Breaking free from fossil gas

A new path to a climate-neutral Italy

Presentation overview

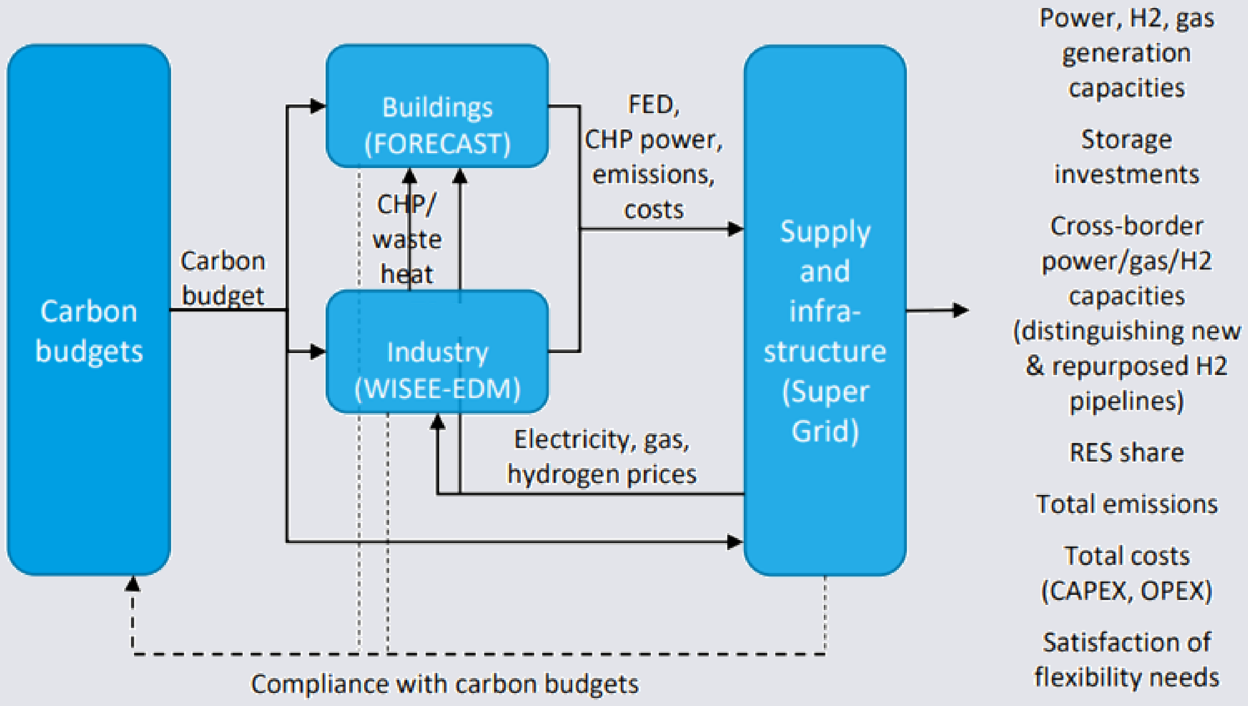
Project background

Project scope

Project setting	Scope
→ Cooperation project between Ecco Climate and Agora Energiewende for Italy, within a consortium of 9 countries to develop national pathways and an EU-wide pathway: • **Bulgaria:** Center for the Study of Democracy (CSD) • **Czechia:** Nano Energies • **Greece:** FACETS S.A. • **Croatia:** University of Zagreb – Faculty of Mechanical Engineering and Naval Architecture • **Hungary:** Regional Centre for Energy Policy Research (REKK) • **Italy:** ECCO Climate • **Poland:** Forum Energii • **Romania:** Energy Policy Group (EPG) • **Slovenia:** University of Ljubljana – Laboratory of Energy Policy (LEST)	→ Decarbonisation pathway until 2050, with fossil gas phase out by 2050 at the latest. Russian gas phase out as quickly as possible (by 2027). → Focus on long-lasting demand reductions, as opposed to short-term behavioural changes. → Cost-optimized balance between direct electrification and “no-regret” applications of hydrogen. → Modelled sectors in 5-year steps: power, buildings, industry + infrastructure including interconnectors and storage (transport and agriculture sectors covered by existing studies). → Energy demand modelled bottom-up by TEP Energy (buildings) and Wuppertal Institute (industry); power sector by Artelys. Energy supply was modelled for the whole EU with an optimisation model by Artelys.

Overall modelling workflow

Data flow between the models



Artelys, TEP Energy, Wuppertal Institute

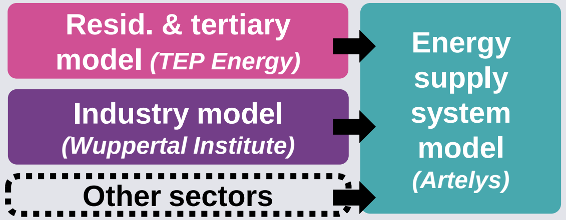
- Three separate models for building, industry and power and energy supply are soft-linked
  - Close coordination between the different models to select the least-cost options, making use of life-cycle costs, preferences and possibly cost abatement curves
  - Facilitates proper reflection of the “communicating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

Assumptions on final energy demand and CO_2 emissions

Approach

Evolution of final energy demand:

- Buildings: TEP Energy (1)
- Industry : Wuppertal Institut (1)
- Transport: Transport & Environment, Road2Zero scenario (2)



Carbon budget approach:

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

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

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

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

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

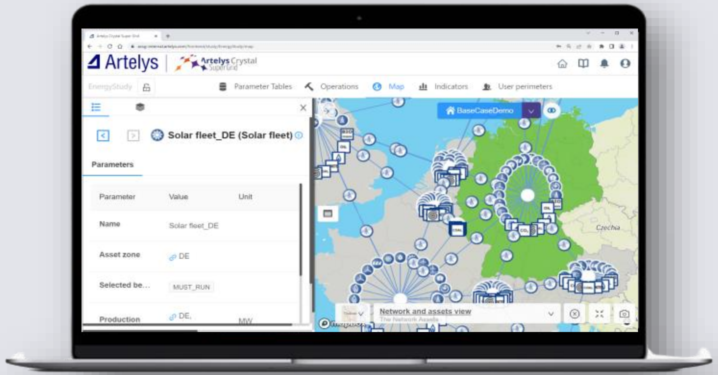
→ In concrete terms, the power sector is considered to be largely decarbonised by 2040.

Energy sector:

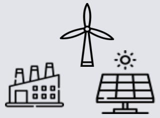
Methodology and assumptions

Energy system modelling in the EU-27

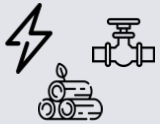
Artelys Crystal Super Grid model



A multi-energy modelling solution dedicated to interconnected systems



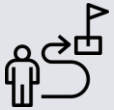
Bottom-up representation



Multi-energy approach

State-of-the-art optimisation techniques

Optimisation models



Advanced **capacity expansion** features

Artelys

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

Energy system modelling

Overview of the power, methane and hydrogen sector modelling

Current energy system

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

Investment options

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

Policy Options

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

Artelys Crystal Super Grid

Multi-Energy Capacity Expansion Pathway

Joint optimisation of :

Investment in new capacities

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

and

Optimal dispatch

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

System KPIs

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

Economic KPIs

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

Policy KPIs

- CO_2 emissions
- Welfare calculations

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

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

→ Capacity expansion optimisation is constrained by GHG emission limits.

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

Overview of technologies considered to move away from fossil gas – EU level

→ **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)

** Investments in nuclear capacity is not considered in Italy*

Assumptions on the power sector – EU level

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 – EU level

Assumptions on available technologies and investment options

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

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

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

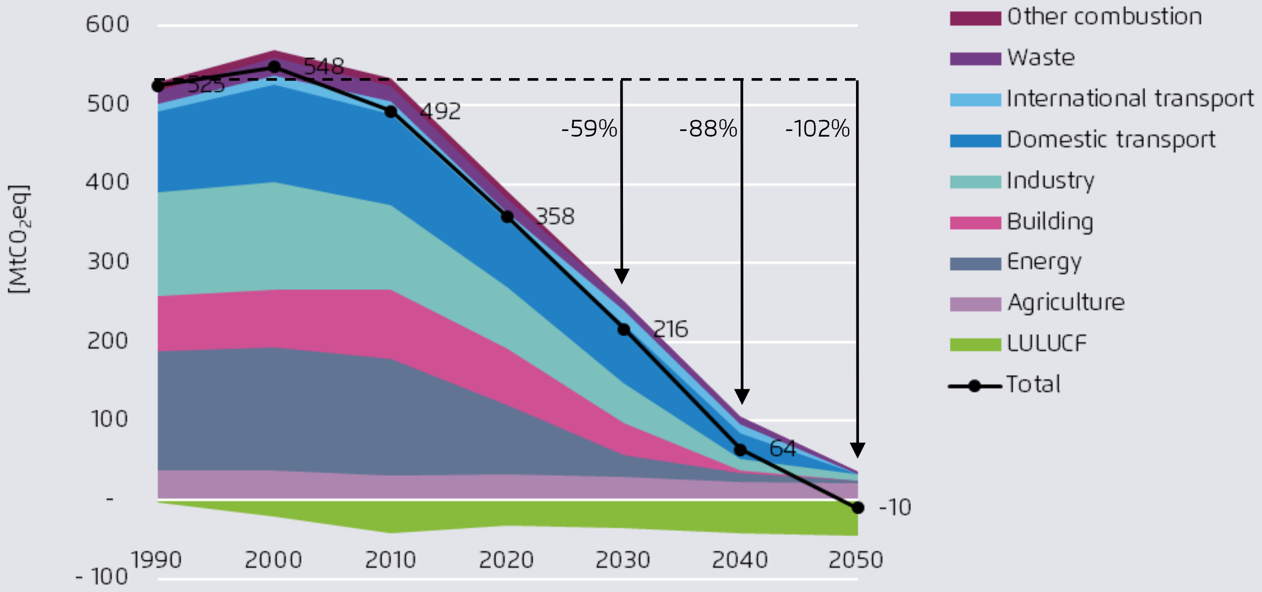
Biogas and biomethane
- Biogas and biomethane considered to be interchangeable with fossil gas
- Conservative approach concerning their availability due to sustainability concerns of biomass overall.
- Total biomass consumption (excluding material use in the study) assumed to remain at today's levels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

Energy sector:

Results –
Overall pathway and energy supply

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

GHG emissions by sector in Italy

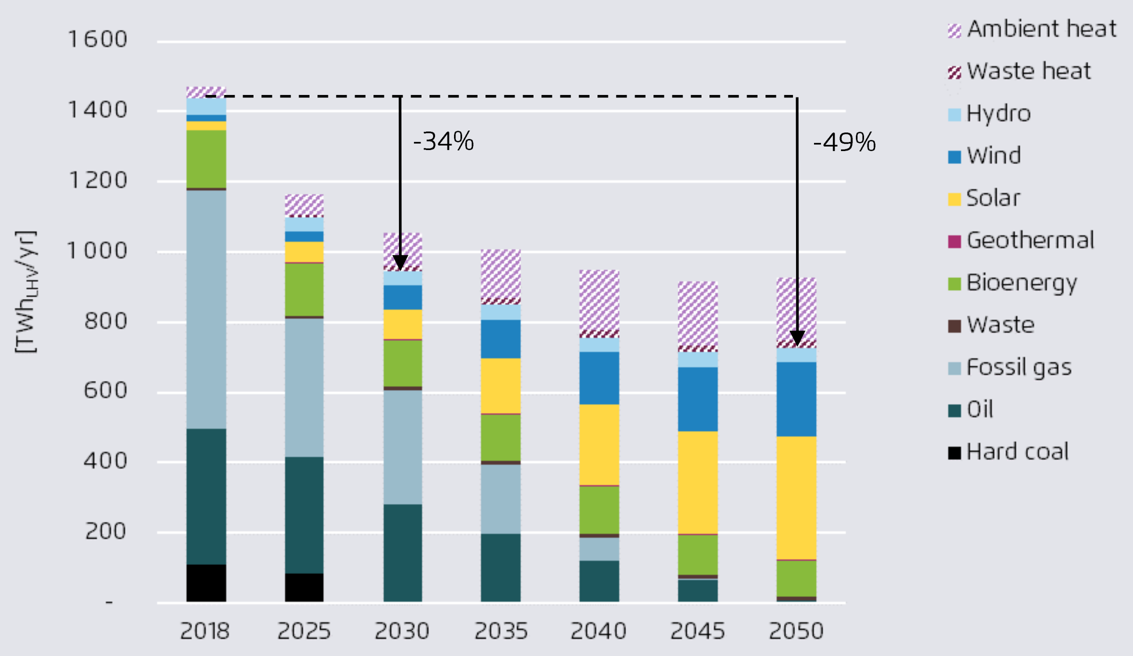


Eurostat; Artelys, TEP Energy, Wuppertal Institute modelling (2023)
* Based on scenarios by Transport & Environment (Transport) and the European Commission (Agriculture & Waste)
** Based on the LULUCF+ scenario from the EC Climate Target Plan impact assessment (assumes a 5-year delay)

- 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 Italy, that would amount to about -88% emissions.
- Transport, agriculture, waste and LULUCF covered by existing studies by Transport & Environment and the European Commision: Additional efforts in these sectors could achieve further reductions by 2040.
- Broadly speaking, the last 10% of residual emissions will be the hardest to mitigate.

Primary energy demand* declines by 34% by 2030 and 49% by 2050, not taking into account ambient and waste heat in the buildings and industry sectors

Primary energy demand* by energy source, Italy



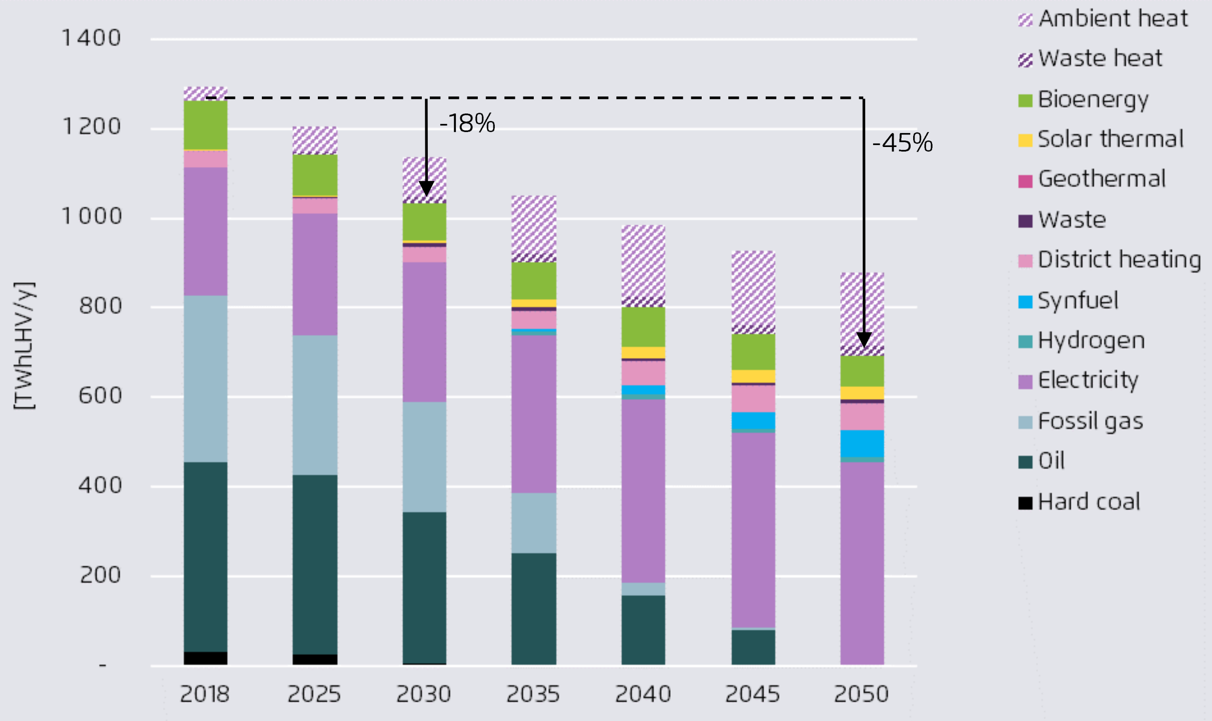
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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

- → Decline primarily thanks to electrification and efficiency increases, in particular the use of heat pumps in buildings and industry making use of ambient heat, as well as waste heat integration.
- → Hard coal is entirely phased-out by 2030. Oil mostly remains in the transport sector after 2025.
- → Renewables, especially wind and solar, massively increase from 18% of PED* in 2018 to 98% in 2050, displacing fossil gas from power production which represented 46% of power generation in Italy in 2018.

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

Final energy demand by energy carrier, Italy

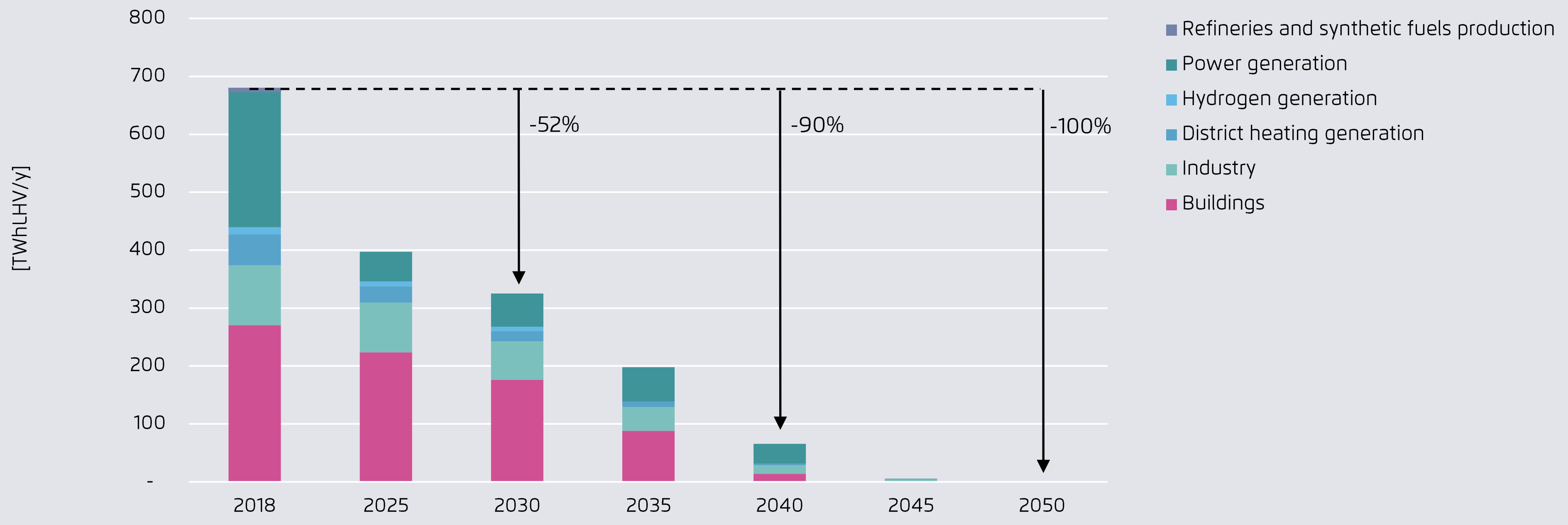


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → 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 23% in 2018 to 30% in 2030 and to 66% in 2050. On the contrary, fossil fuels representing 66% of FED in 2018 are phased out by 2050, oil in transport being the longest in the energy system.

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

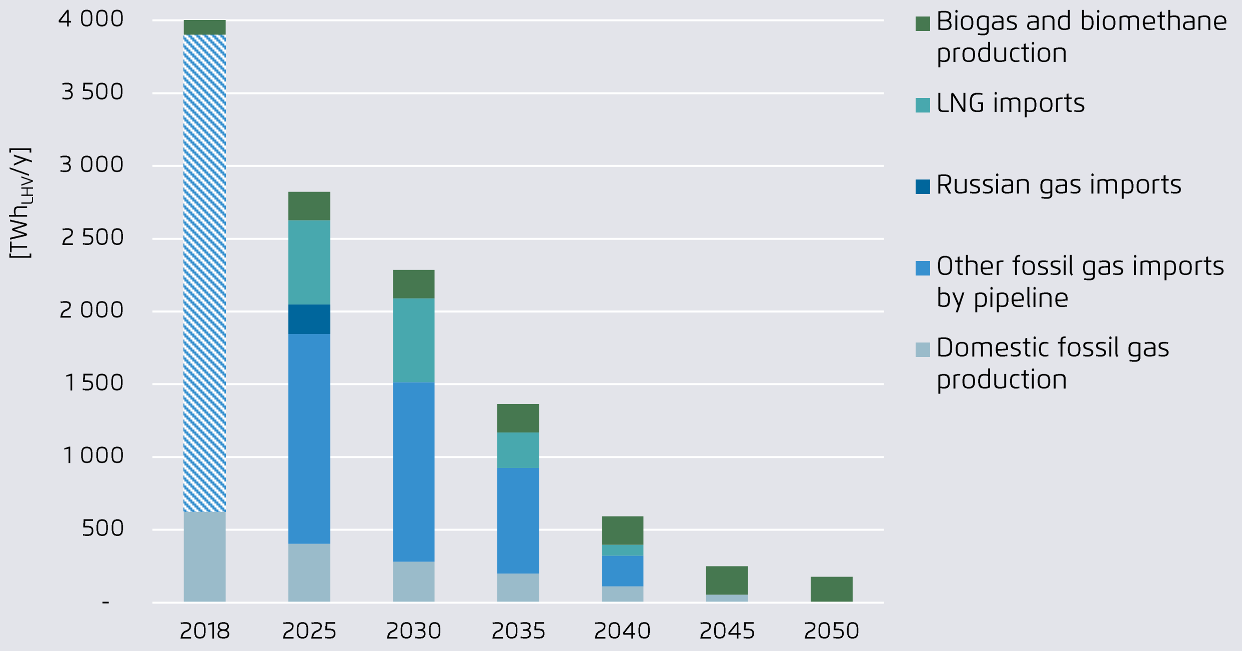
Evolution of total fossil gas consumption in Italy, 2018-2050 (in TWh_{LHV})



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

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

Methane supply, EU-27

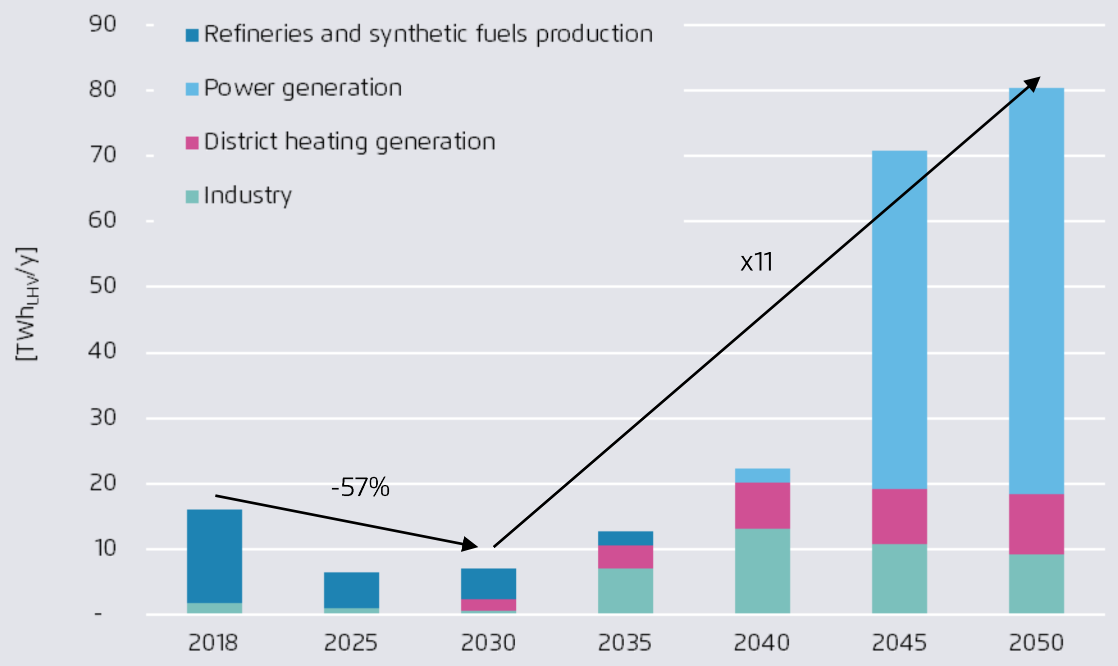


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → 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 57% until 2030, but is then expected to be multiplied by 11 between 2030 and 2050

Hydrogen consumption by sector for Italy

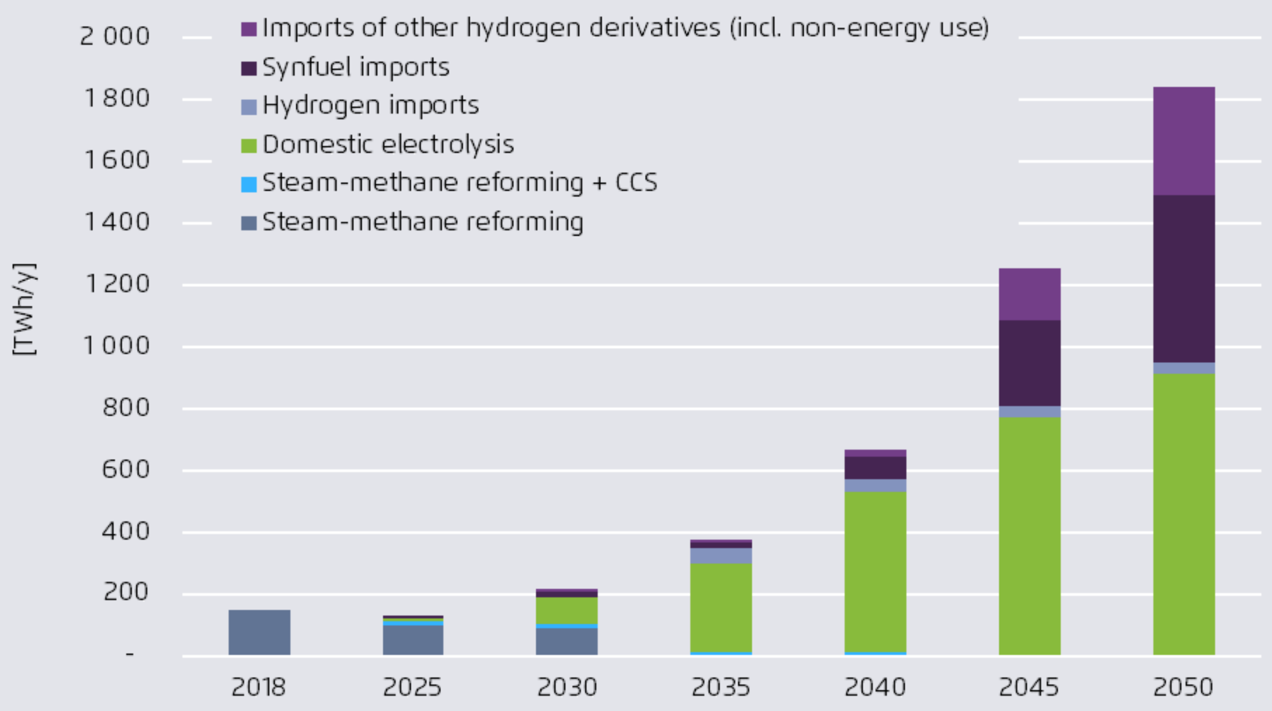


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- By 2050, hydrogen demand will reach 80 TWh, about 12% 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 Italy, 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, hydrogen turbines emerge to provide flexibility services to the power system, which is expected to represent more than 75% of H2 demand in the last decade in Italy.

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

Hydrogen and hydrogen derivatives supply mix, EU-27

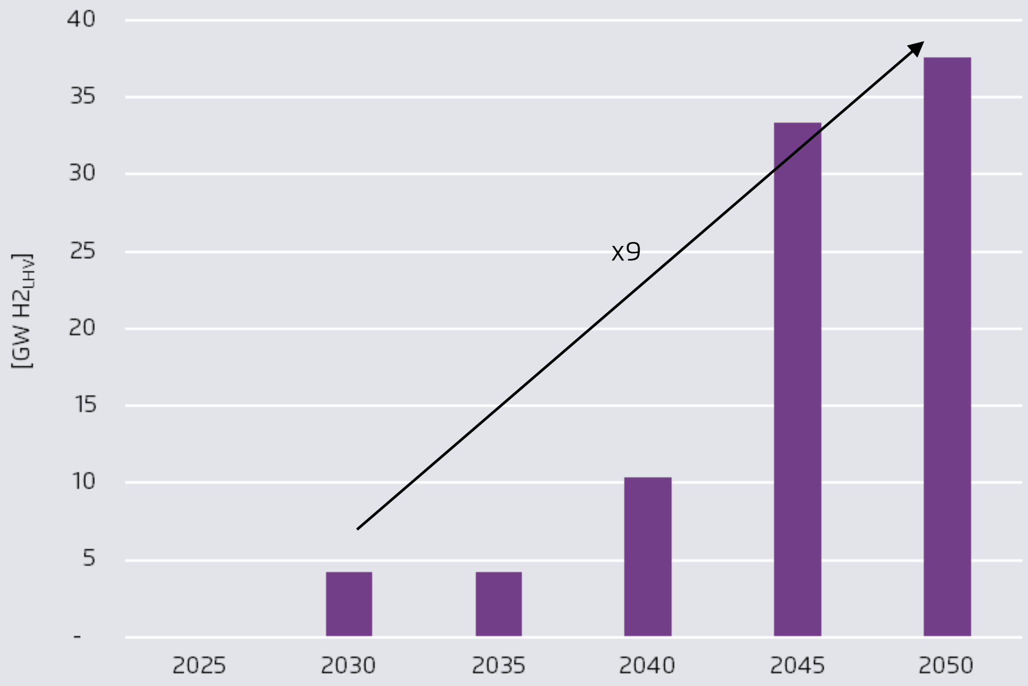


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

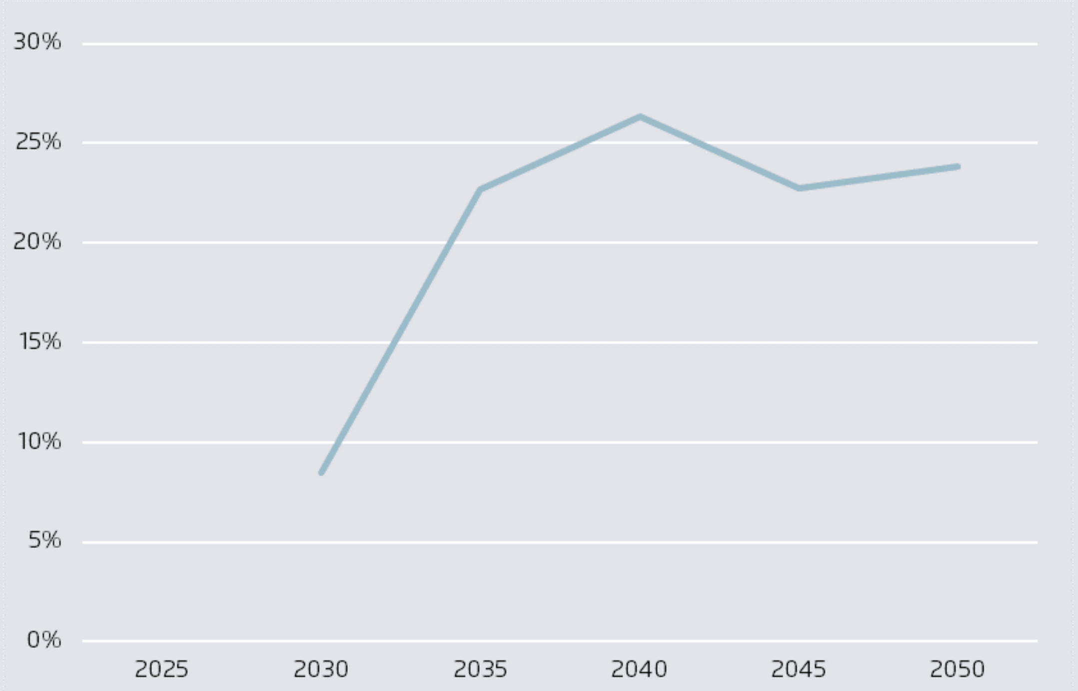
- → Renewable hydrogen produced in Europe reaches 90 TWh (2.7 Mt) by 2030 to first replace fossil-based hydrogen. It scales significantly until 2050 to reach 910 TWh (27 Mt).
- → Imports of renewable hydrogen only start in 2035 with 52 TWh/y (about 15% of supply) and remain low until 2050. SMR hydrogen 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 4 GW in 2030 and is multiplied by 9 until 2050. This is below the 10 time increase in renewable hydrogen demand, allowing for an optimised use of the electrolysers.

Installed electrolyser capacity, Italy



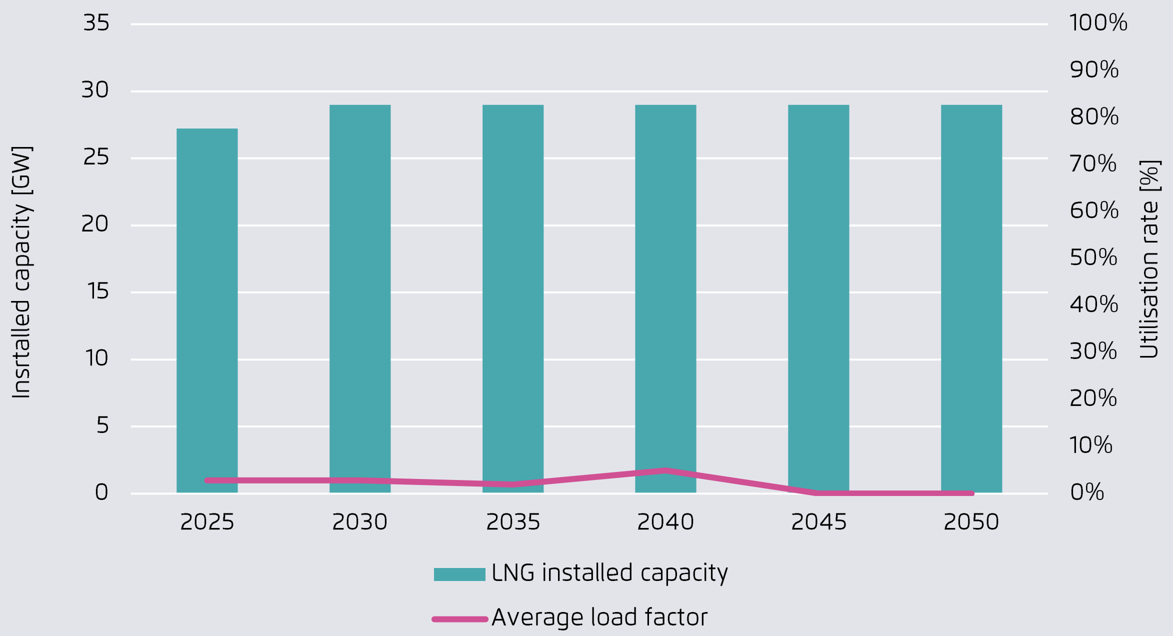
Load factor of electrolysers



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, Italy

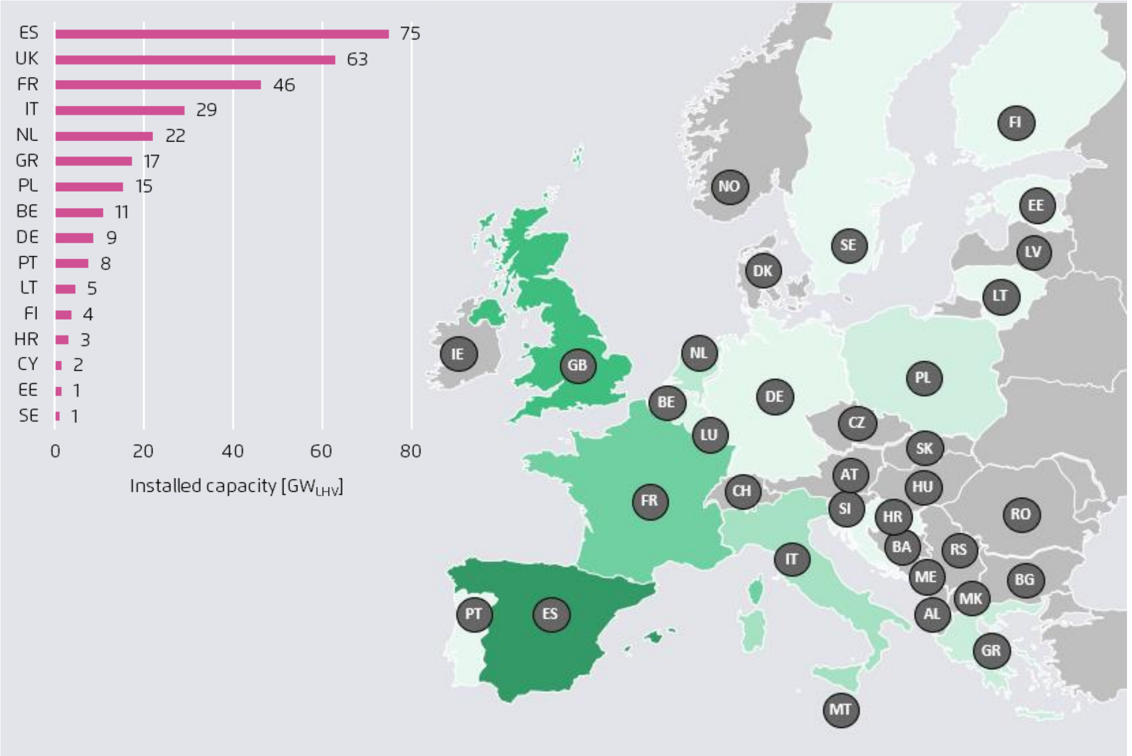


Artelys, TEP Energy, Wuppertal Institute modelling (2023)

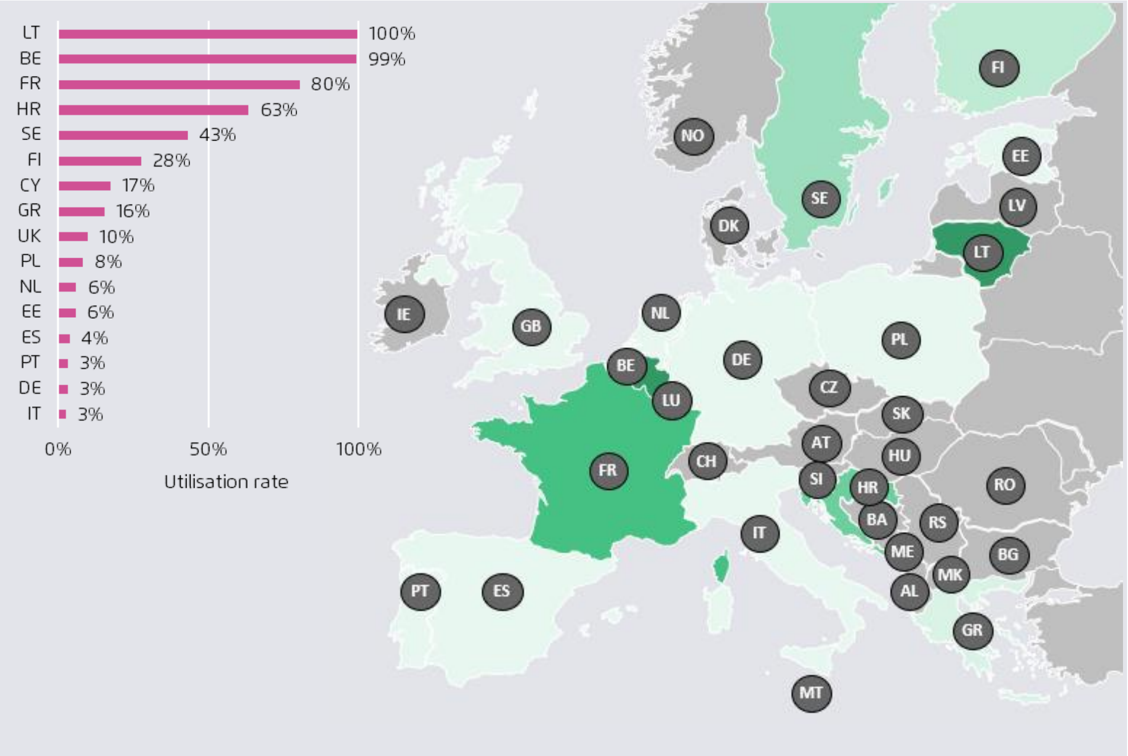
- As a response to the fossil gas supply crisis, LNG import capacity in the EU-27 will expand by 21%, or 53 GW compared with 2021. In Italy, an increase of close to 60% has been planned (2 additional FSRU units for 3 existing).
- If demand declines as it should in order to ensure energy sovereignty and for Italy to achieve its climate targets, those investments will be used very little (average utilisation rate of the terminals will peak at about 5% in 2035-2040 from about 40% on average between 2018 and 2020) and become stranded assets by the time they are being built.

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

LNG terminal installed capacity by country in 2030 (GW)



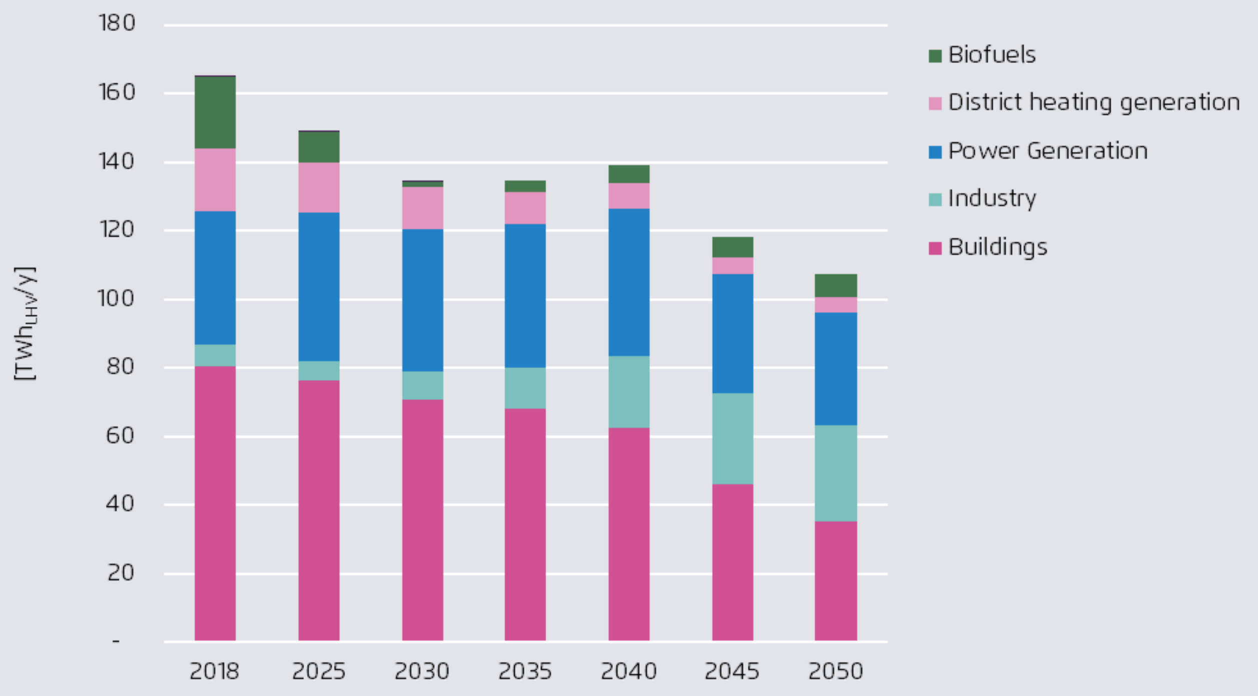
LNG terminal utilisation rate by country in 2030 (GW)



Artelys, TEP Energy, Wuppertal Institute modelling (2023)

The use of biomass for bioenergy and non-energy feedstock purposes declines in buildings and district heat

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

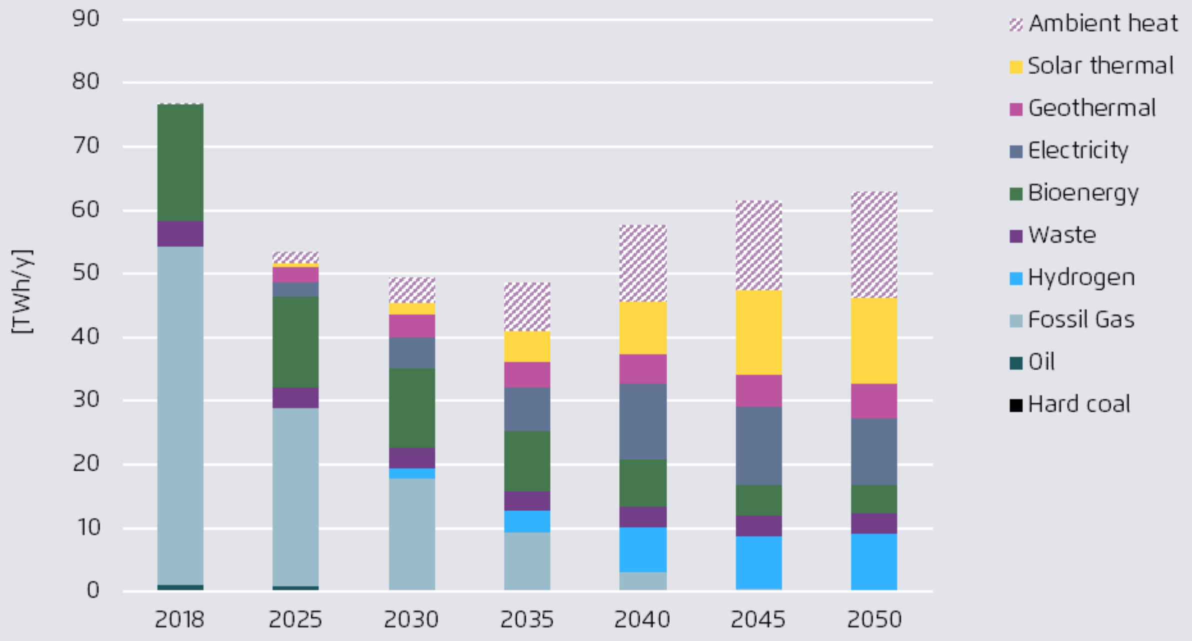


Artelys, TEP Energy, Wuppertal Institute modelling (2023)
Note: Including non-energy consumption of biomass feedstocks in chemicals and refineries, but excluding material uses

- → 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 and industry sectors, including for district heating generation.
- → Consumption declines from about 165 TWh in 2018 to 110 TWh in 2050. It is more than halved in the buildings sector and for DH generation until 2050 but quadruples in the industry.
- → The role of biomass for power generation remains stable until 2050 with a slight increase during the transition.
- → 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), Italy

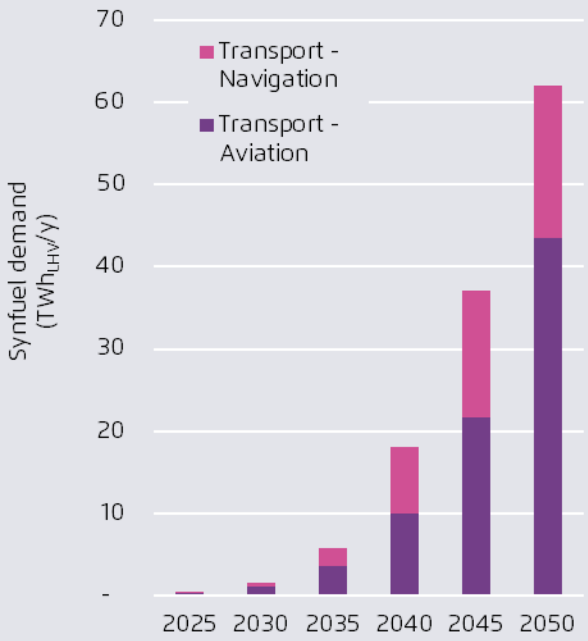


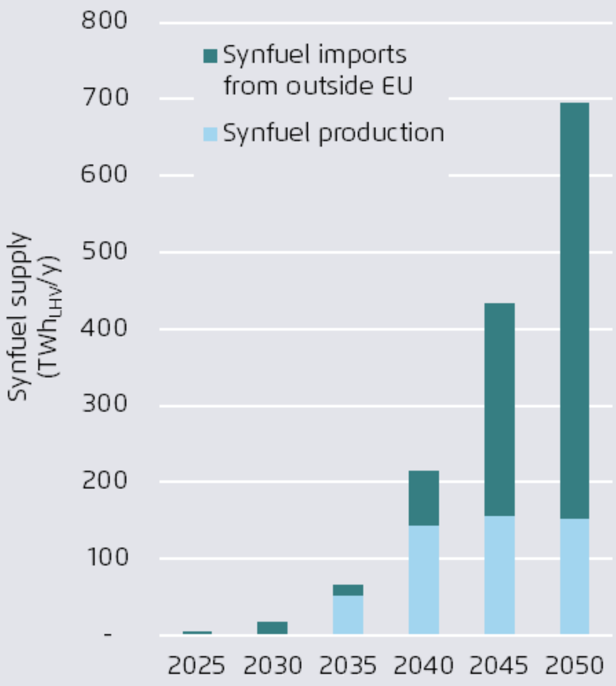
Artelys, TEP Energy, Wuppertal Institute modelling (2023)

- → In 2018, the district heating supply mix is dominated by fossil gas (69% of the total), biomass (24%) and waste (5%).
- → District heating sees a quick reduction in fossil-gas demand, declining by 67% from 2018 to 2030 to 18 TWh, and is almost phased out by 2040.
- → Fossil gas is gradually replaced by heat-pumps, solar thermal and geothermal. These technologies account for roughly 75% of the energy consumption by 2050 if considering ambient heat.
- → Hydrogen starts playing a role in 2030 to replace fossil gas, while biomass declines, from 18 TWh in 2018 to 5 TWh in 2050.

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

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





Artelys, TEP Energy, Wuppertal Institute modelling (2023)

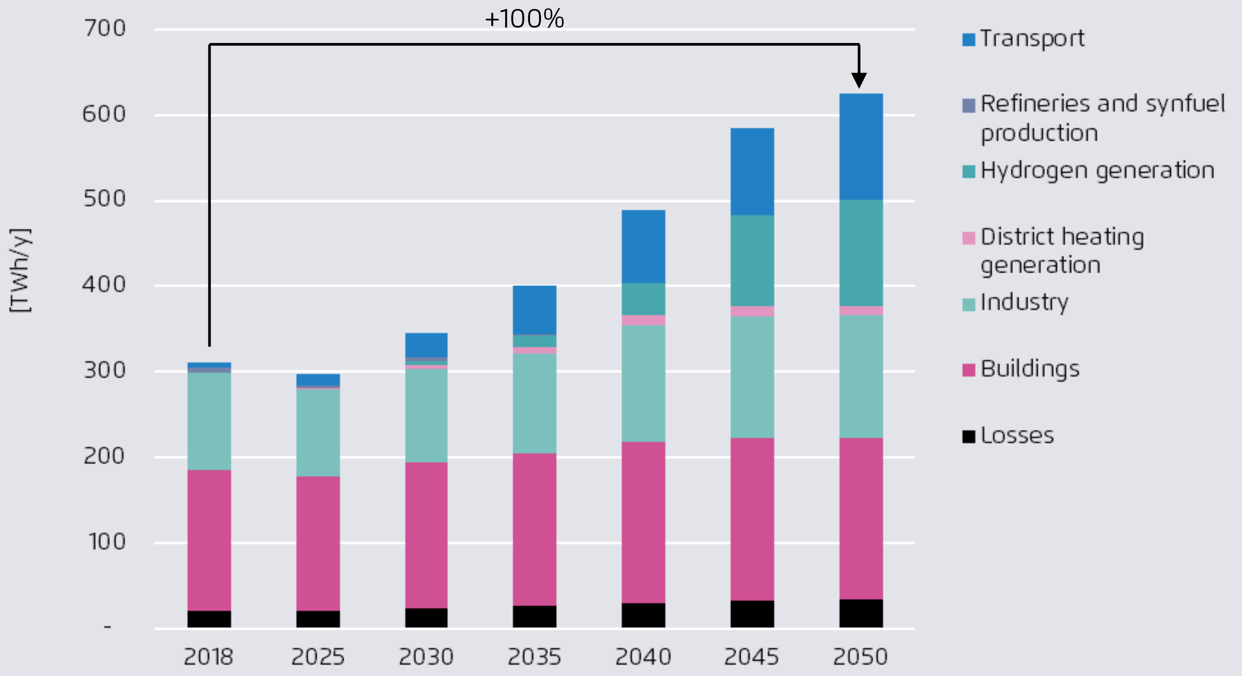
- The T&E scenario included in this project foresees a very strong electrification of surface transport (both private and goods transport).
- Synthetic fuels are being used in particular in aviation and navigation, and imported starting 2025. Imports represent up to 78% of supply by 2050 for production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

Energy sector:

Results – Power sector

Electricity demand

Power consumption by sector for Italy

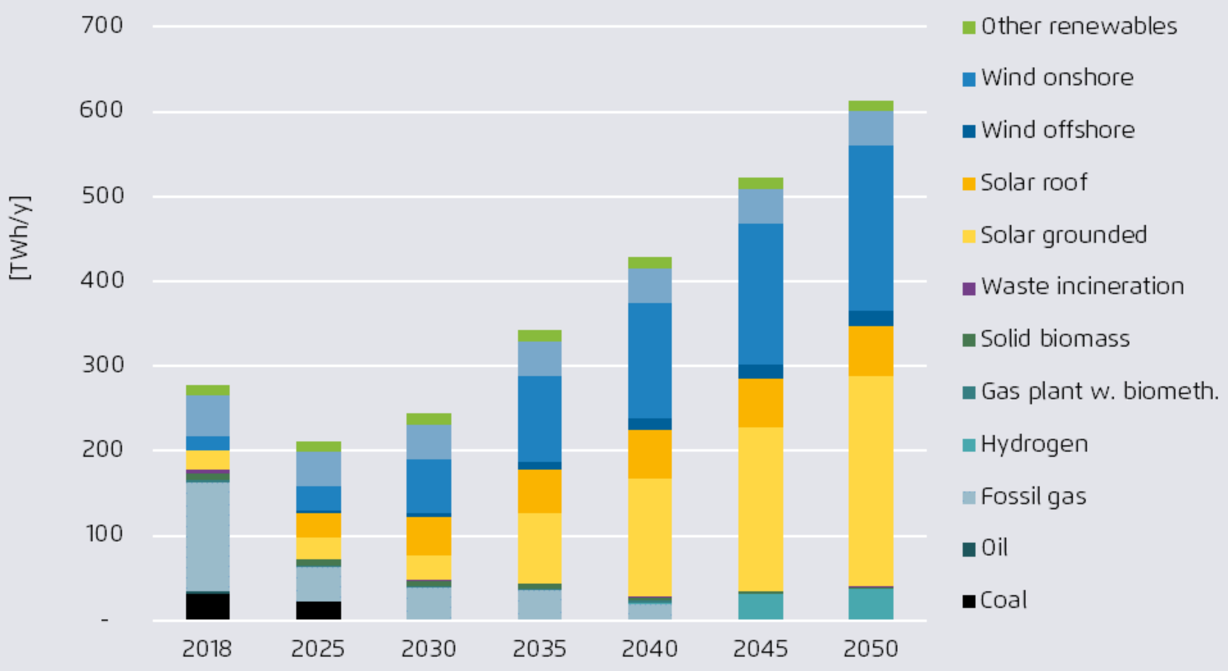


Artelys modelling (2023)

- Total electricity consumption doubles between 2018 and 2050.
- The increase is mainly due to electrolysis (+126 TWh) and the electrification of transport (+118 TWh).
- Due to the combined effect of energy efficiency measures (incl. building renovations) and electrification of heating devices (mainly through heat-pumps), power demand in the buildings and industry sector only slightly increase between 2018 and 2050 (~+30 TWh respectively).

Power generation

Power generation in Italy

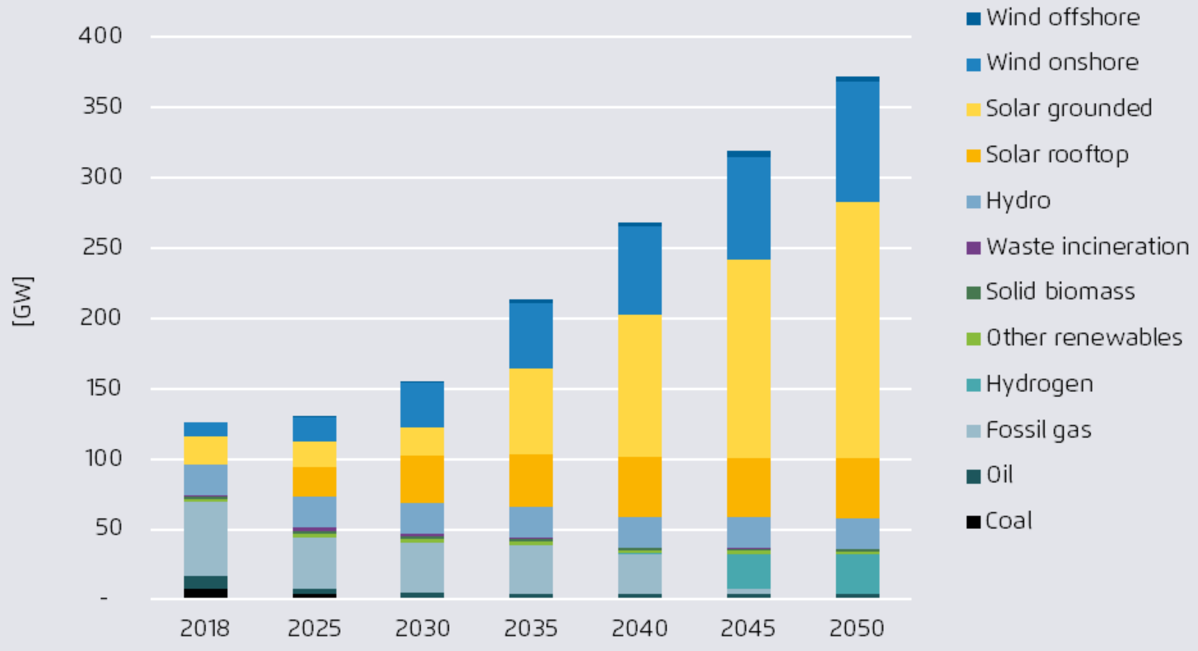


Artelys modelling (2023)

- Coal is phased out in the period 2025-2030. In the NECP, Italy committed to phase out coal plants by 2025, or by 2028 at the latest in Sardinia
- 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, historically representing about 45% of power generation, decreases strongly between 2018 and 2025 (-68%) and can be replaces by renewables.
- Renewables (solar + wind + hydro + biomass + renewable hydrogen) account for 84% of total power supply by 2030 and 100% by 2050.
- Hydrogen power generation replaces fossil gas as dispatchable power generation technology by 2045 and represents about 6% of total generation by 2050.

Installed capacity

Power generation capacity, Italy

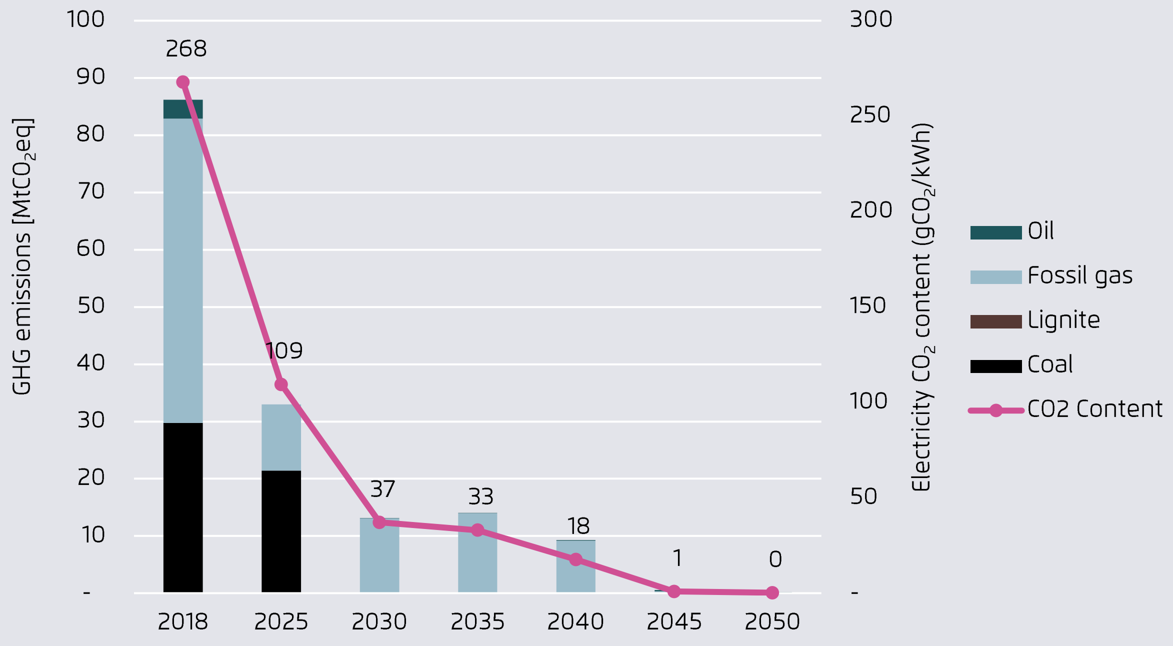


Artelys modelling (2023)

- The power generation mix is dominated by solar and wind power (by 2050, solar accounts for 57% of installed capacity and wind for 24% for a total of 82% of capacity).
- Wind reaches 32.5 GW by 2030 (31 GW onshore and 1.5 GW offshore) and 90 GW in 2050.
- Solar reaches 54 GW by 2030 and 225 GW by 2050.
- Dispatchable capacities decrease by 54%, from 70 GW in 2018 to 32 GW in 2050.
- From 2040 onwards, gas powered capacities are gradually phase-out and replaced by hydrogen powered capacities.

CO_2 content Power sector

Evolution of electricity CO_2 content, Italy

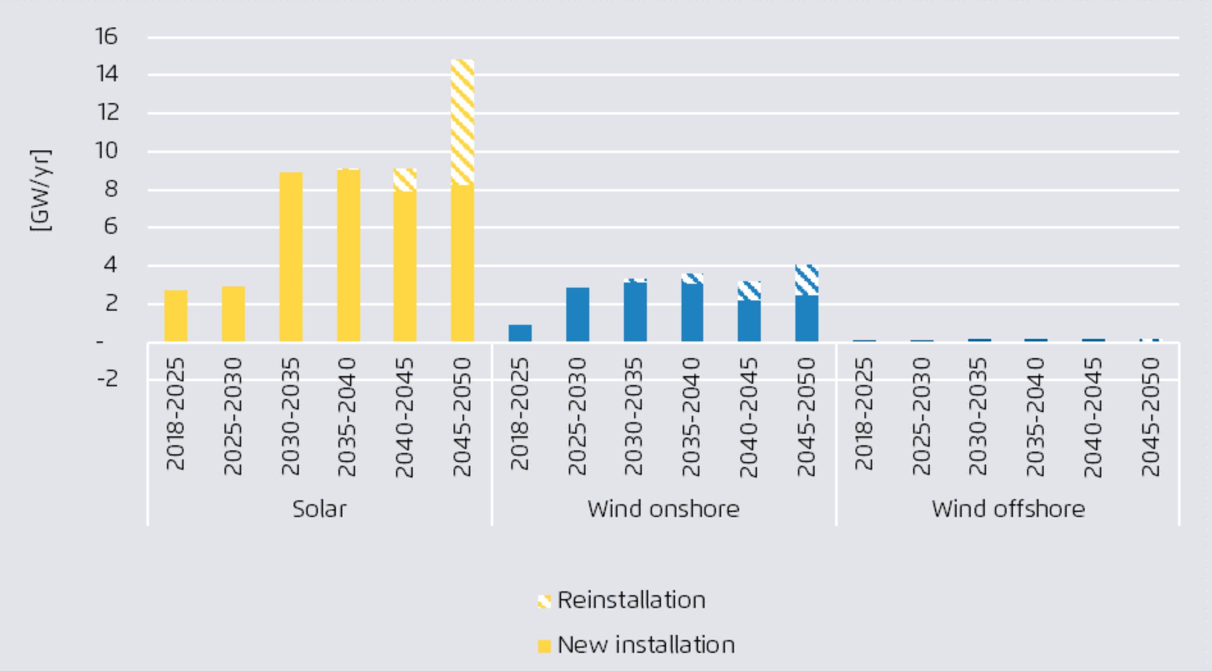


Artelys modelling (2023)

→ The power sector will be almost emissions free by 2030. Some fossil gas will remain in the power sector until 2040, leaving a limited CO_2 content.

Capacity installation rate – renewables

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

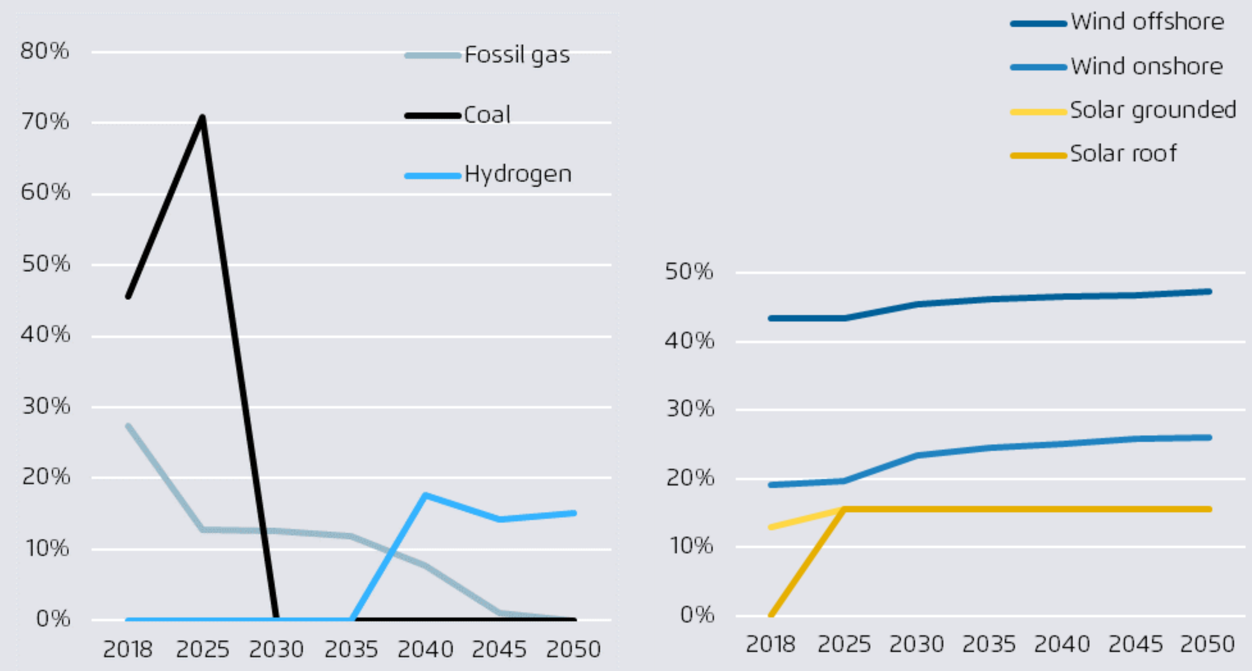


Artelys modelling (2023)

- 8 GW of solar, 3 GW of onshore wind and 160 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. This allows to reduce the dependence of the Italian power sector on fossil gas quickly.
- For onshore and offshore wind, 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 (%)

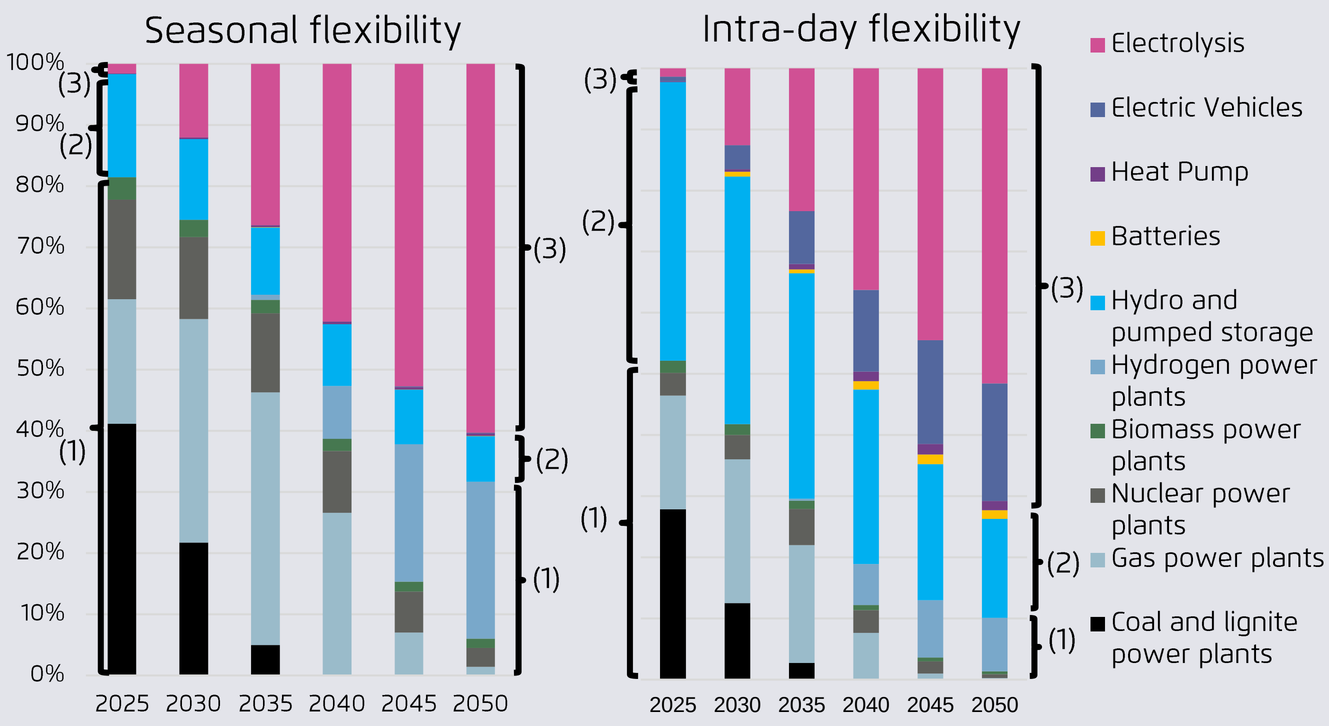


Artelys modelling (2023)

- The average capacity factor of carbon-intensive dispatchable technologies strongly decreases during the transition
- Indeed, despite the important decrease in generation from dispatchable technologies (-77% between 2018 and 2050), installed capacity only declines by half during the same period as they develop a "capacity value", offering security of supply and flexibility to the system.
- 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 27% to 13%). Despite low generation, more than 70% of gas capacities remain online to provide flexibility to the system.

Flexibility provision

Evolution of the provision of flexibility in EU-27

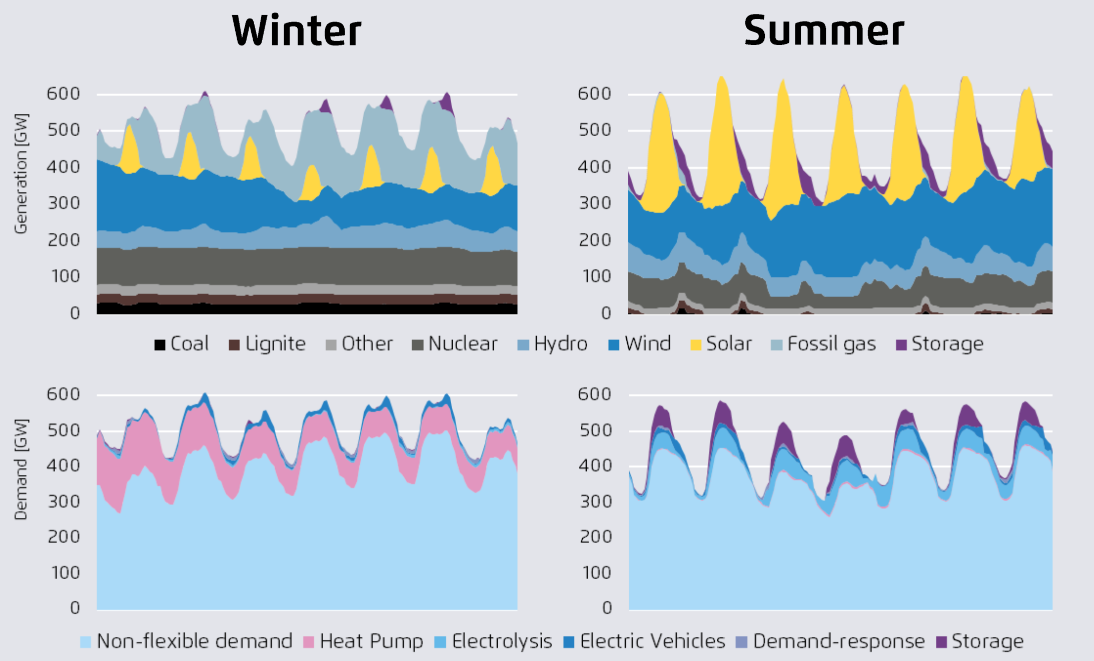


Artelys modelling (2023)

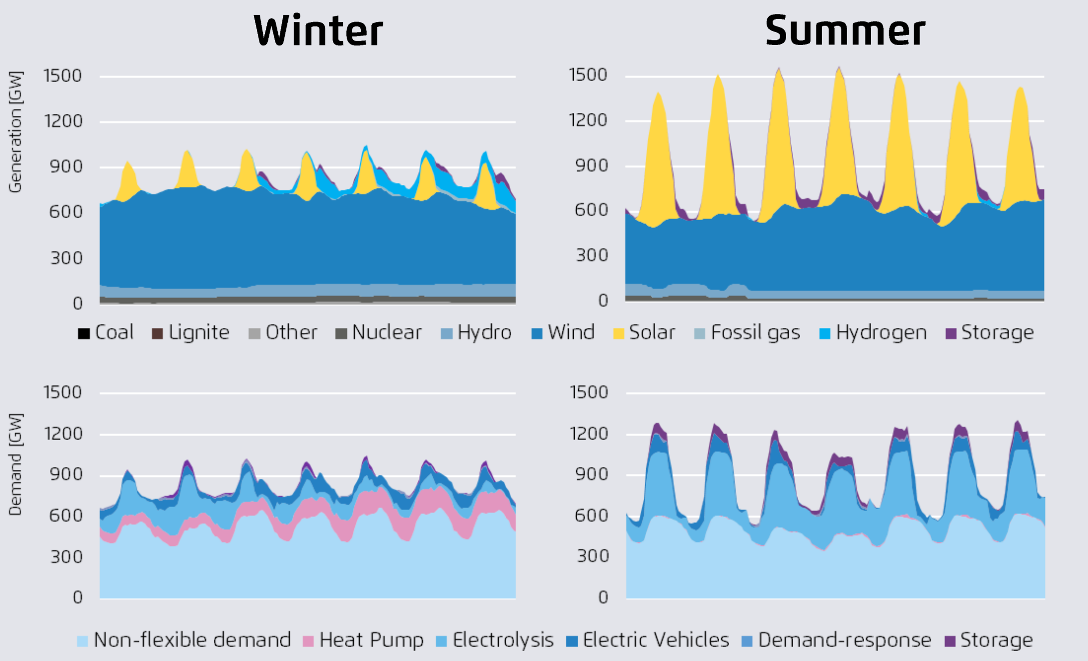
- Currently, system flexibility needs are mainly met by conventional power plants (1) and storage technologies (2) for both seasonal and short-term flexibility
- In future, demand side flexibility (3) will play a predominant role
  - Electrolysis alone will provide 60% of the seasonal flexibility needs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

Flexibility requirements will significantly increase until 2050

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



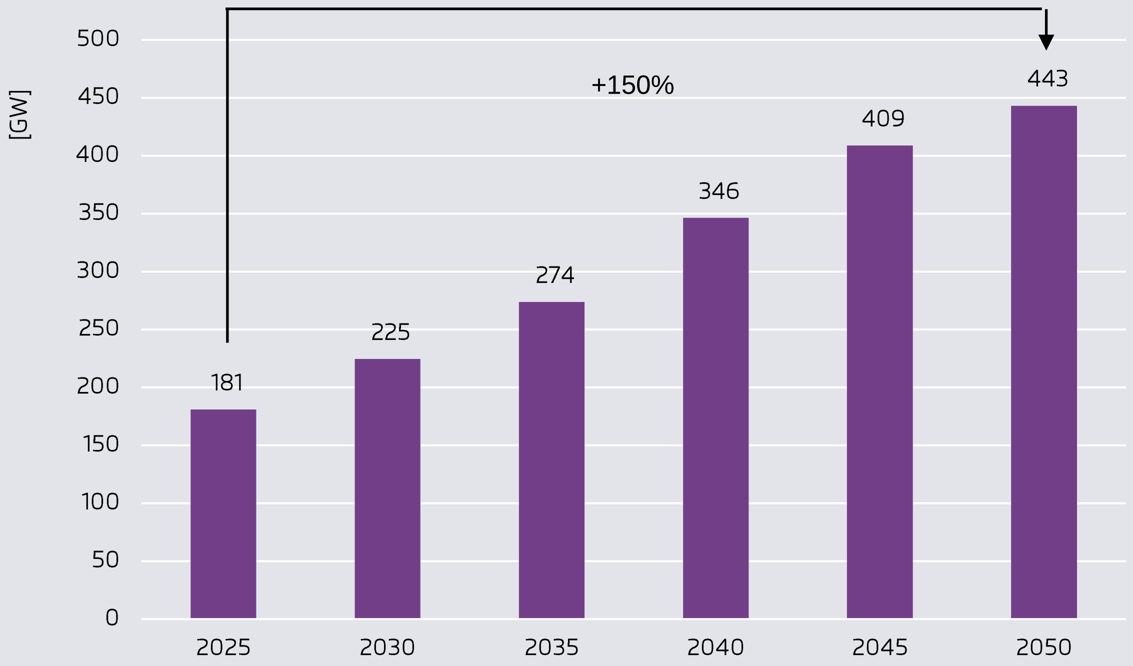
Demand-supply balance during a typical week in 2050 in the EU



Artelys modelling (2023)

Evolution of power transmission infrastructure

Power transmission cross-border capacities in the EU-27



Artelys modelling (2023)

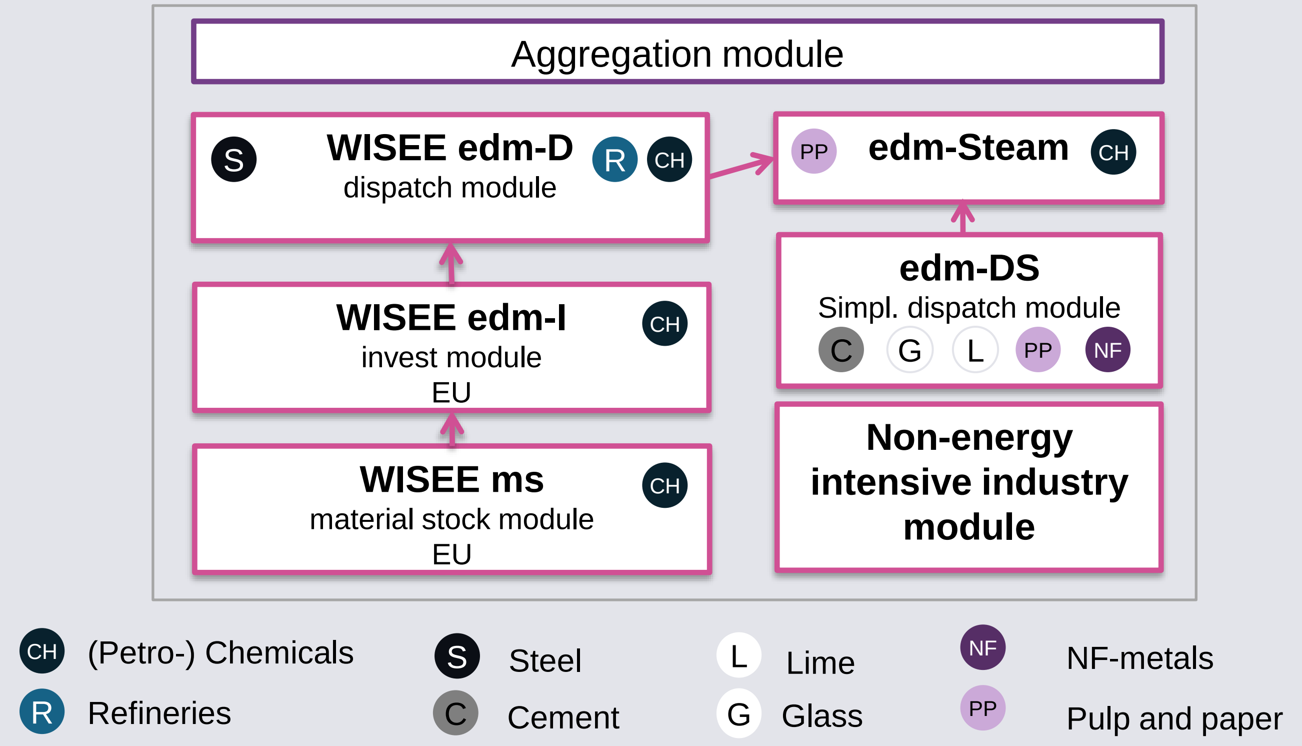
- Electricity interconnections are multiplied by 2.5 between 2025 and 2050.
- Interconnections are found to be very efficient flexibility solutions to foster variable renewable generation. Their development may nevertheless be constrained by social acceptance issues which need to be tackled.

Industry & refineries:

Methodology and assumptions

Industry modelling: country and technology specific

Overview of the WISEE-EDM modelling system



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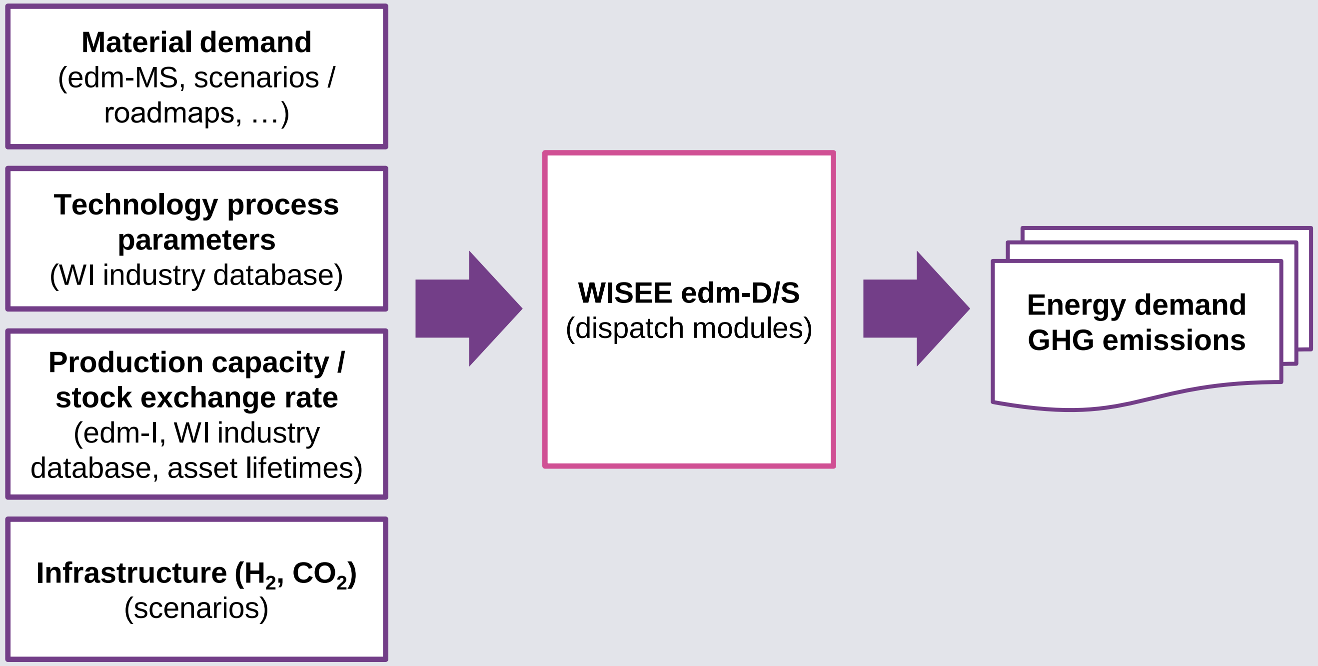
Graduated modelling approach:

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

Industry modelling: A glimpse at the edm-Dispatch model

Main drivers and outputs of the edm-D



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

Selected model features:

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

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

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

Key parameters and assumptions on the industry sector

Industrial production	Industrial sites & infrastructure
→ Gross Value-Added of industry and its branches → Evolution of production volumes for energy intensive products and market shares within the EU → Assumptions / simulation results for core (re-)investments such as Fischer-Tropsch refineries, iron reduction or steam crackers → Substitution rates for fossil gas boilers → Market shares in the substitution in the branches and at different levels of temperature of: • Heat pumps • Electric heaters (electrode boilers) • Hydrogen boilers • Concentrated solar power (CSP) → Evolution of industrial CHP per country: • MWth and MWel • Energy carrier use • Electricity shares • Full load hours	→ Evolution of the H_2 backbone in the country and connection dates for important sites (chemicals, refineries, steel) → Evolution of the CO_2 grid in the country and connection dates for important sites

Assumptions on the industry sector

- Only slight relocation of production:
  - The industrial structures and value chains in the EU countries are stable.
  - Some extra-EU ammonia imports (compared to 2021 and earlier) and relocation of ammonia production within the EU
- Fast electrification via heat pumps and electric boilers to displace fossil gas
- Industrial ovens are replaced by electric devices after 2030
- Use of fossil gas as a bridge in the transformation of integrated steel mills
- 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)
- Use of biogas to cover a part of gas demand

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; it remains a little share of production of primary steel to ensure the availability of all steel qualities.
- → Scrap becomes the main iron input in steel making and reaches 67% in 2050 (compared to ca. 50% today).
- → The second iron input is DRI, which is mainly produced in Europe.
- → The EU is a frontrunner in DRI production, but imports are accepted, starting with 8% in 2030 and reaching a peak in 2040 at 27% (8% in 2050).

Chemicals in the EU
Characterization of the general development

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

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

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

EU refineries
Characterization of the general development

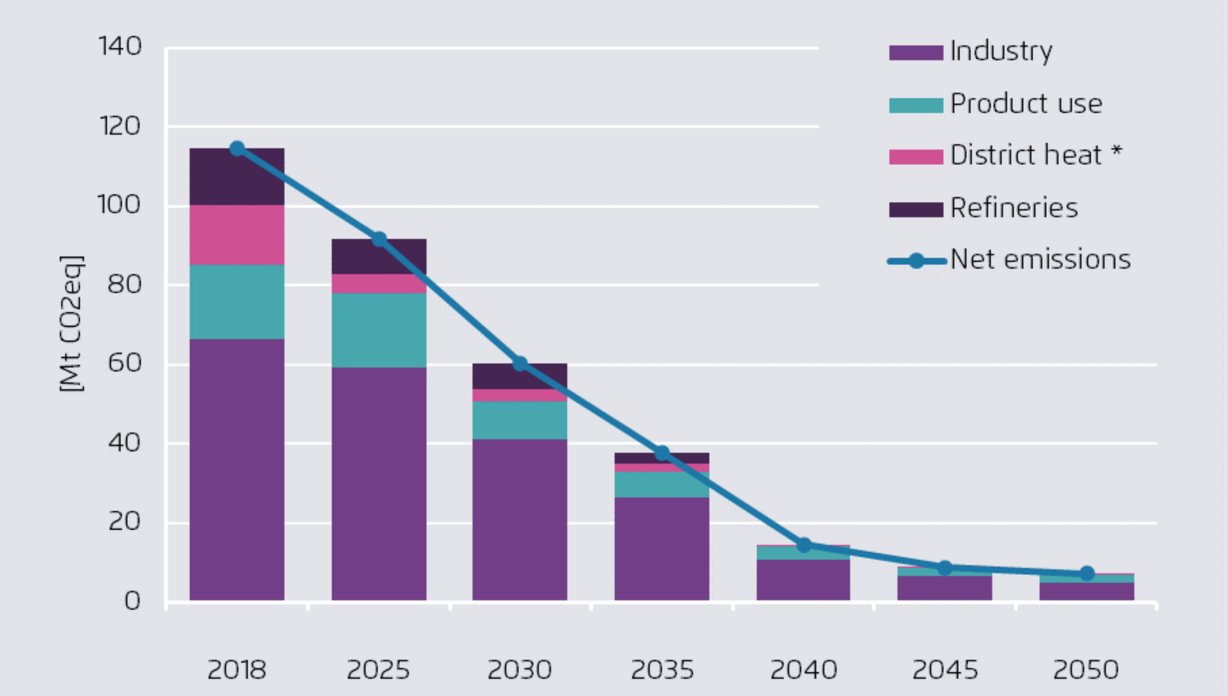
- Due to electrification of the transport sector, fuel demand will decline quickly throughout the EU.
- Processing of crude oil is completely phased-out in Europe until 2050.
- Refineries are assumed to be closed according to their age (typical lifetime of 60 years)
  → need for refinement to account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

Industry & refineries:

Results

Greenhouse gas emissions

GHG emissions from industry & refineries in Italy



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

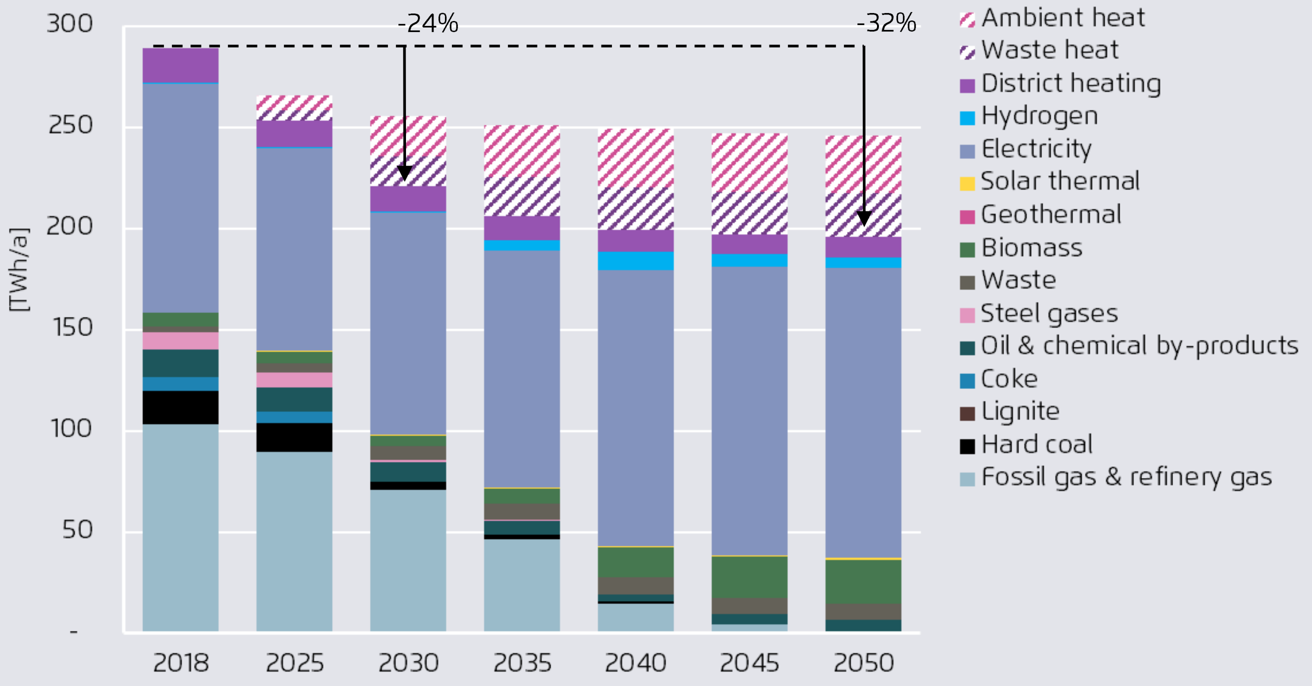
- The trajectory for GHG emissions of the industry and the crude oil refining sectors shows a steep decline between today and 2040. Emissions can already decline by 47% by 2030.
- In 2040, the decarbonisation of energy supply is almost accomplished. The main remaining emissions are process-related.
- After 2040, negative emission contributions are added via green feedstock and BECCS. However, the sector does not achieve zero emissions by 2050.

Until 2030, …

- ...the bulk of emission reductions are achieved in the iron & steel industry (8 Mt CO_{2eq} or 60%).

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

Final energy demand in industry in the EU-27

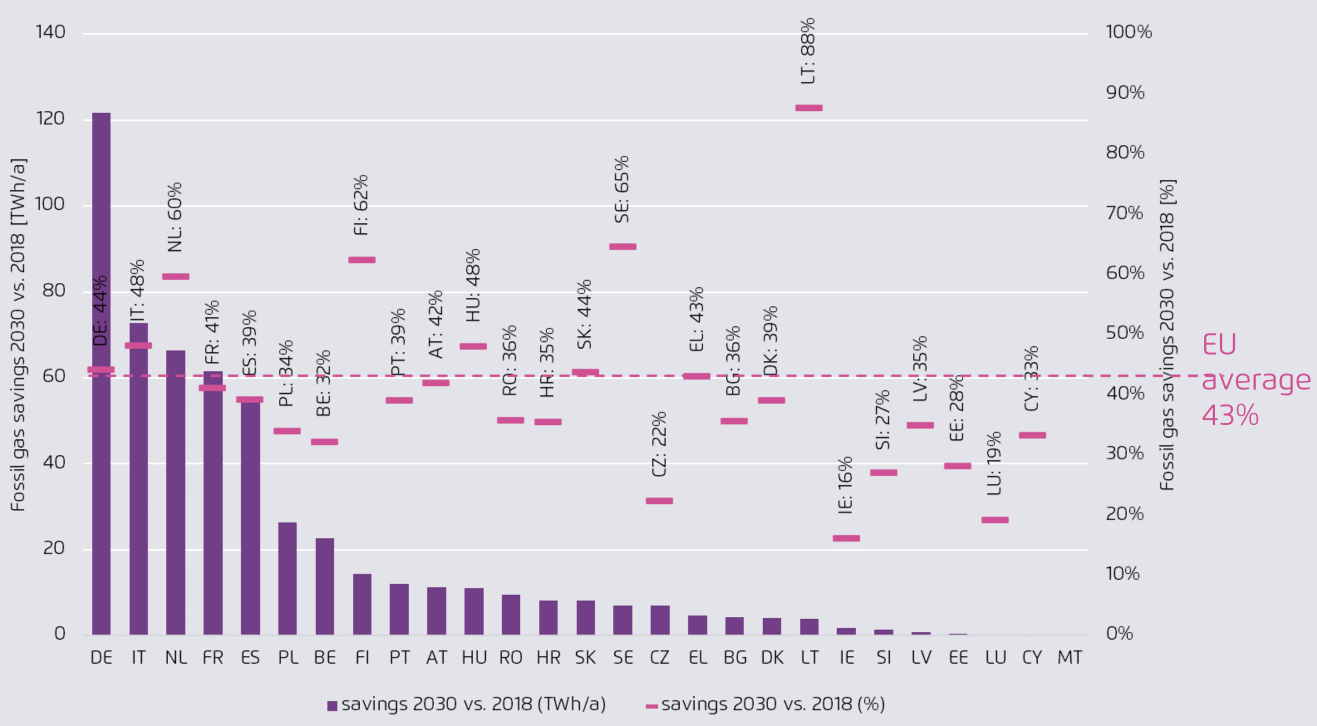


Wuppertal Institute (2023)

- Final energy demand in the sector declines by 24% by 2030 and by 32% 2050 (not including ambient and waste heat).
- The share of fossil fuels declines from 48% in 2018 to 38% in 2030 (direct use in industry). It further declines to 10% in 2040 with a limited remainder of oil consumption by 2050 (3%, 7 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 39% of total in 2018, 68% by 2030 and 73% by 2050.
- Energetic biomass and waste are restricted to high temperature generation and are mainly used in plants with carbon capture.

The Italian industry and refinery sectors can save 48% of fossil gas by 2030, ranking second in the EU-27 in volume.

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

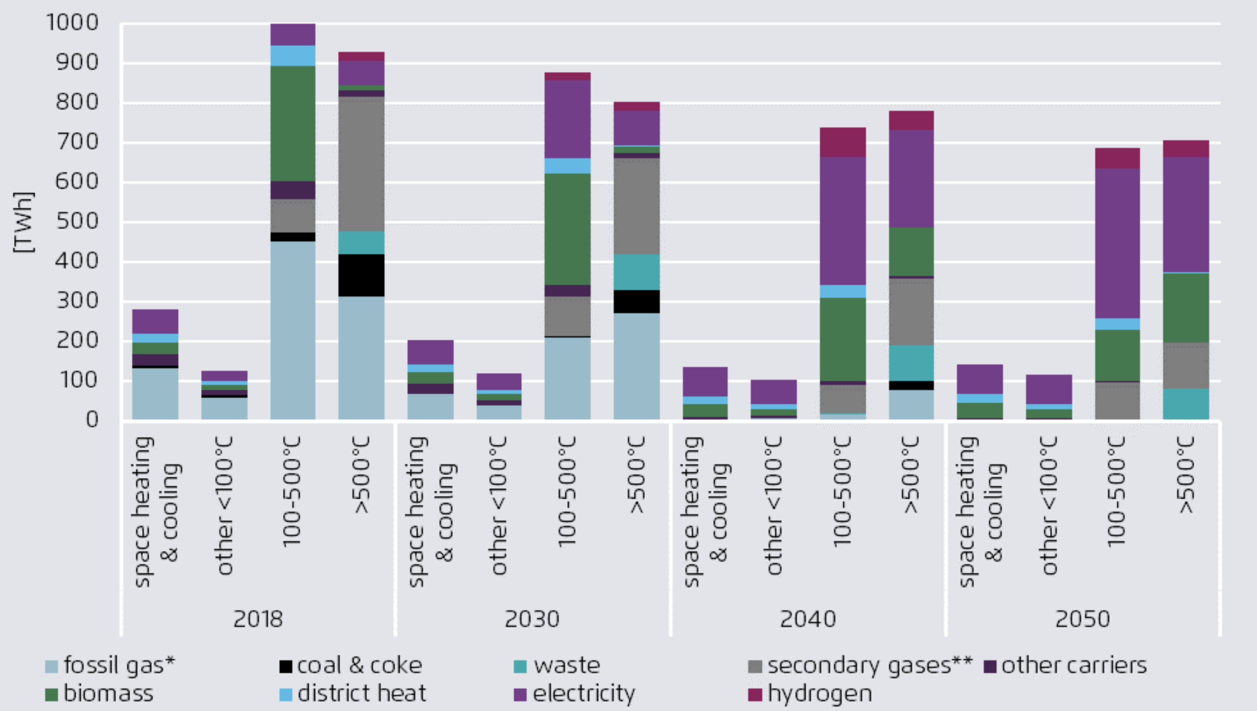


Wuppertal Institute (2023)

- Savings stretch from 16 to 88% according to the Member State.
- The largest savings are achieved in Germany, Italy, the Netherlands, France and Spain, together representing 70% of the industrial savings in volume.
- Italy alone represents 14% of the savings of the sector in the EU-27.
- Fossil gas use is spread across all the sub-sectors in Italy. The minerals, iron & steel, chemicals, machinery and transport equipment sub-sectors represent today 67% of the demand, the minerals sub-sector representing a third of it.

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 per temperature level, EU-27

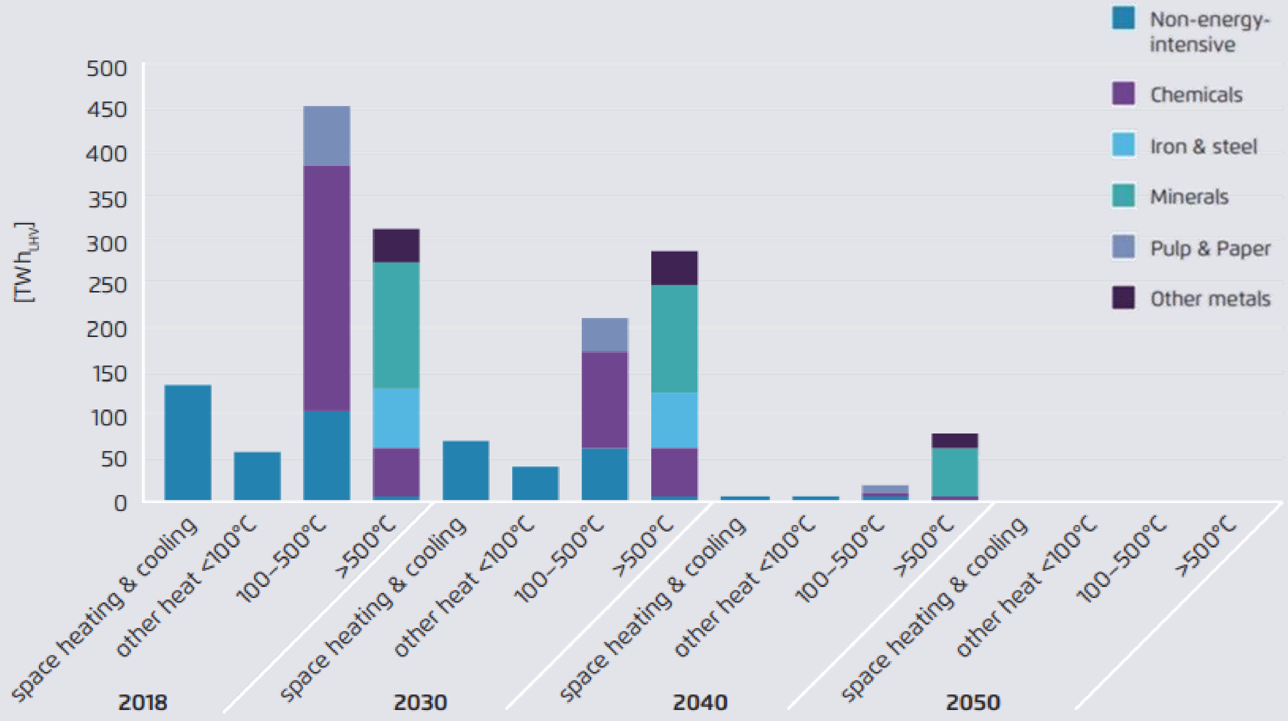


Wuppertal Institute (2023) * "fossil gas" includes fossil gas, refinery gas and LPG; **"secondary gases" include coke oven gas, blast furnace gas, basic oxygen furnace gas and steam cracker by-products

- → 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, especially for low and medium 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

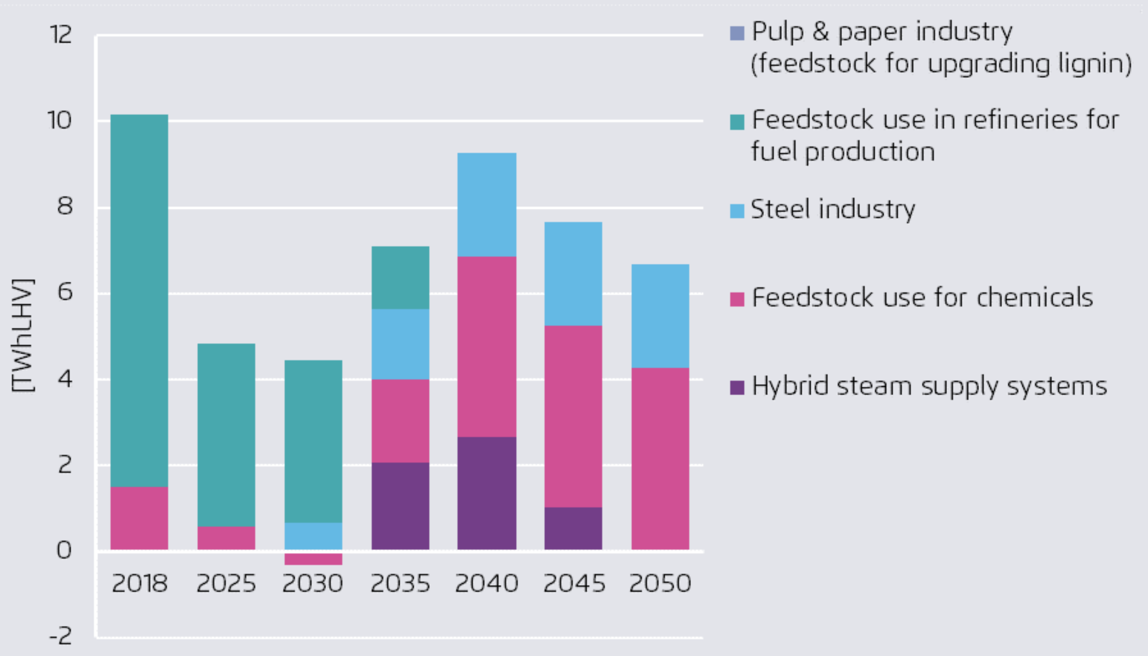


Wuppertal Institute (2023).
* Fossil gas includes fossil gas, refinery gas and LPG.

- → 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 decline with the phase out of refineries, but increase back after 2030 to cover for new applications replacing fossil fuels

Net* hydrogen demand per sector and appliance in industry and refineries in Italy

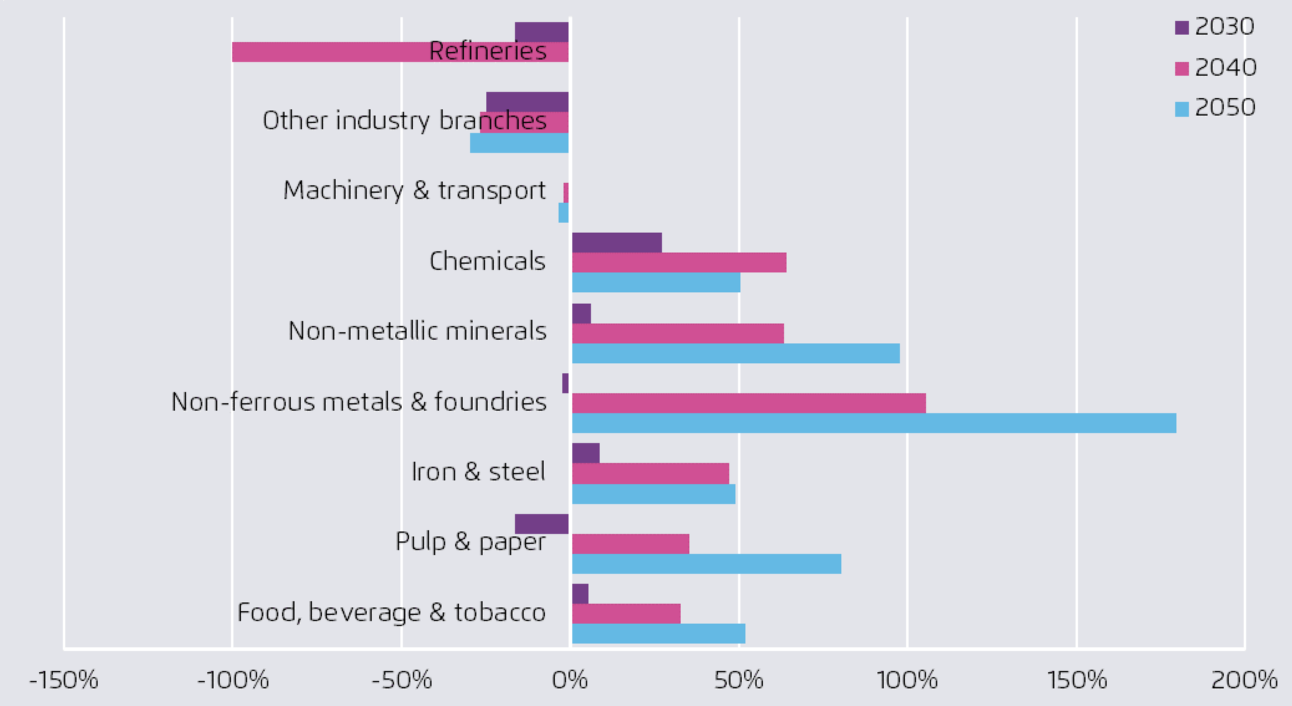


Wuppertal Institute (2023) * Gross hydrogen demand and gross by-production (e.g. by chlorine production) are balanced out, leaving only net demand to be covered by sources such as SMR or water electrolysis.

- Despite some new applications in 2030, total H2 demand will remain stable. Indeed, 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. Also, part of the ammonia demand will be imported and substituting the EU domestic production as already started in 2022.
- Demand increases after 2030 but remain at lower levels than today if direct electrification is prioritised as a more mature and efficient technology to displace fossil 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 strongly increase by 2050 in most of the sub-sectors of the industry

Gross power demand evolution compared to 2018 in the Italian industry

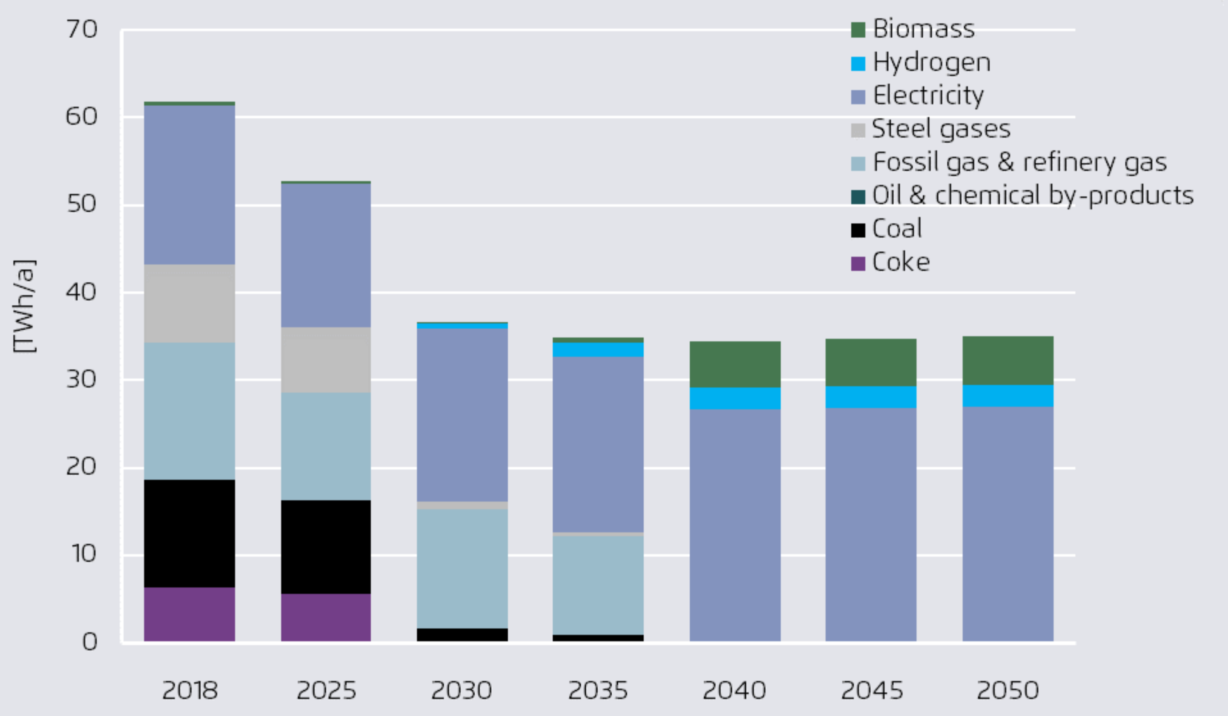


Wuppertal Institute (2023)

- Electricity use increases in the energy-intensive branches by an average of 90% until 2050.
- 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).

Sub-sector transformation: Iron & steel

Final energy use of the steel industry, Italy

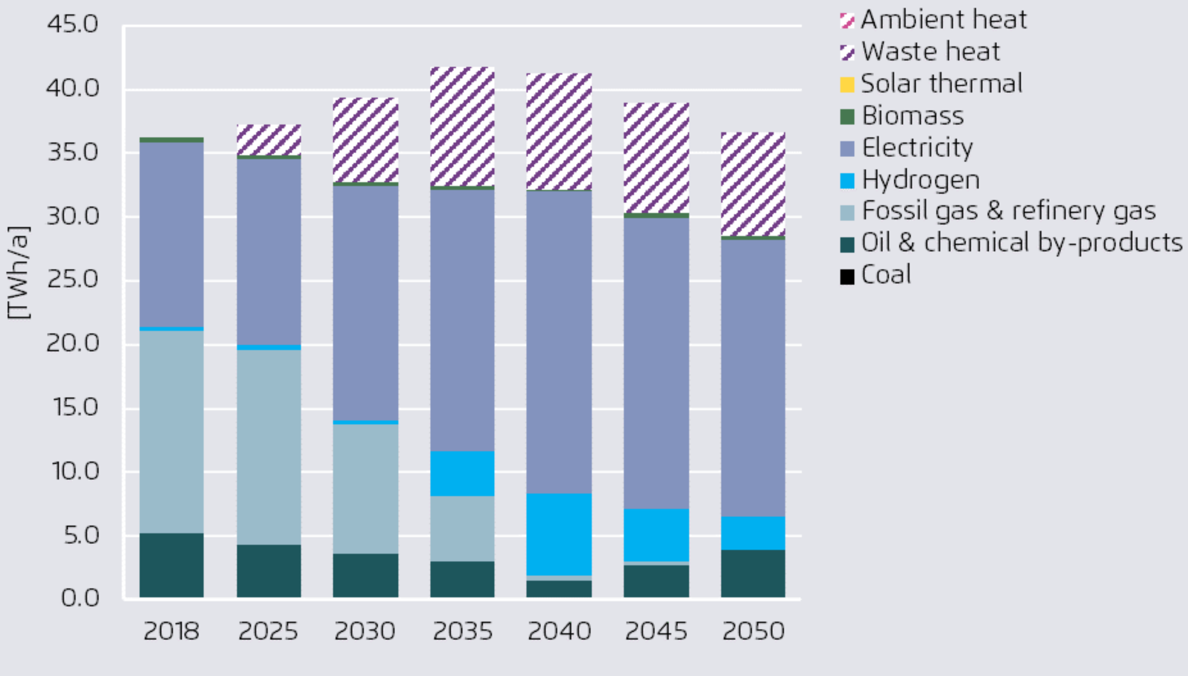


Wuppertal Institute (2023)

- Italy already has the largest secondary steel production capacity in the EU. Thanks to a further shift to secondary steel using electric arc furnaces and a (limited) process shift to direct reduction in primary steel production, primary energy demand declines by 41% by 2030 and will remain stable until 2050.
- Only limited decline in gas demand until 2035, but the sector can be fossil-gas free by 2040.
- Coal and coke use may almost be phased-out until 2030.
- Electricity represents more than 50% of final energy demand in the sub-sector in 2030, and almost 80% by 2050.
- Biomass use in the steel industry only partly related to carbon requirements (carburation in the EAF and BOF process).

Sub-sector transformation: Chemicals

Final energy use and feedstock input in the chemical industry, Italy

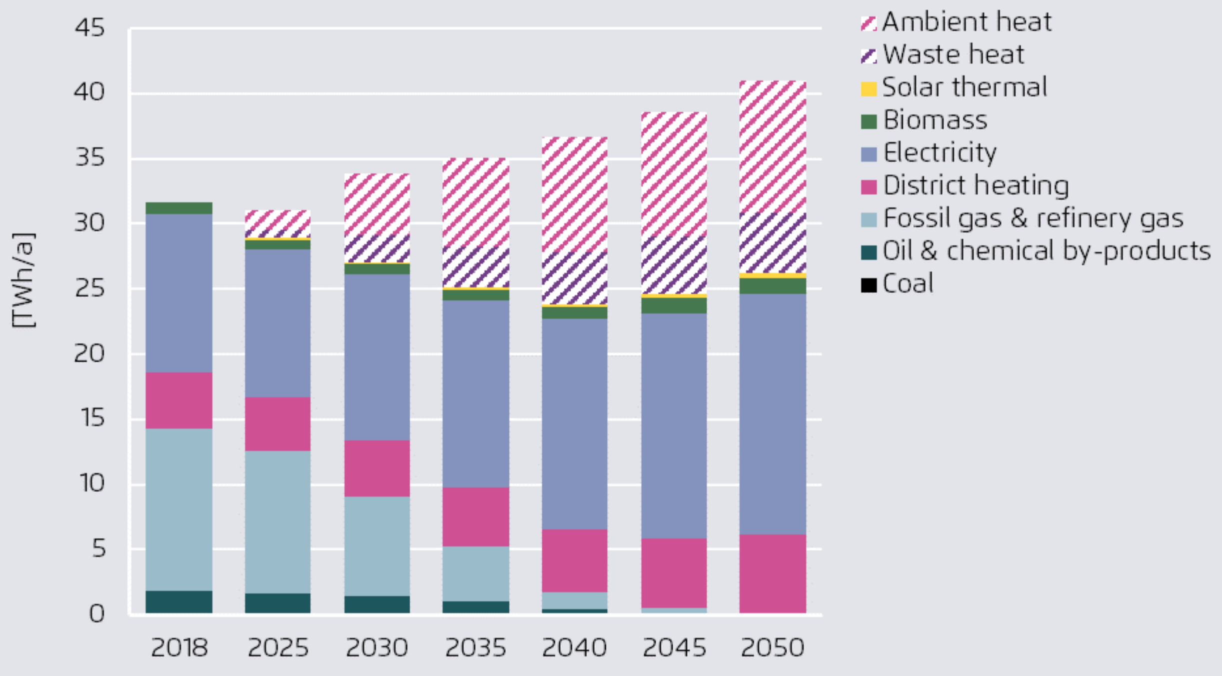


Wuppertal Institute (2023)

- Thanks to efficiency increases and electrification, final energy demand declines by 10% by 2030 and 21% 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, the high temperature heat pumps making also use of waste heat) 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 green hydrogen. On the way towards a circular economy the complete feedstock supply is defossilized by 2050.
- The renewable feedstock (e.g. methanol from atmospheric CO_2 and hydrogen from water electrolysis) serves as a carbon sink delivering net negative emissions. Green refineries in Europe and CCU in Southern Europe (e.g. from cement plants) help to diversify the feedstock supply.

Sub-sector transformation: Food, Beverages & Tobacco

Final energy demand in the manufacturing of food, beverages & tobacco, Italy

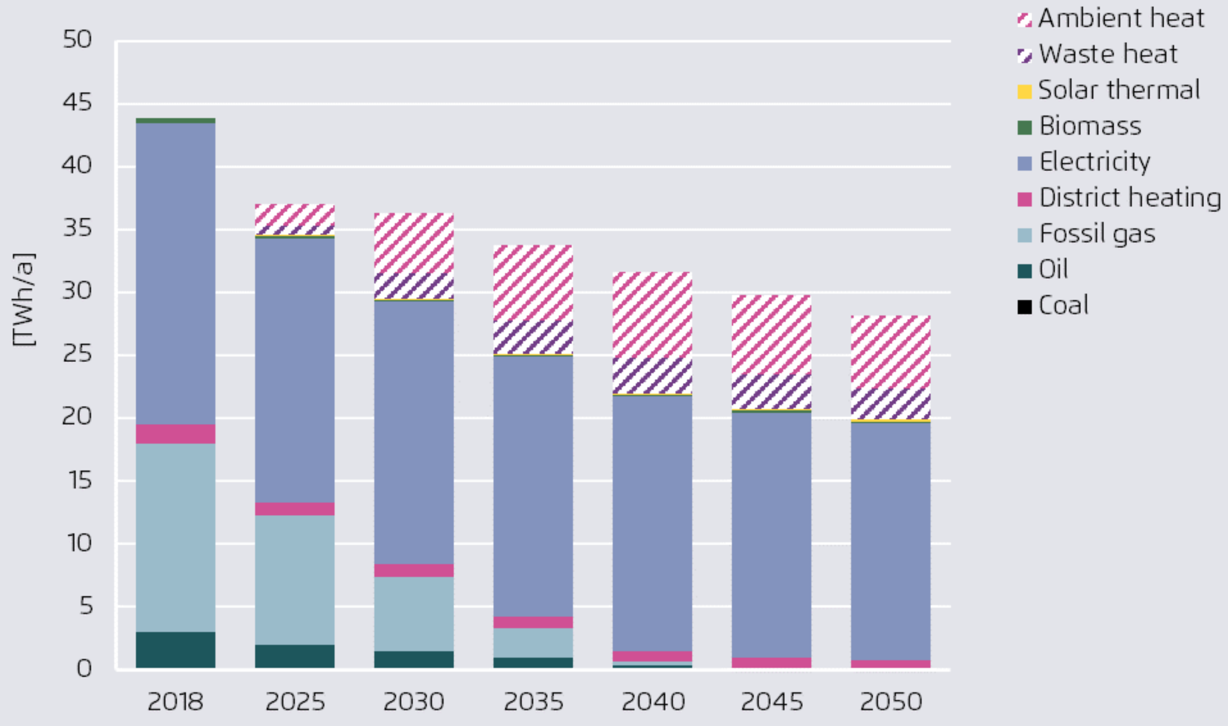


Wuppertal Institute (2023)

- → The strong efficiency increases in the sector are partly compensated by a strong economic growth, resulting in limited final energy demand decline: only 15% until 2030 and 25% by 2040 (excluding ambient and waste heat) and going back up by 2050.
- → The sub-sector can be close to fossil-gas free by 2040.
- → 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 38% to represent up to 70% of final energy demand (excluding ambient and waste heat) by 2050.
- → District heat 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, Italy

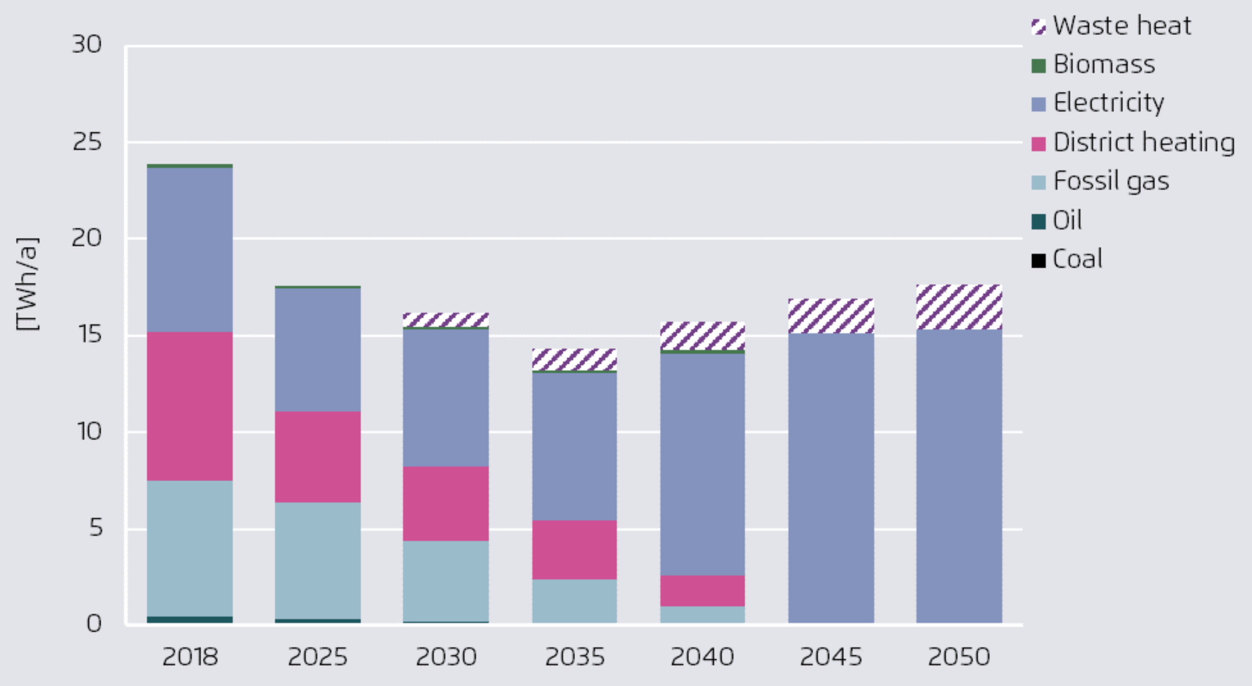


Wuppertal Institute (2023)

- The sub-sector already relies largely on power today (up to 55% of final energy demand). Thanks to efficiency increases and electrification, final energy demand declines by 33% by 2030 and 55% by 2050 (excluding ambient and waste heat).
- The sub-sector can be close to fossil-gas free by 2040. 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 3% between 2018 and 2050. Power demand represents up to 95% 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, Italy

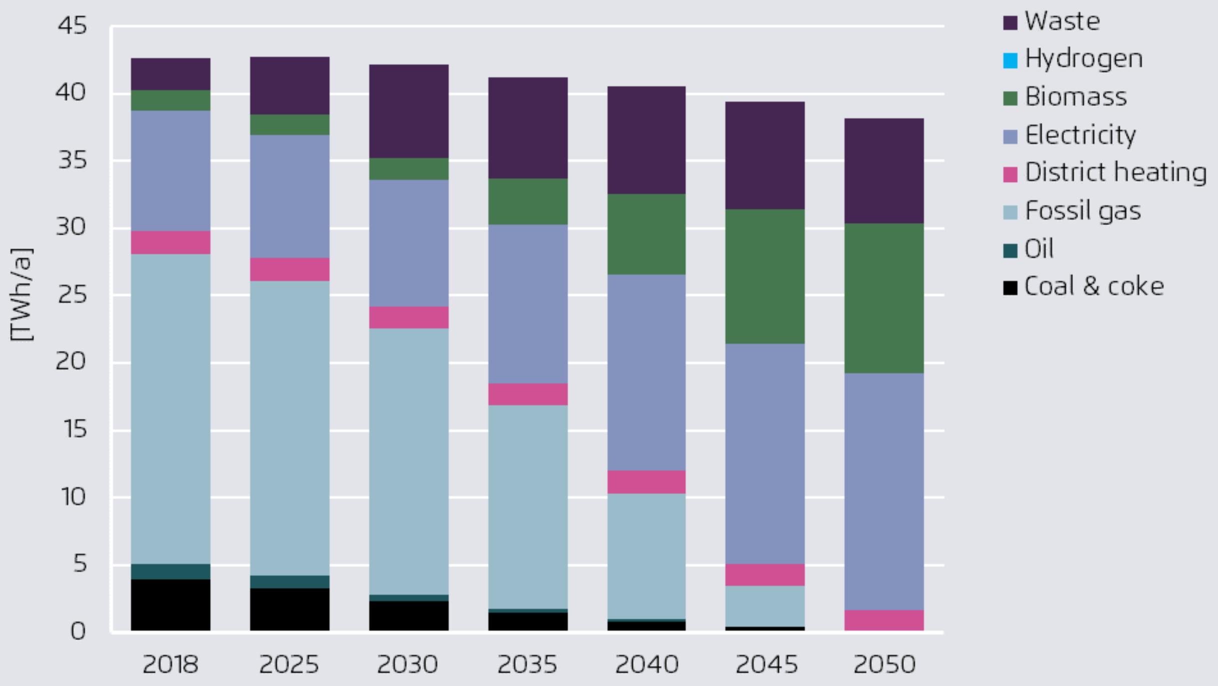


Wuppertal Institute (2023)

- Thanks to efficiency increases and electrification, final energy demand declines by 35% by 2030 and will remain roughly stable until 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.
- Fossil gas is used mostly in mid-temperature ranges for steam production, especially in the paper production process.
- The Italian industry already uses a large share of electric heat and district heat compared to other Member States relying largely on biomass. The sub-sector will shift further towards electricity.
- Power demand will scale up to represent 100% of final energy demand by 2050, up from 36% in 2018 (excluding waste heat).

Sub-sector transformation: Non-metallic minerals

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

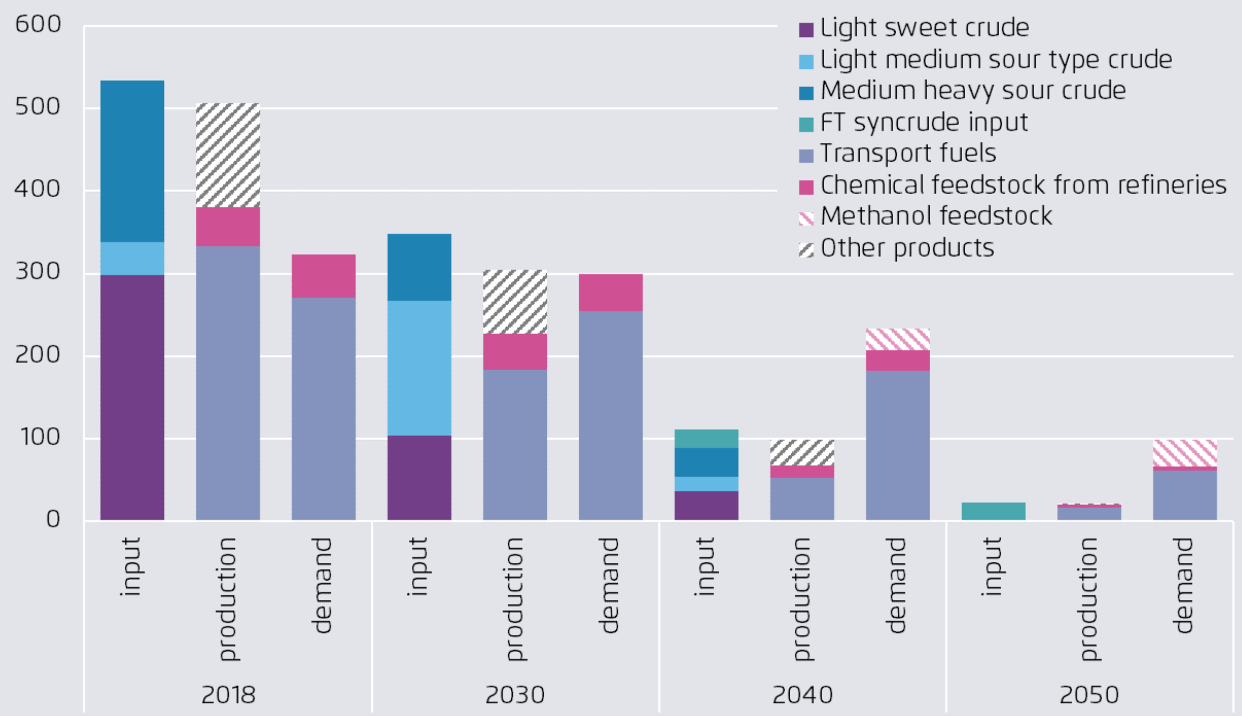


Wuppertal Institute (2023)

- → Final energy demand decline will remain limited in this sub-sector, to reach -10% 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 14% 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 2045.
- → Easy investments into technologies such as waste use are quickly made, but the further decarbonisation of energy supply requires rather large investments into core technologies of the sector, i.e. in 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). Power and biomass represent 75% of energy demand by 2050.

Sub-sector transformation: Refineries (EU level)

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

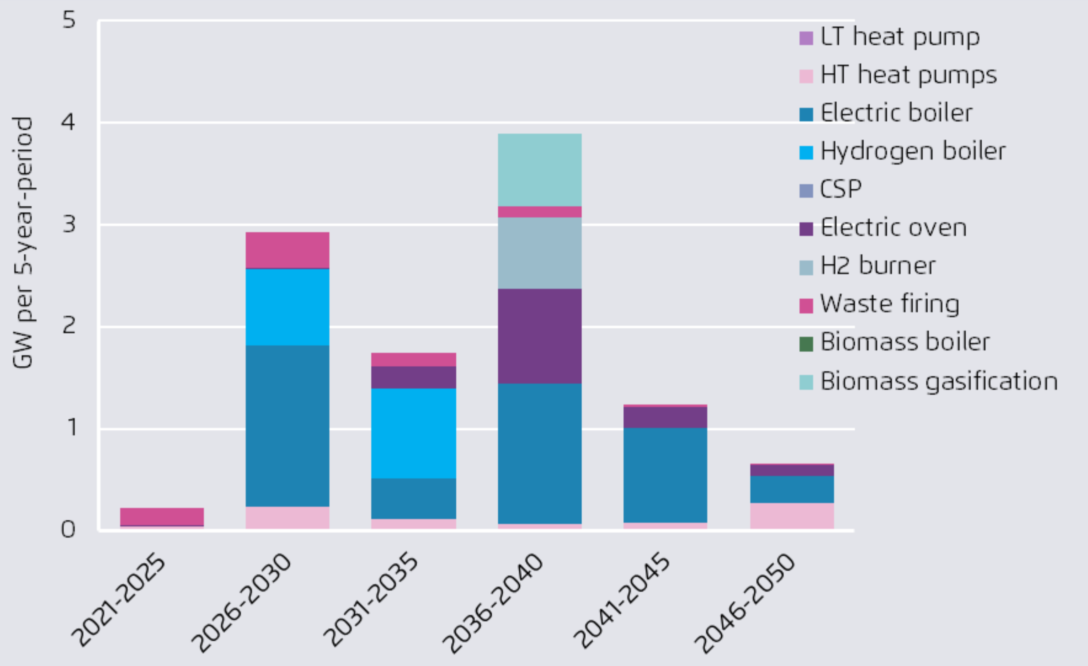


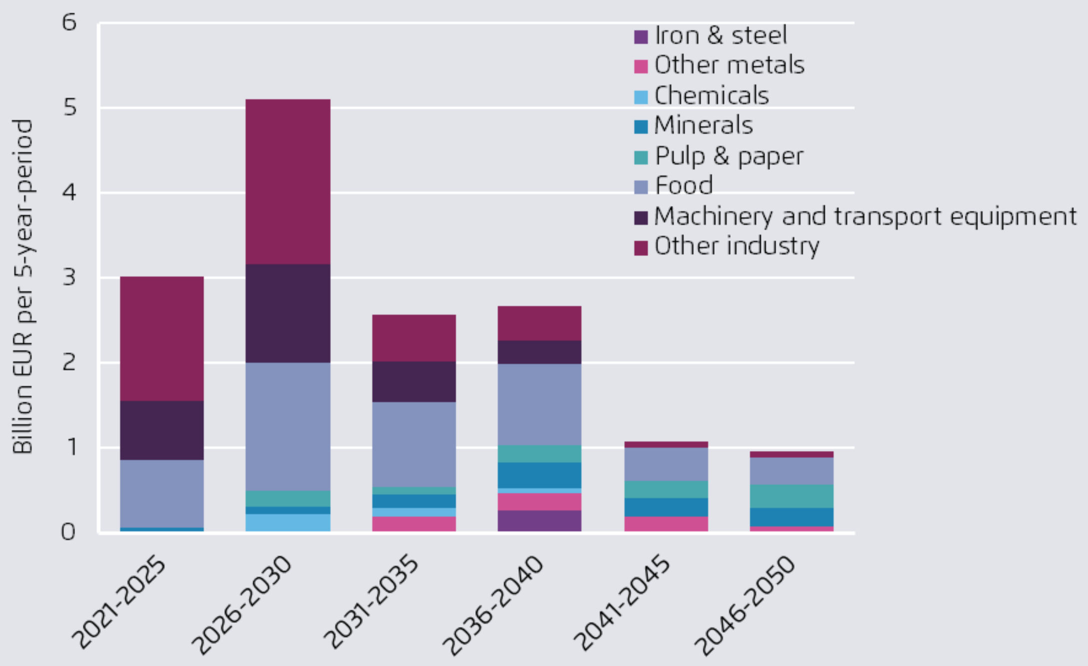
Wuppertal Institute (2023)

- → 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.

Investments in fuel switch for heat supply

Investments in $GW_{thermal}$ (left) and billion Euros in the Italian industry (right)*





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

Buildings:

Methodology and assumptions

Buildings: Scope

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

FORECAST Model – Focus Buildings Sector

Main input parameters residential sector

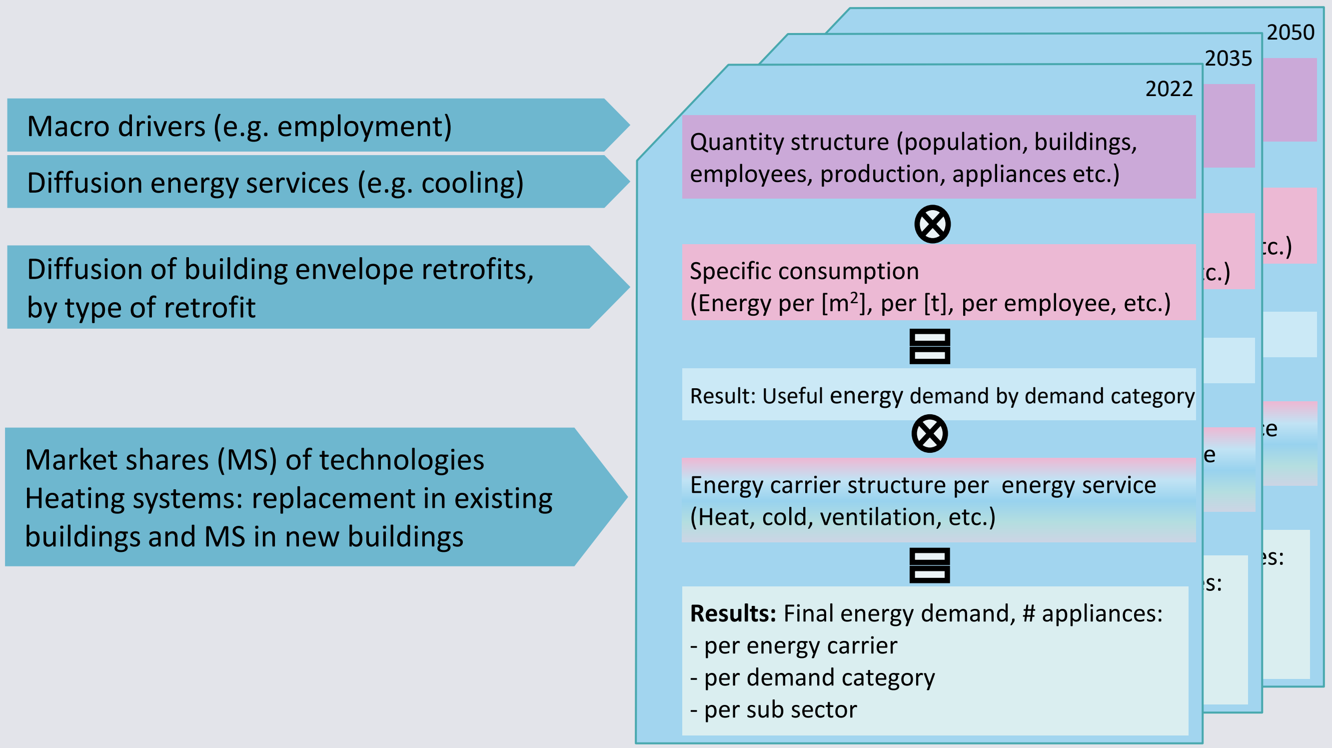
	Residential sector
Main drivers	- No of households - Building area [m²] by type of building and by age class
Prices	- Energy prices - Taxes
Technology data	**Building related data:** - Insulation levels - Heating system efficiency - Heating system and envelop retrofit costs - Lifetime **Appliance data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

Source: TEP Energy and Fraunhofer ISI

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

FORECAST Model – Focus Buildings Sector

Methodology: example services sector



TEP Energy and Fraunhofer ISI

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  - ○ Codes and standards, energy-prices and taxes, subsidies, willingness to pay

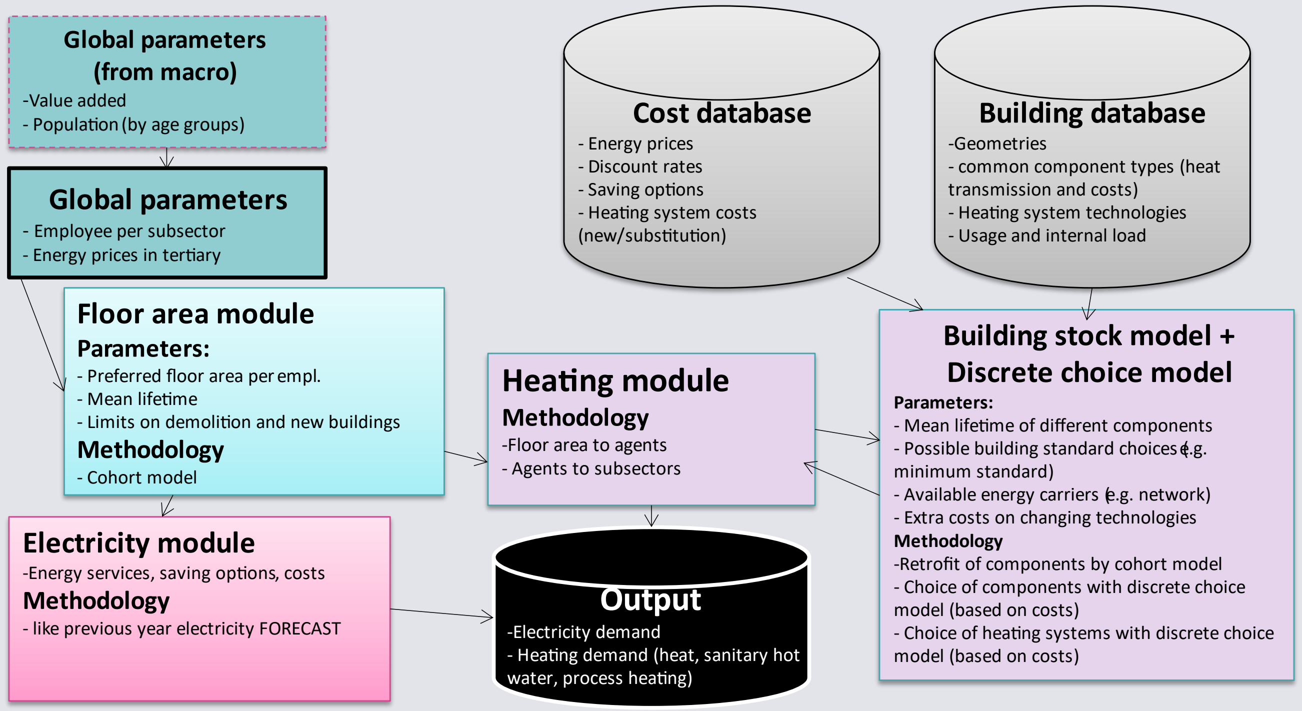
FORECAST Model – Focus Buildings Sector

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

FOREcasting Energy Consumption Analysis and Simulation Tool

FORECAST Model – Focus Buildings Sector

Model and data base



TEP Energy and Fraunhofer ISI

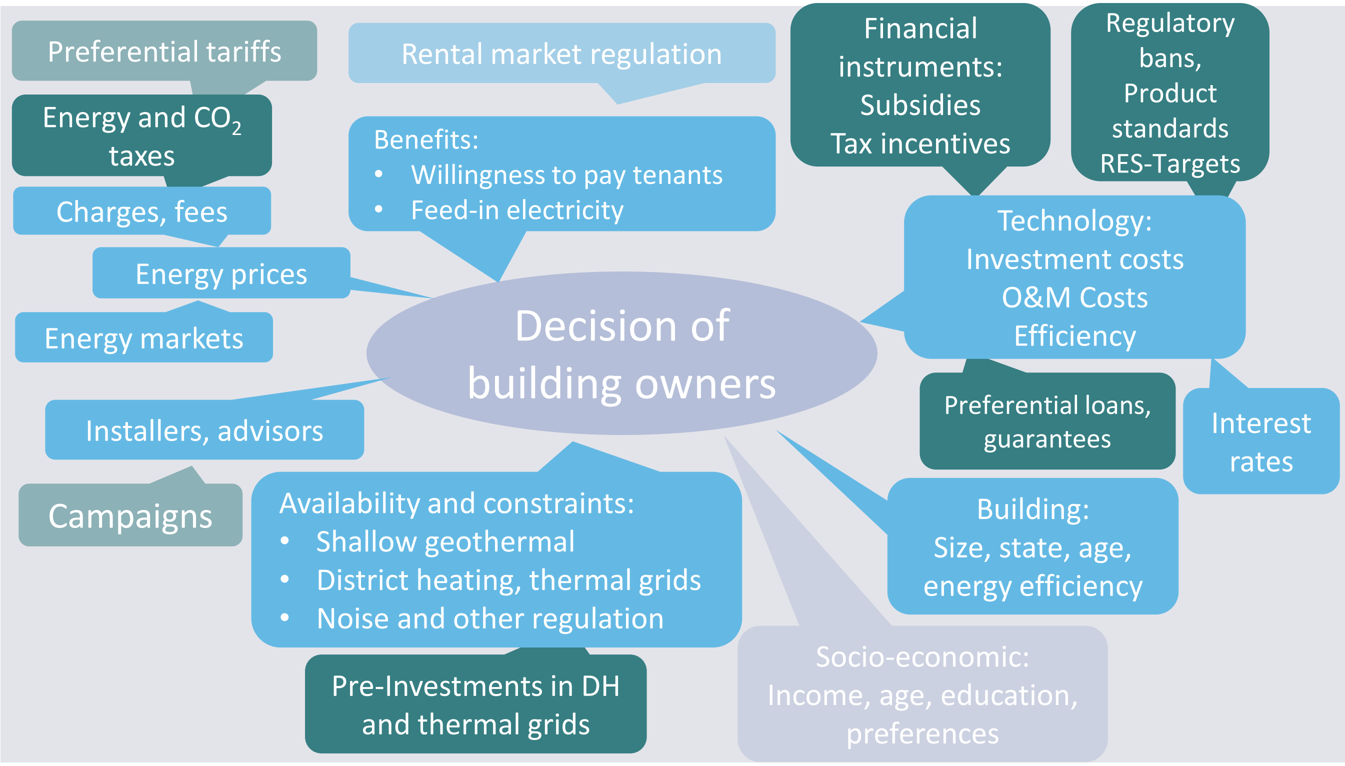
Scope

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

FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

FORECAST Model – Decision modelling

Owners' decisions are influenced by exogenous drivers and policy measures



TEP Energy and Fraunhofer ISI

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

→ Exogenous drivers such as interest rates, energy prices, regulation, availability of local renewable energy sources, market supply, technical parameters

→ Preferences and socio-economic context

→ Policy measures that impact on both of the above:

- Energy taxes, CO_2-levy, preferential loans, subsides or other financial instruments to balance relative economic performance
- Provide energy infrastructure / clean energy
- Ban non-renewable energy use and set minimal performance standards

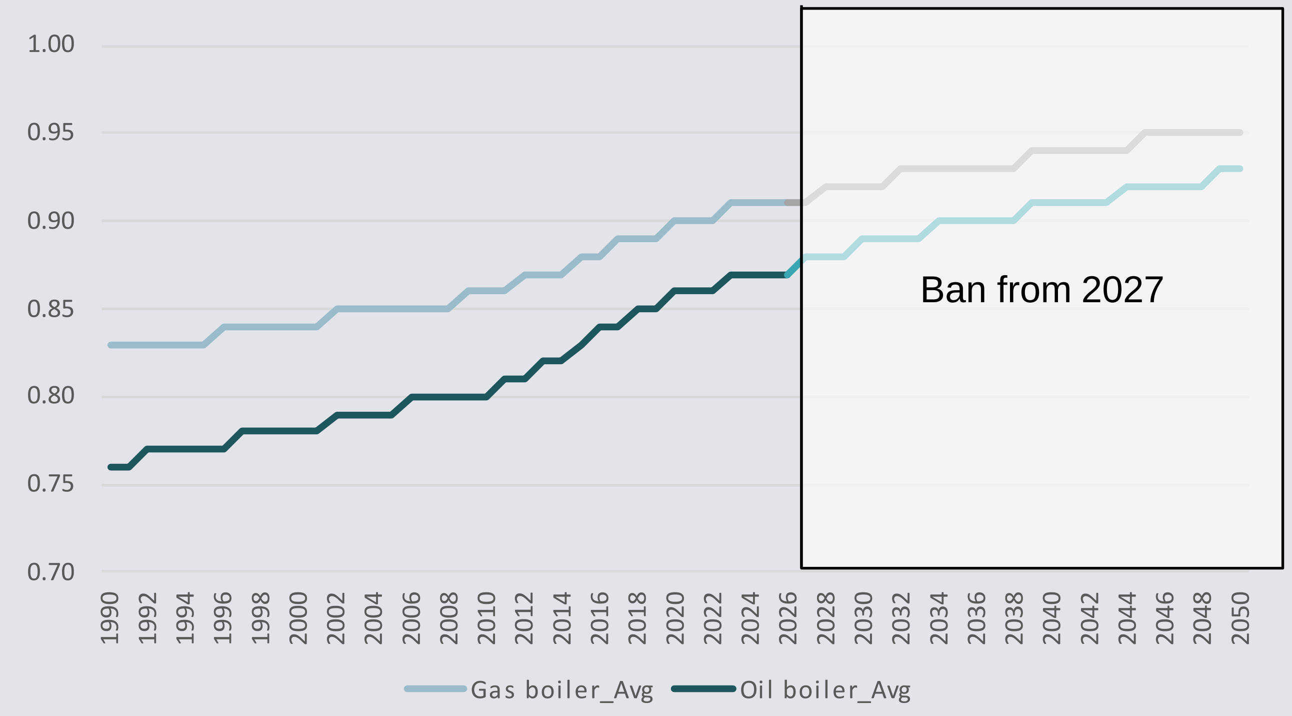
Legend: *Exogenous drivers* *Policy measures*

Key policy assumptions for buildings – EU level

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

Key assumptions (EU level): Phase out of stand-alone fossil fuel boilers

Efficiency of heating system

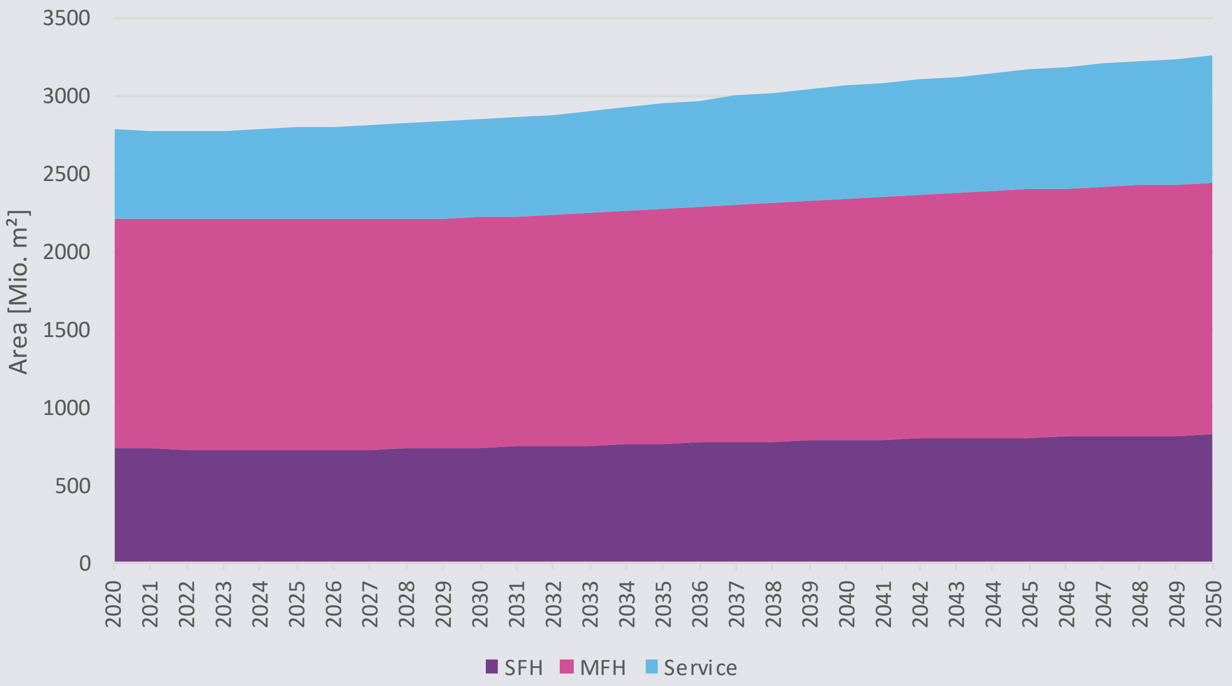


TEP Energy (2023)

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

Key assumptions:
Households and floor area

Floor area by building type in Italy

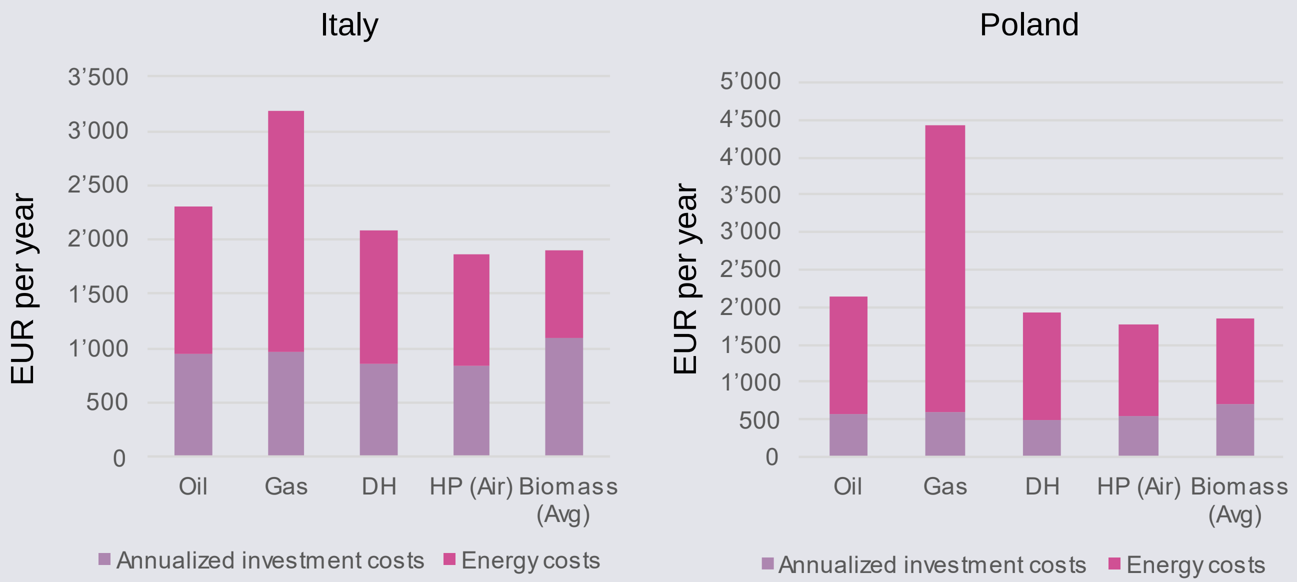


TEP Energy (2023)

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

Key assumptions:
Economics and policy of heating system changes

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



TEP Energy modelling (2023)

Ranking of heat generation costs of individual heating systems depend on

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

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

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

Key assumptions:
Energy prices and technology data

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

TEP Energy (2023)

Energy prices

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

Technology data

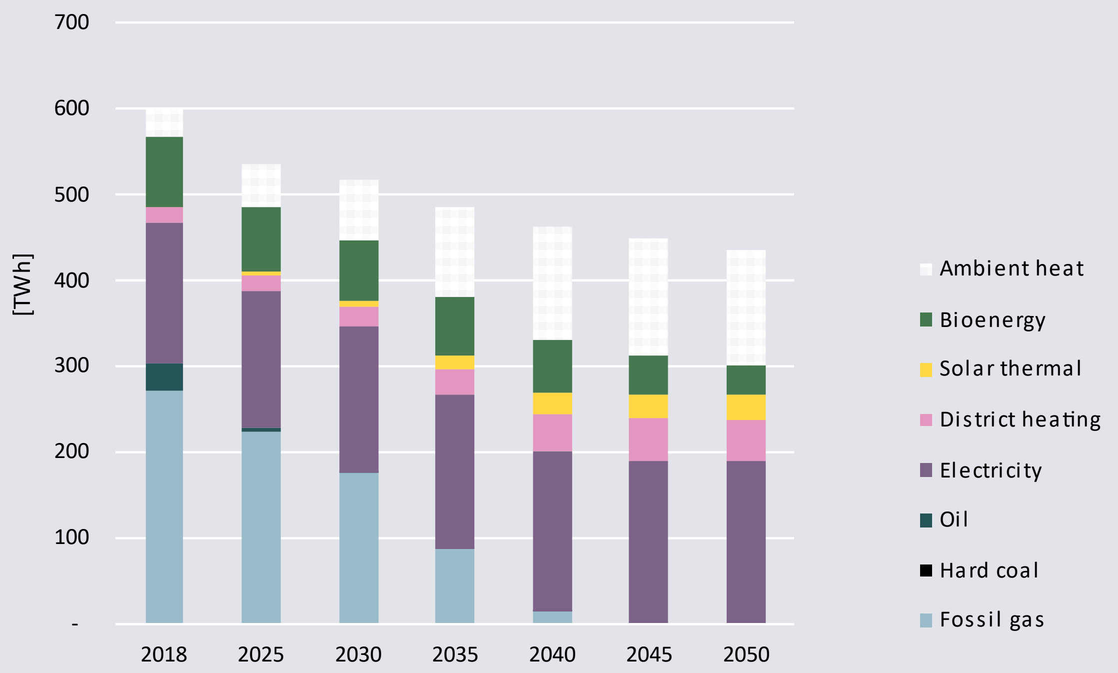
- → Technical and economic parameters of the different heating systems are defined in the simulation framework of FORECAST.
- → This data is used and updated in numerous European projects (e.g. sEEnergies, Building Market Briefs - BMB).

Buildings:

Results

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, Italy



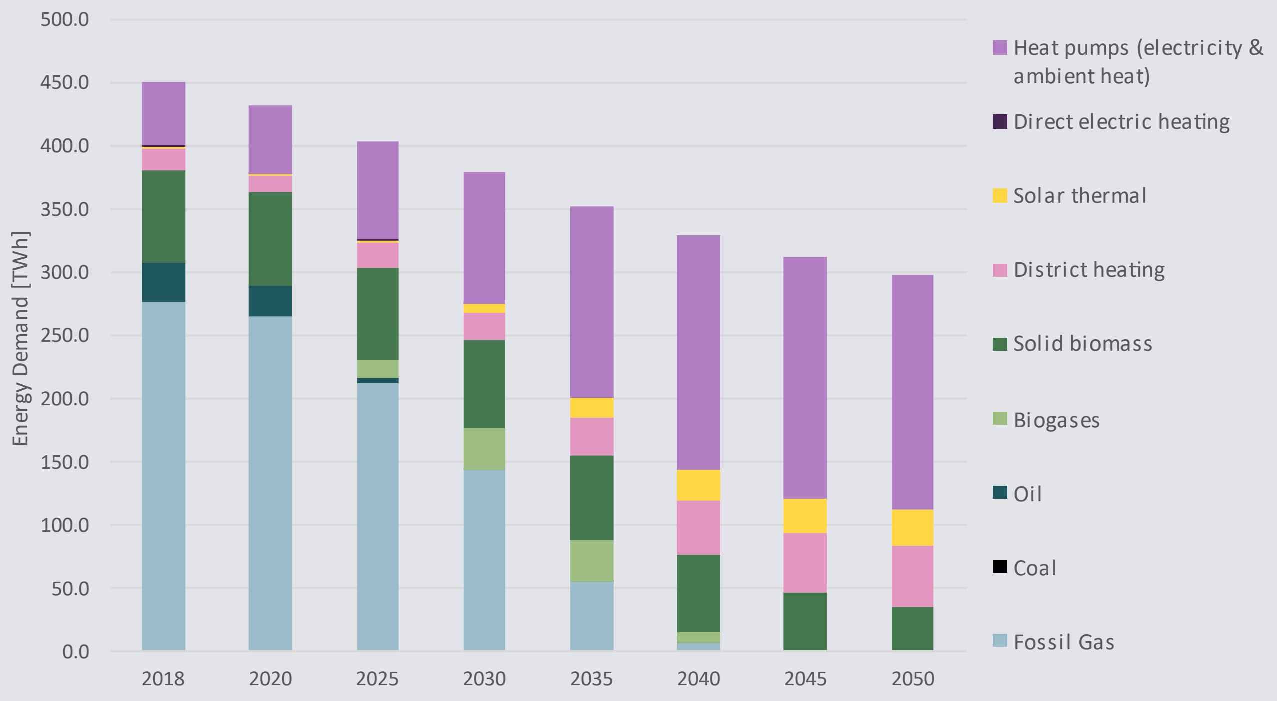
* Including demand of household, ICT and other appliances and building technologies (e.g. ventilation, cooling)

TEP Energy, Wuppertal Institute modelling (2023)

- → Total final energy demand: reduced by 14% from 2018 to 2030, by 27% from 2020 to 2050.
- → Fossil fuel consumption phase out: decrease of 68% by 2035 and 95% by 2040.
- → Ambient heat drastically increases to cover 31% 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, Italy

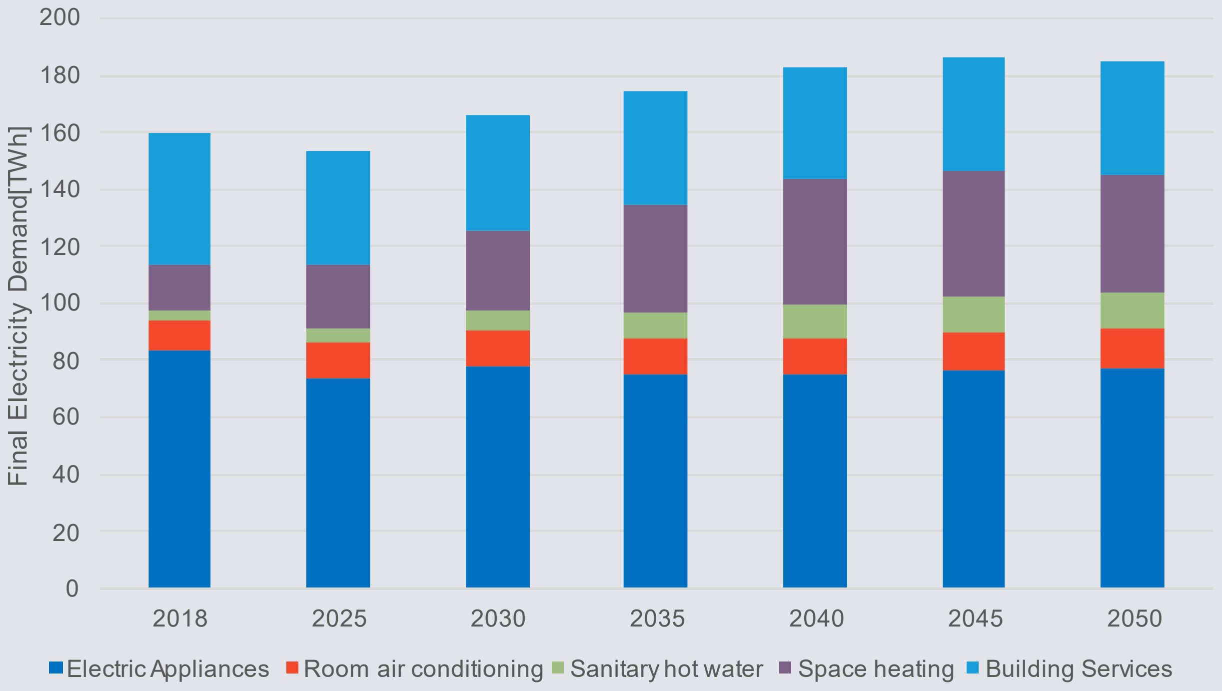


EP Energy, Wuppertal Institute modelling (2023)

- → 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, Italy

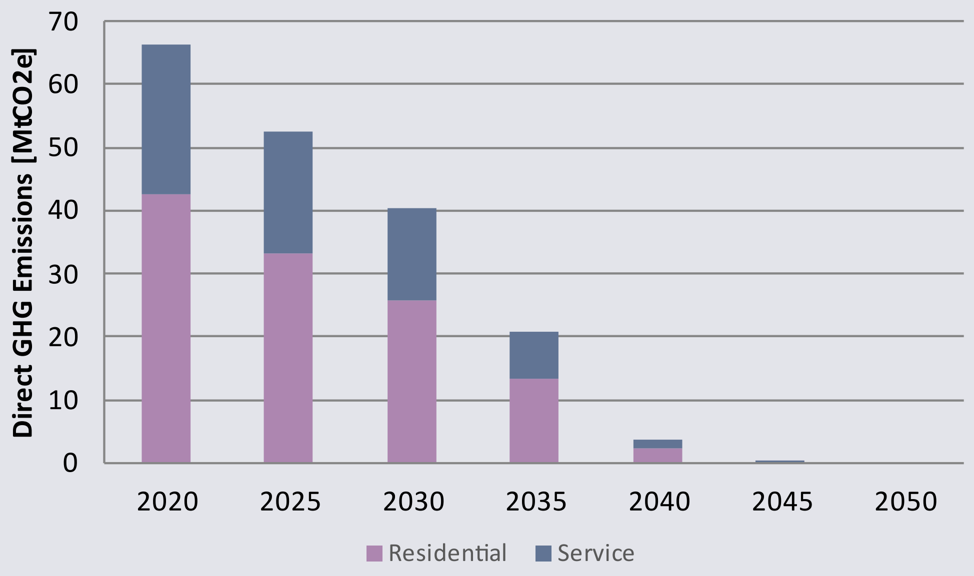


Source: TEP Energy (2023)

- Total development of electricity demand about 160 TWh in 2018, slight increase to 2030 with 166 TWh and further increase to 184TWh in 2050
- Explained by counteracting effects
  - Electricity demand from space heating: increases from 16 TWh (2018) to 41 TWh (2050)
  - Electricity demand from water heating increases (by 10 TWh)
  - Electricity demand from appliances: decrease from 83 TWh to 77 TWh
  - Electricity demand building services including cooling 46 TWh to 40 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], Italy

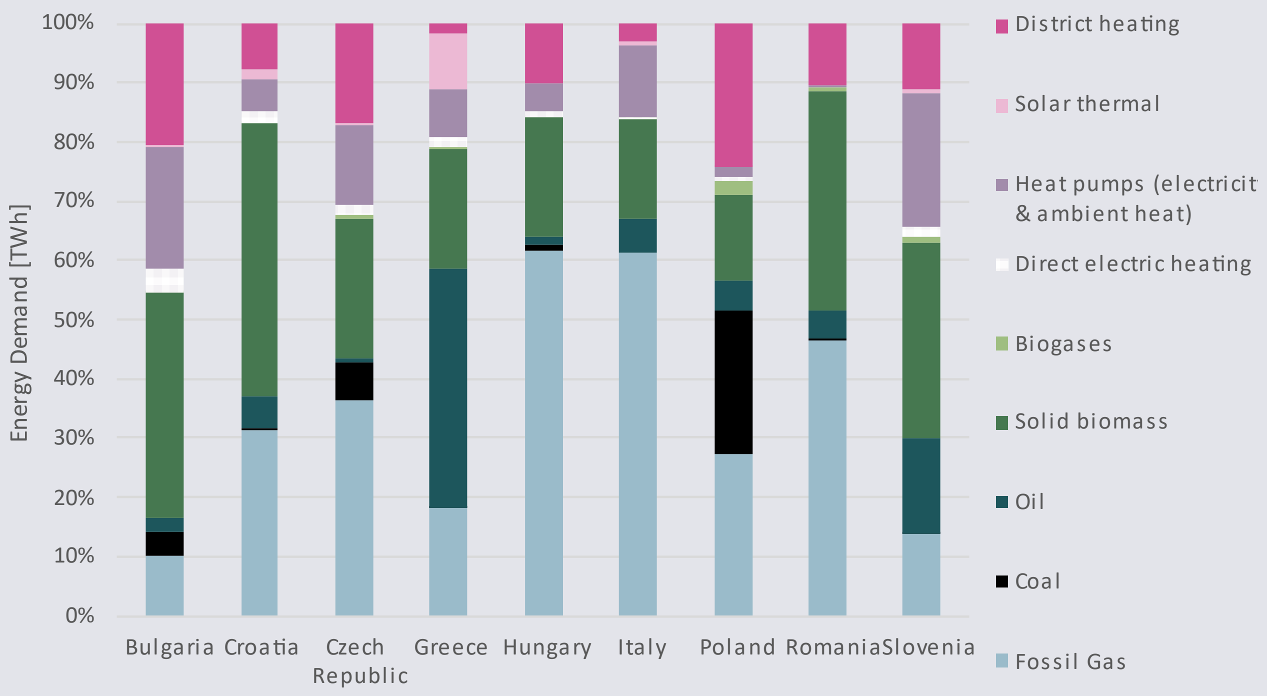


TEP Energy modelling (2023)

- → Direct greenhouse gas emissions decline by 39% from 2020 to 2030
- → Decarbonisation almost achieved in 2040
- → The service sector is responsible for 36% of emissions in 2020 and rising slightly to 37% 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

Country deep dives: quite different starting situations in 2020

Final energy consumption space heating and hot water in buildings, EU27



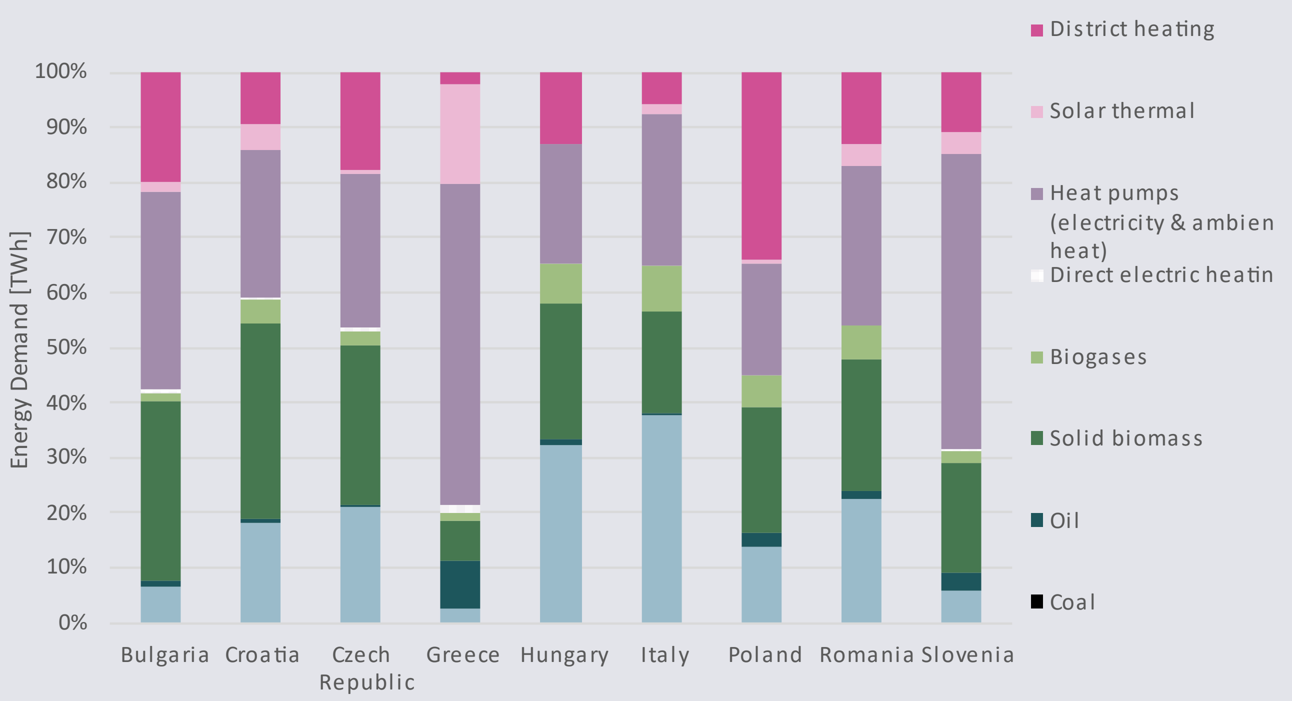
TEP Energy modelling (2023)

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, EU27



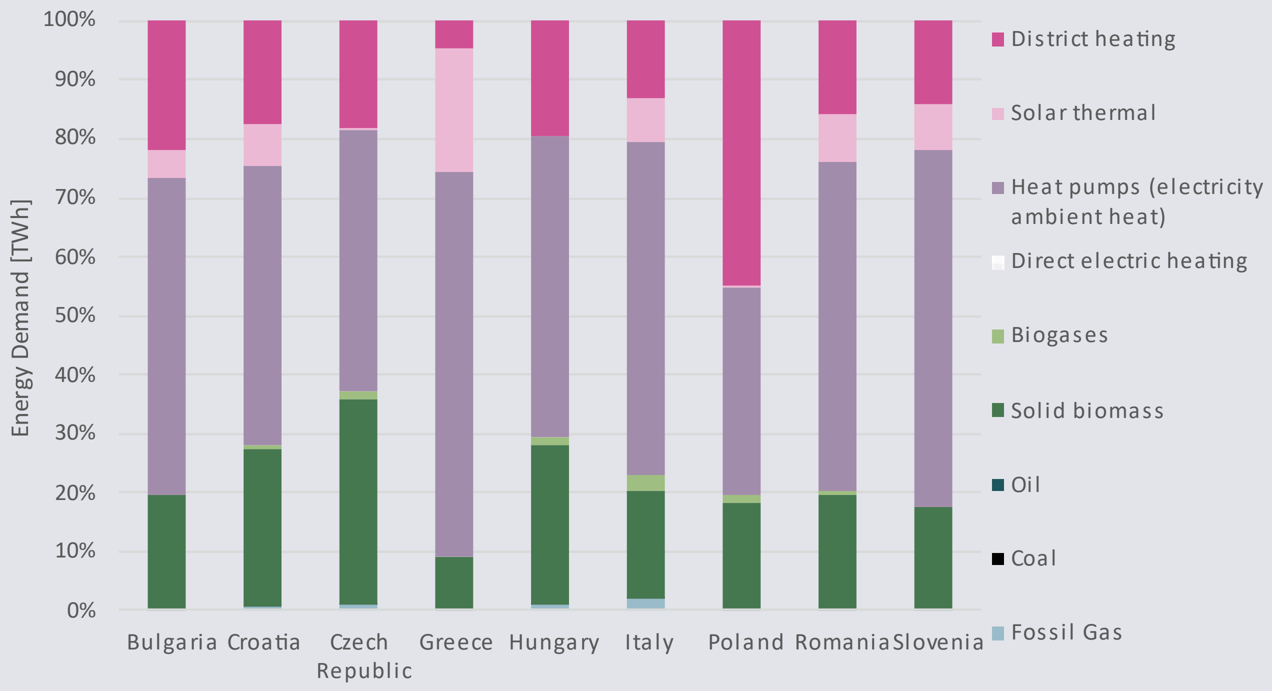
TEP Energy modelling (2023)

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, EU27



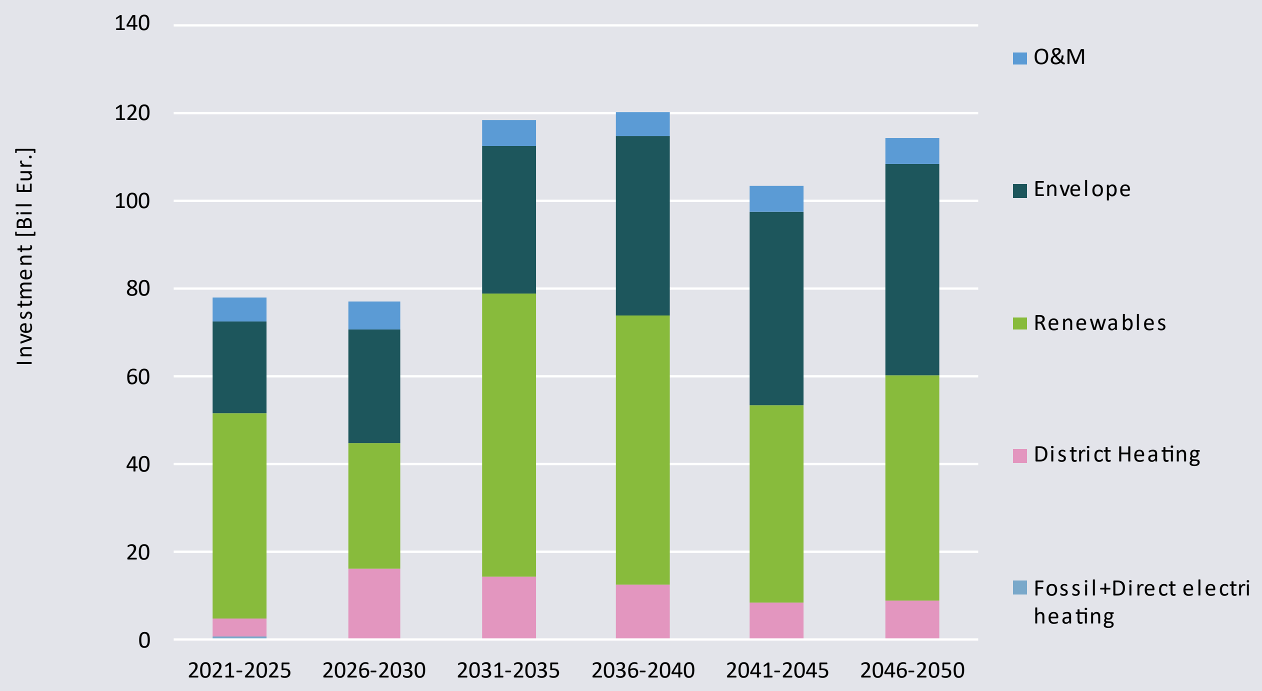
TEP Energy modelling (2023)

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

Deep dive: total investment needs for the buildings sector

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

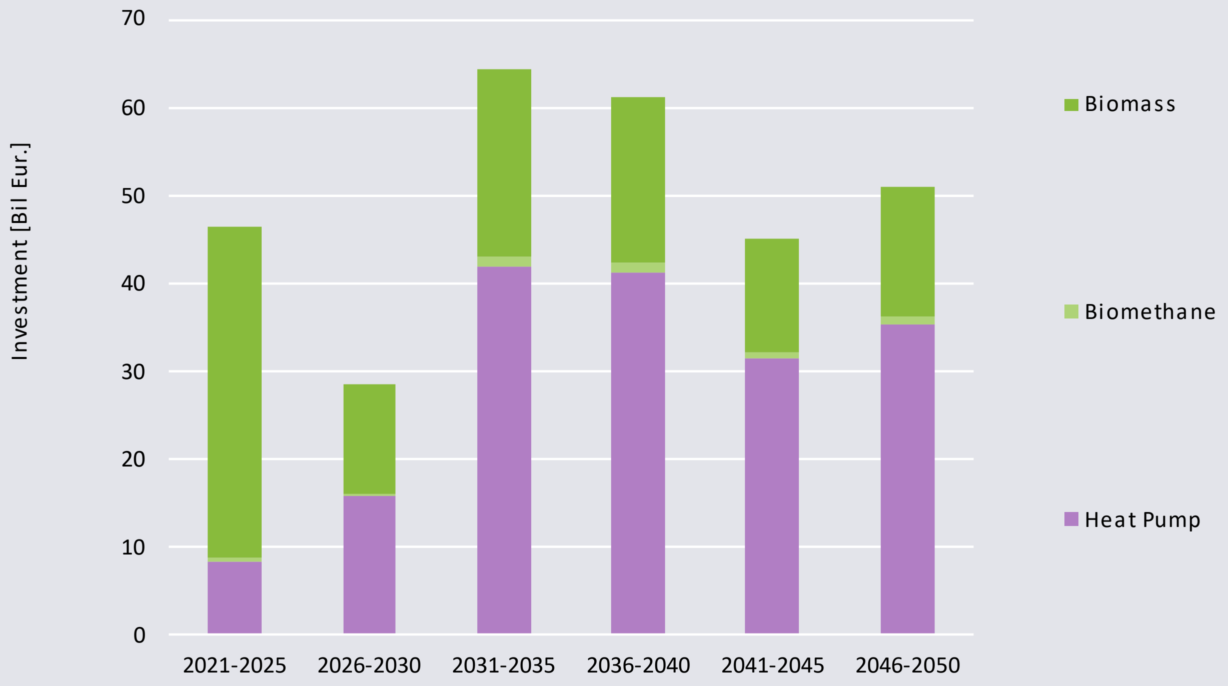


Source: TEP Energy

- 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 60% up to 2035 to meet greenhouse gas emissions reduction goals. When comparing investments from 2020 and 2050 they increased by 56%.
- 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 envelop 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, Italy

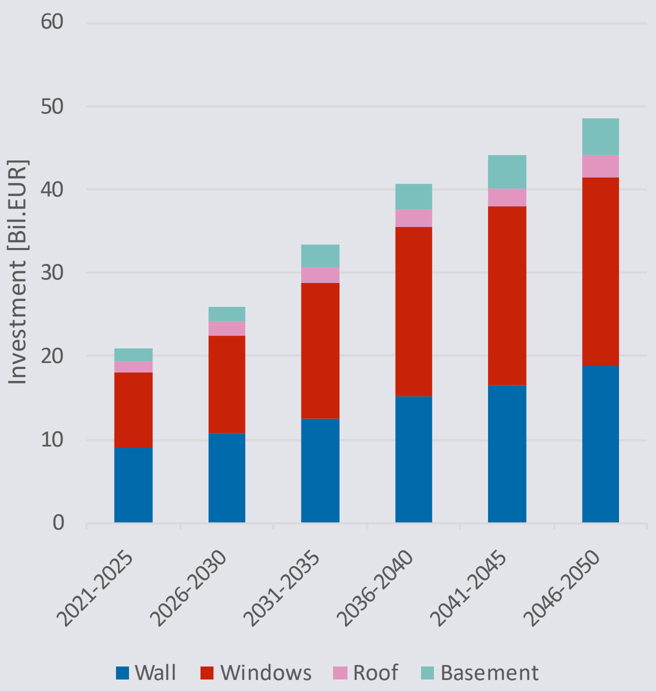


Source: TEP Energy

- → 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, Italy



TEP Energy modelling (2023)

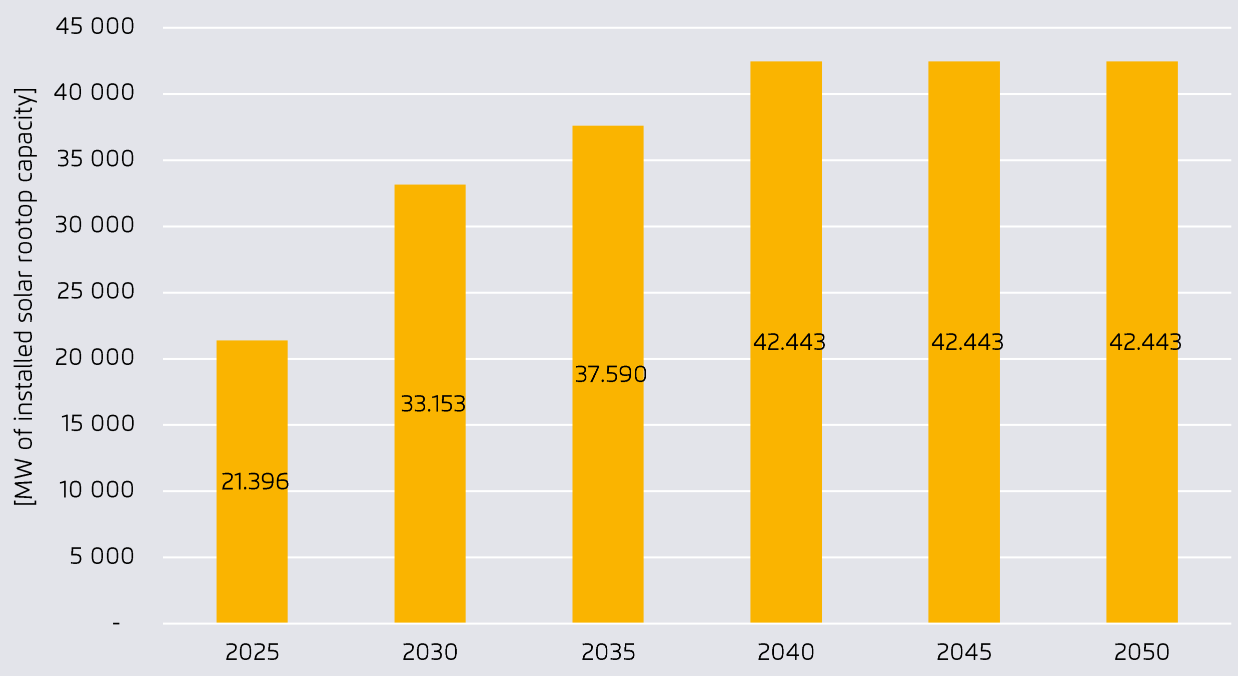
Specific energy demand (kWh/m2), Italy

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 then 20 bn EUR to more than 45 bn EUR
- As a result of these investments, specific energy demand in existing buildings is substantially reduced by about
  - 14% between 2020 and 2030
  - 27% between 2020 and 2040

Deep dive: Solar rooftop PV

Installed solar rooftop PV capacity (in MW) – Italy



Artelys

→ Installed solar rooftop capacity and generation grows rapidly, but slows/saturates after 2040:

- 33.2 GW (2030); 42.4 GW (2040); 42.4 GW (2050)
- 45.3 TWh (2030); 58 TWh (2040); 58 TWh (2050)

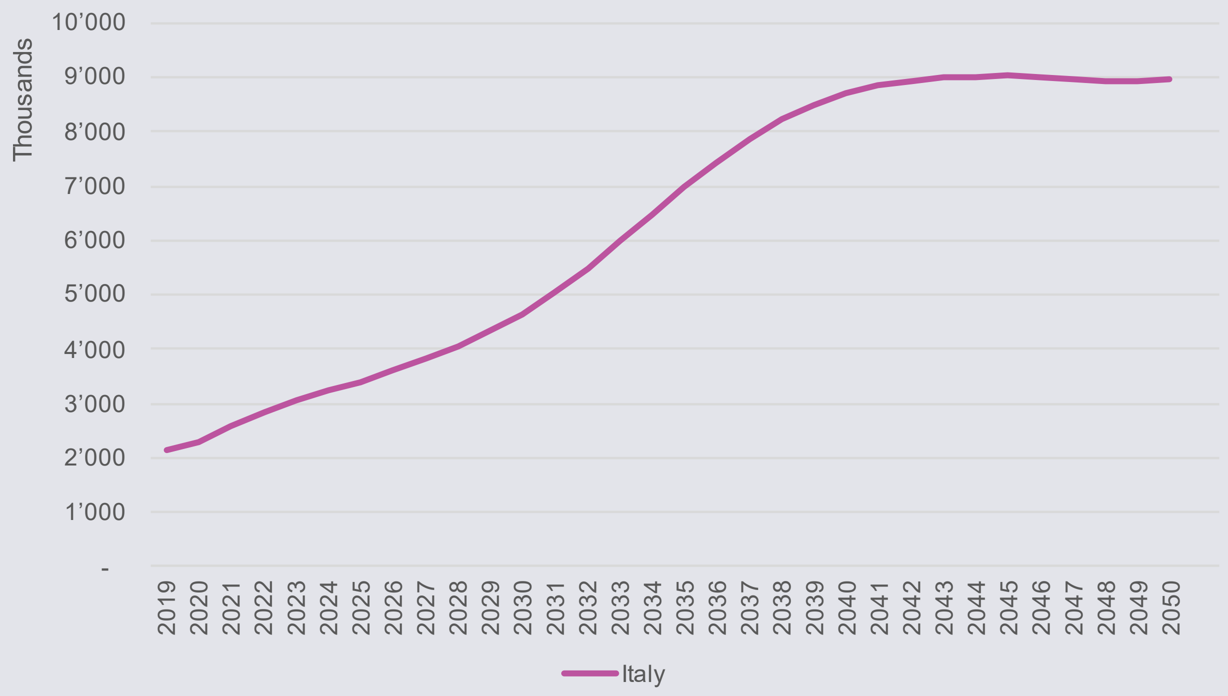
→ The share of rooftop solar in total solar capacity and generation is expected to peak at 61% in 2030 before declining to 19% in 2050.

→ Rooftop PV generation is on an aggregate yearly balance able to cover a moderate-stable share of electricity consumption in buildings :

- (%) total electricity demand in buildings (excl EVs): 27% (2030); 31% (2040); 31% (2050)
- (%) of electricity for heating, cooling & ventilation: 51% (2030); 54% (2040); 54% (2050)

Deep dive: heat pumps

Number of Heat Pumps, Italy



TEP Energy modelling (2023)

- Number of heat pumps increases from 2.3 Mio in 2020 to 4.6 Mio in 2030, to 8.4 Mio. in 2040 and 8.9 Mio. in 2050.
- This represents an average increase of ~240 000 heat pumps per year from 2020-2030 and ~640 000 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:

Methodology and assumptions

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

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

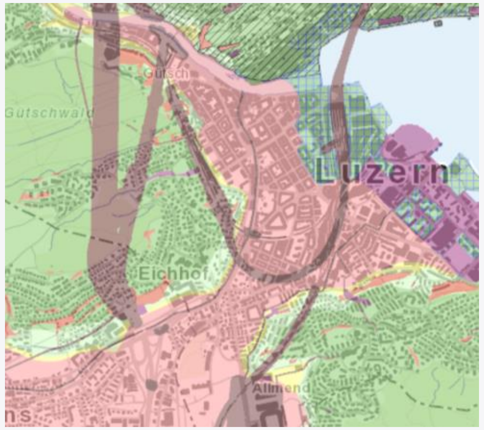
→ Positive motivation:

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

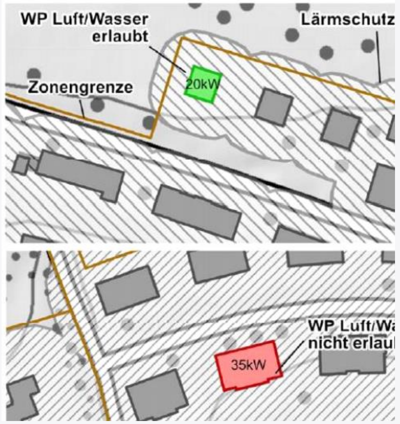
→ Decentralized systems

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

Borehole HP not allowed in ground-water areas



Air/water HP emit noise in and need space



Topology resulting from spatial energy analysis

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

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

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

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

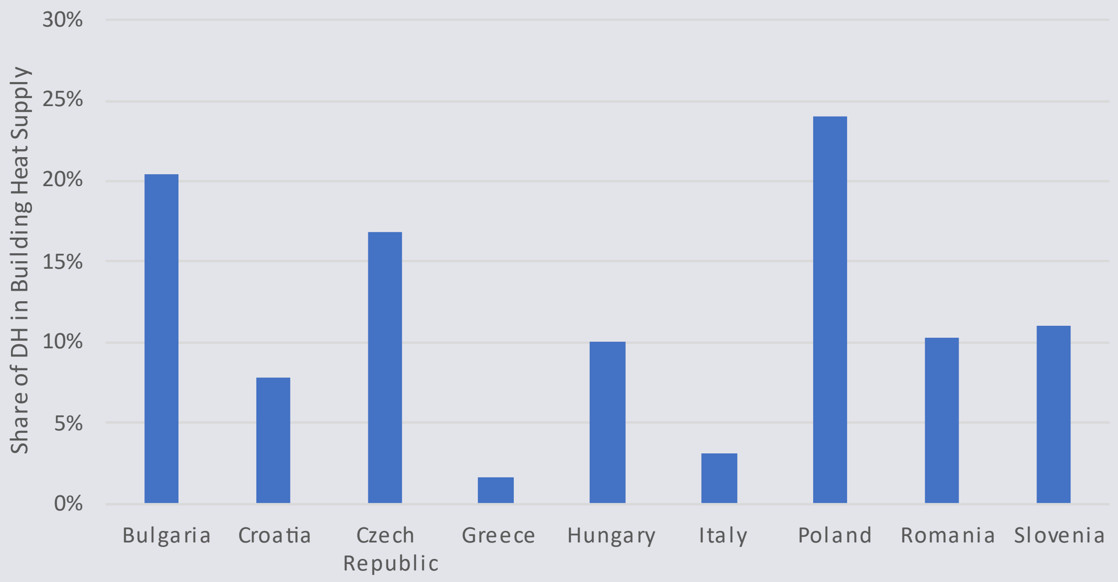
Spatial energy analysis: topology of centralized/non-centralized options.

Results (example Switzerland):

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

District heating (DH): starting from very different situations

Share of district heating at Building Heat Supply in 2020



TEP Energy and Wuppertal Institute (2023)

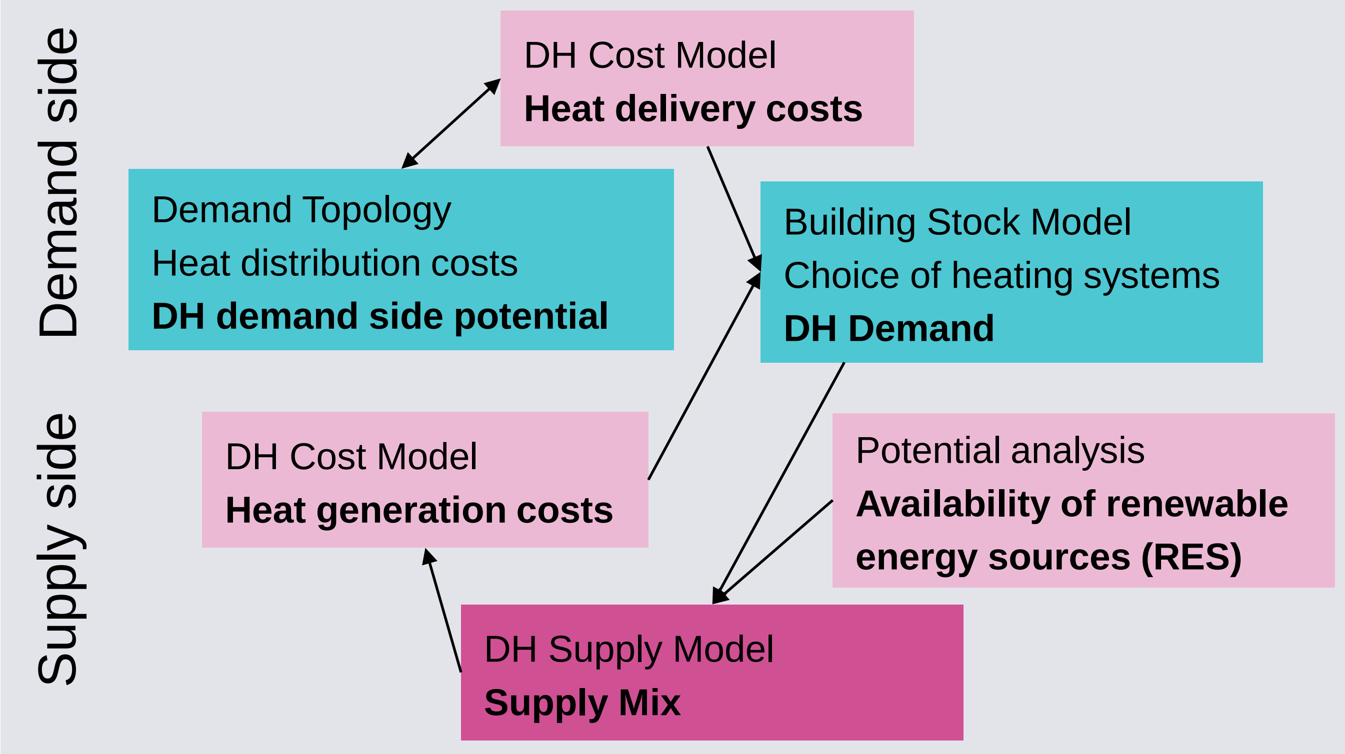
Two types of countries (focus on 9 national partners):

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

District heating modelling: demand and supply

Conceptual modelling approach district heating generation and provision



TEP Energy and Wuppertal Institute (2023)

Demand side :

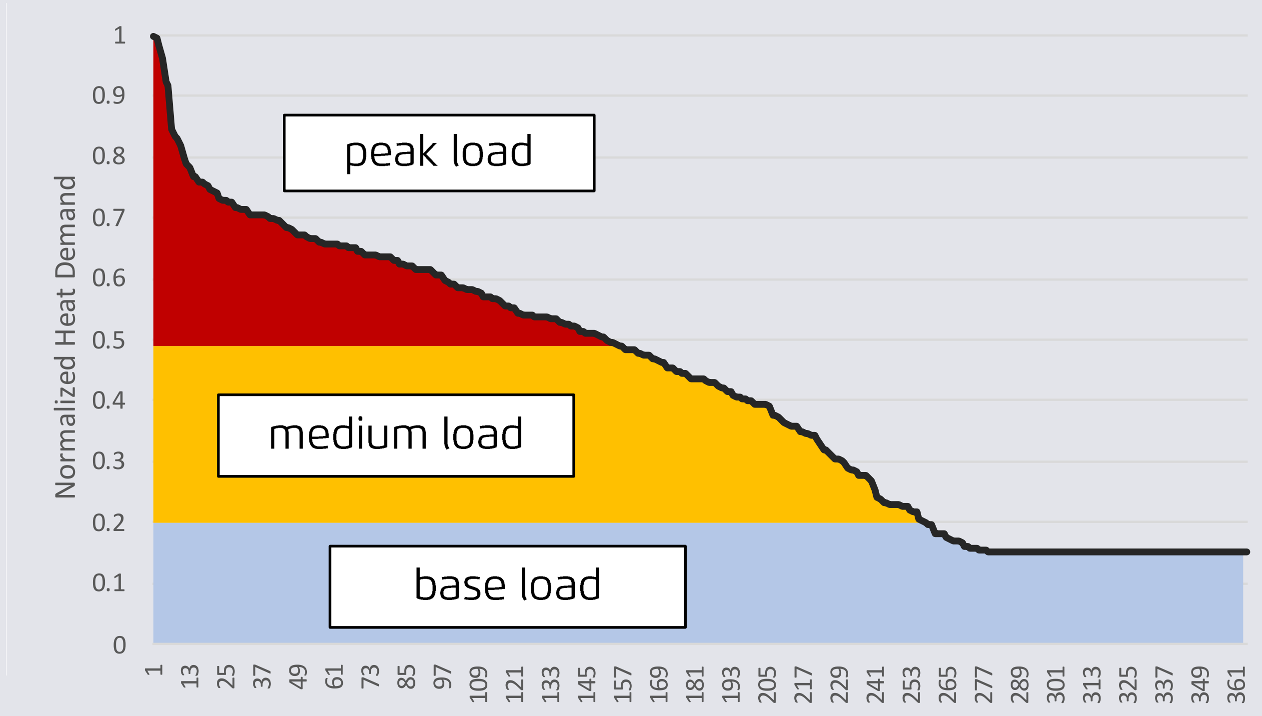
- → Heat distribution costs
- → Constraints (depending on topology of built environment)
- → Decision of owners to connect (also depending on competitiveness of decentral alternatives)

Supply side

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

District heating modelling: conceptual approach

Illustration of assumed heat supply logic



TEP Energy (2023)

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

District heating:

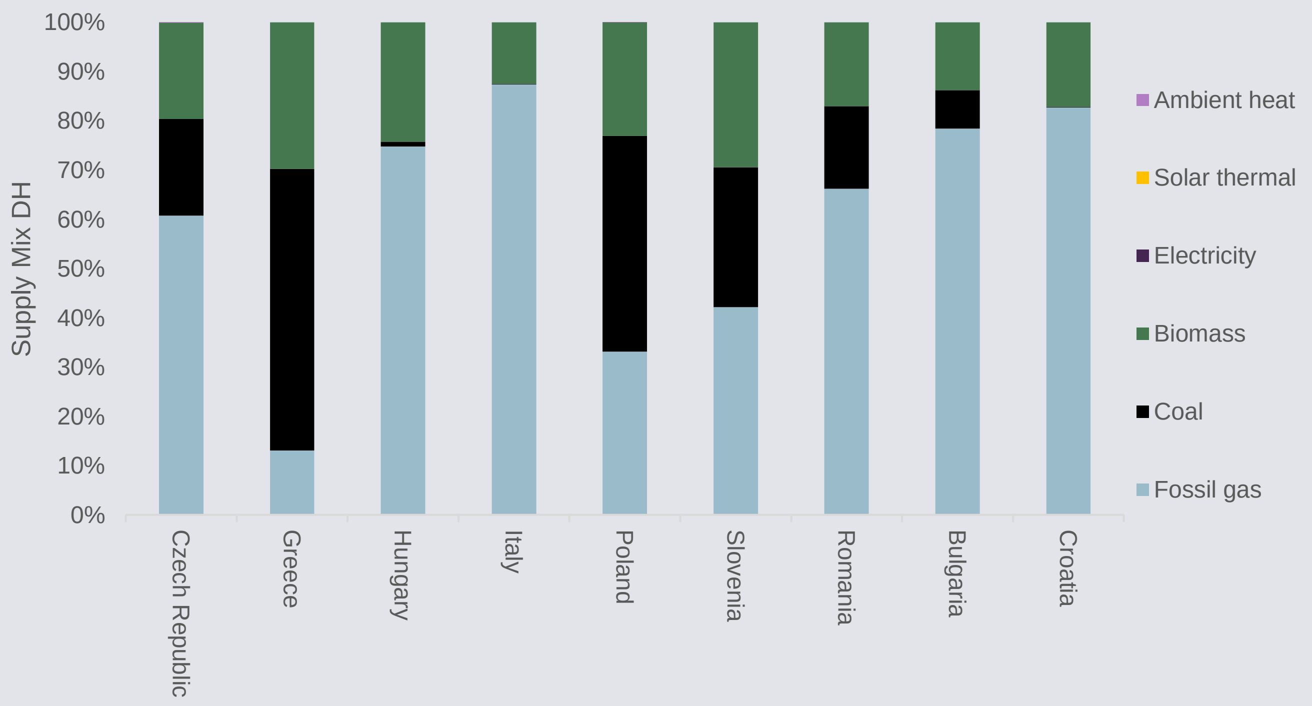
Results

District heat: Background note for interpreting the results

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

District heating generation: starting from very different situations

Share of district heating energy provision mix



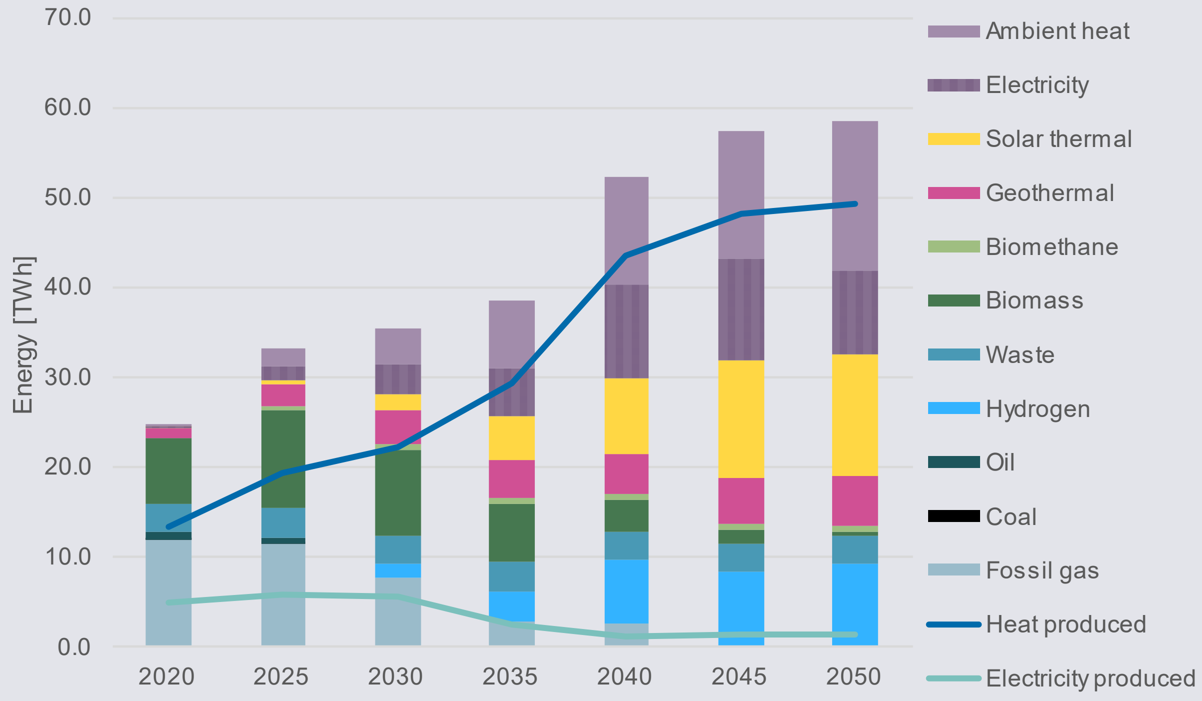
TEP Energy and Wuppertal Institute (2023)

Starting from very different situations

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

Energy consumption in district heating plants

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

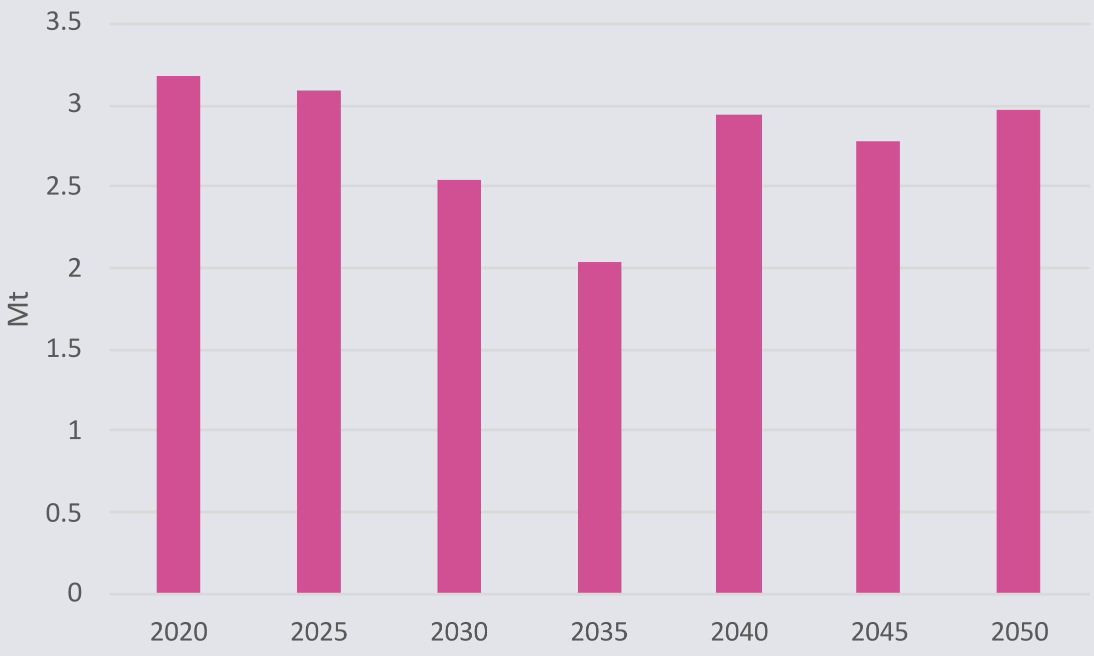


TEP Energy

- Energy consumption increases by 43% until 2030 and doubles by 2040 (+113%) in comparison to 2020 thanks to efficiency improvements.
- District heating sees a quite linear reduction in fossil-gas demand over time, declining by 68% from 2020 to 2030 to 18 TWh, and by 94% by 2040.
- Coal is phased out by 2035.
- Electricity production is 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 2030 to replace fossil gas, while biomass declines, from 14 TWh in 2025 to 5 TWh in 2050.

Greenhouse gas emissions in district heating

Direct GHG emissions in the DH sector [in Mt CO2eq], Italy

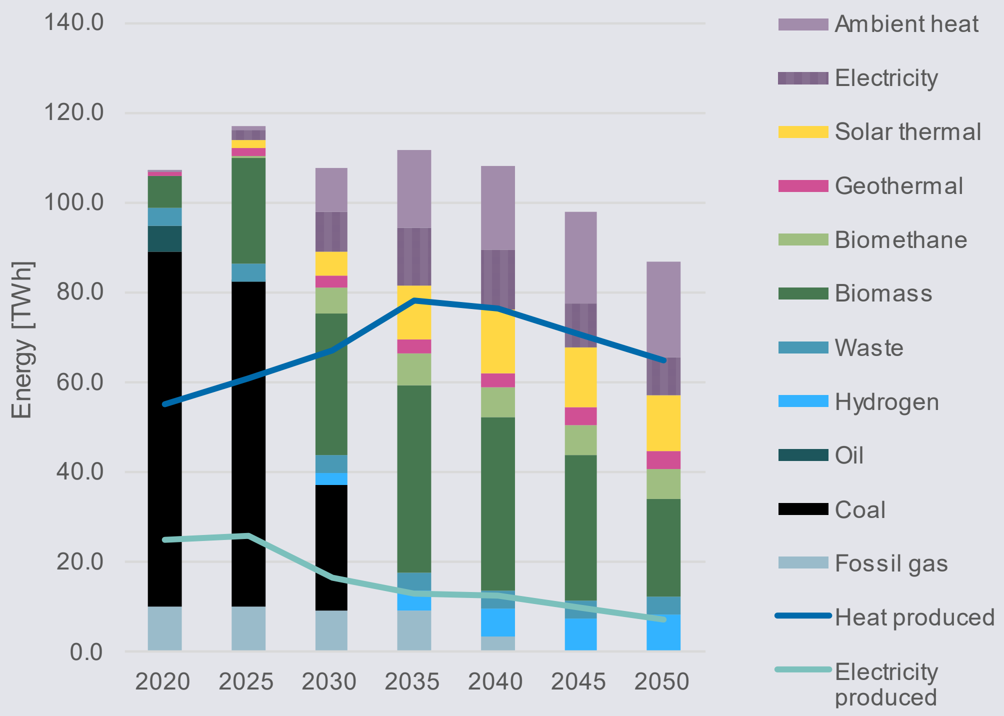


TEP Energy modelling (2023)

- Greenhouse gas emissions decline by 23% until 2030, between 2020and 2040 it only decreases by 8%.
- District heating generation sees steady reduction in fossil gas demand over time, declining by 36% in the period from 2020 to 2030, reaching 79% 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.

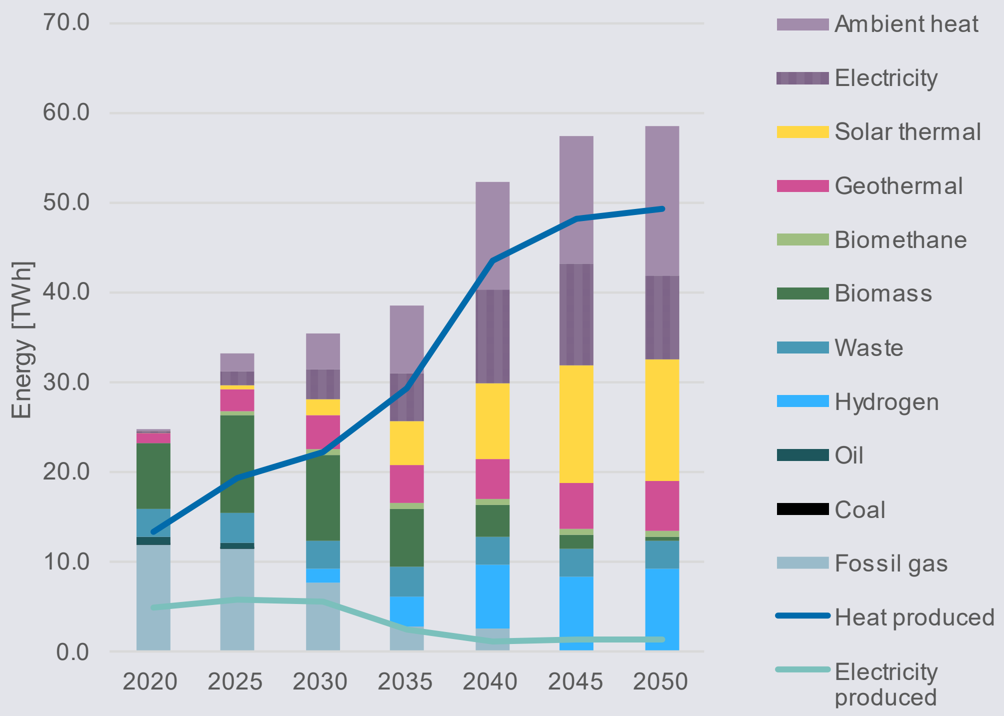
Role of district heating for achieving a fossil free building stock: historical and “newcomers” district heating countries

Energy consumption in district heating, Poland



TEP Energy, modelling (2023)

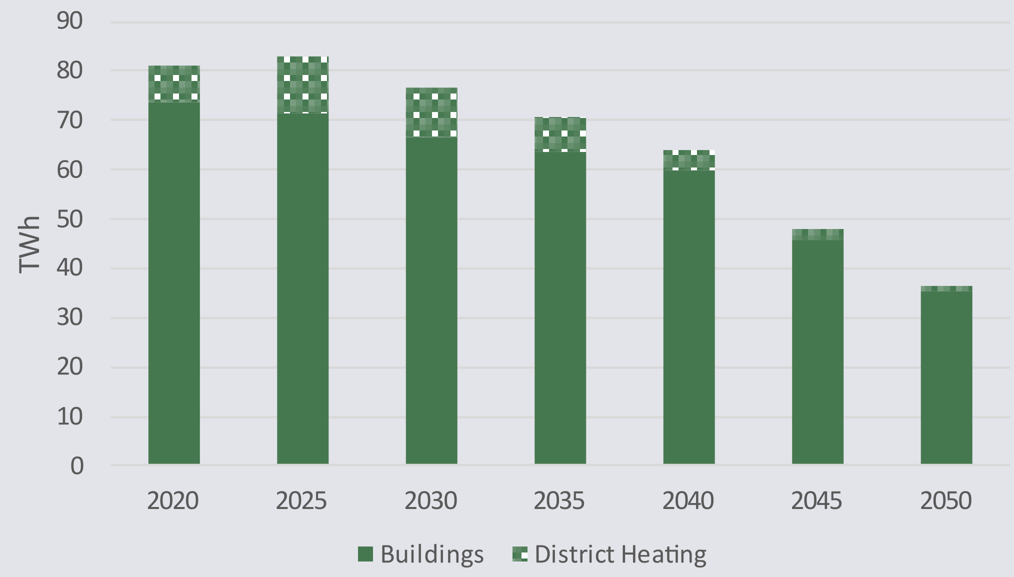
Energy consumption in district heating, Italy



TEP Energy, modelling (2023)

Deep dive: solid biomass

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

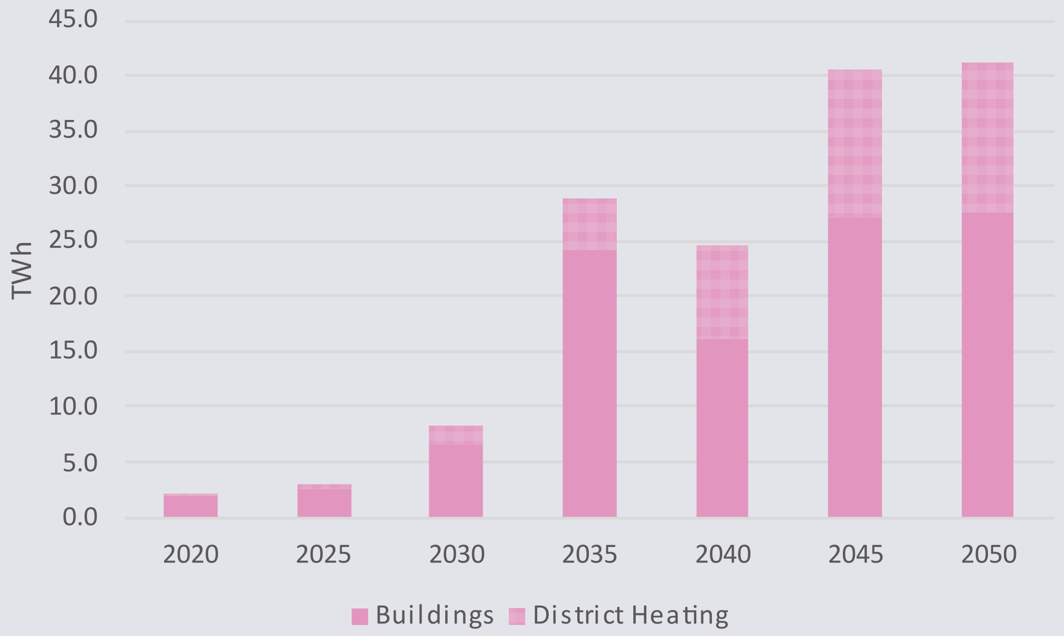


TEP Energy modelling (2023)

- 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 than 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), Italy

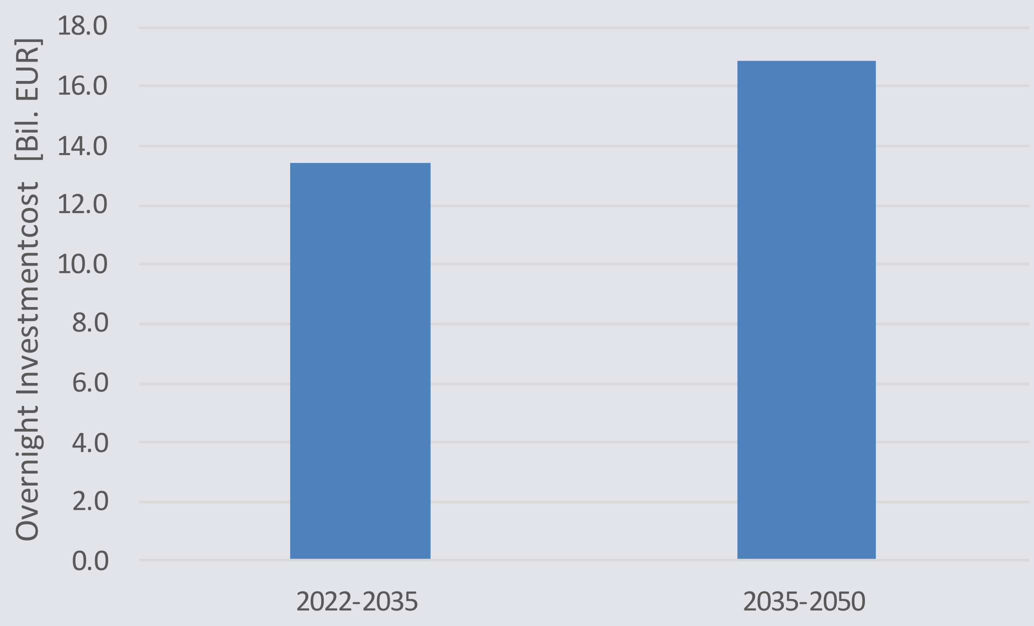


TEP Energy

- Solar thermal buildings produces 27.7 TWh by 2050
- Solar thermal in district heating produces 13.5 TWh by 2050
- 31.4 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, Italy



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 until 2035 13 Bil. EUR, from 2035 to 2050: 17 Bil. EUR