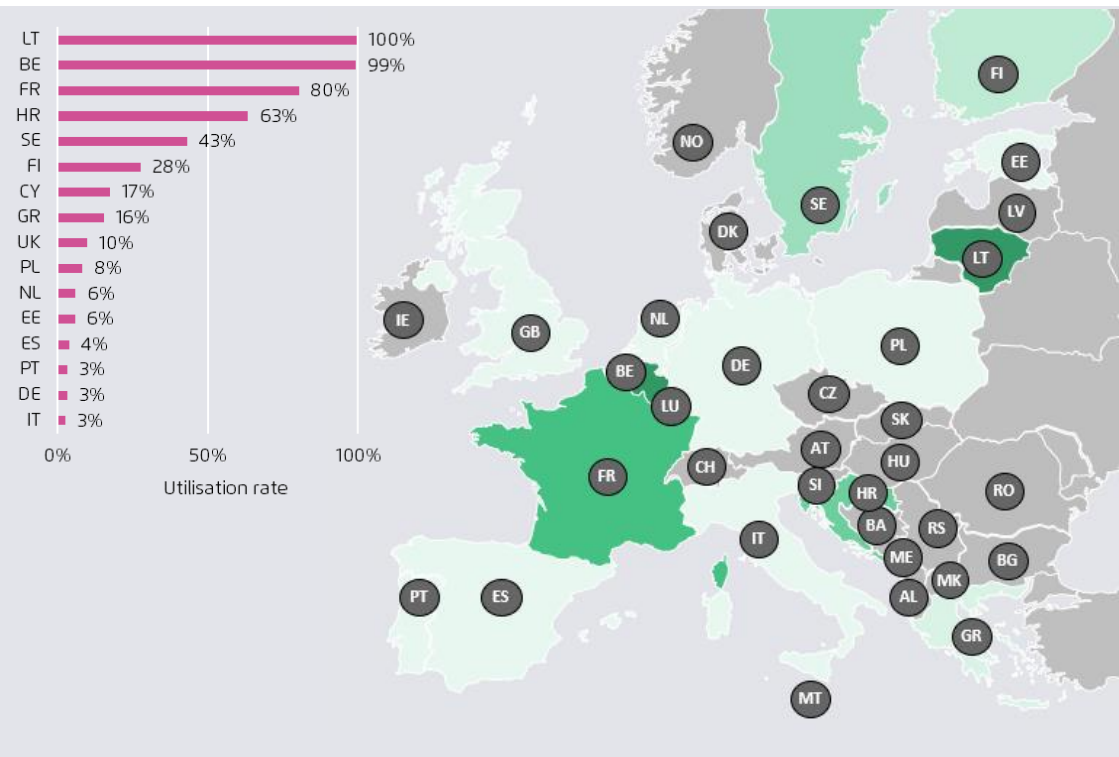
- As a response to the fossil gas supply crisis, LNG import capacity in the EU-27 will expand by 21%, or 53 GW compared with 2021. In Greece, a significant increase has been planned, with 4 to 5 additional FSRU units by 2025 for 1 existing that has historically been underutilised (below 20% of capacity).
- If demand declines as it should in order to ensure energy sovereignty and for Greece to achieve its climate targets, those investments will be used very little (average utilisation rate of the terminals will remain at about 16% in 2025-2030, about the historical average) and become stranded assets by the time they are being built.

LNG terminals currently being built in Greece risk becoming stranded assets by 2030 already

LNG terminal installed capacity by country in 2030 (GW)



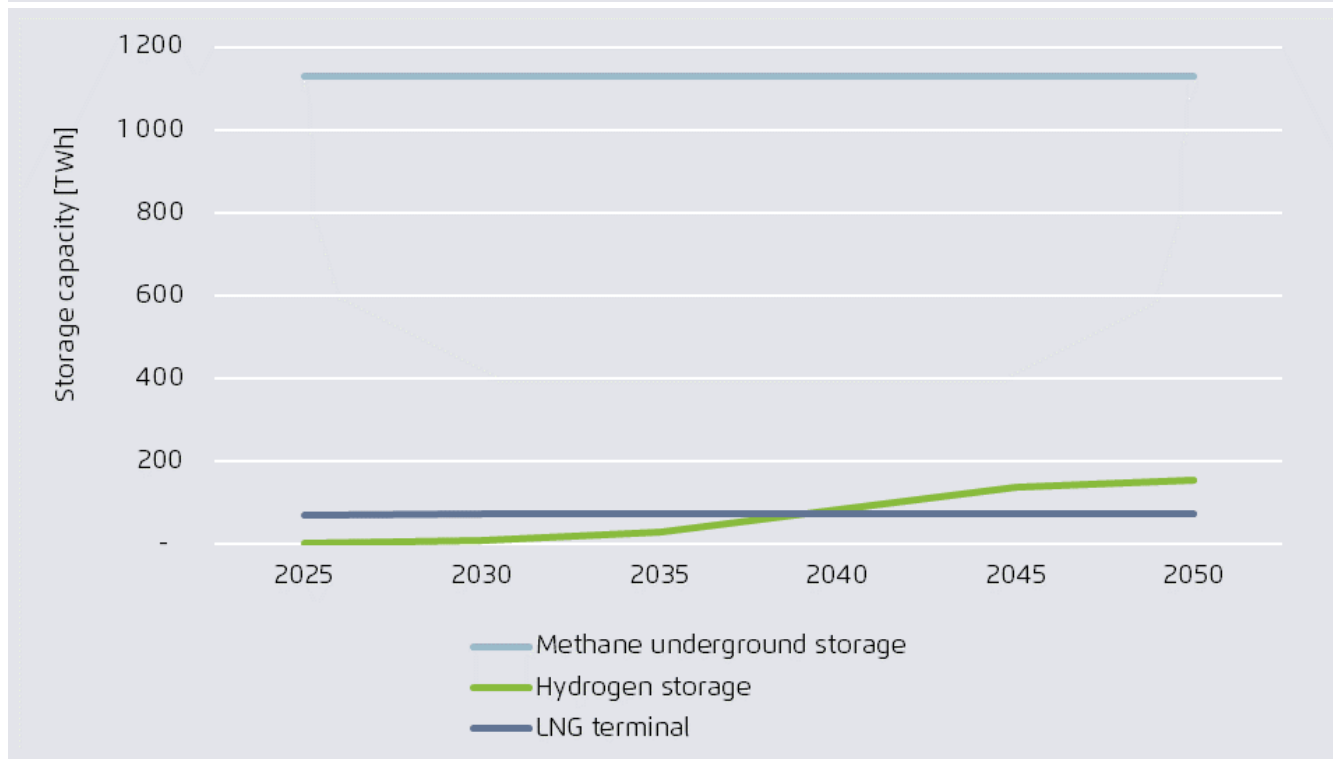
LNG terminal utilisation rate by country in 2030 (GW)



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

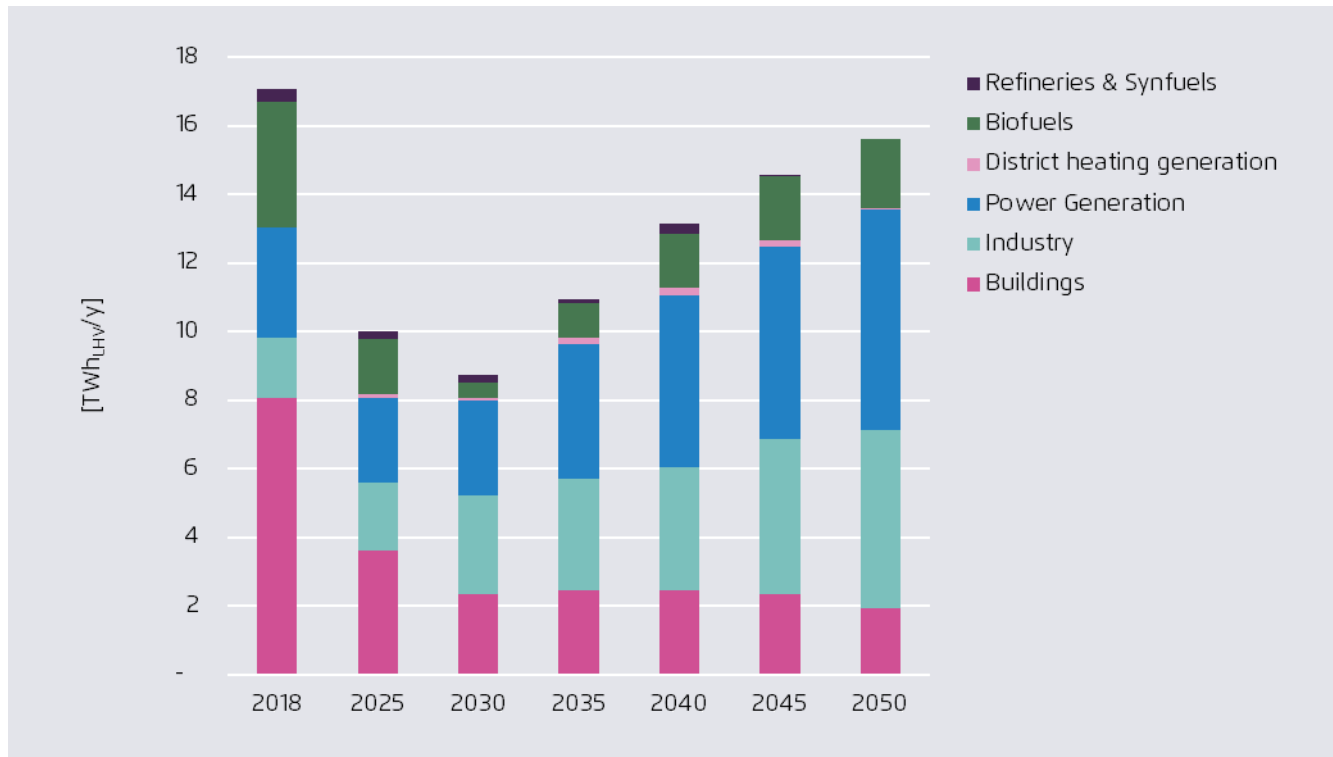


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- 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 Greece



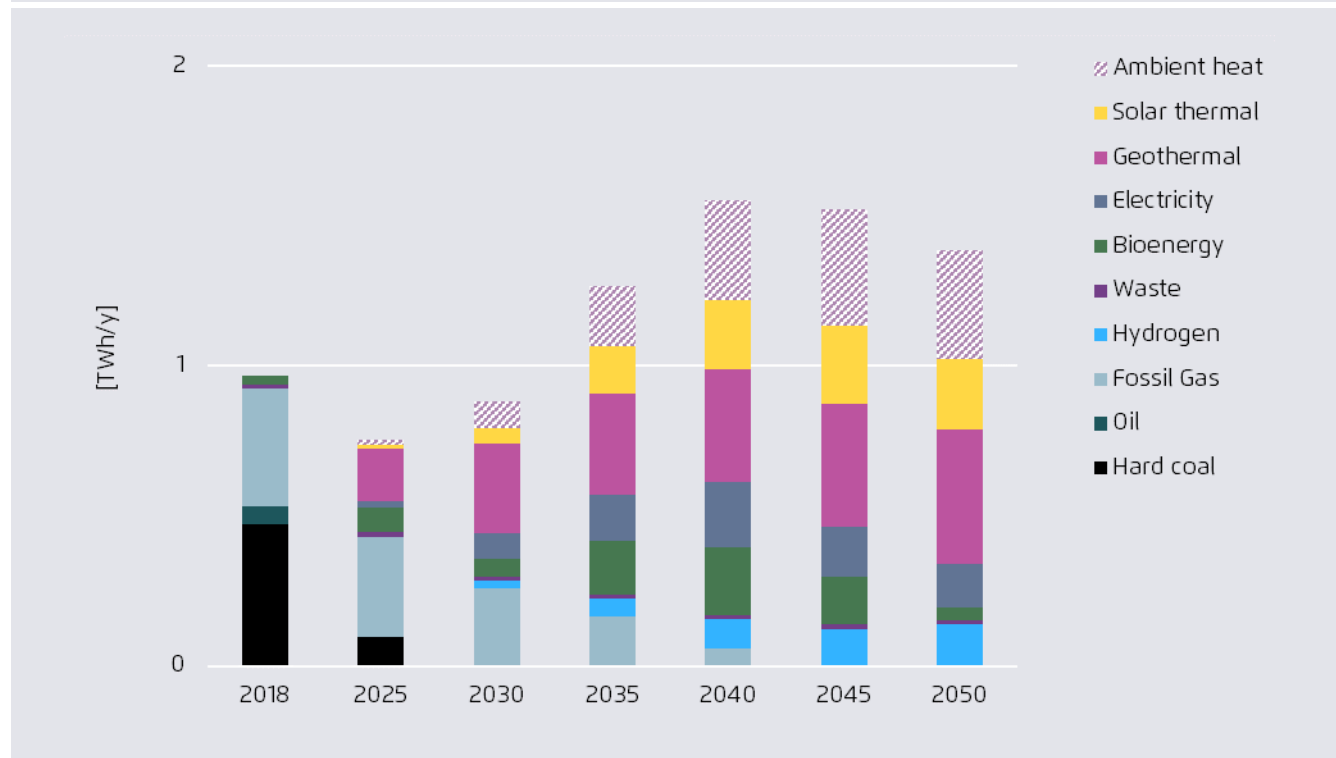
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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.
- Bioenergies are mainly consumed in the buildings, power and industry sectors in Greece.
- Consumption declines from about 17 TWh in 2018 to 15.5 TWh in 2050. It declines by 75% in the buildings sector until 2050, which is strongly being electrified, but triples in the industry and doubles in the power sector.
- 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), Greece

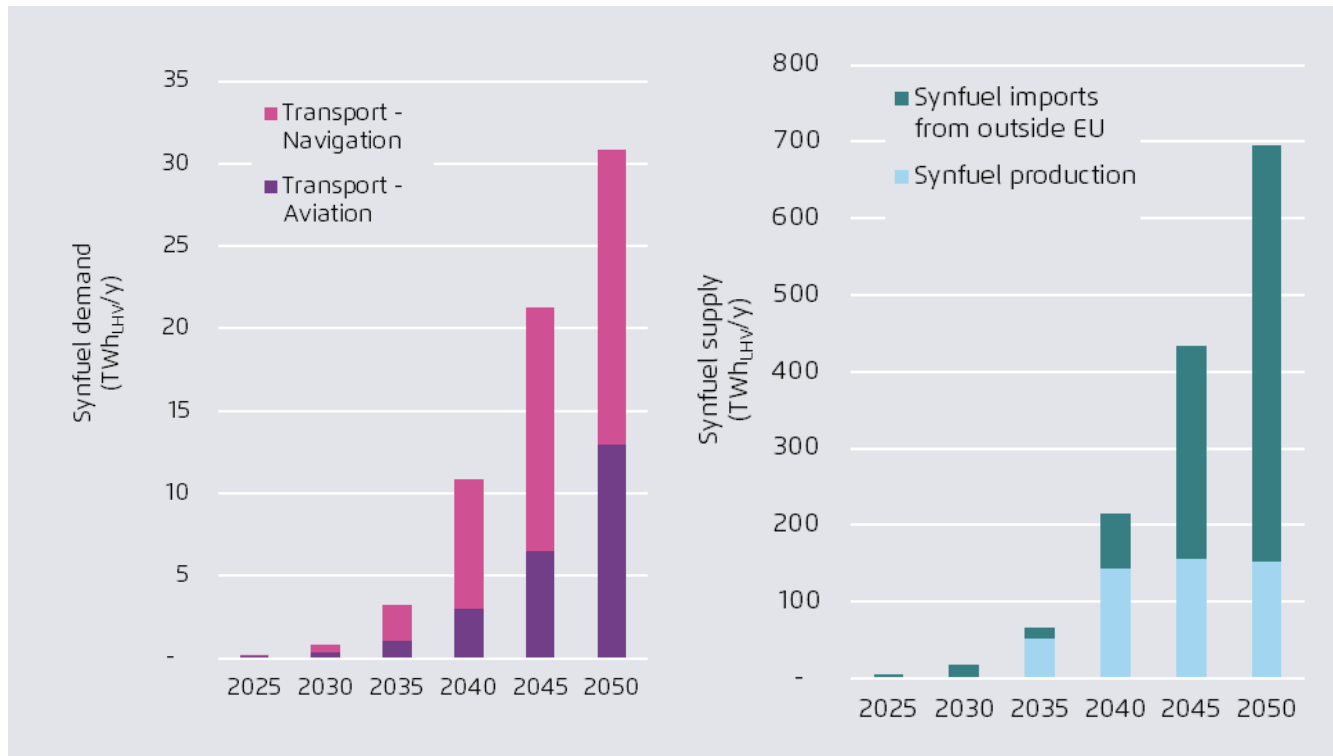


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- In 2018, the district heating supply mix is dominated by coal (49% of the total) and fossil gas (40%).
- District heating sees a steady reduction in fossil-gas demand, declining by 34% from 2018 to 2030, and is phased out by 2045.
- Fossil gas is gradually replaced by heat-pumps, geothermal and solar thermal. These technologies account for roughly 86% of the energy consumption by 2050 if considering ambient heat.
- Hydrogen and biomass start playing a role in 2030-2035 to replace fossil gas.

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

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

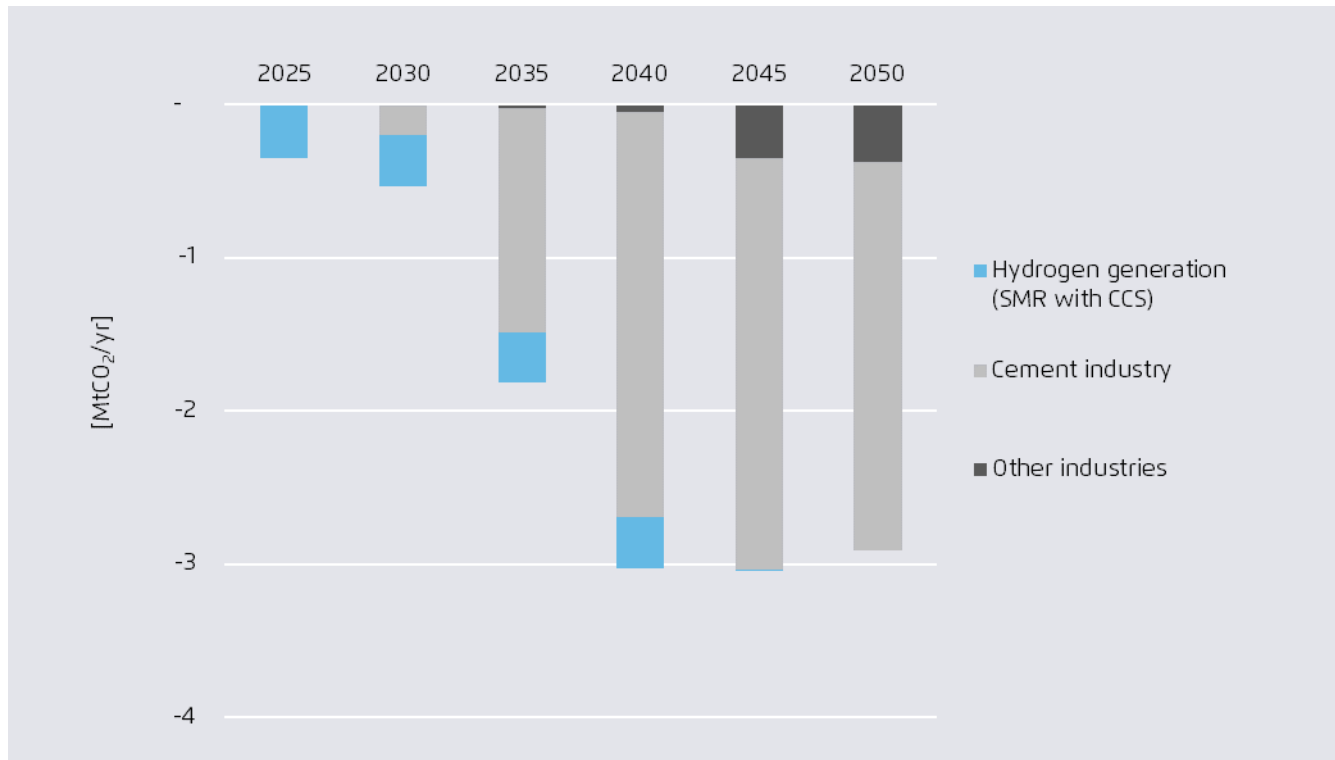


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- 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 3 MtCO₂ per year by 2050.

CCS balance in Greece'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 hydrogen production and 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 (88%).
- The use of CCS in the power sector has not been considered in this study.

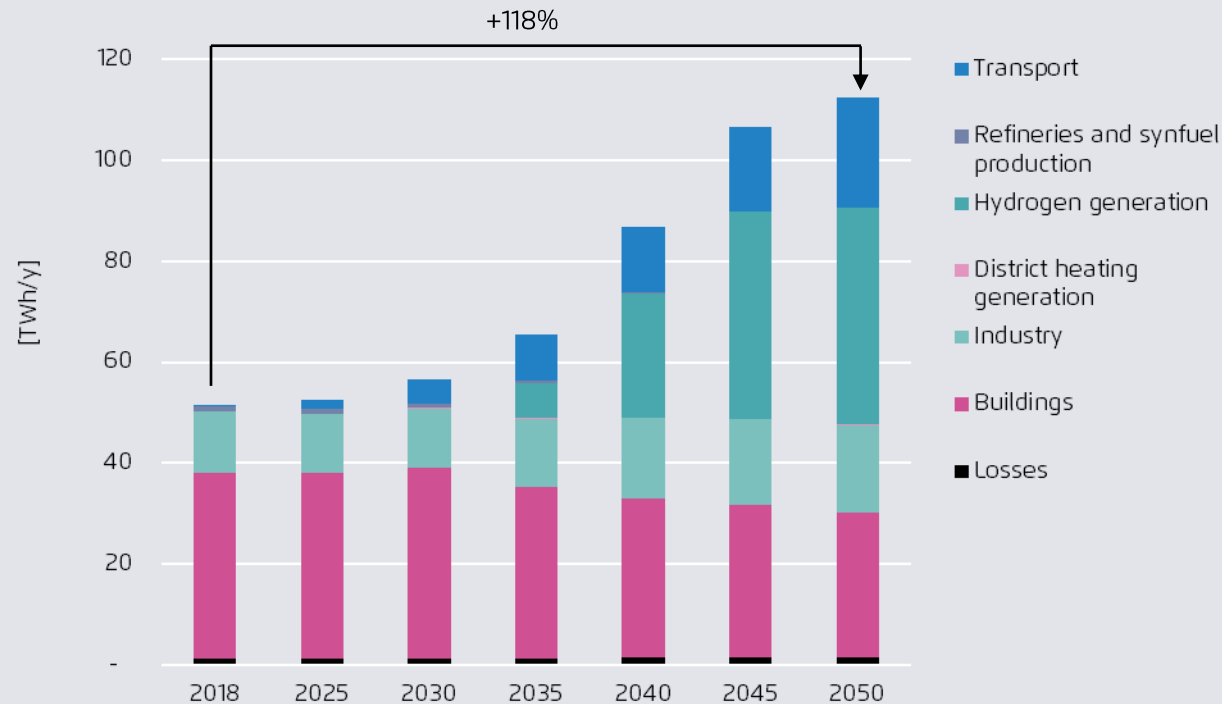
Energy sector:

***Results –
Power sector***



Electricity demand

Power consumption by sector for Greece

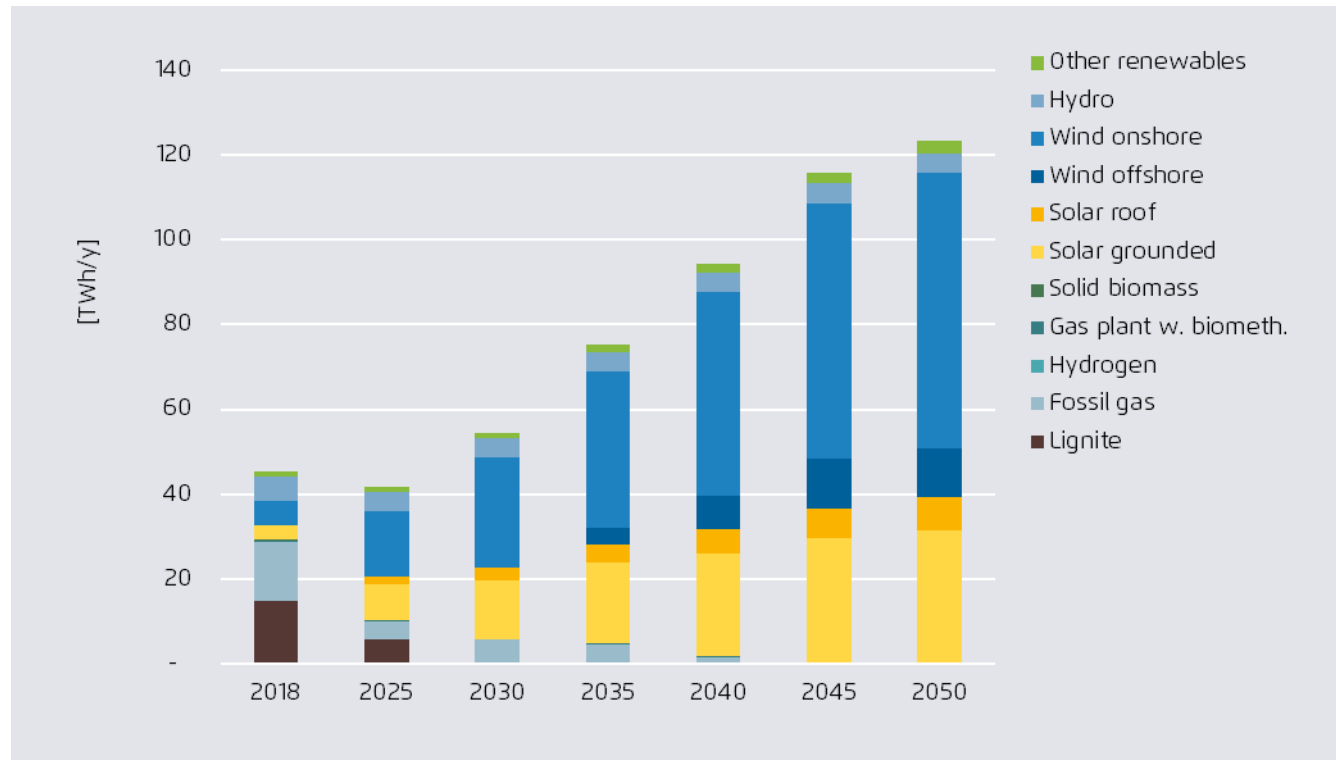


Artelys modelling (2023)

- Total electricity consumption more than doubles between 2018 and 2050.
- The increase is mainly due to electrolysis (+43 TWh) and the electrification of transport (+22 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 declines between 2018 and 2050 (-8 TWh) and only slightly increases in the industry (+5 TWh).

Power generation

Power generation in Greece

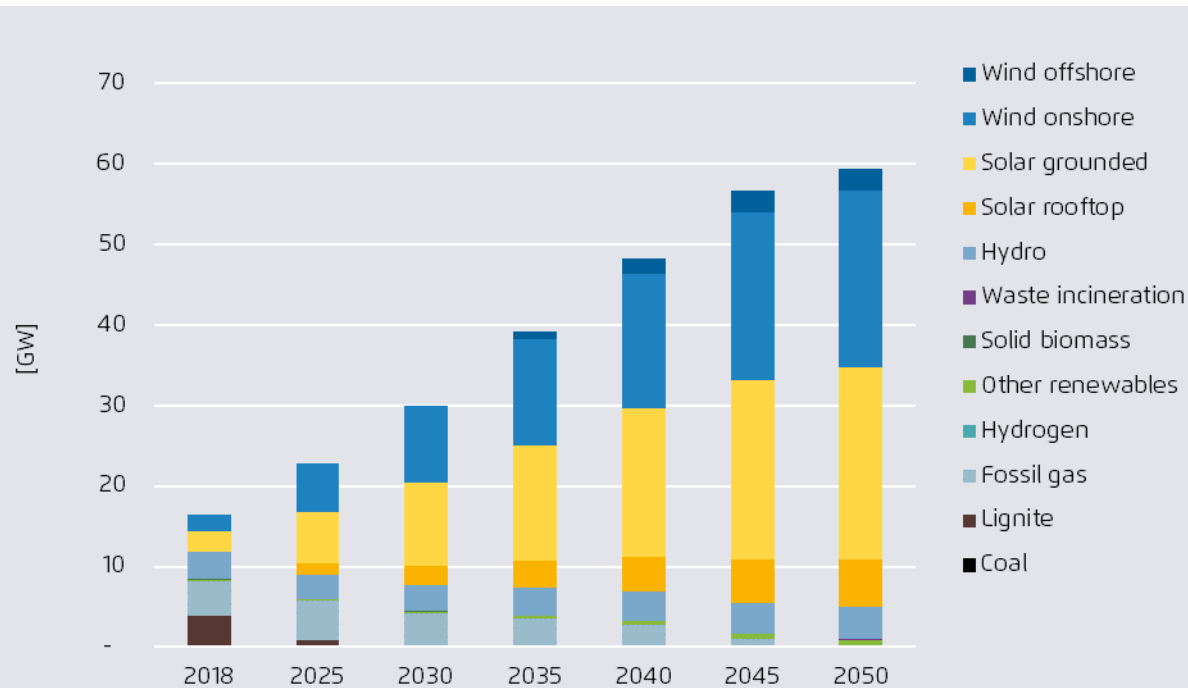


Artelys modelling (2023)

- Lignite is phased out by 2028 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, which represented historically about a third of power generation, decreases strongly between 2018 and 2025 (-71%), replaced by renewables.
- Renewables (solar + wind + hydro + biomass + renewable hydrogen) account for 90% of total power supply by 2030 and 100% by 2045.

Installed capacity

Power generation capacity, Greece

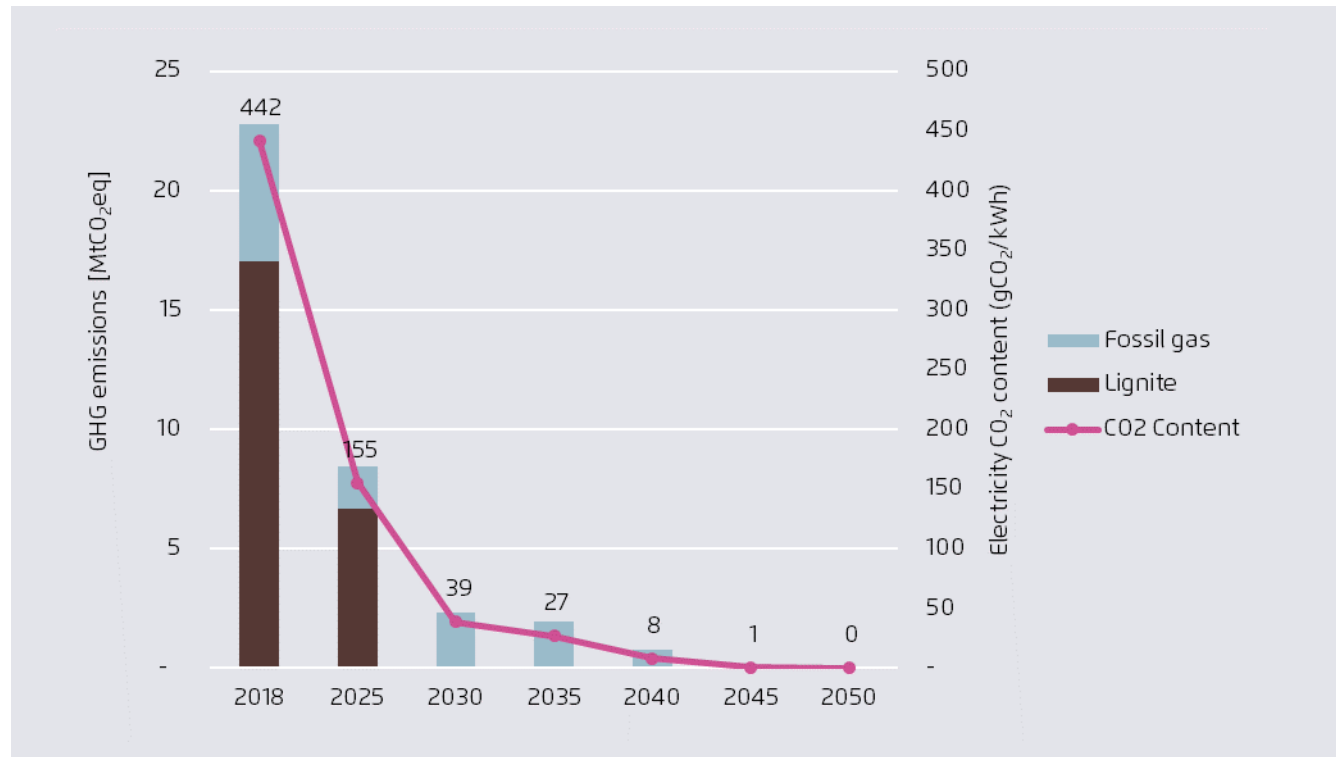


Artelys modelling (2023)

- The power generation mix is dominated by solar and wind power (by 2050, solar accounts for 50% of installed capacity and wind for 41% for a total of 91% of capacity).
- Wind reaches 10 GW by 2030 (onshore wind) and 25 GW in 2050 (22 GW onshore wind and 3 GW offshore wind).
- Solar reaches 13 GW by 2030 and 30 GW by 2050.
- Dispatchable capacities decrease by 97%, from 8 GW in 2018 to 300 MW in 2050.
- From 2040 onwards, gas powered capacities are gradually phase-out. Hydro power and biomass power plants allows to ensure security of supply and flexibility to the system.

CO₂ content Power sector

Evolution of electricity CO₂ content, Greece

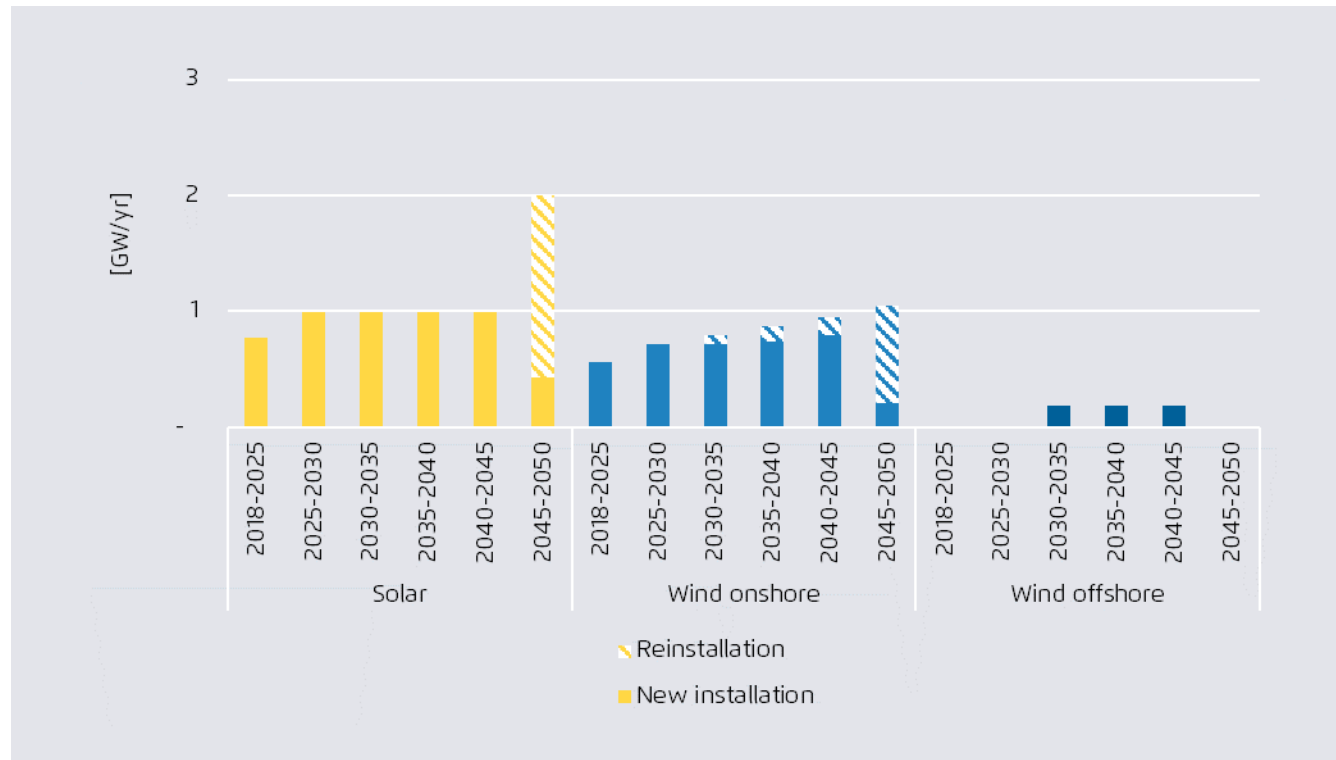


Artelys modelling (2023)

→ The power sector will be almost emissions free by 2030. Some fossil gas will remain in the power sector until 2040, leaving a limited CO₂ content.

Capacity installation rate – renewables

Power generation capacity installation rate per 5-year period in Greece

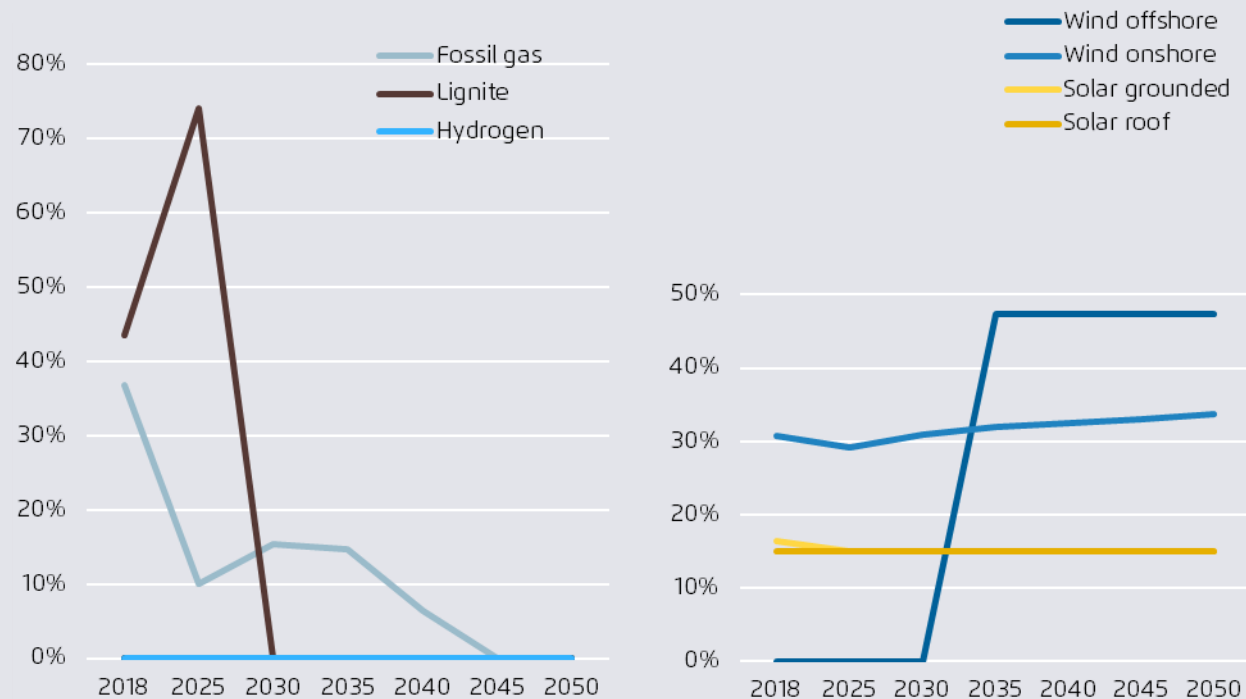


Artelys modelling (2023)

- 1 MW of solar, 800 MW of onshore wind and 90 MW of offshore 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, due to reinstallation (decommissioning of capacities at the end of their lifetime, replaced with new capacities)
- For solar, reinstallation increases strongly from 2045.

Capacity factor of different technologies

Capacity factor per technology (%)

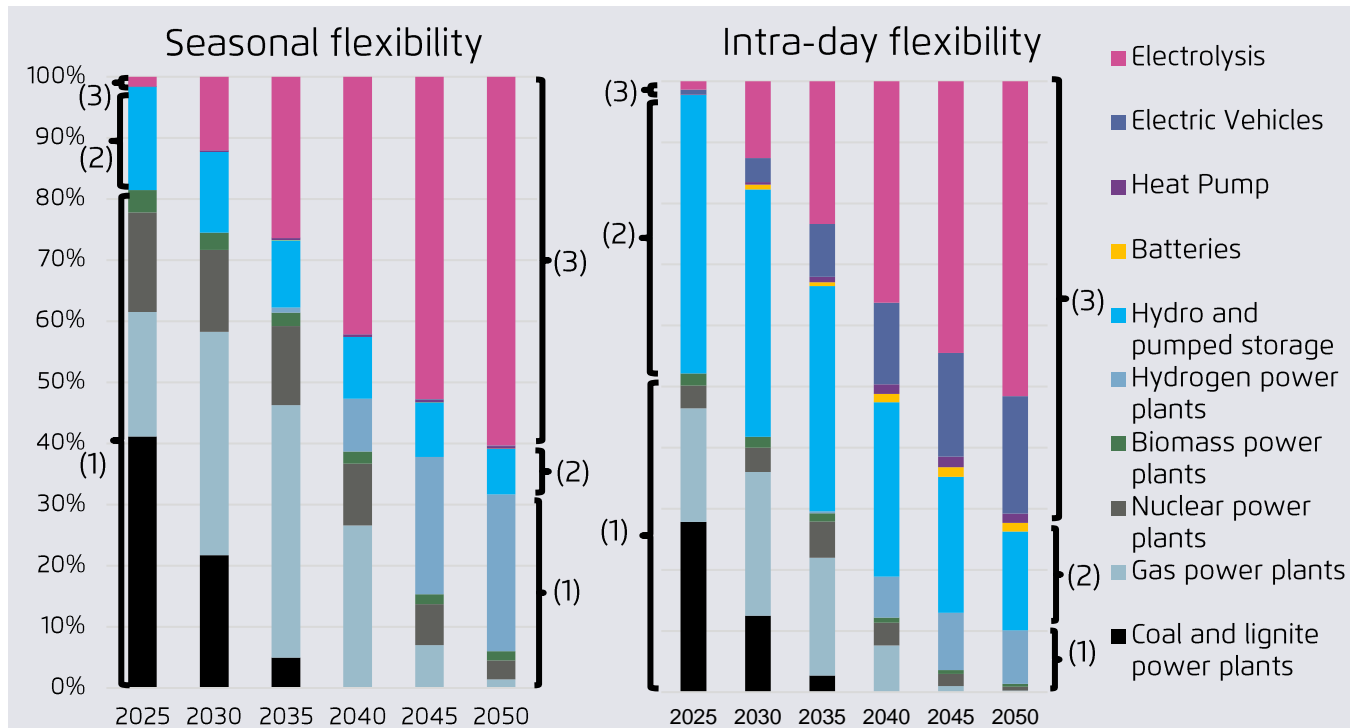


Artelys modelling (2023)

- The average capacity factor of carbon-intensive dispatchable technologies strongly decreases by 2030 already.
- Due to the current context and the high gas prices, the average load factor of gas power plants decreases strongly between 2018 and 2025 (from 37% to 10%). Despite low generation, more than 65% of gas capacities remain online until 2040 to provide flexibility to the system.

Flexibility provision

Evolution of the provision of flexibility in EU-27

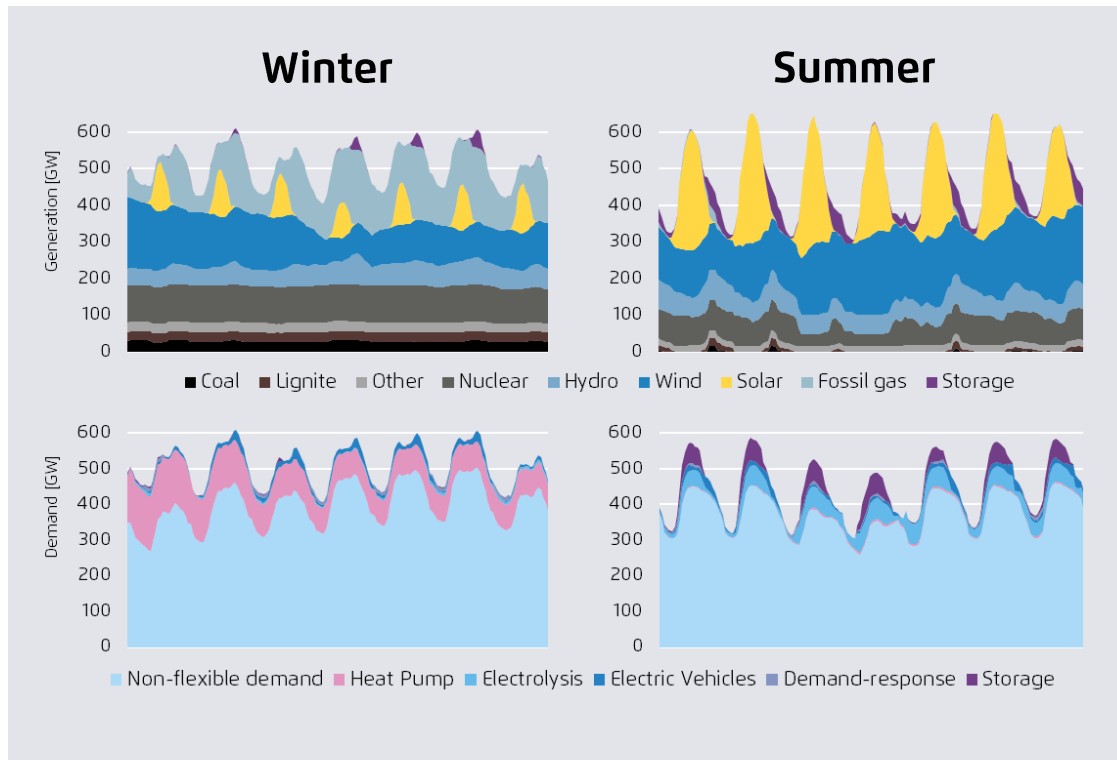


Artelys modelling (2023)

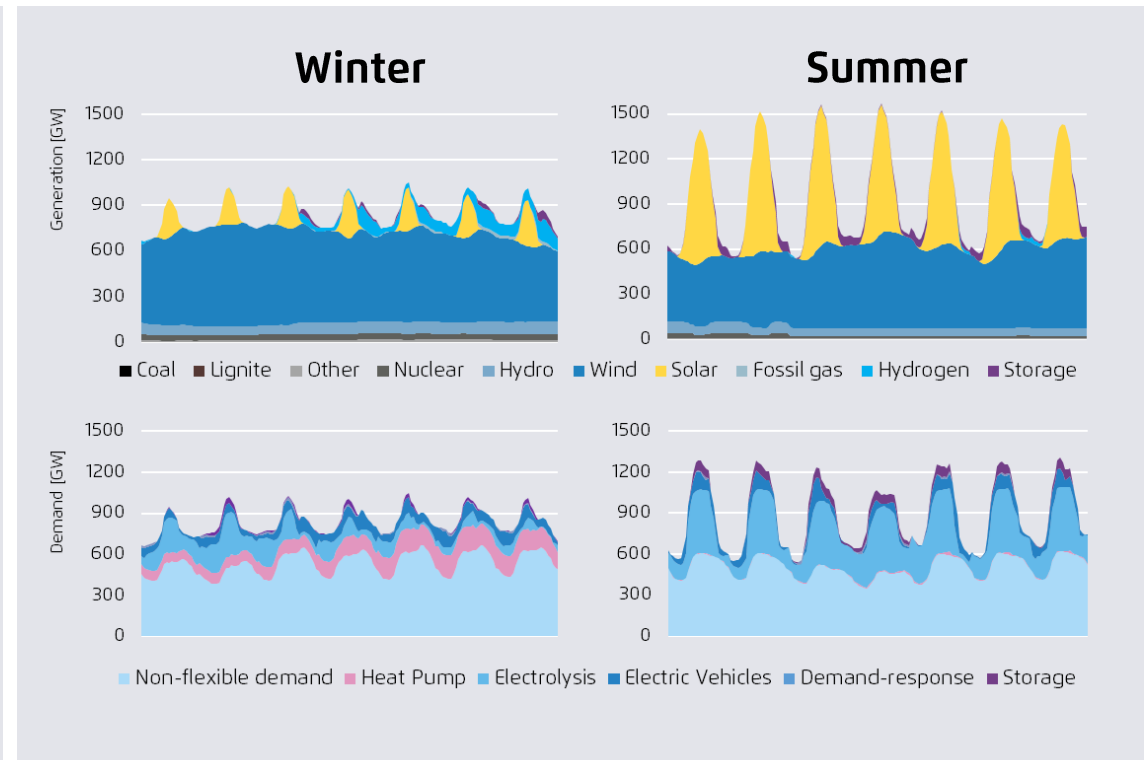
- Currently, system flexibility needs are mainly met by conventional power plants (1) and storage technologies (2) for both seasonal and short-term flexibility
- In future, demand side flexibility (3) will play a predominant role
 - Electrolysis alone will provide 60% of the seasonal flexibility needs 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.
- Hydro and pumped storage continue to offer the same level of flexibility over the transition, though its share in overall flexibility services declines. In Greece, biomass capacities will be also delivering flexibility to the power system.
- 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



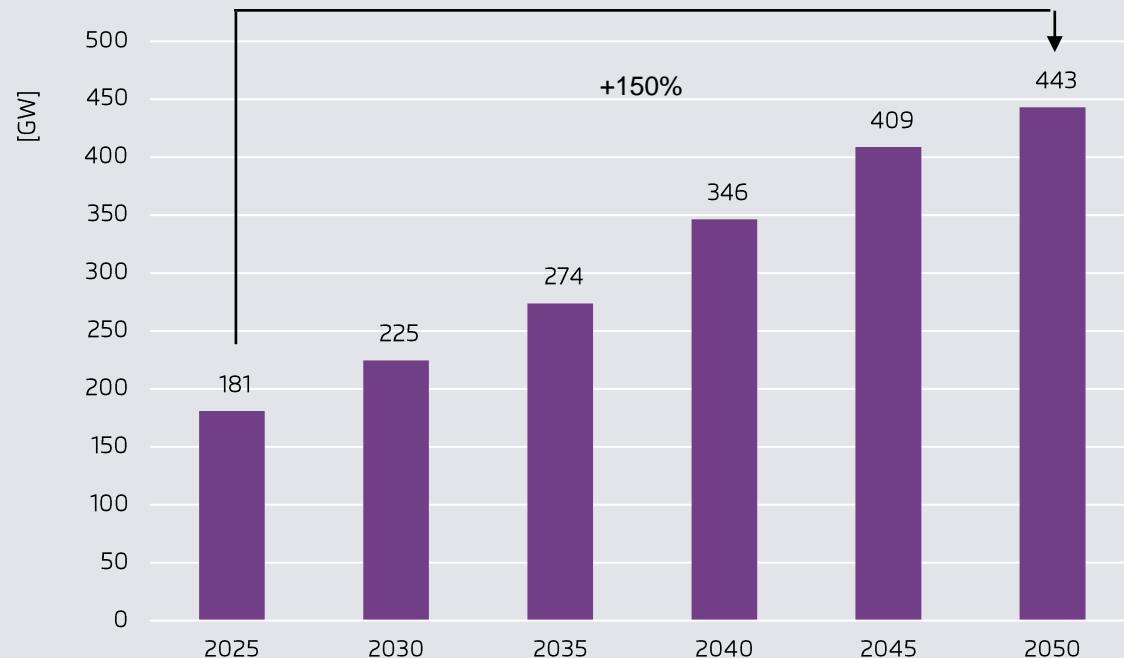
Demand-supply balance during a typical week in 2050 in the EU



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.

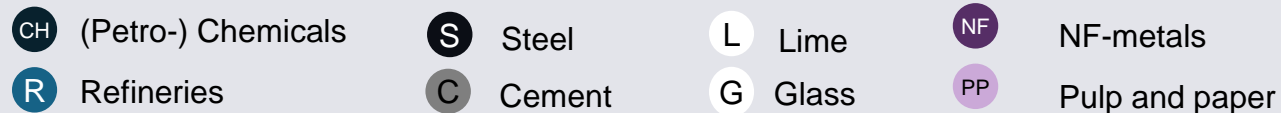
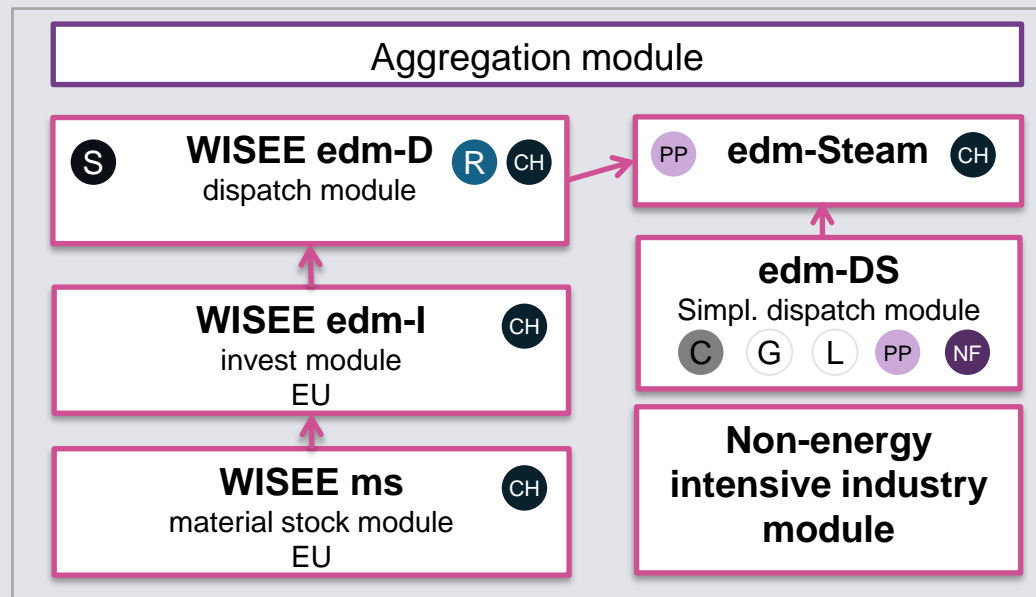
Industry & refineries:

***Methodology and
assumptions***



Industry modelling: country and technology specific

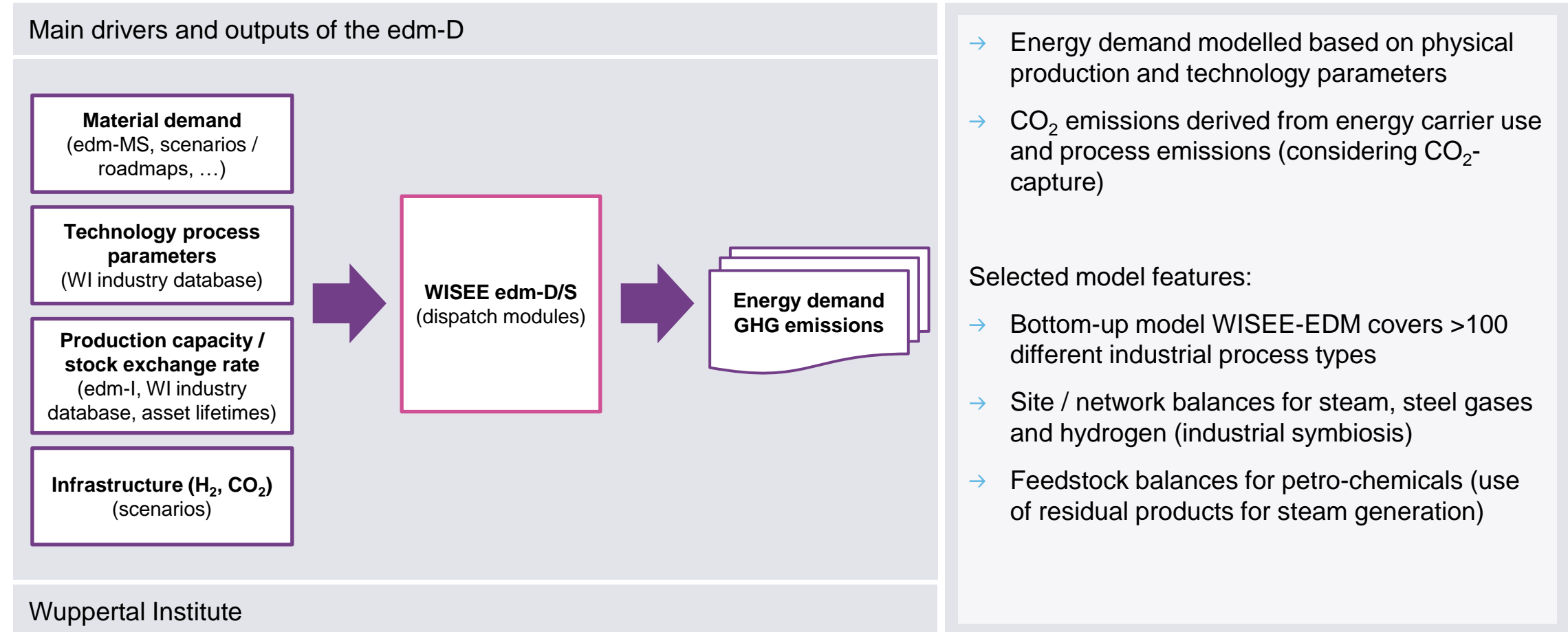
Overview of the WISEE-EDM modelling system



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



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

- **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)

Key parameters

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 H₂ backbone in the country and connection dates for important sites (chemicals, refineries, steel)
- Evolution of the CO₂ 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 MWeI
 - Energy carrier use
 - Electricity shares
 - Full load hours

Industrial sites & infrastructure

- Evolution of the H₂ backbone in the country and connection dates for important sites (chemicals, refineries, steel)
- Evolution of the CO₂ 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

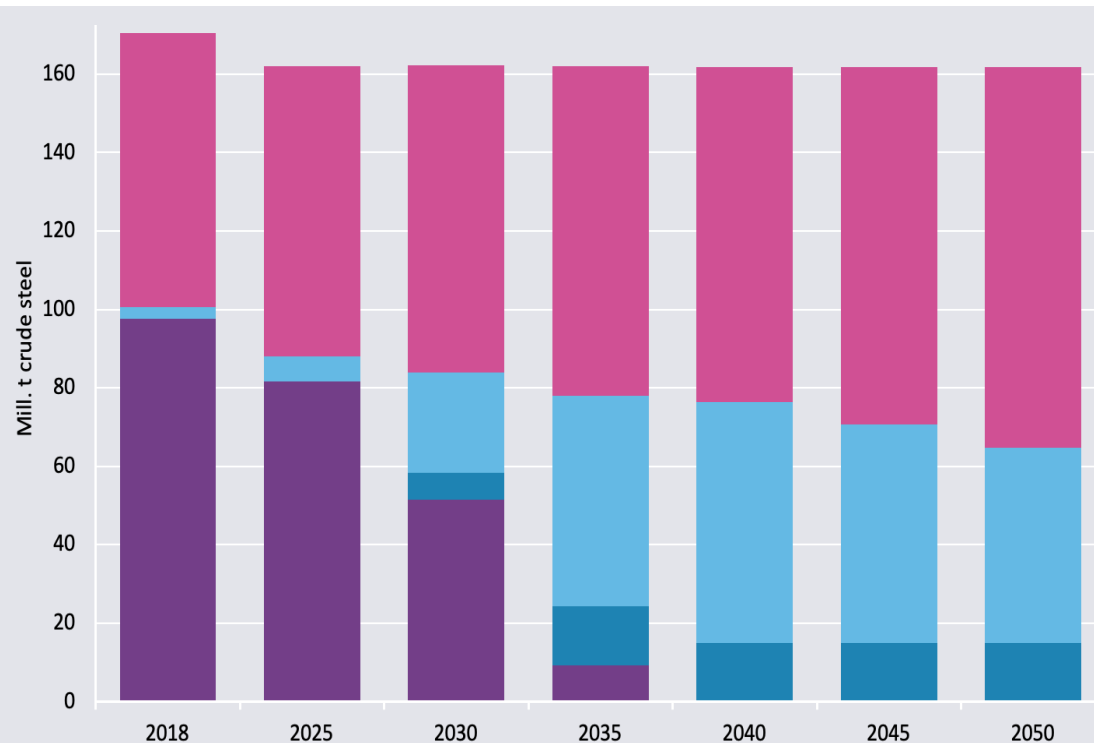
**) Industrial Fuel Switching Market Engagement Study

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 address process-related emissions.
- Focus is therefore on:
 - Efficiency gains and waste firing (in the short term)
 - Biomass firing, (partial) electrification and CCS in the mid- and long-term

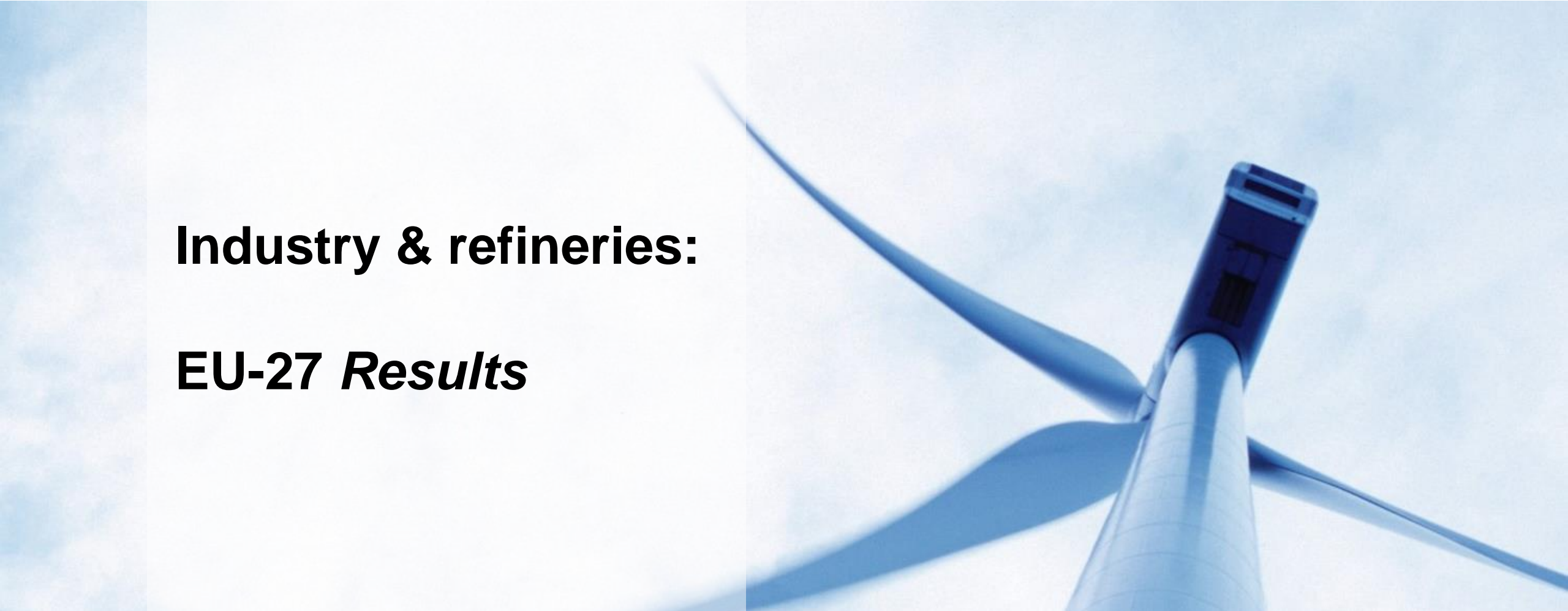
EU refineries

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

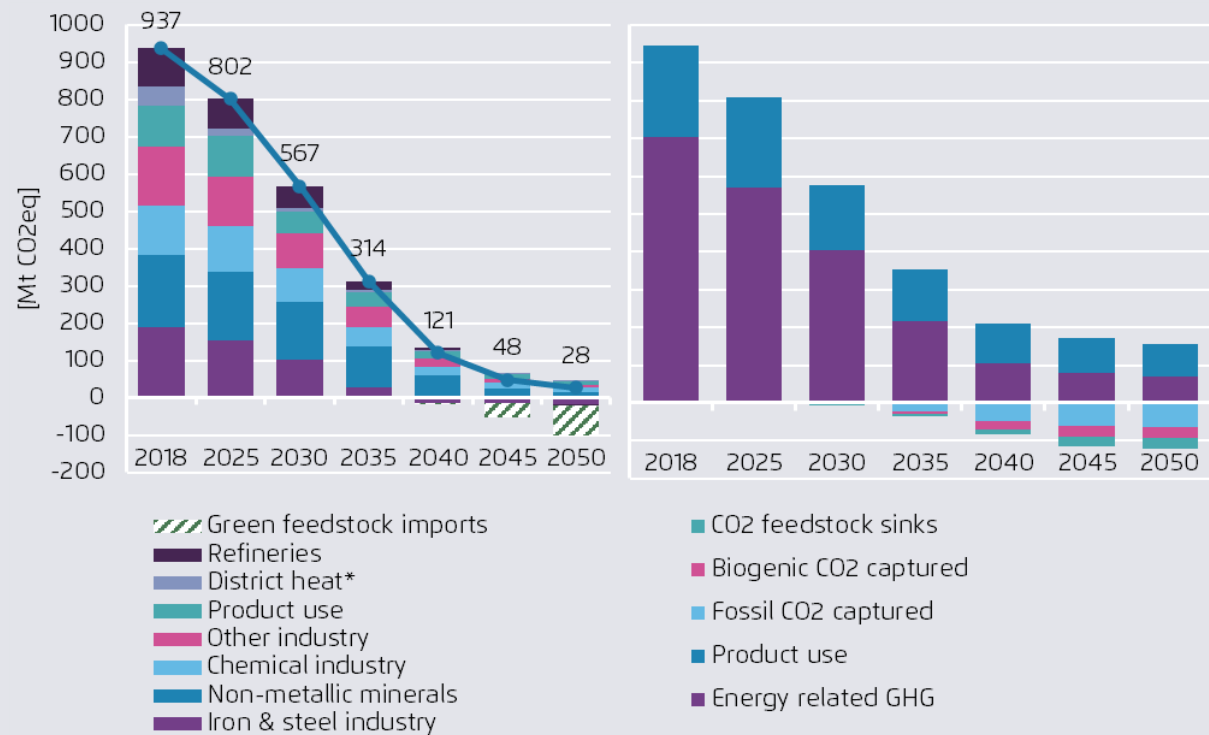
Industry & refineries:

EU-27 Results



Greenhouse gas emissions

GHG emissions from industry & refineries in the EU-27



- 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, ...

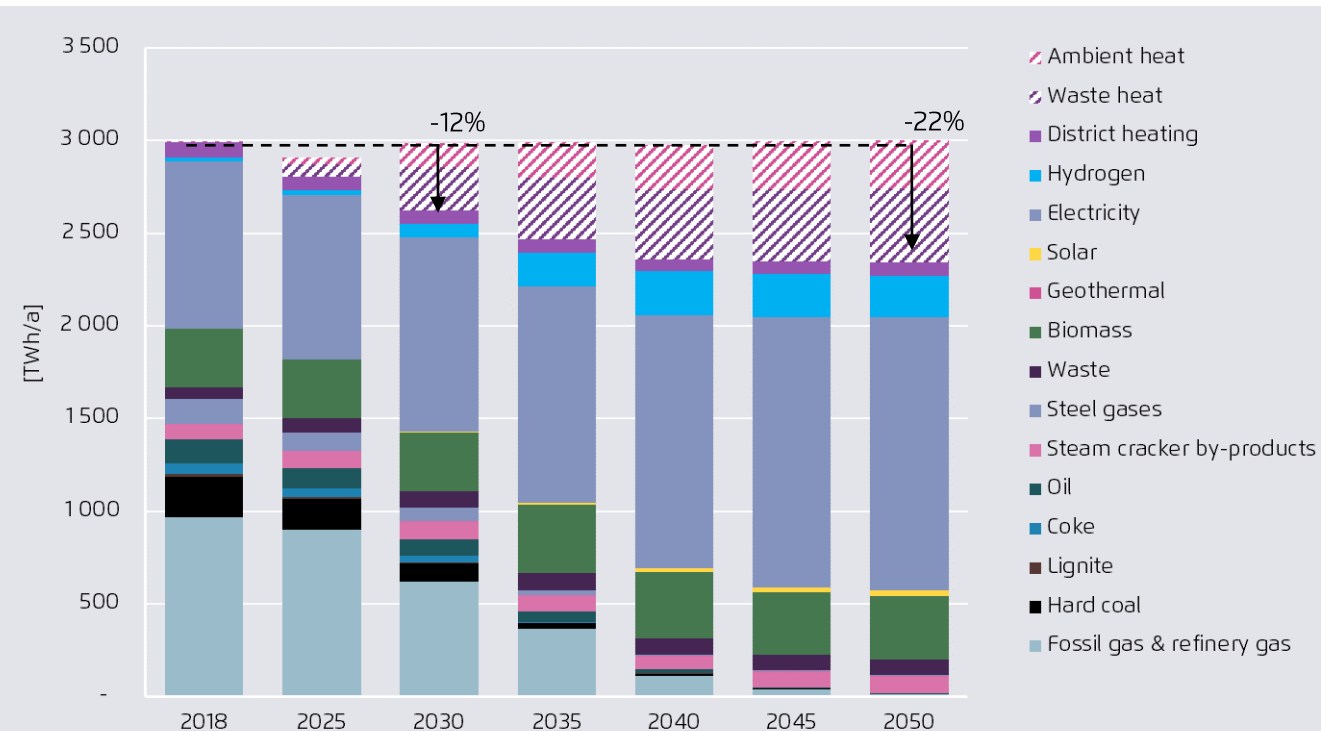
- ...the bulk of emission reductions are achieved in the iron & steel industry (89 Mt CO_{2eq} or 47%).
- ... the non-GHG intensive industries achieve a reduction by 61%, mainly by phasing out fossil gas.
- ... the chemical industry and refineries reduce their GHG emissions by 45 and 46 million tons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

Wuppertal Institute (2023)

* District heat = external heat supply in sectors other than chemicals and refineries

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

Final energy demand in industry in the EU-27

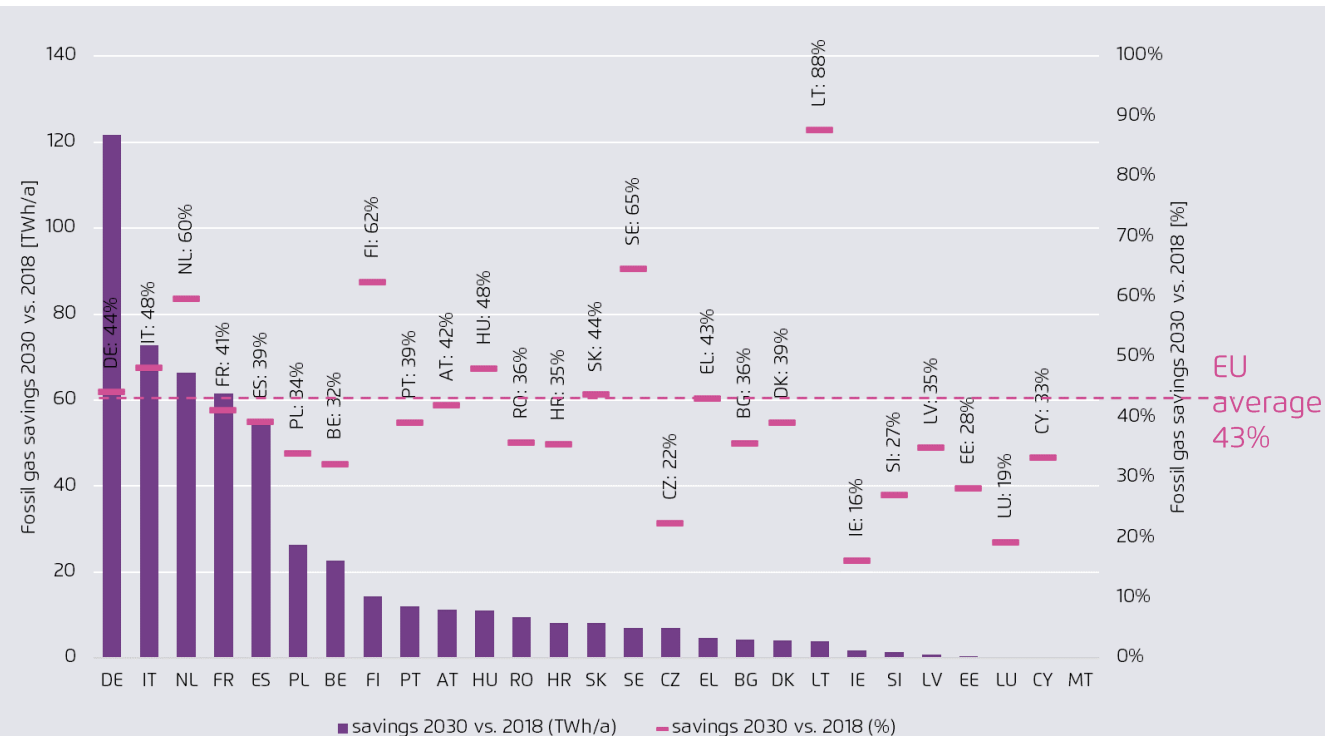


Wuppertal Institute (2023)

- 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

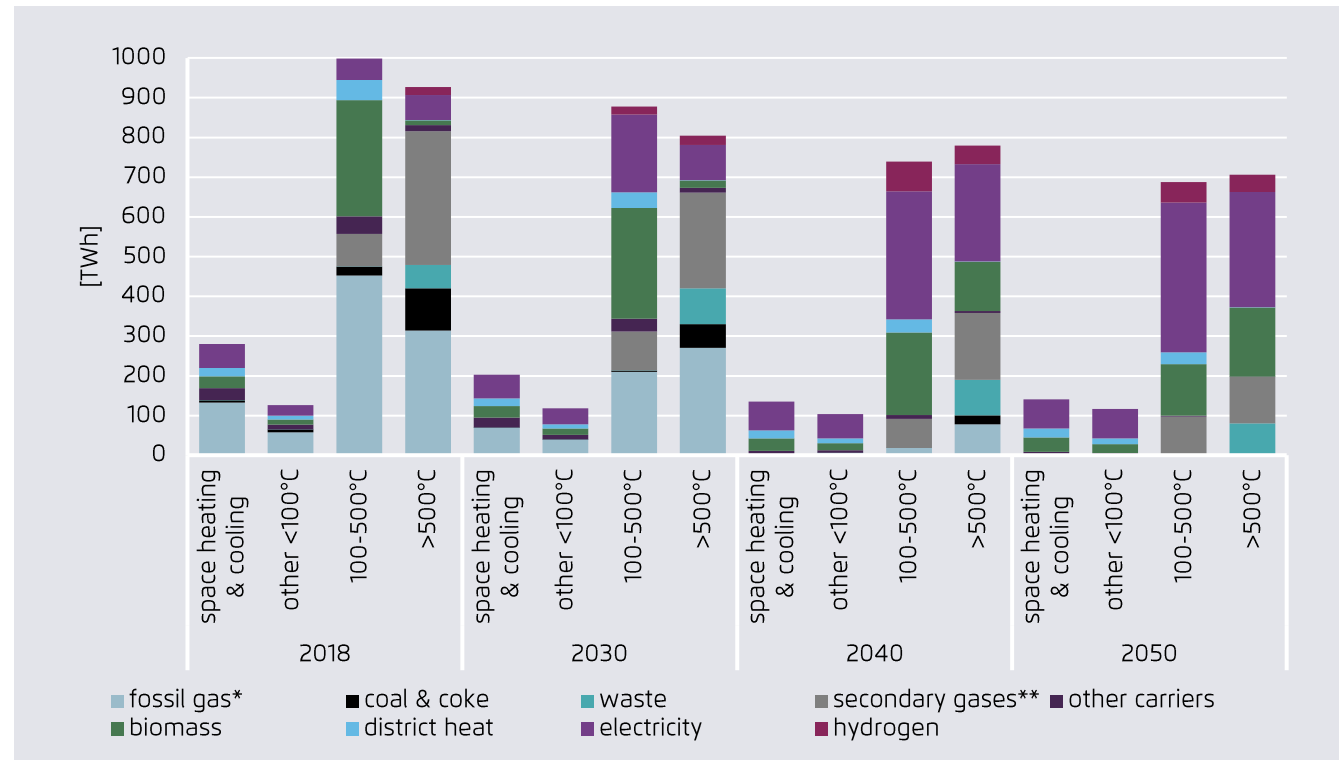


- Savings stretch from 16 to 88% according to the Member State.
- The largest savings are achieved in Germany, Italy, the Netherlands, France and Spain, together representing 70% of the industrial savings in volume.

Wuppertal Institute (2023)

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

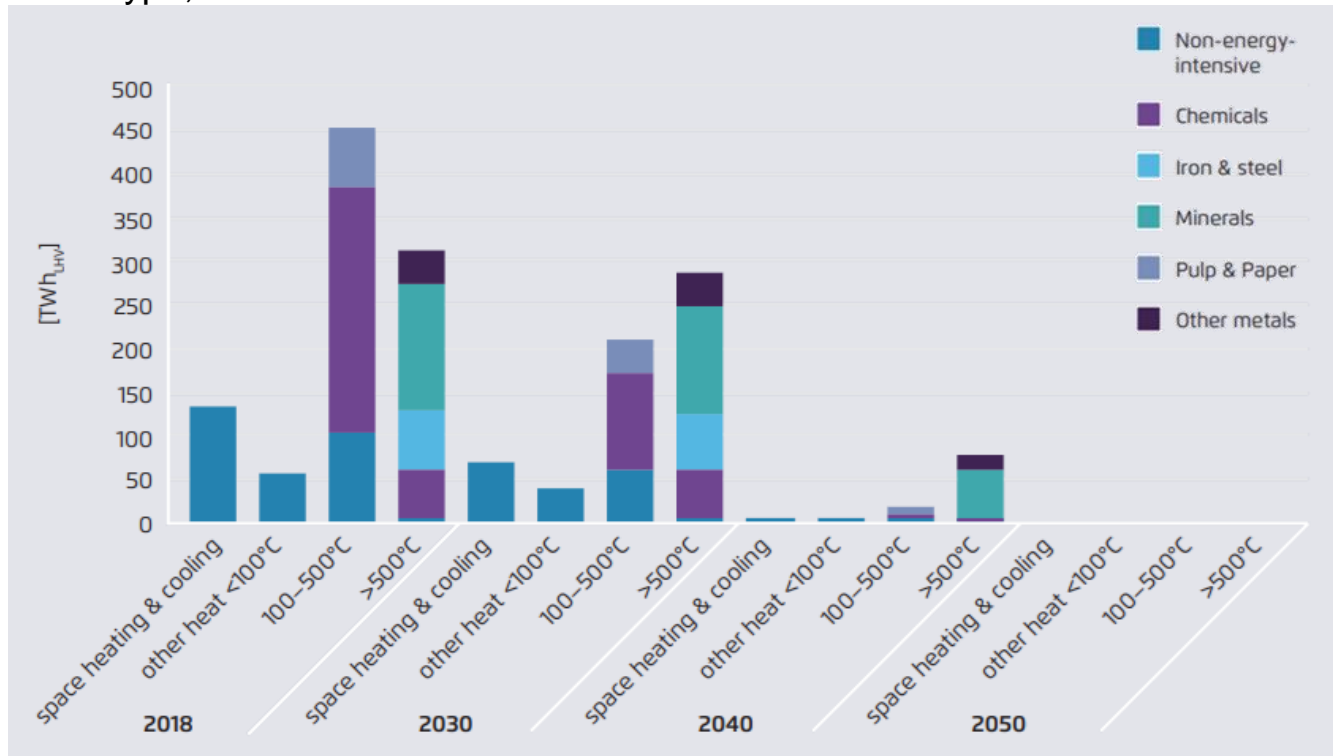


Wuppertal Institute (2023) * "fossil gas" includes fossil gas, refinery gas and LPG; **"secondary gases" include coke oven gas, blast furnace gas, basic oxygen furnace gas and steam cracker by-products

- 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



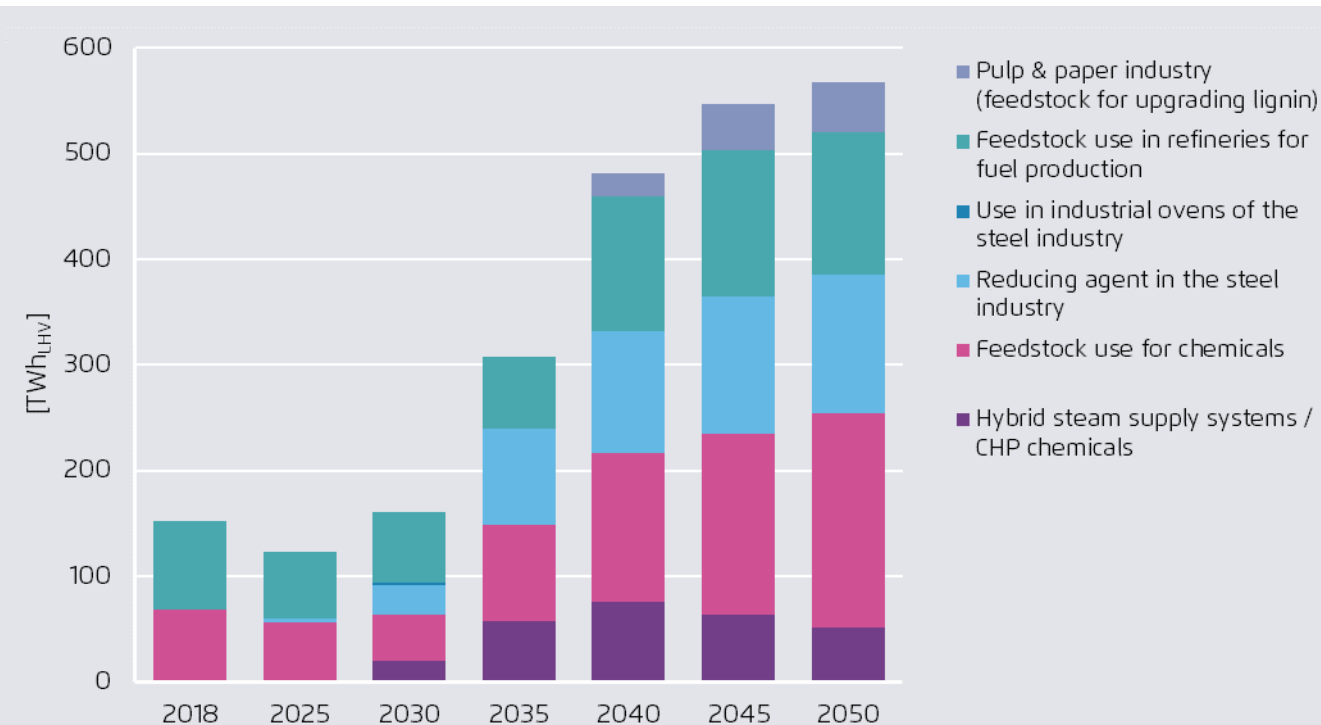
Wuppertal Institute (2023).

* 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

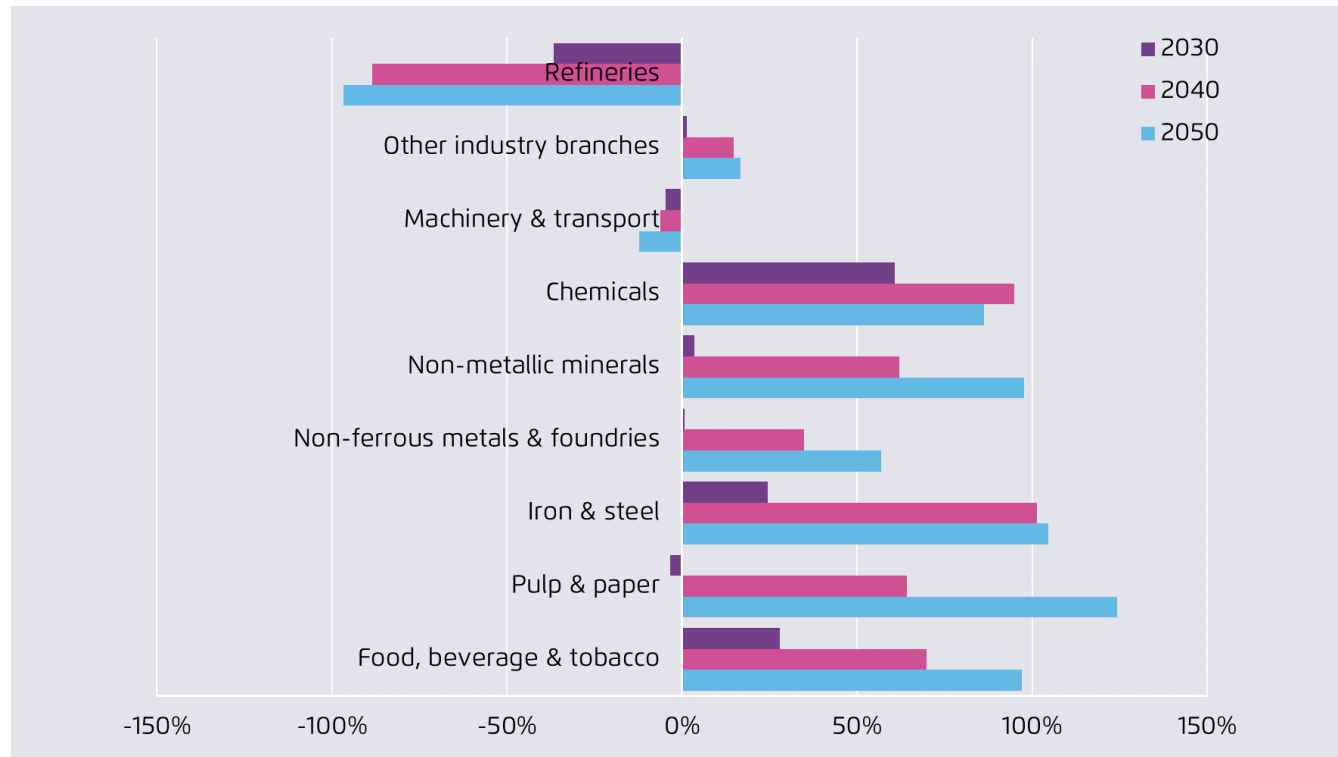


Wuppertal Institute (2023) * Gross hydrogen demand and gross by-production (e.g. by chlorine production) are balanced out, leaving only net demand to be covered by sources such as SMR or water electrolysis.

- 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

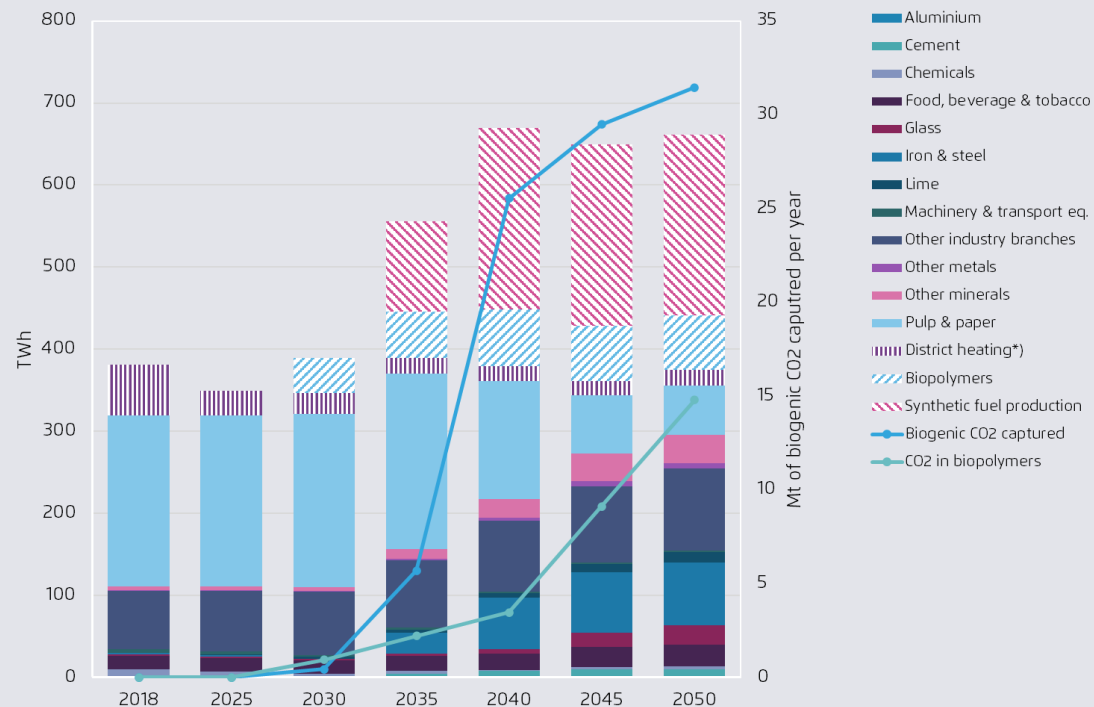


Wuppertal Institute (2023)

- 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

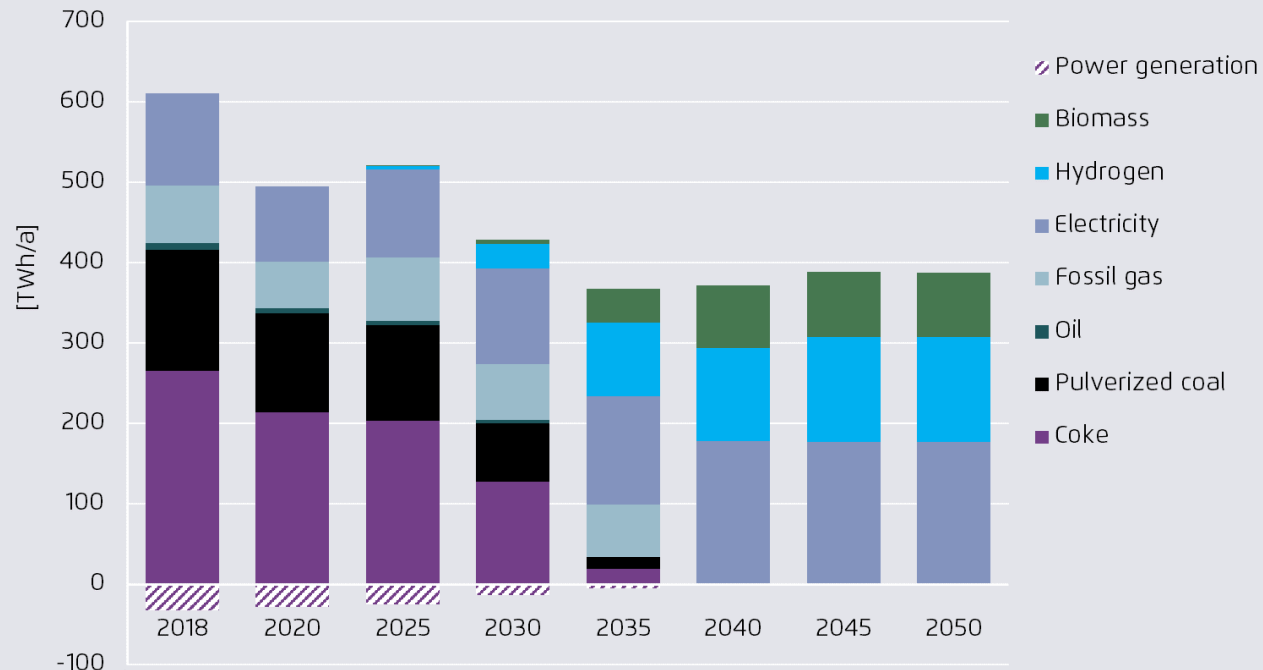


- Biomass demand will shift from pulp & paper production to the glass, iron & steel, minerals and other industry branches, mostly combined with CCS to achieve negative emissions.
- Starting 2030, the production of biopolymers replacing carbon-based polymers will create new demand, as well as the production 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 CO₂ per year by 2050, compared with about 100 Mt through CCS in the industry.

Wuppertal Institute (2023)

Sub-sector transformation: Iron & steel

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

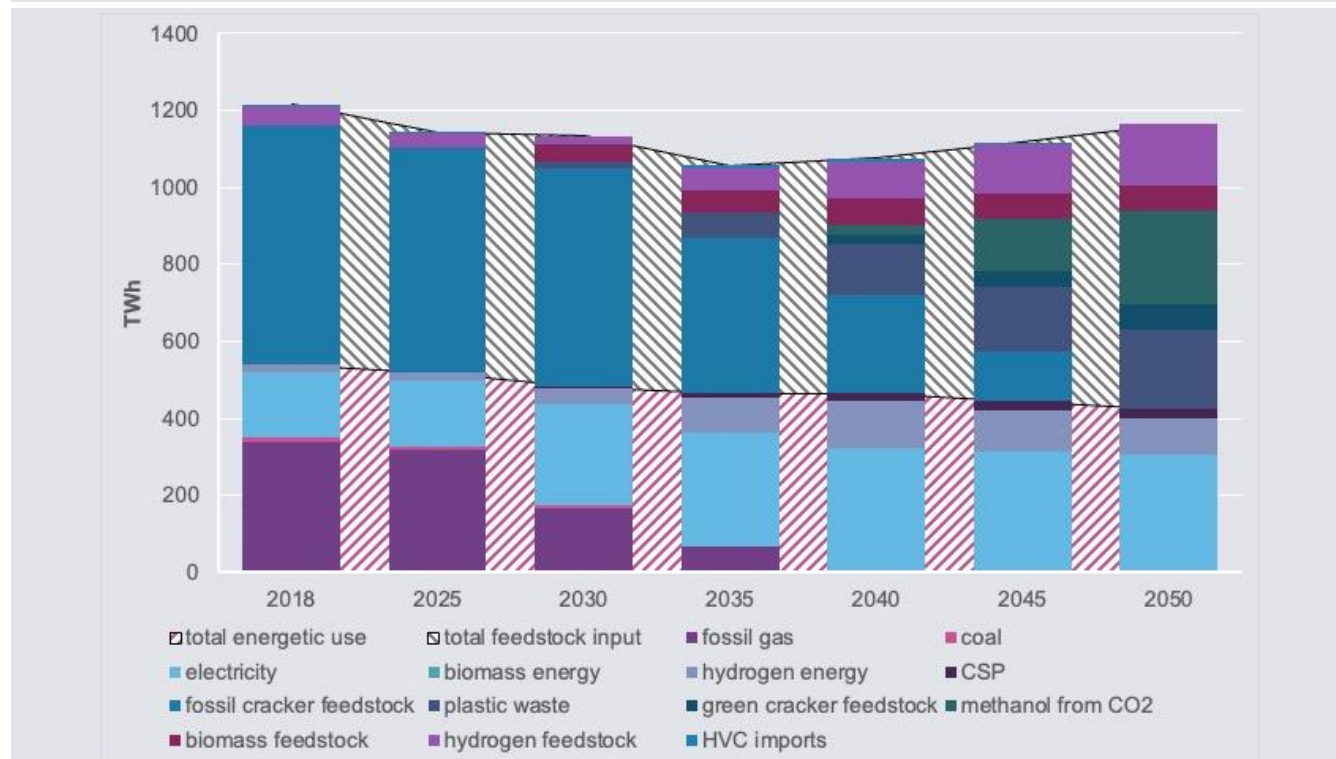


- Thanks to a (limited) shift to secondary steel and a process shift to direct reduction in primary steel production the primary energy demand declines by 28% by 2030 and ca. 35% by 2035.
- Only limited decline in gas demand until 2030, but the sector can be fossil-gas free by 2040.
- Coal and coke use 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).

Wuppertal Institute (2023)

Sub-sector transformation: Chemicals

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

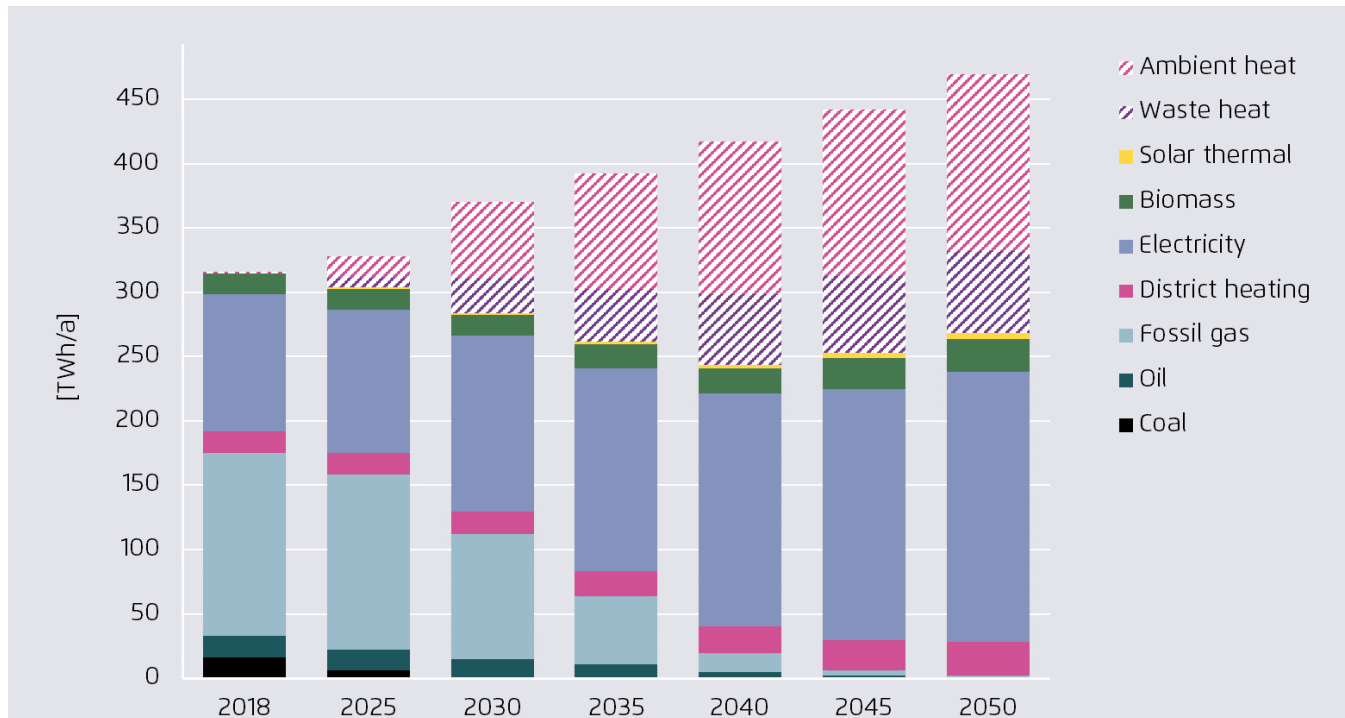


Wuppertal Institute (2023)

- 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 CO₂ 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

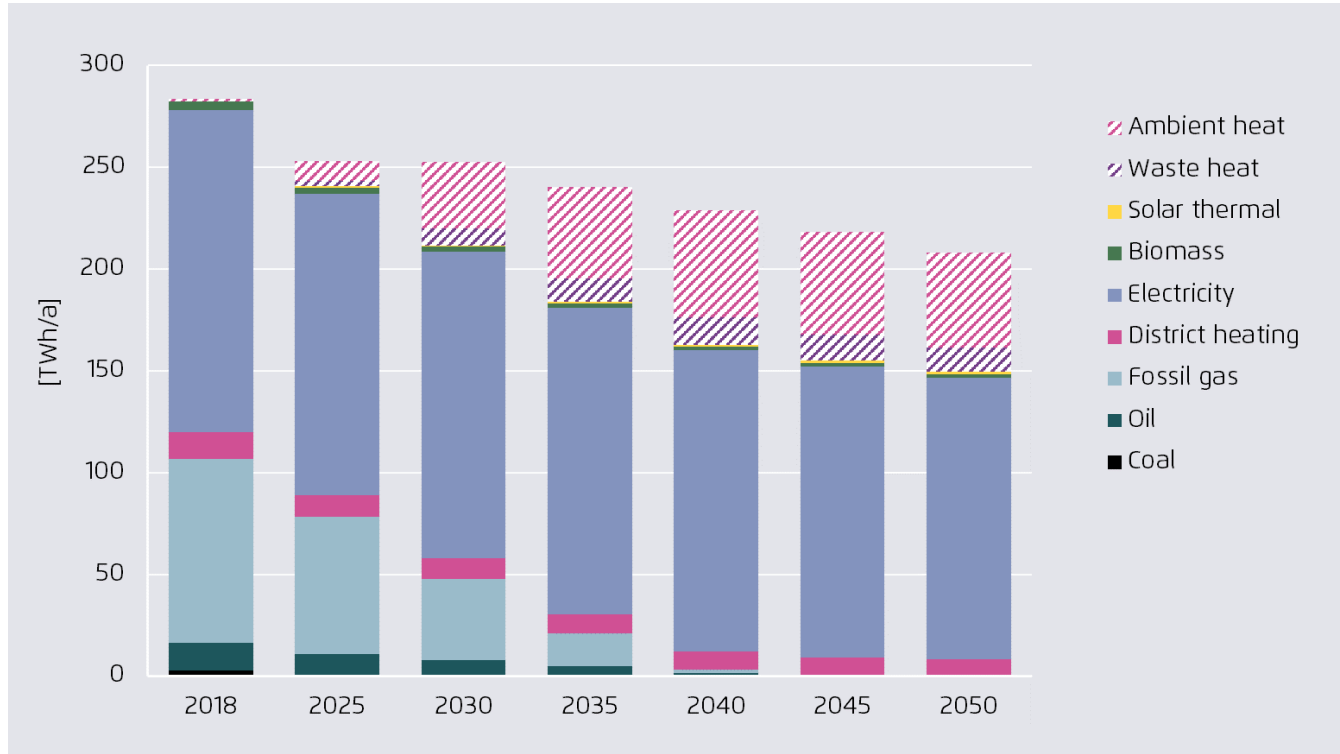


Wuppertal Institute (2023)

- 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

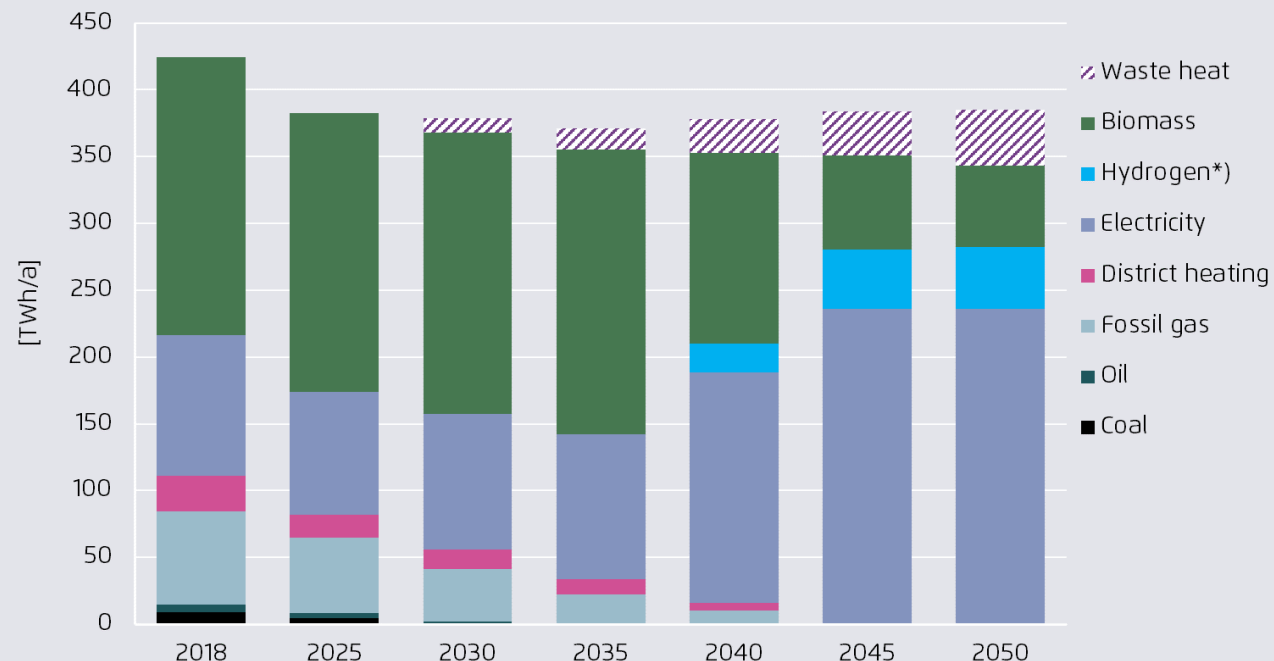


Wuppertal Institute (2023)

- 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



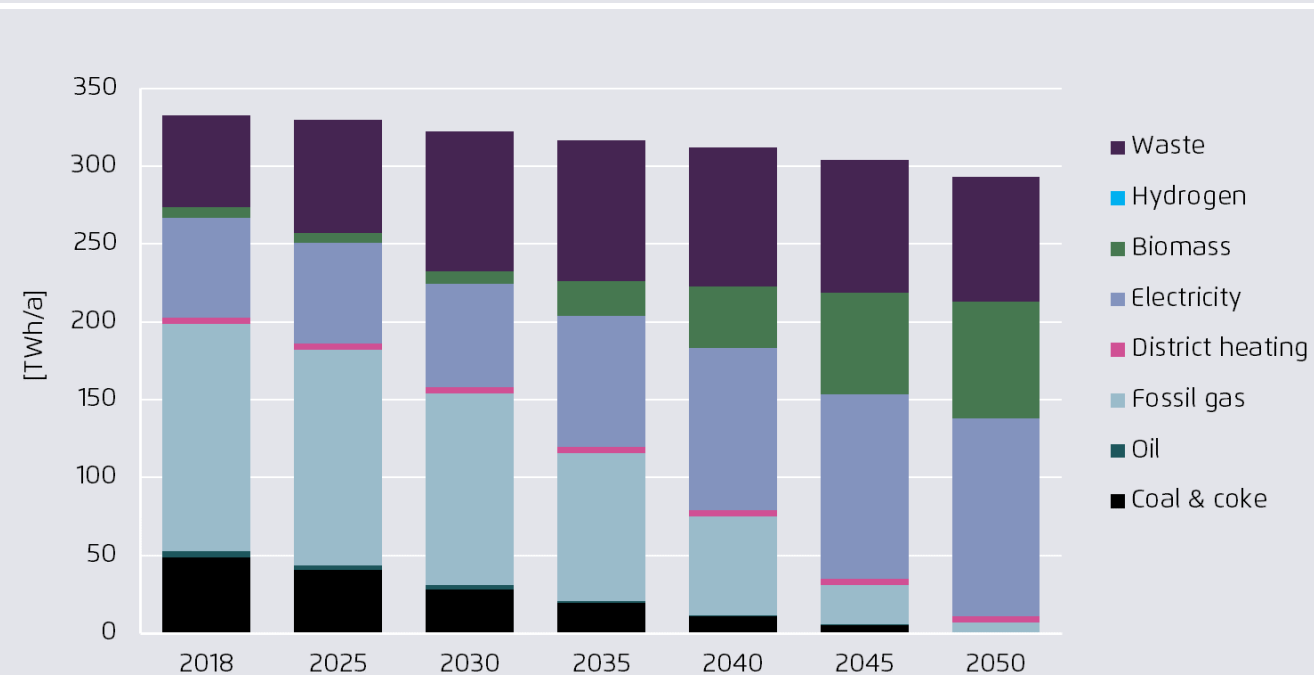
Wuppertal Institute (2023)

*) 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

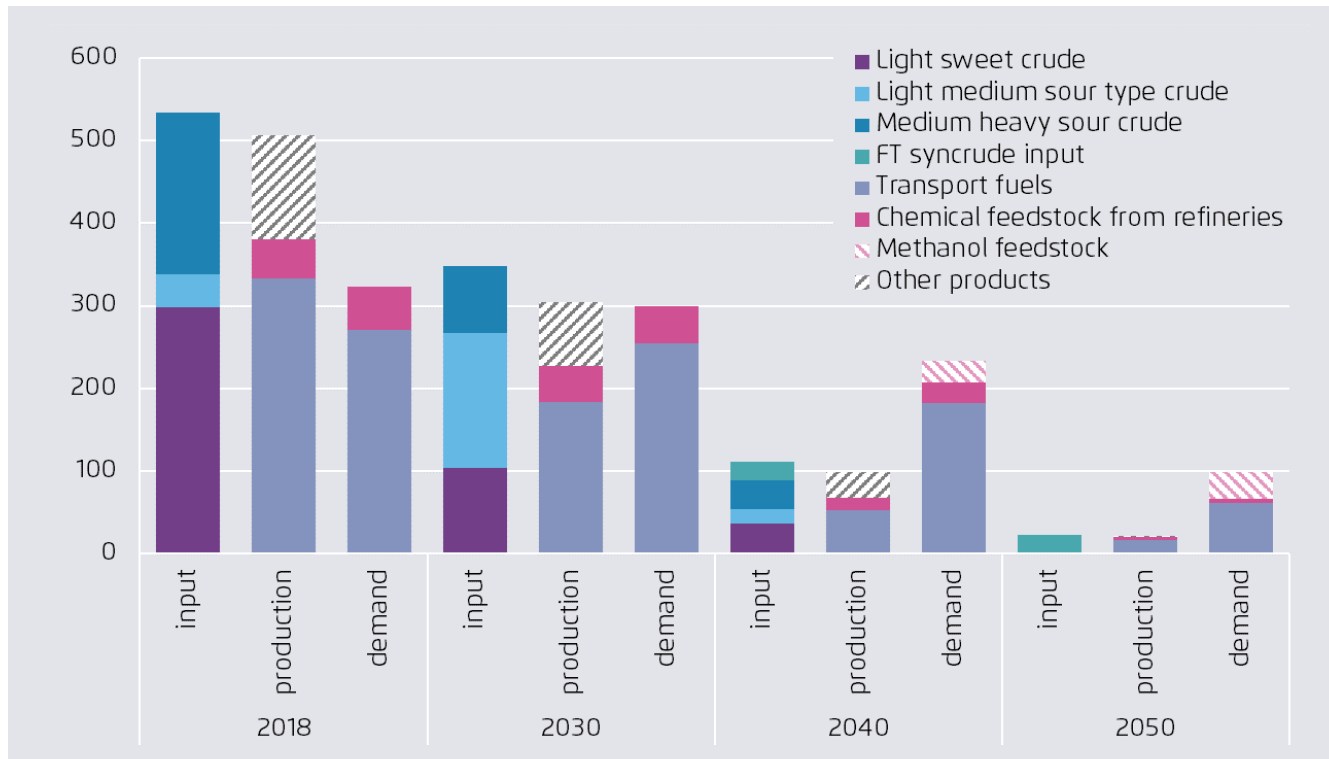


Wuppertal Institute (2023)

- 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

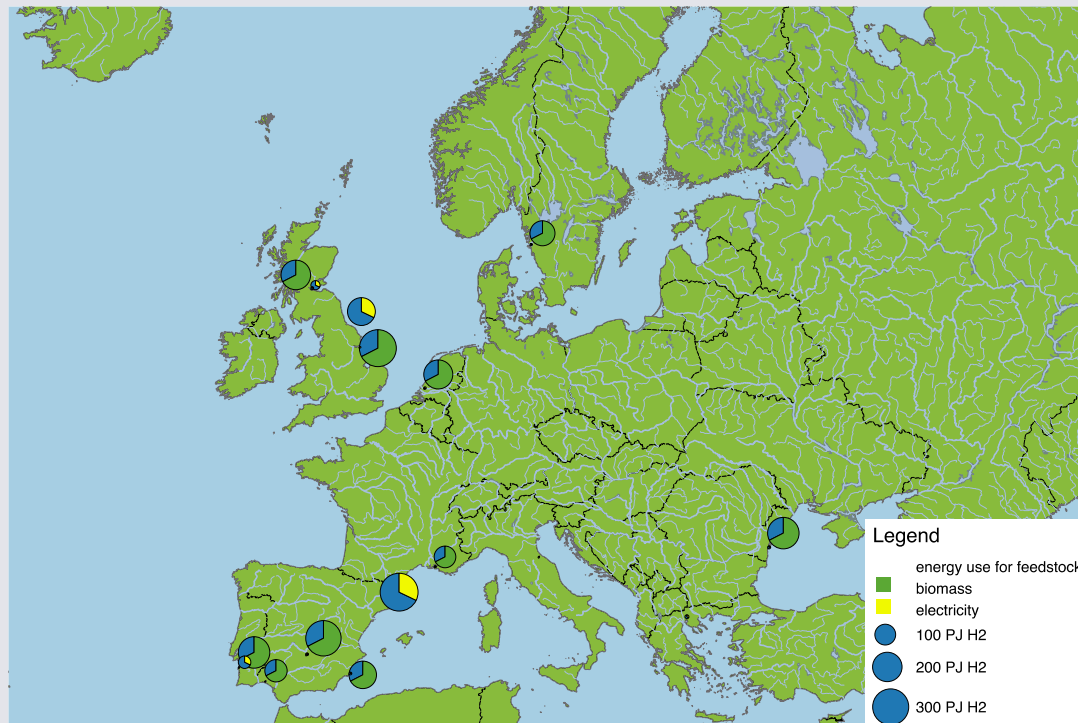


Wuppertal Institute (2023)

- 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)

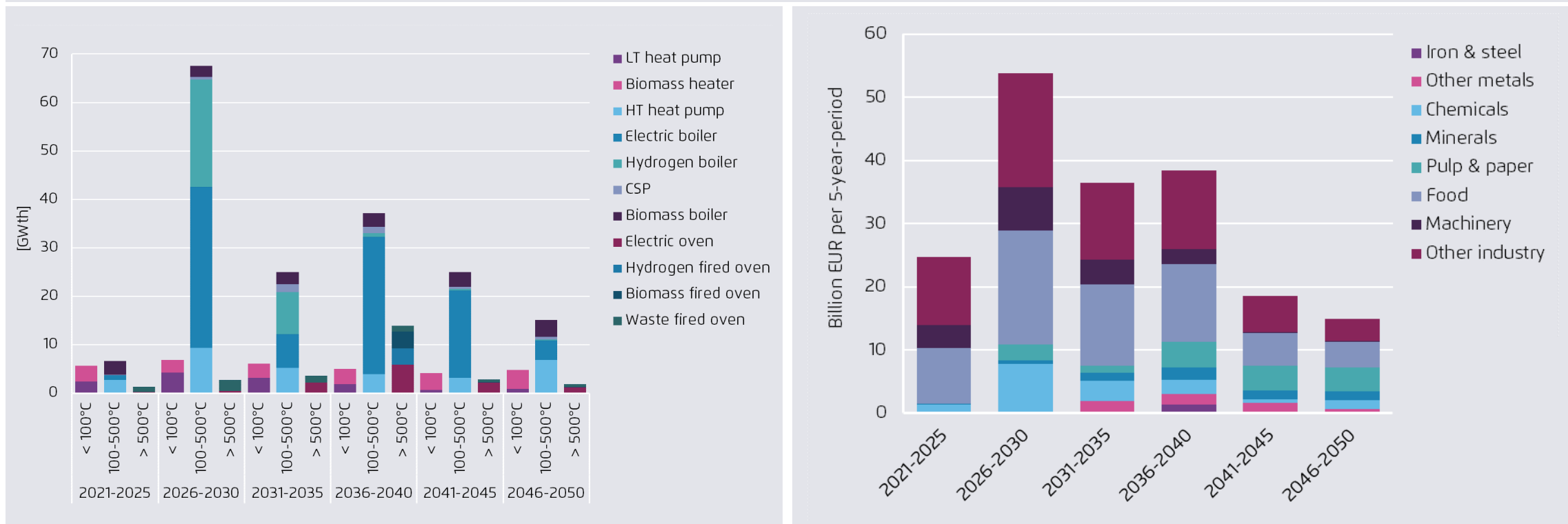
EU28 fuel and feedstock balance 2050 [Mt/a]

	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

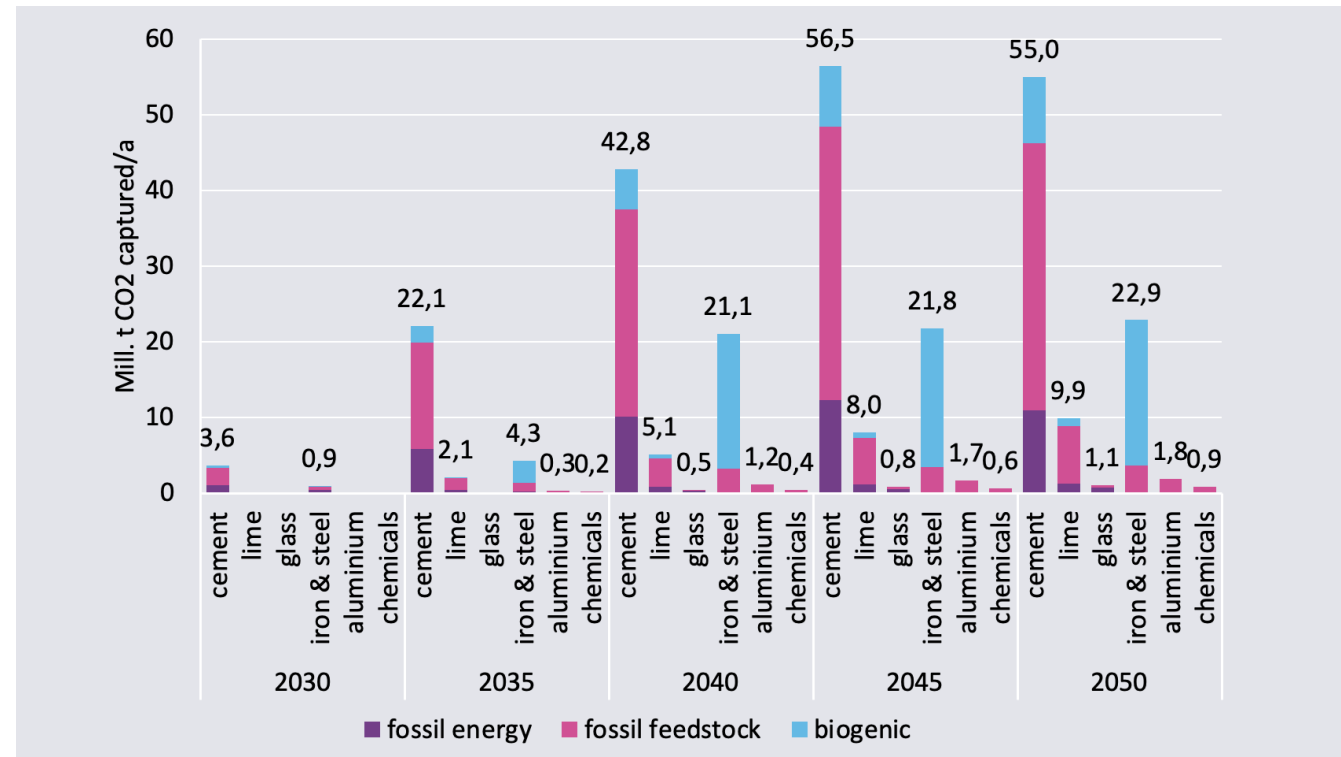
Invest in GW_{thermal} (left) and billion Euros in EU-27 industry (right)*



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

CO₂ 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 CO₂ 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 CO₂ 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).

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

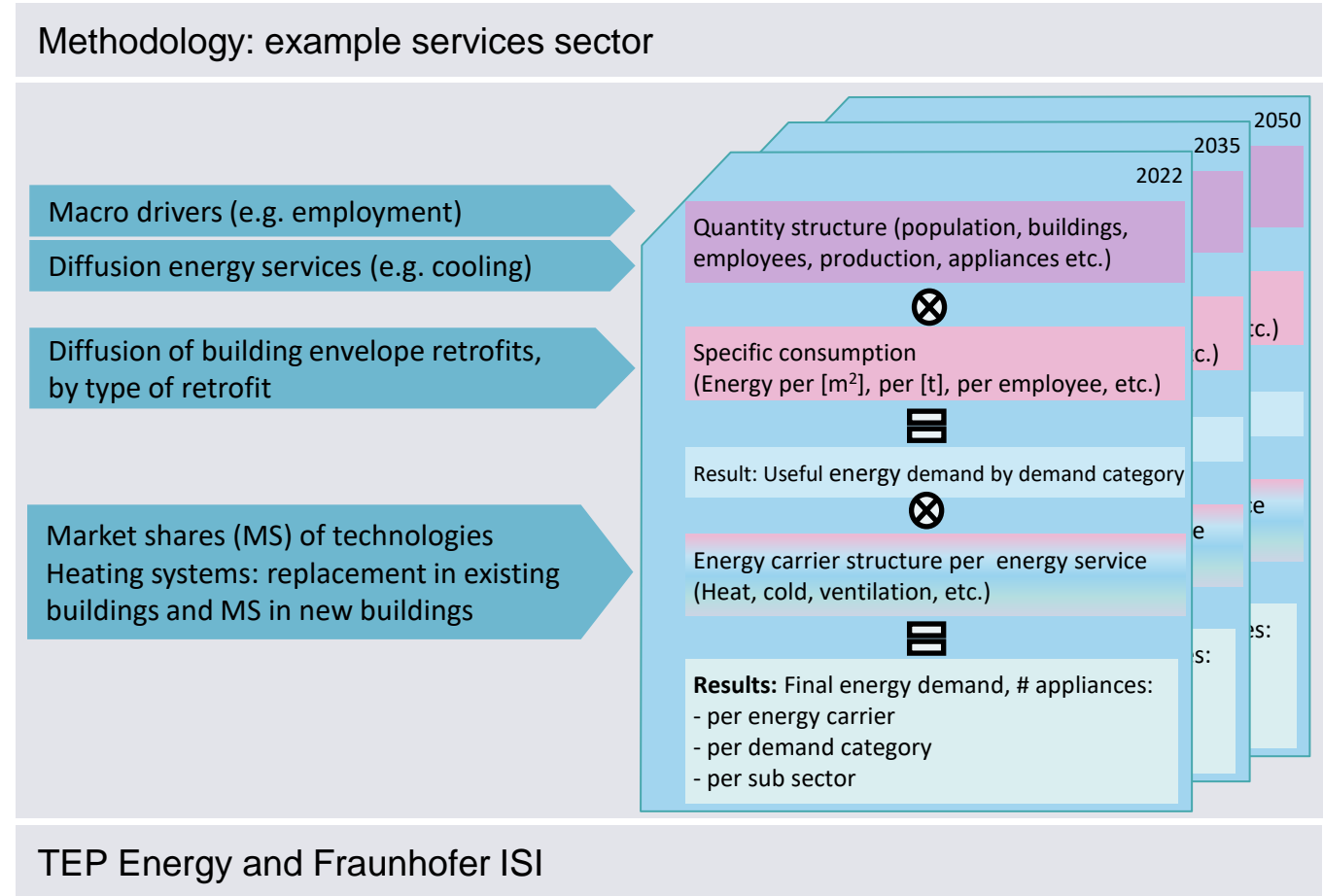
Main input parameters residential sector

	Residential sector
Main drivers	<ul style="list-style-type: none"> - No of households - Building area [m²] by type of building and by age class
Prices	<ul style="list-style-type: none"> - Energy prices - Taxes
Technology data	<p>Building related data:</p> <ul style="list-style-type: none"> - Insulation levels - Heating system efficiency - Heating system and envelop retrofit costs - Lifetime <p>Appliance data by efficiency class</p> <ul style="list-style-type: none"> - 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

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FORECAST Model – Focus Buildings Sector

Input

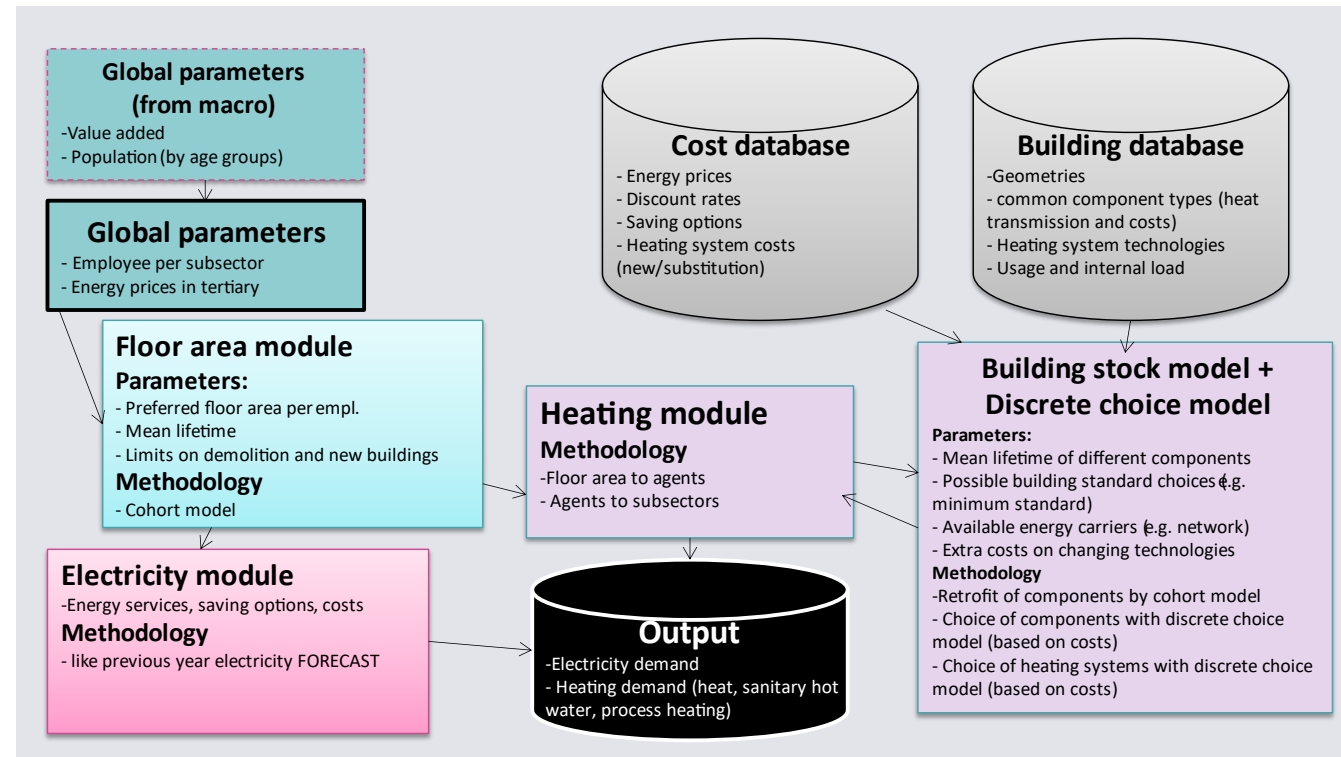
- Population, number of employees
- Specific floor area per employee or person
- Detailed building stock data:
 - 2+8 building typologies, 5 age classes
 - 4 building elements: walls, windows, roof, basement
 - Building codes per building element
 - Investment & life-cycle costs of refurbishment measures
 - 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

Output

- Final energy demand per energy carrier (including district heating) and country, per year
- Specific heat demand per m² energy reference area
- Energy related CO₂ 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

FORECAST Model – Focus Buildings Sector

Model and data base

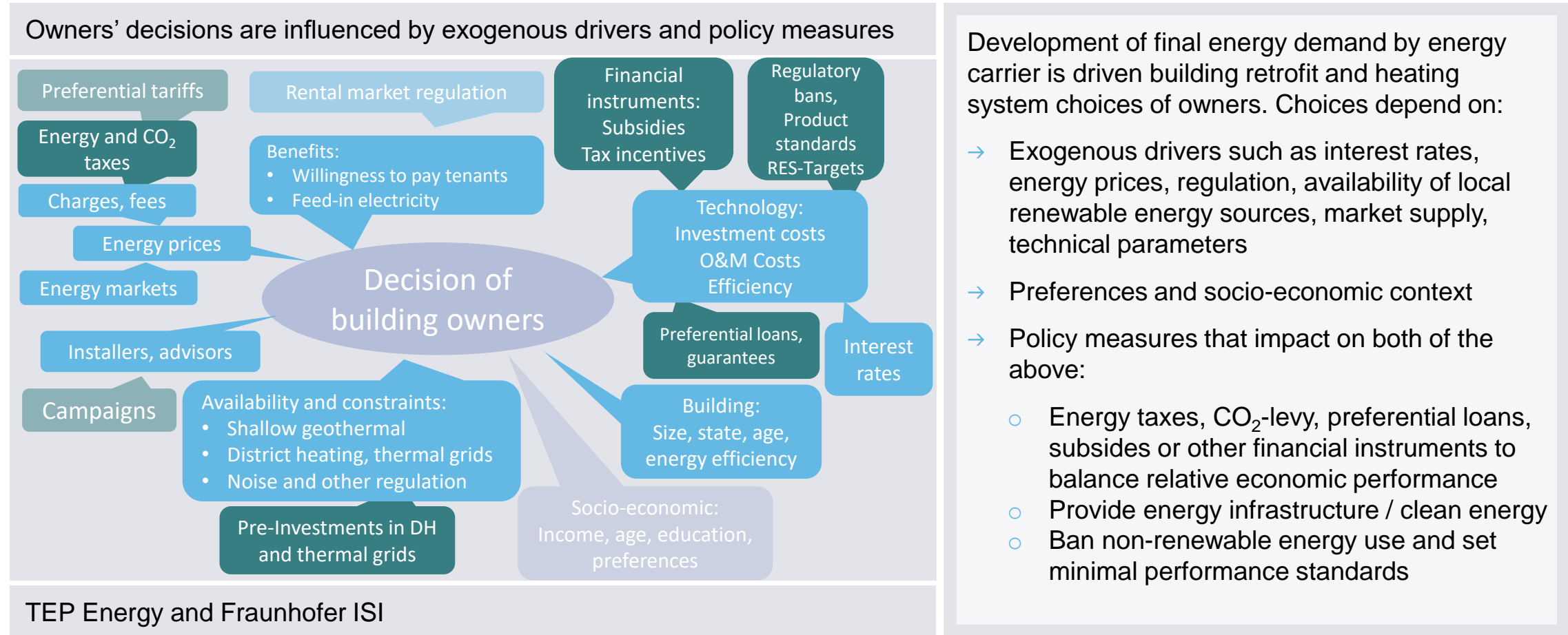


TEP Energy and Fraunhofer ISI

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 Model – Decision modelling



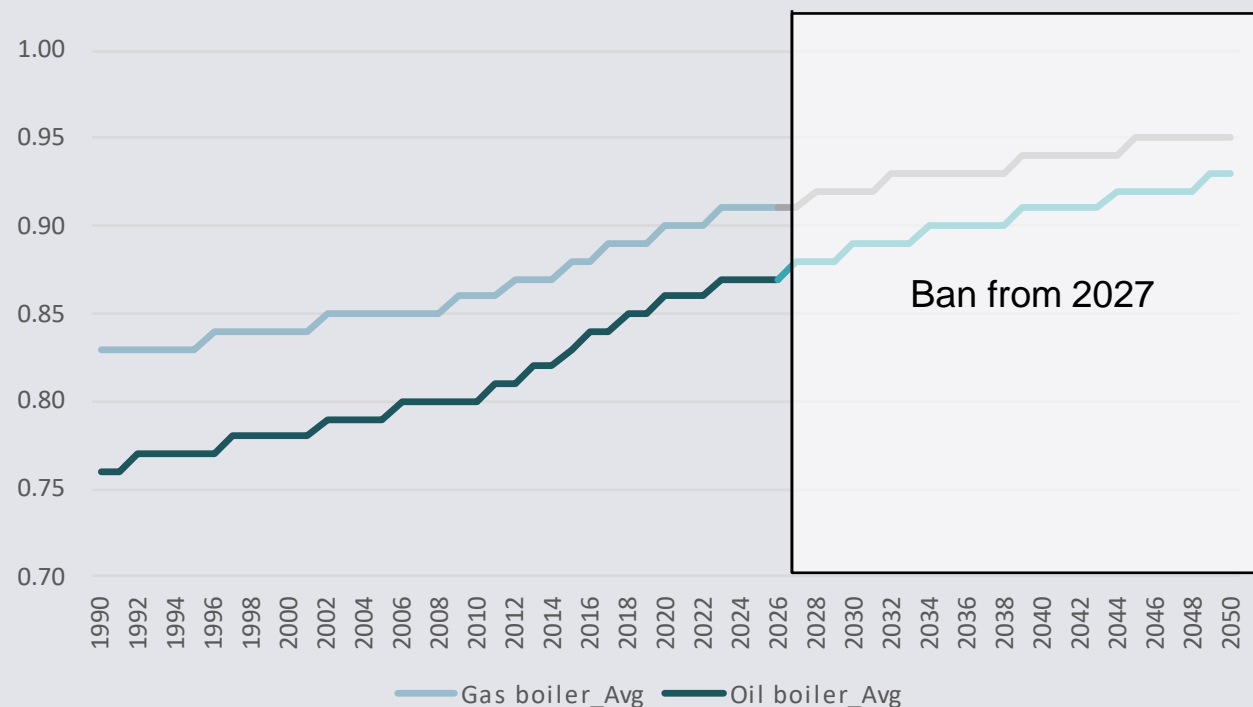
Legend: Exogenous drivers Policy measures

Key policy assumptions for buildings

- **Fossil fuel subsidies:** No explicit fossil fuel subsidies enabled in the modelling.
- **Carbon pricing:** CO₂ price of 39 €/tCO₂ in 2027 rising to 49 €/tCO₂ in 2030 and 200 €/tCO₂ 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

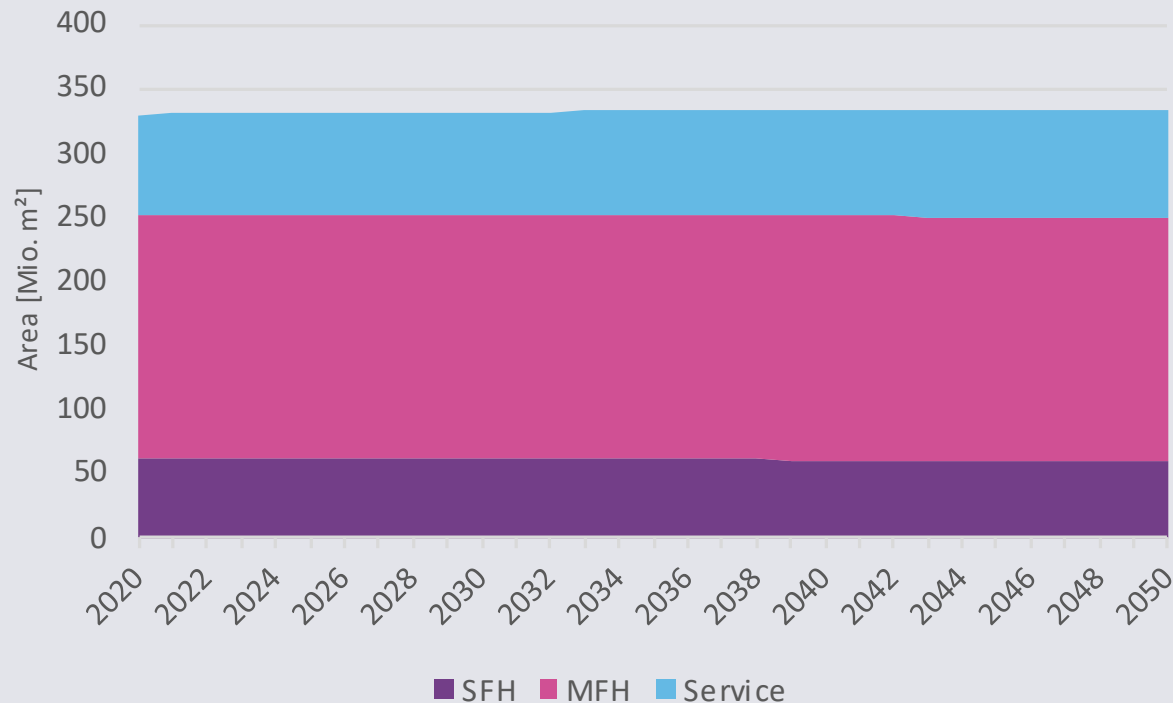


- Ban of stand-alone fossil fuel boilers from 2027 based on boiler efficiency values, simulating a revision of Ecodesign rules for heating appliances currently under discussion.
- The rule is assumed to only apply to new installations, not existing ones.
- The efficiency values for heating appliances 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.

TEP Energy (2023)

Key assumptions: Households and floor area

Floor area by building type, Greece

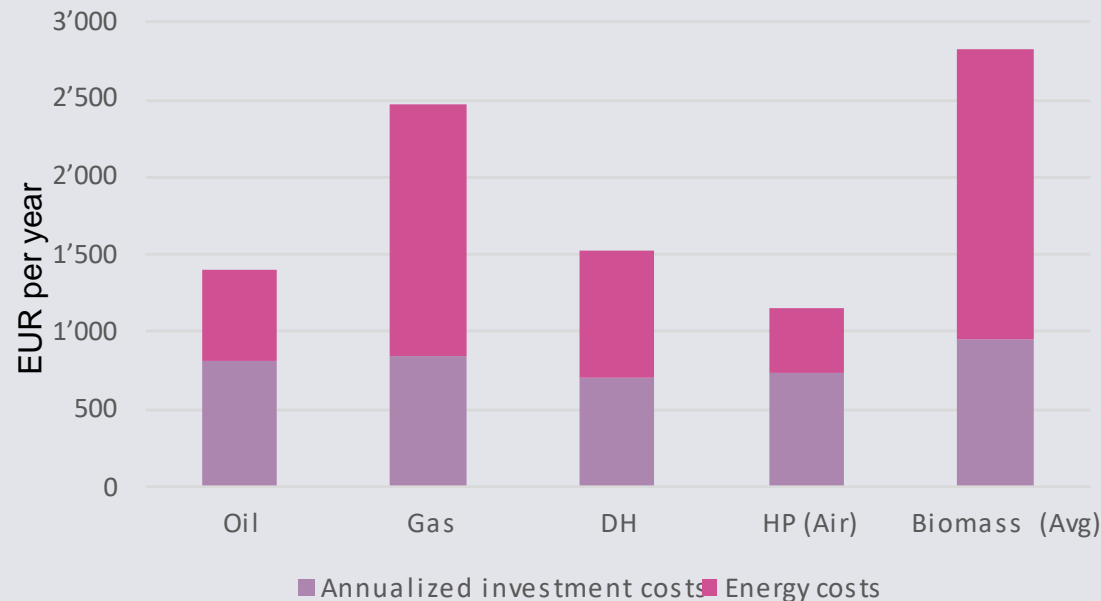


TEP Energy (2023)

- 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 remains more or less constant between 2020 and 2050 (slight increase by 1.3%)

Key assumptions: Economics and policy of heating system changes

Annualized heat generation costs single family house: heating system change 2025, Greece



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: 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 (a less costly with high energy prices)

Key assumptions: Energy prices and technology data

Exemplary energy prices 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).

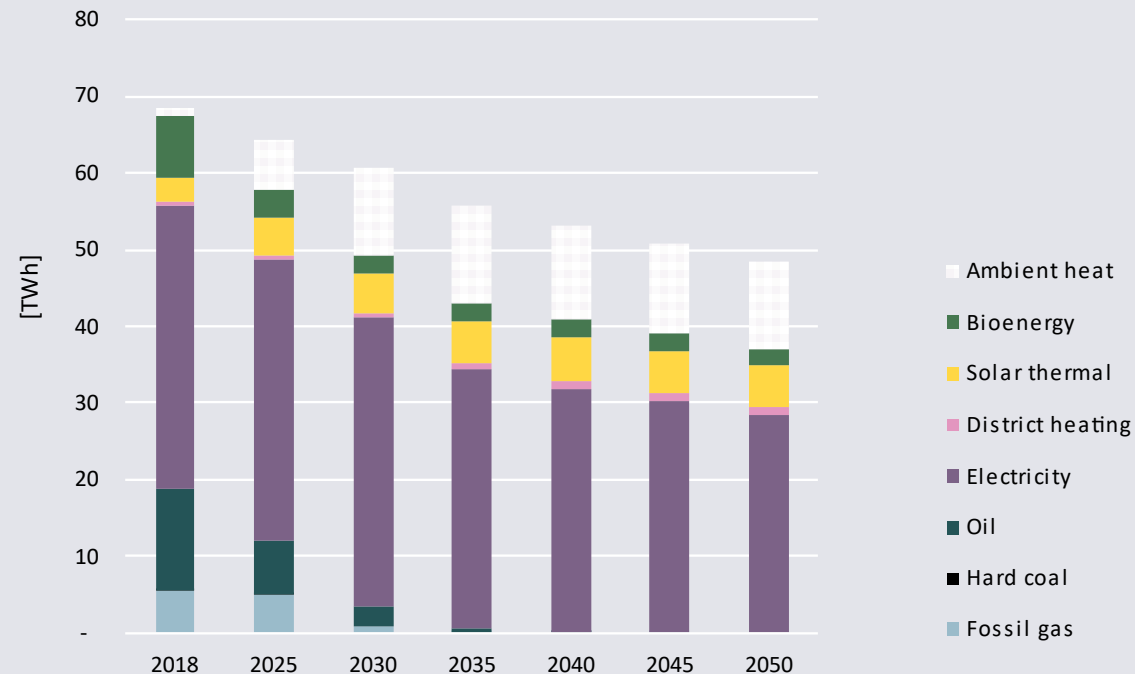
Buildings:

Results



Buildings are nearly fossil gas-free by 2040. Efficiency, heat pumps & decarbonized district heating are the key levers for achieving a fossil free building stock.

Total final energy consumption* in buildings, Greece



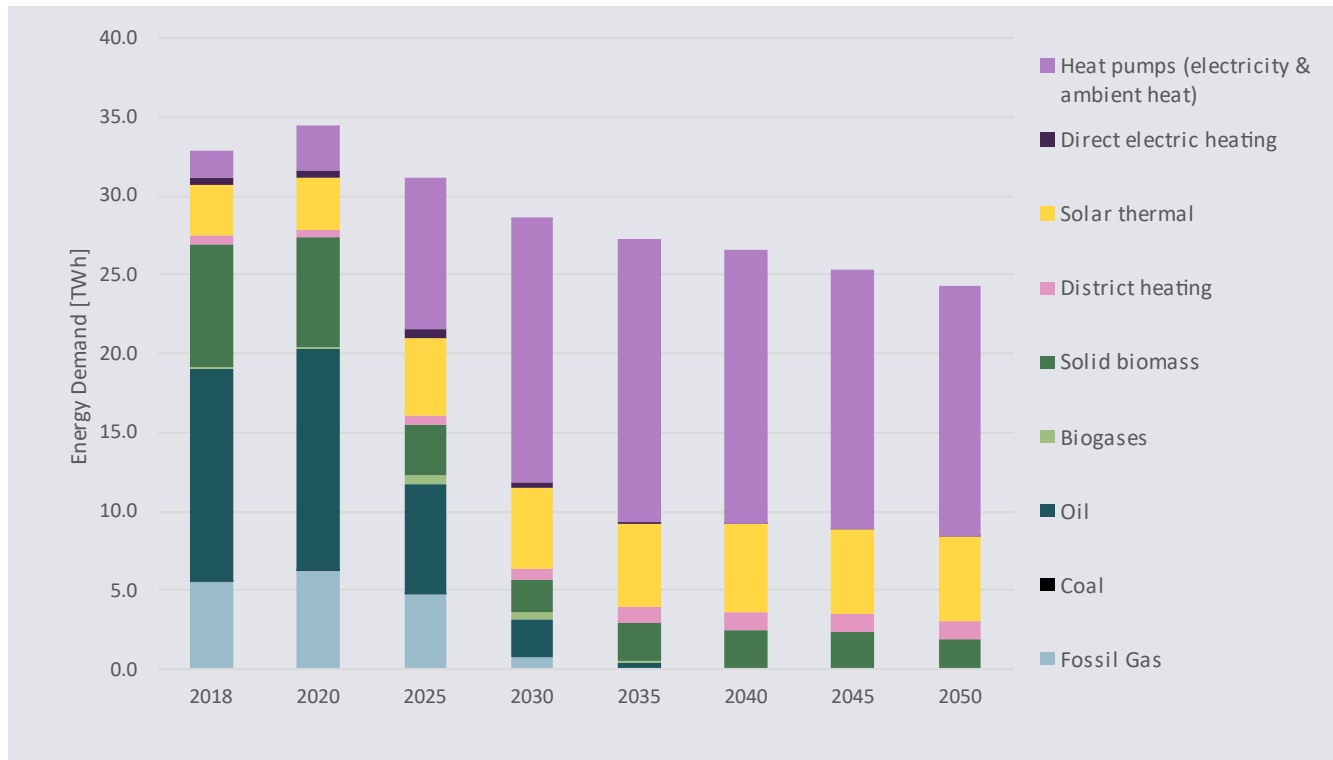
* Including demand of household, ICT and other appliances and building technologies (e.g. ventilation, cooling)

TEP Energy, Wuppertal Institute modelling (2023)

- Total final energy demand: reduced by 25% to 31%
- Fossil fuel consumption: almost phased out by 2035 (98%)
- Ambient heat drastically increases to cover 24% of buildings' total final energy demand by 2050 (ambient heat: thermal energy from air, water, ground tapped by heat pumps)
- Electricity demand stagnates because increasing and decreasing trends balance out
- District heat is becoming more efficient and expands its market share by 2050
- Other direct renewable heat sources, notably solar thermal and the continued use of bioenergy (though slightly lower) allow for additional gas displacement.

Buildings are nearly fossil gas-free by 2040. Efficiency, heat pumps & decarbonized district heating are the key levers for achieving a fossil free building stock.

Final energy consumption for space heating and hot water in buildings, Greece

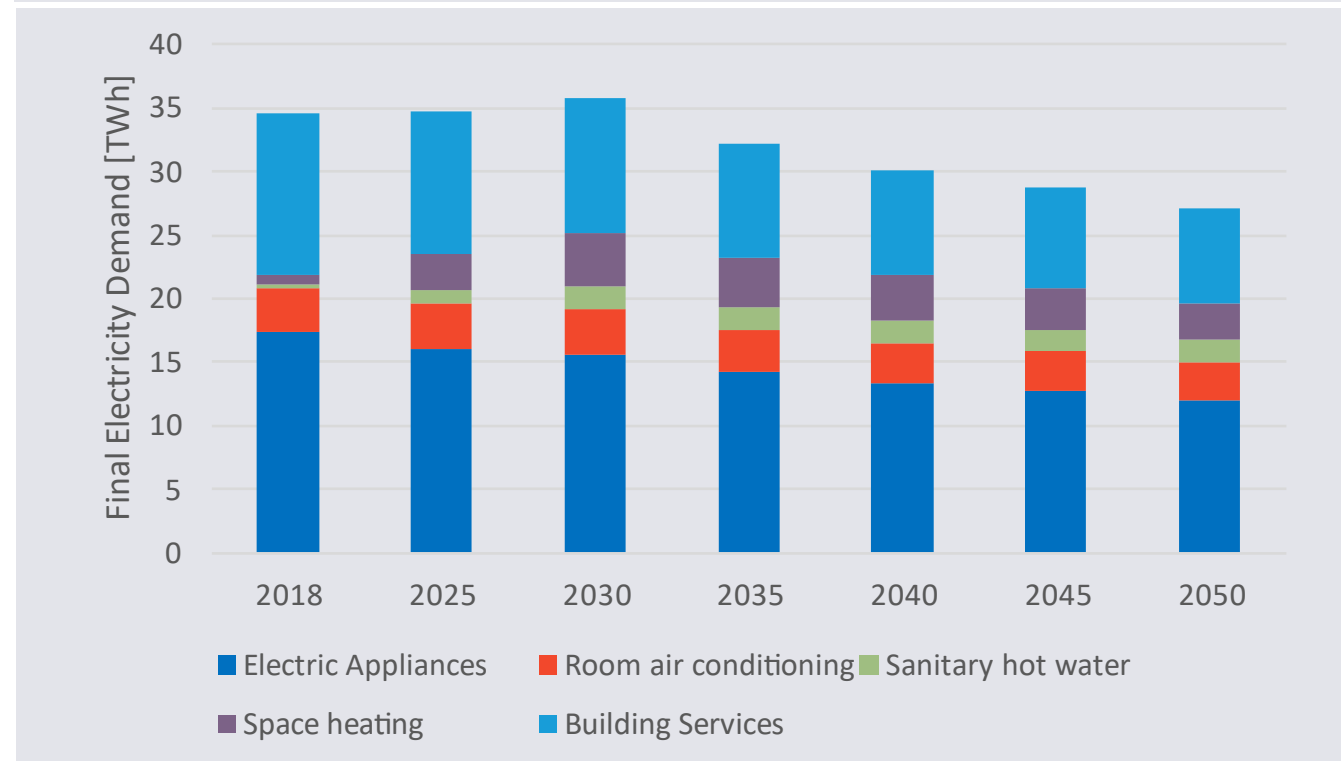


EP Energy, Wuppertal Institute modelling (2023)

- Fossil energy in 2020 still dominating
- Accelerated decrease from now
- Phase-out of fossil energy (coal, heating oil, gas) up to 2035-2040
- Heat pumps to become the dominating technology after 2030
- District heating increases slightly in absolute terms, a bit more in relative terms
- Solar thermal gains in importance
- This structural change also is enabled by efficiency improvements (retrofit, new buildings)

Deep dive: electricity demand in buildings

Final electricity demand in buildings, Greece

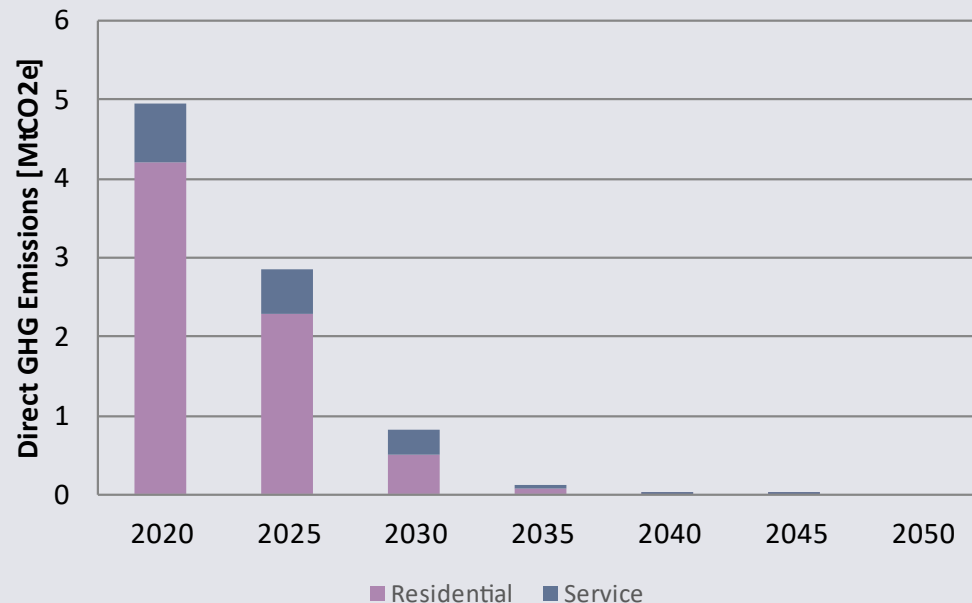


Source: TEP Energy (2023)

- Total development of electricity demand about 35 TWh in 2018, slight increase to 2030 and stark reduction to 27 TWh in 2050
- Explained by counteracting effects
 - Electricity demand from space heating: decreases from 34.6 TWh (2018) to 27 TWh (2050)
 - Electricity demand from water heating increases (by 2 TWh)
 - Electricity demand from appliances: decrease from 17 TWh to 12 TWh
 - Electricity demand building services including cooling 13 TWh to 7 TWh
- Energy efficiency improvements (appliances & buildings) & replacement of older appliances through more efficient technology (e.g. heat pumps) help to keep electricity consumption in check.
- Note: These results don't include electric vehicle charging.

Greenhouse gas emissions in the building sector

Direct greenhouse gas emissions in buildings [in Mt CO₂eq], Greece

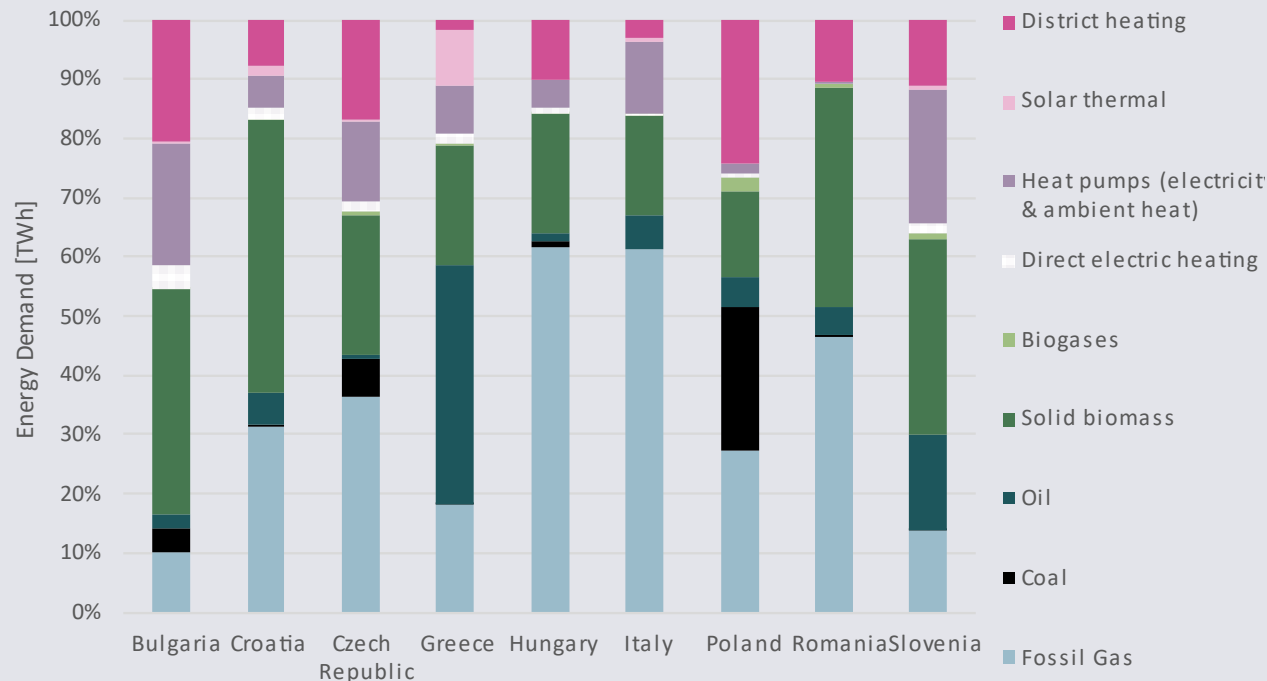


- Direct greenhouse gas emissions decline by 83% from 2020 to 2030
- Decarbonisation almost achieved in 2040
- The service sector is responsible for 15% of emissions in 2020, 40% in 2030 and rising to 54% in 2040
- This development is achieved through a phase-out of fossil heating systems that are displaced
 - by decentralized heating systems using renewable energy sources or
 - by a connection to district heating

TEP Energy modelling (2023)

Country deep dives: quite different starting situations in 2020

Final energy consumption space heating and hot water in buildings



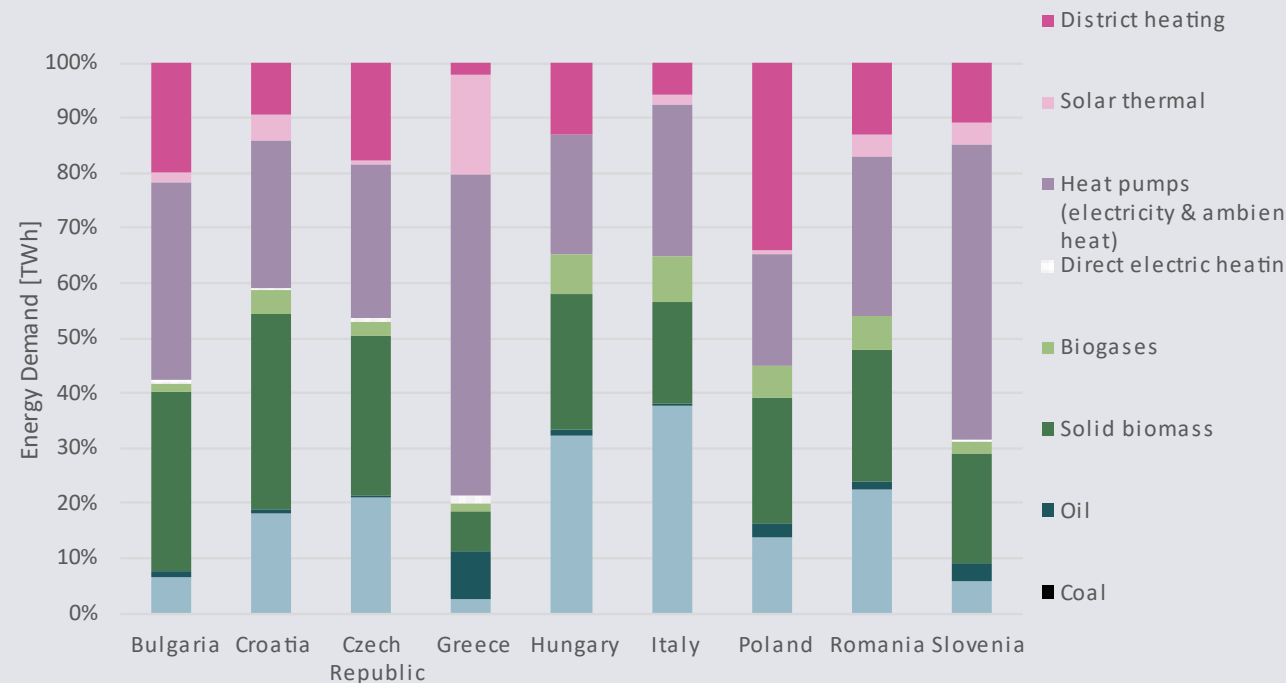
TEP Energy modelling (2023)

Starting situation in 2020 – differences and similarities

- Fossil energy carriers make up between 15% to 60% of total energy consumption. The share is lowest in Bulgaria and Slovenia.
- Challenge to phase-out fossil gas highest in Hungary, Italy and Romania. Also challenging in Czech Republic, Croatia and Poland
- Solid biomass still plays a significant role in most deep dive countries – in particular in Bulgaria, Romania, Croatia, and Slovenia

Country deep dives: short-term development up to 2030

Final energy consumption space heating and hot water in buildings



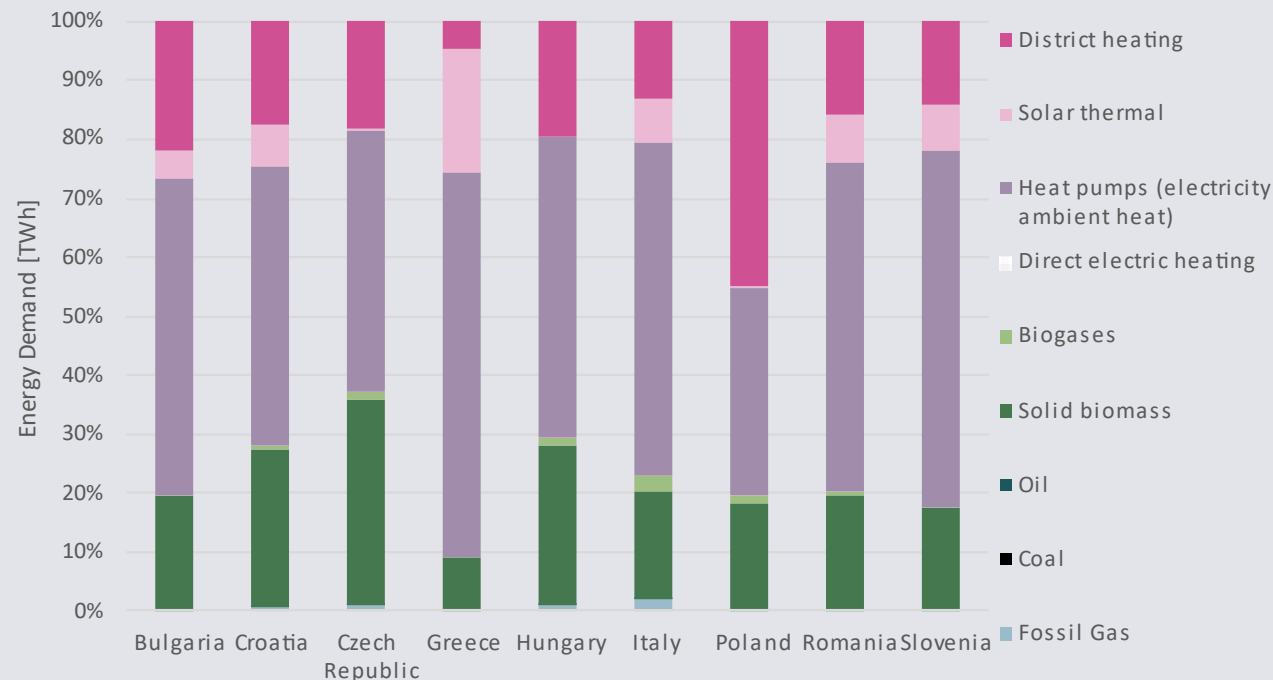
TEP Energy modelling (2023)

Urge to phase-out fossil gas and to strongly reduce direct greenhouse gas emissions from the buildings sector results in

- A reduction of fossil gas use by half in comparison to 2020
- A stark increase of heat pumps in most countries, especially in Greece and Slovenia
- A slight reduction of solid biomass (due to a general trend towards heat pump systems which are more convenient to operate)

Country deep dives: medium-term development up to 2040

Final energy consumption space heating and hot water in buildings



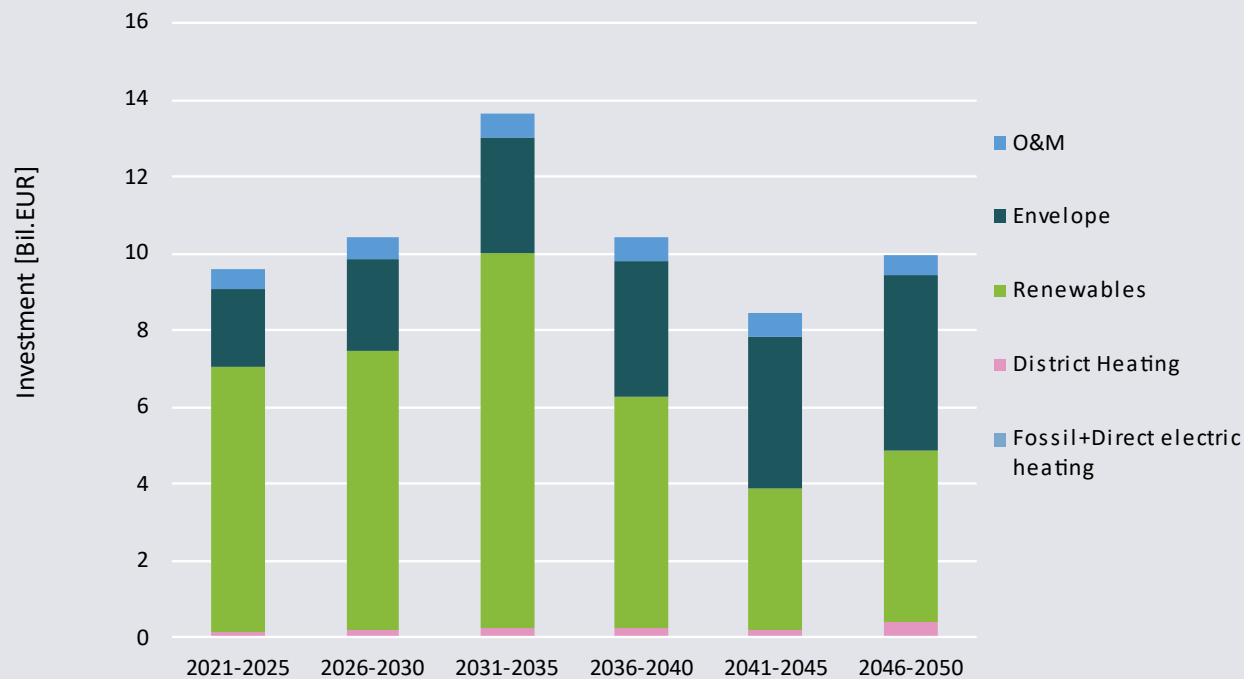
In the medium-term up to 2040

- Heat Pumps will deliver the majority of energy for hot water and space heating
- District heating will gain in importance
- Fossil gas will have faded out almost completely
- Biomass continues to play a visible role (10% to more than 30%), partly also in local thermal/heat grids

TEP Energy modelling (2023)

Deep dive: total investment needs for the buildings sector

Sum of overnight investments into buildings during 5-year periods, Greece

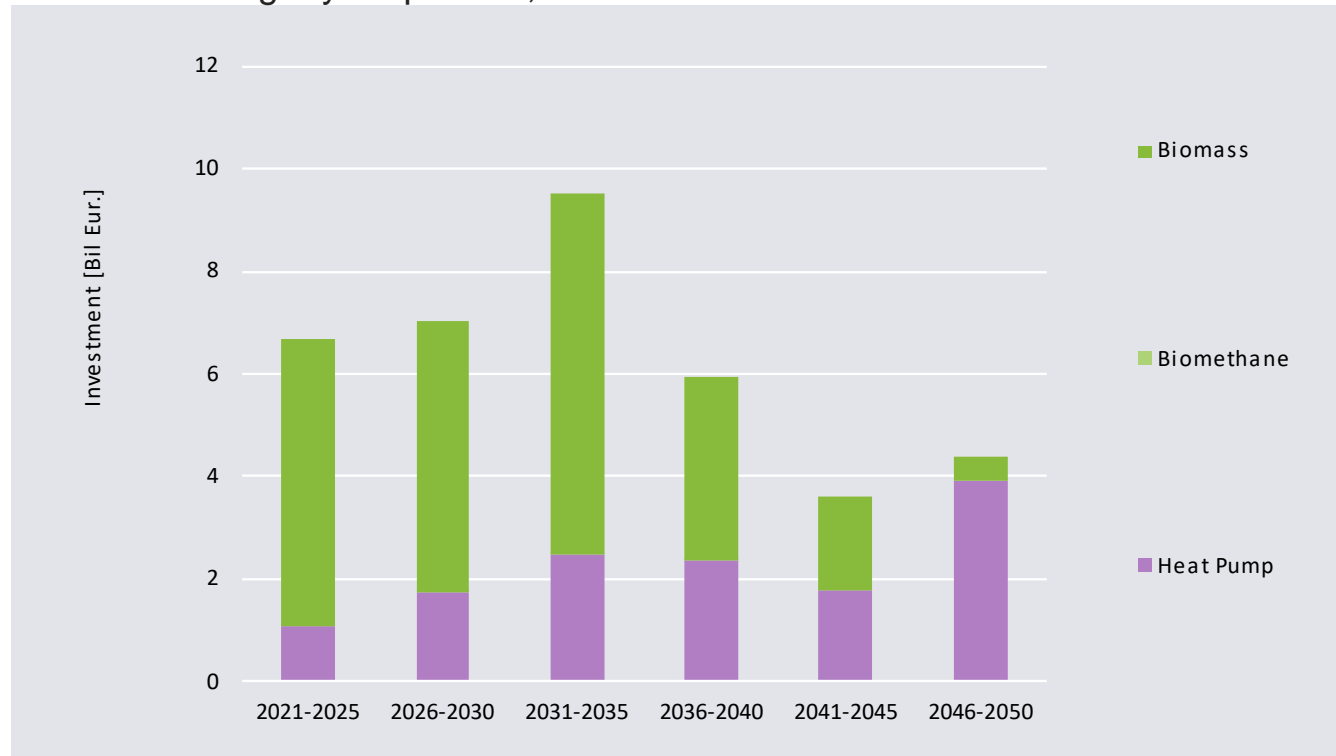


Source: TEP Energy

- Decarbonisation needs investment into Renewable Energy Systems (RES), district heating systems, and energy-efficiency measures (building envelope).
- Total investment in buildings to be increased by 42% up to 2035 to meet greenhouse gas emissions reduction goals. When comparing Investments from 2020 and 2050 they only increased by 5%.
- No investments into fossil energy systems and Direct electric heating from 2027
- Building envelope investments remain relevant, to ensure energy-efficiency and to prevent building value depreciation and technical degradation.
- District heating (inside the building)
- Bottom-line: first, investments in renewables dominate, then investments into the building envelope gain in importance (also as a result of the age structure of the building stock)

Deep dive: investment needs for decentralized heating systems using renewable energy sources

Overnight investments in decentralized heating systems using renewable energy sources during 5-year periods, Greece

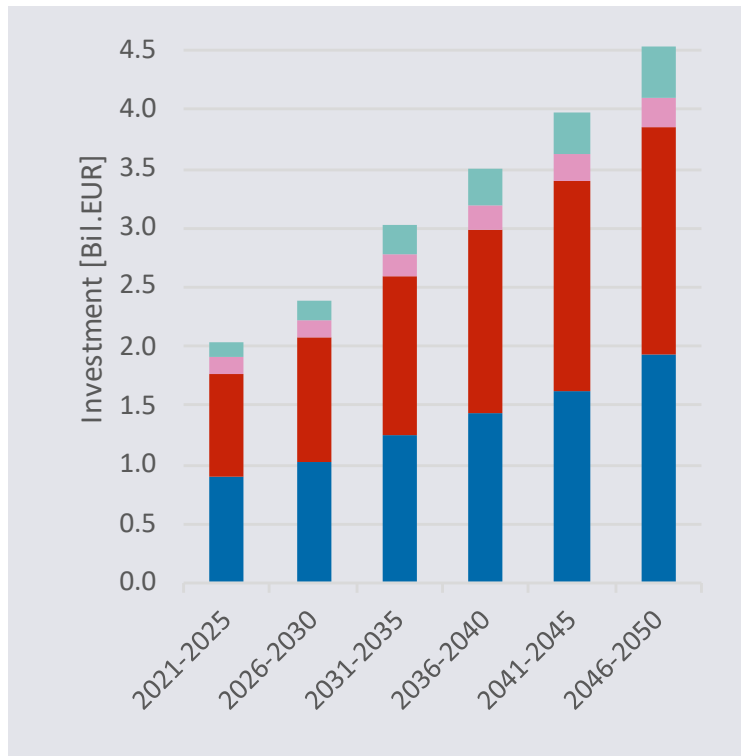


Source: TEP Energy

- Decarbonisation needs investment into decentralized heating systems using renewable energy sources
- Strong increase, especially up to 2035, in order to achieve greenhouse gas emission reduction goals
- Within decentralized systems: Highest share of investments into heat pumps
- Investments in (solid) biomass and biomethane stay approximately constant.
- Investments in hydrogen minimal.

Deep dive: building renovations & construction

Investment in building components, Greece



TEP Energy modelling (2023)

Specific energy demand (kWh/m²), Greece

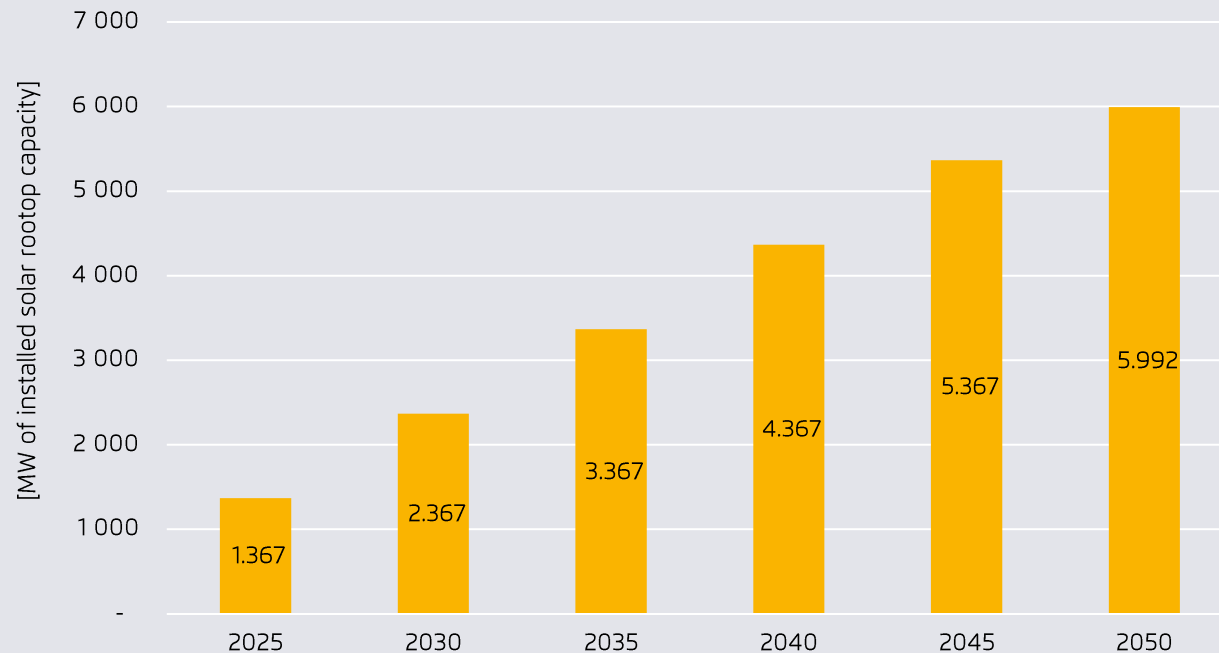


TEP Energy modelling (2023)

- Improving energy-efficiency of building needs investment into building components: Wall, window, roof and basement.
- Due to high retrofit rates and high specific costs (per m²), windows are of high relevance
- Building investments to increase from less than 2 bn EUR to more than 4.5 bn EUR
- As a result of these investments, specific energy demand in existing buildings is substantially reduced by about
 - 12% between 2020 and 2030
 - 24% between 2020 and 2040

Deep dive: Solar rooftop PV

Installed solar rooftop PV capacity (in MW) – Greece

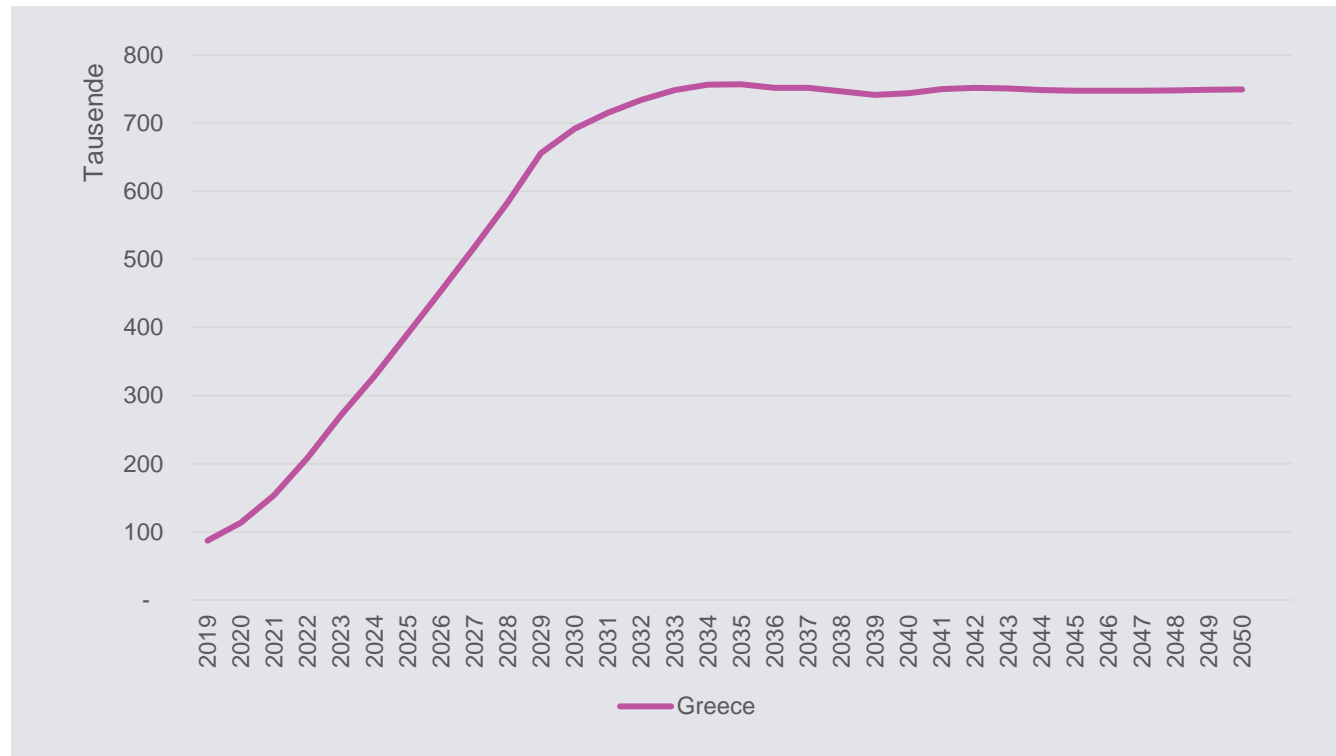


Artelys

- Installed solar rooftop capacity and generation grows rapidly, especially after 2030:
 - 2.4 GW (2030); 4.4 GW (2040); 6.0 GW (2050)
 - 3.1 TWh (2030); 5.7 TWh (2040); 7.9 TWh (2050)
- Rooftop solar is expected to represent 17-20% of total solar capacity and generation
- Rooftop PV generation is on an aggregate yearly balance able to cover a moderate-rising share of electricity consumption in buildings :
 - (%) total electricity demand in buildings (excl EVs): 15% (2030); 30% (2040); 42% (2050)
 - (%) of electricity for heating, cooling & ventilation: 15% (2030); 34% (2040); 52% (2050)

Deep dive: heat pumps

Number of Heat Pumps, Greece



TEP Energy modelling (2023)

- Number of heat pumps increases from 0.1 Mio in 2020 0.7 Mio in 2030 and stays at this level until 2050.
- This represents an average increase of 58 thousand heat pumps per year from 2020-2030 and 5000 heat pumps per year from 2030-2040.
- Note: The number of heat pumps are calculated based on the modelled energy demand and aligned with the stock numbers of European Heat Pump Association. Future higher buildings standards and lower heat demand per building/dwelling is considered by assuming in average smaller heat pump devices.

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

→ Positive motivation:

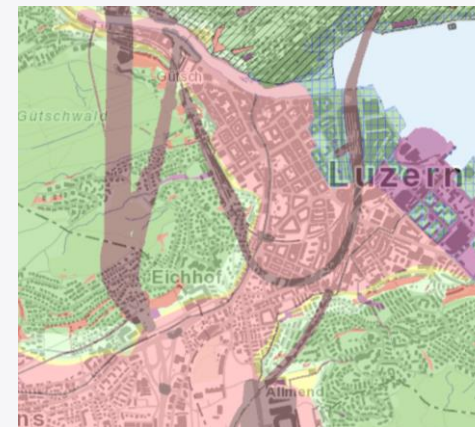
- Favourable energy density
- Low-cost solution for building owners (depending on the price model of utilities)
- Few actors to decarbonise building stock

→ 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

Two examples of constraints for decentralized heating systems

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 <u>and</u> 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.

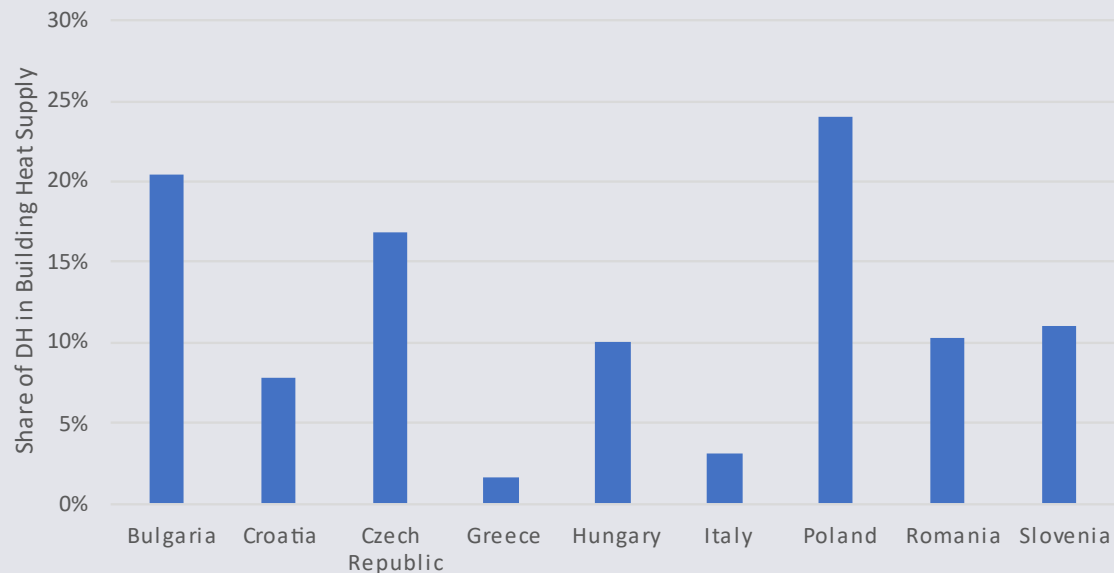
Spatial energy analysis: topology of centralized/non-centralized options.

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-out): 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 situations

Share of district heating at Building Heat Supply in 2020

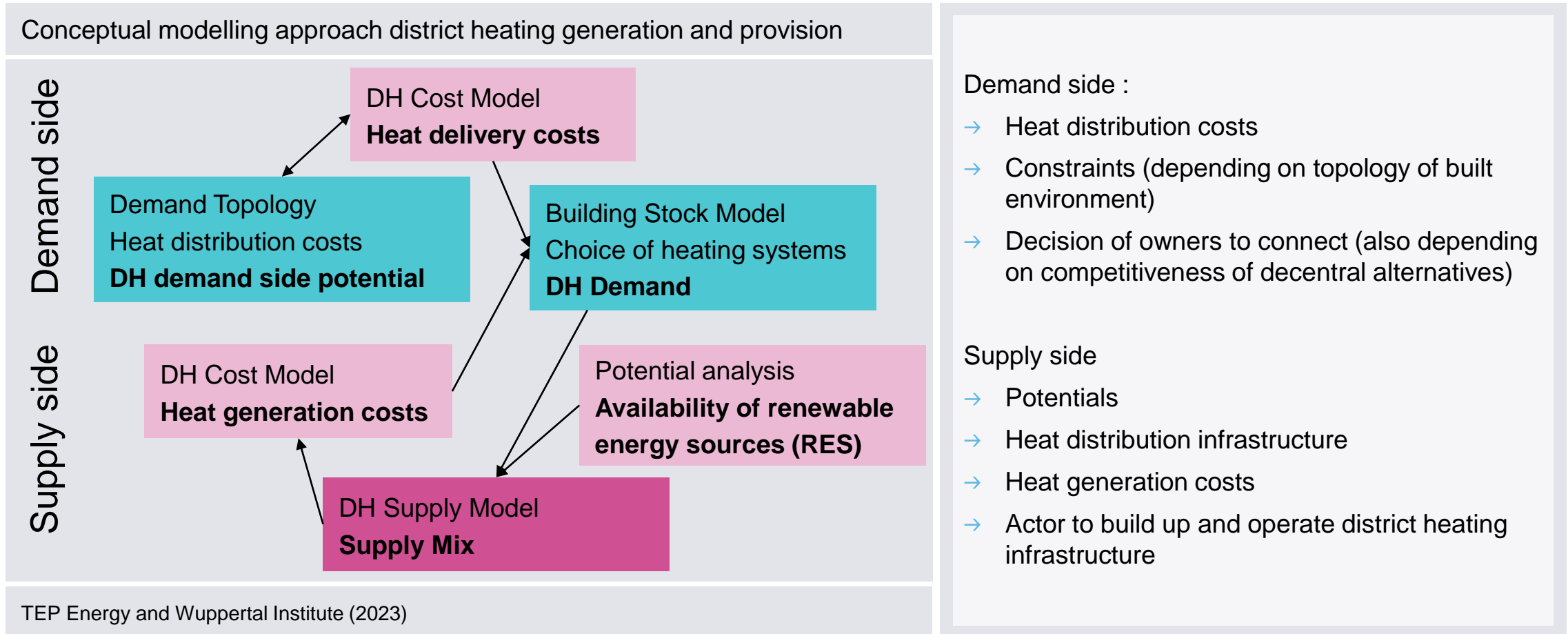


TEP Energy and Wuppertal Institute (2023)

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

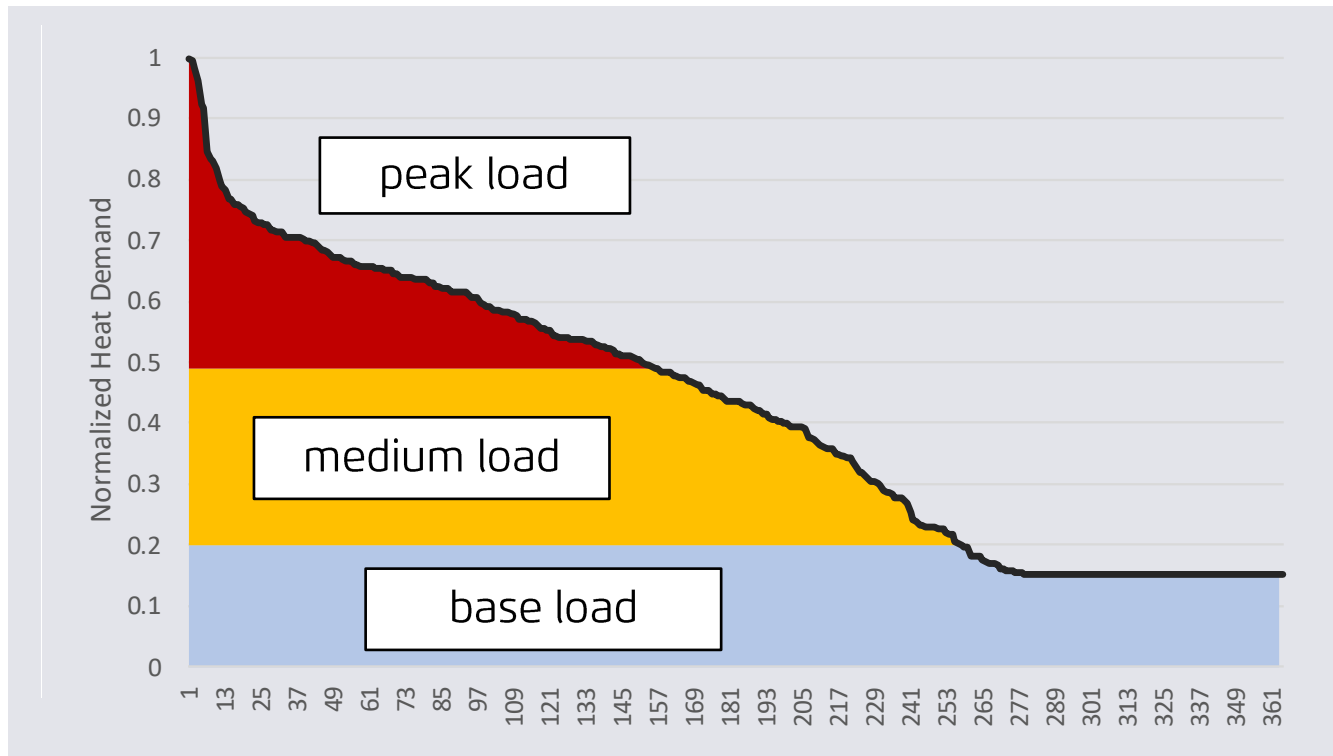
- Historical experience countries (PL, CZ, BG) :
 - to lower district heating temperature to accommodate RES
 - to get DH provision more efficient
 - to keep and slightly increase district heating coverage
- “Newcomer” countries with a current share of about 10% or less (IT, GR, HR, HU, RO, SI):
 - to 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



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

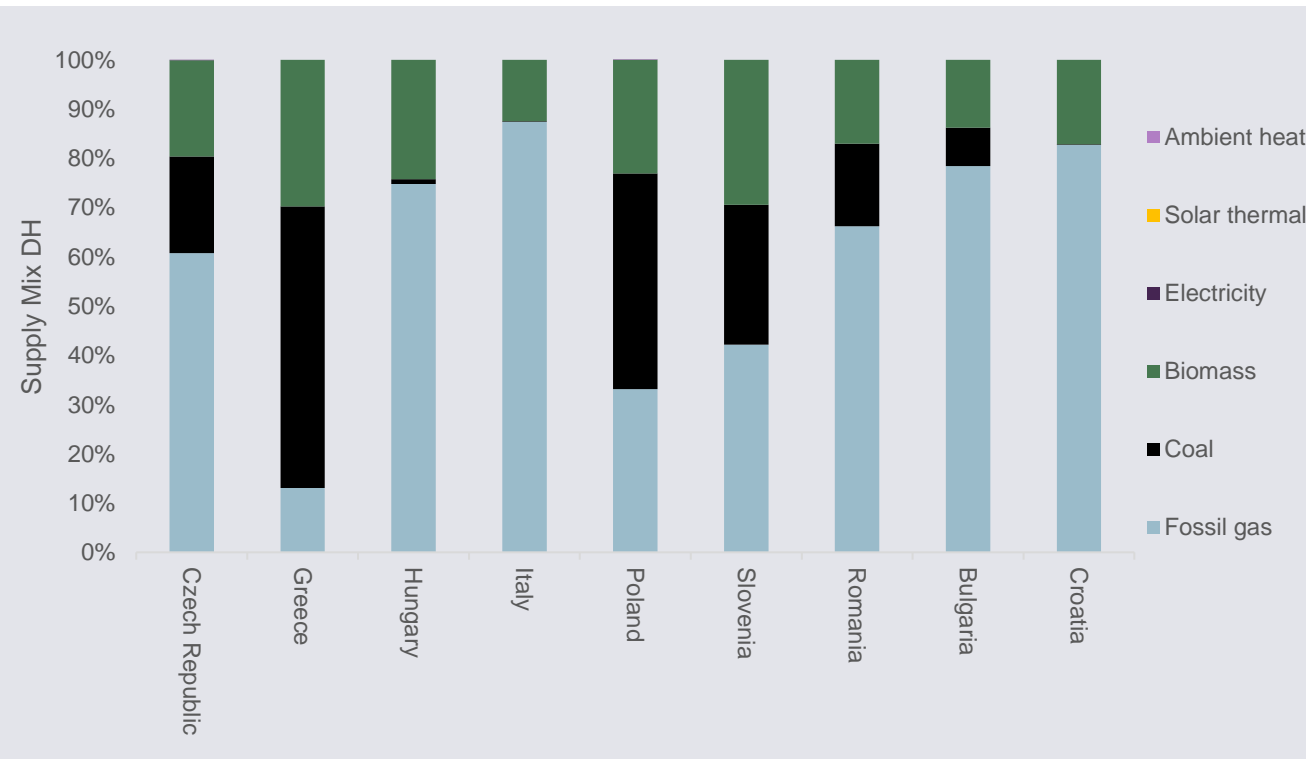


District heat: Background note for interpreting the results

- 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



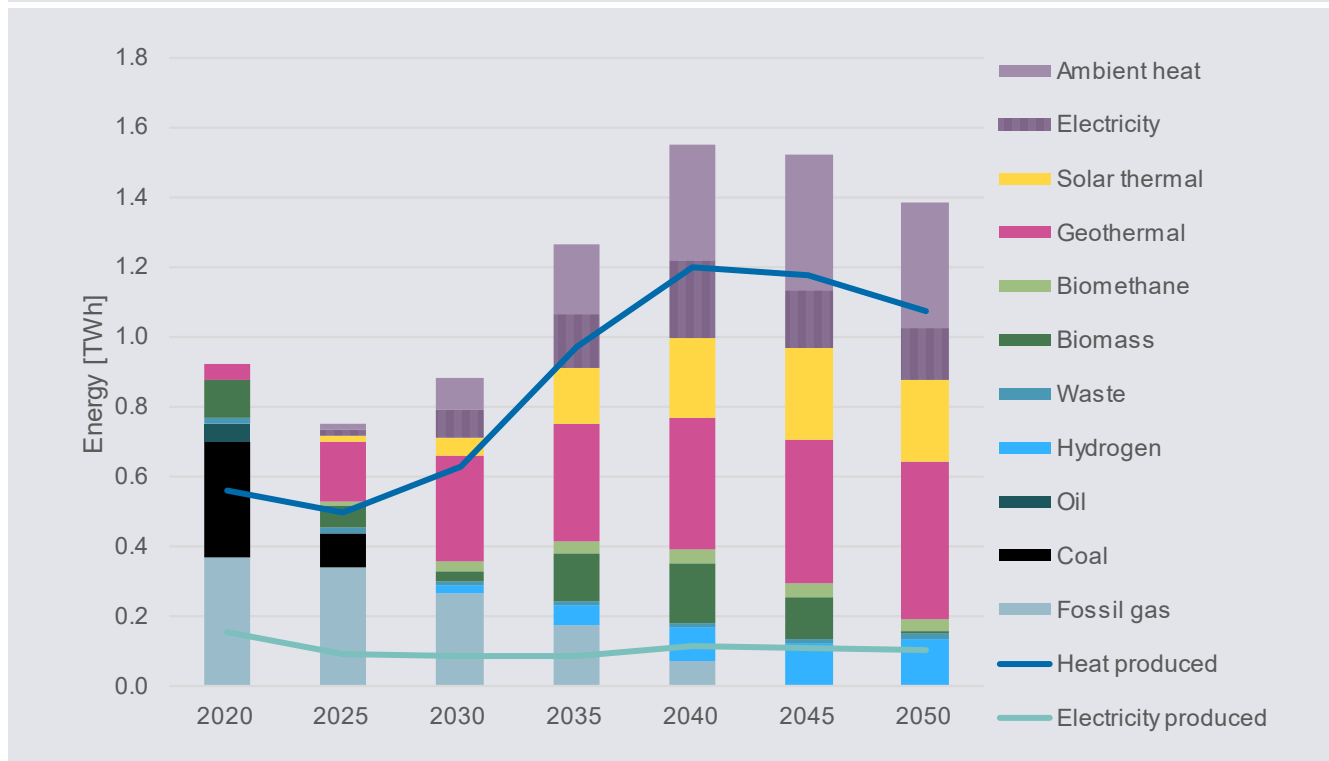
TEP Energy and Wuppertal Institute (2023)

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

Energy consumption in district heating plants

Energy consumption (input) and provision in district heating systems, Greece

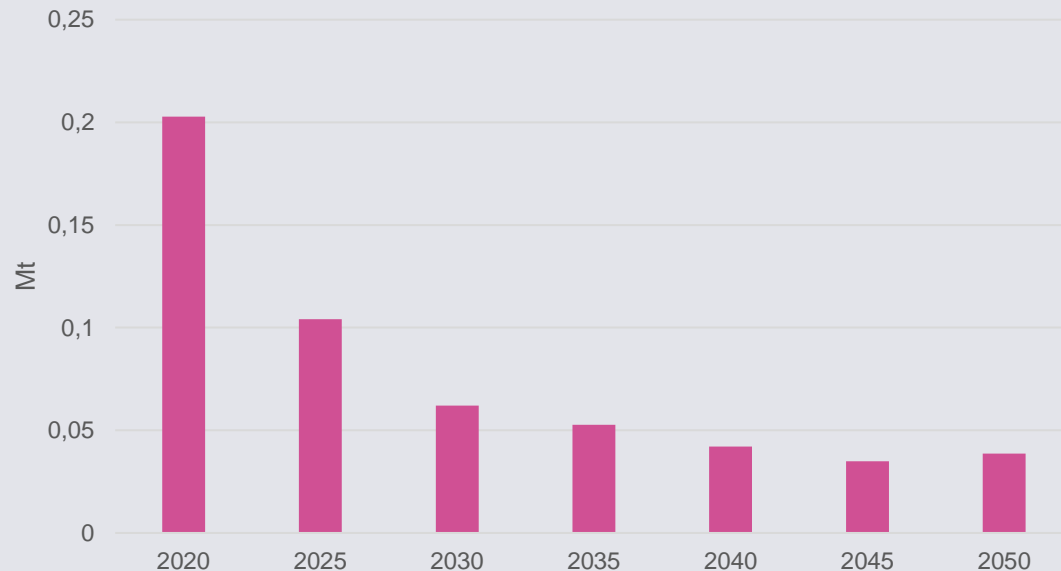


TEP Energy

- Energy consumption first decreases by 5% until 2030 but increases by 68% by 2040 in comparison to 2020. Reasons are fossil phase out and efficiency improvements.
- District heating sees a quite linear reduction in fossil-gas demand over time, declining by 34% from 2020 to 2030 to 0.3 TWh, and by 85% by 2040. to 0.1 TWh.
- Coal is phased out by 2035.
- Electricity production is slightly reduced
- Used energy sources for district heating heat generation: strong structural change from gas and coal to geothermal, solar, ambient heat and electricity (for heat pumps and possibly peak boilers)
- Hydrogen starts playing a role in 2035 to replace fossil gas, while biomass declines, from 0.2 TWh in 2035 to almost 0 in 2050.

Greenhouse gas emissions in district heating

Direct GHG emissions in the district heating sector [in Mt CO₂eq], Greece

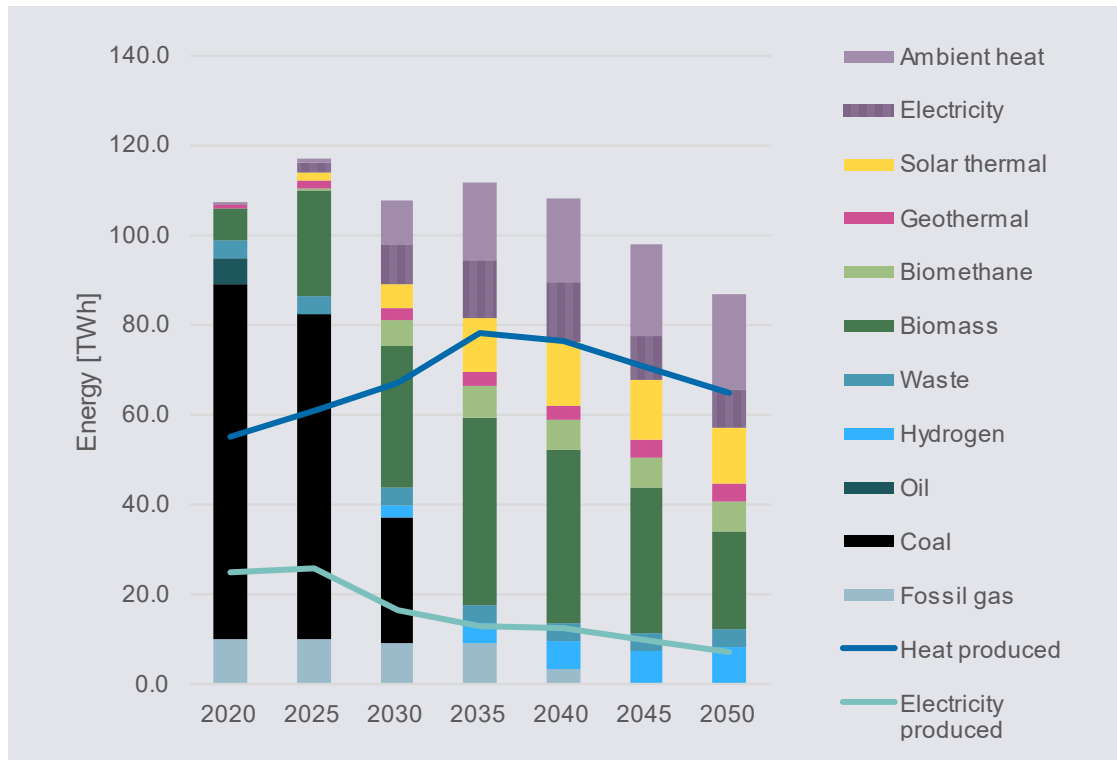


TEP Energy modelling (2023)

- Greenhouse gas emissions decline by 80 % until 2040
- District heating generation sees steady reduction in fossil gas demand over time, declining by 28% in the period from 2020 to 2030, reaching 81% reduction by 2040 and nearly phasing out by 2045 in comparison to 2020.
- The slightly slower fossil gas reduction before 2030 can be explained by growing demand for district heating, as more homes are connected to new and existing district heating networks to displace fossil gas in decentralized heating.
- Remaining emissions from waste treatment plants (could be captured and stored)

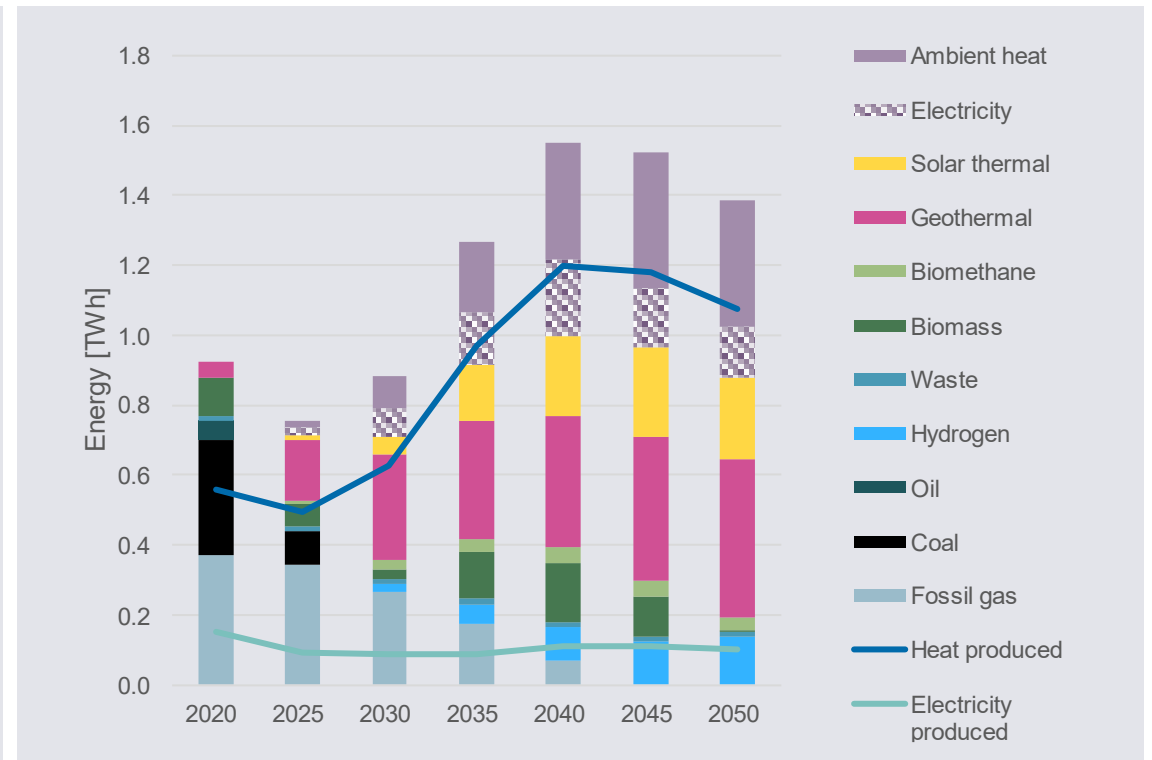
Role of district heating for achieving a fossil free building stock: historical DH countries and DH “newcomers”

Energy consumption in district heating, Poland



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

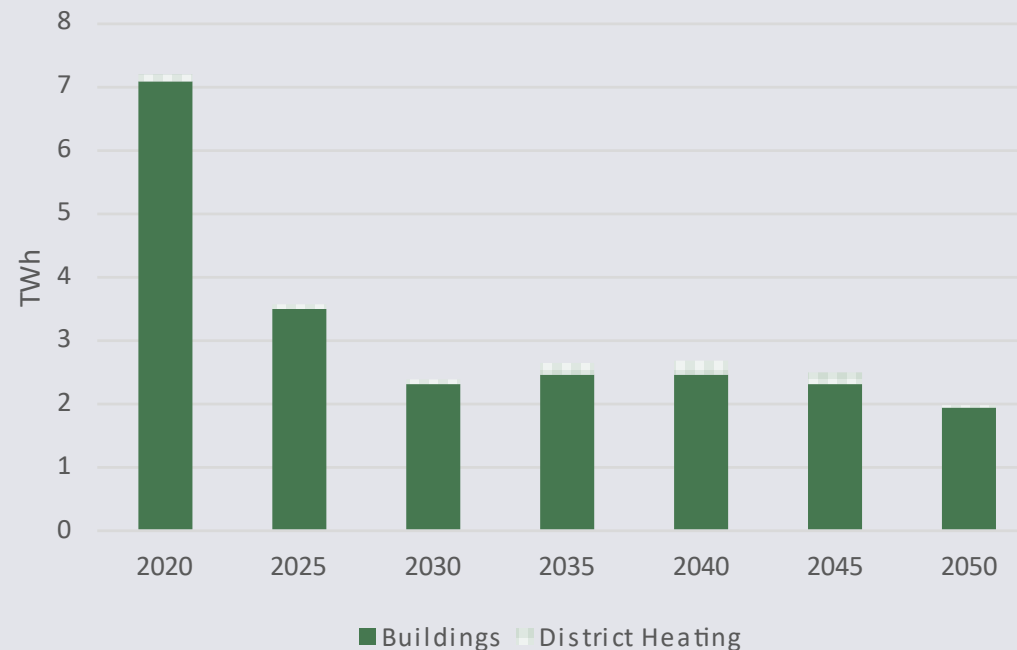
Energy consumption in district heating, Greece



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

Deep dive: solid biomass

Final energy demand for solid biomass in buildings and district heating, Greece

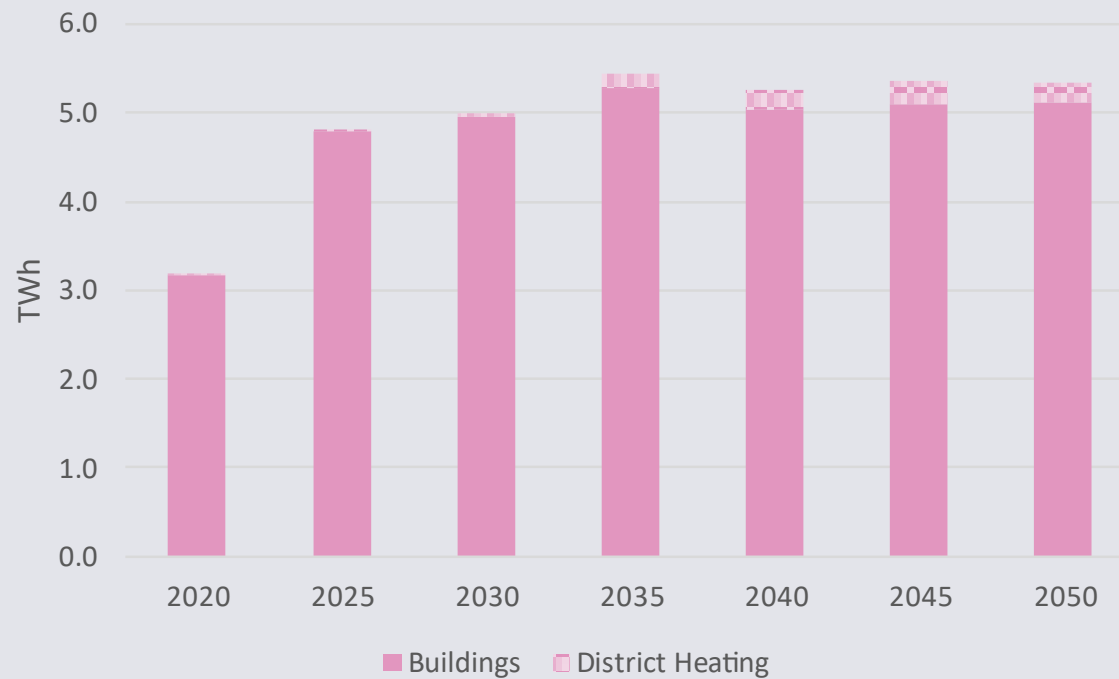


TEP Energy modelling (2023)

- In buildings, decentralized solid biomass heating systems decrease slowly but steadily, due to a general trend towards heat systems with higher degree of convenience and utility (less labor, allows for cooling [in the case of heat pump])
- In district heating generation, solid biomass first increase (to compensate for the fade-out of fossil energy such as gas and coal) and then also decreases (due to uses in other sectors which are prioritized)

Deep dive: Solar Thermal

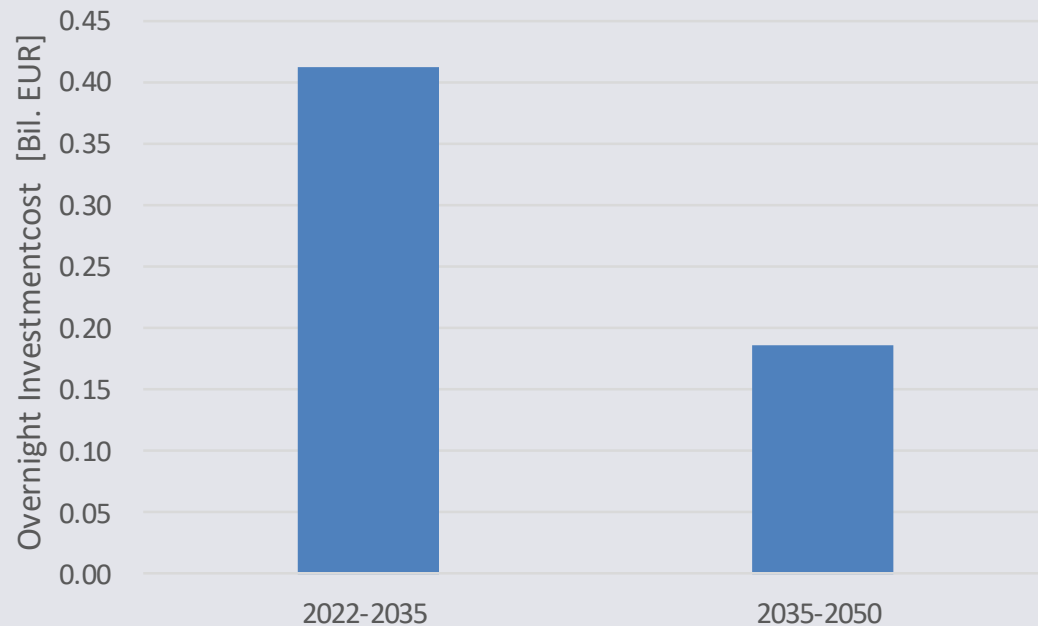
Solar thermal production in buildings and district heating (in TWh), Greece



- Solar thermal buildings produce 5.1 TWh by 2050
- Solar thermal in district heating produces 0.2 TWh by 2050
- 1.5 bil. Euro invested in Solar thermal in by 2050
- Note: Solar thermal is modelled as secondary system in combination with other heating system.

Investments in district heating grid and generation infrastructure

Calculation Approach, Investments, Greece



TEP Energy (2023)

- Approach: investment into distribution and generation is financed by their costs at given rate and over economic period
- Investment costs are based on the additional DH energy demand of the buildings sector (between 2022 and 2050), meaning they only cover grid expansion, not maintenance or replacement of the existing grid.
- Assumptions
 - Cost for heat generation: 4 ct/kWh heat in Germany, transferred to other countries via producer price index
 - Economic period: 25 years (heat generation) and 35 years (grid) respectively
 - Discount rate: aligned with energy sector: 5.25%
- Result: Investments in district heating infrastructure of 0.4 Bil. EUR until 2035 and 0.2 Bil. EUR up to 2050

Annexes

