Potentials and levels for the electrification of space heating in buildings

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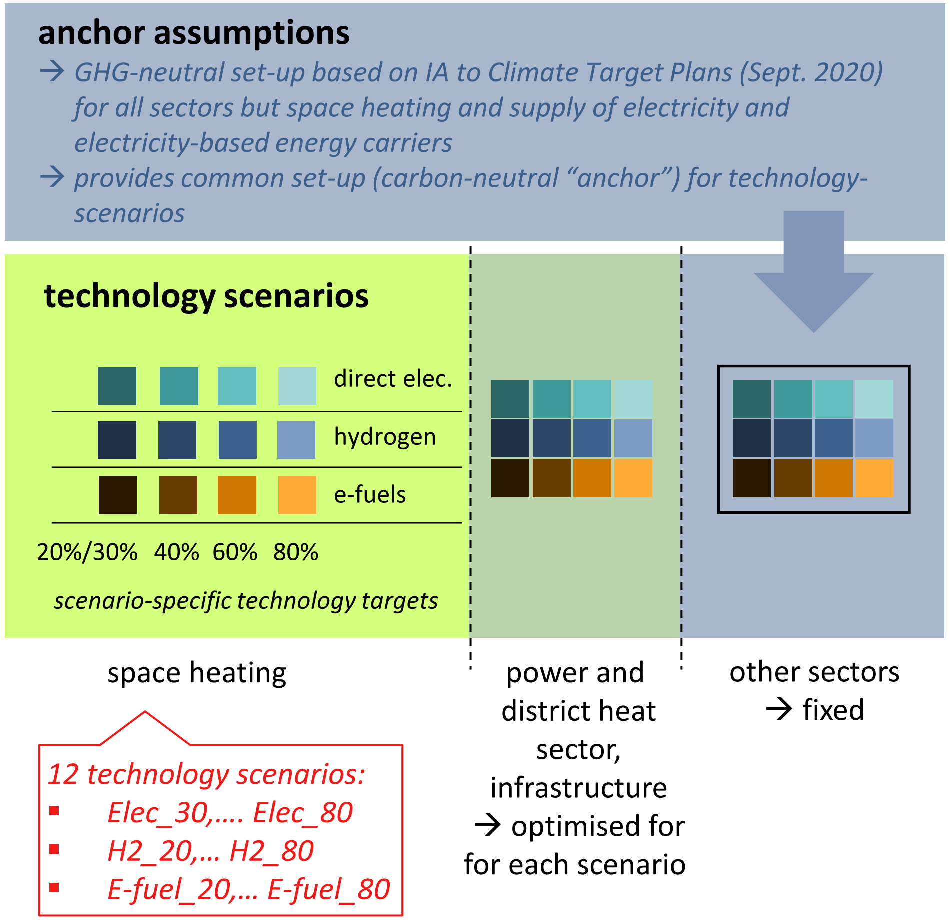
REKK e-think Energy Research TU Wien Technische Universität Wien Fraunhofer ISI consentec

EU study on the electrification of space heating:
Background and goal of the study

- **decarbonising space heating is a crucial factor for reaching EU climate targets**
- several studies and scenarios point to electrification of heating as a main solution for heat decarbonisation
- electrification of heat → different implementations possible
  - direct electrification (in particular decentral / central heat pumps, partially electric boilers)
  - indirect electrification based on RES-E: via hydrogen and/or via e-fuels (in particular, synthetic methane)
- less clear: **effects of different levels of the various ways of electrification in technical and economic terms**
- **analyse possible levels of electrification** of space heating (buildings) in EU
  - consider **direct electrification** (in particular heat pumps) as well as **indirect** (green H2, e-gas)
  - analyse by using **model based scenarios** of space heating sector
    - each scenario reflects different levels of electrification in categories named above
    - analyse time period up to 2050 with focus on 2050
    - due to close interaction of heating sector with other energy sectors these are considered as well

EU study on the electrification of space heating:
Study design

overview on scenario design



anchor assumptions

→ *GHG-neutral set-up based on IA to Climate Target Plans (Sept. 2020) for all sectors but space heating and supply of electricity and electricity-based energy carriers*

→ *provides common set-up (carbon-neutral "anchor") for technology-scenarios*

technology scenarios

direct elec.

hydrogen

e-fuels

20%/30% 40% 60% 80%

scenario-specific technology targets

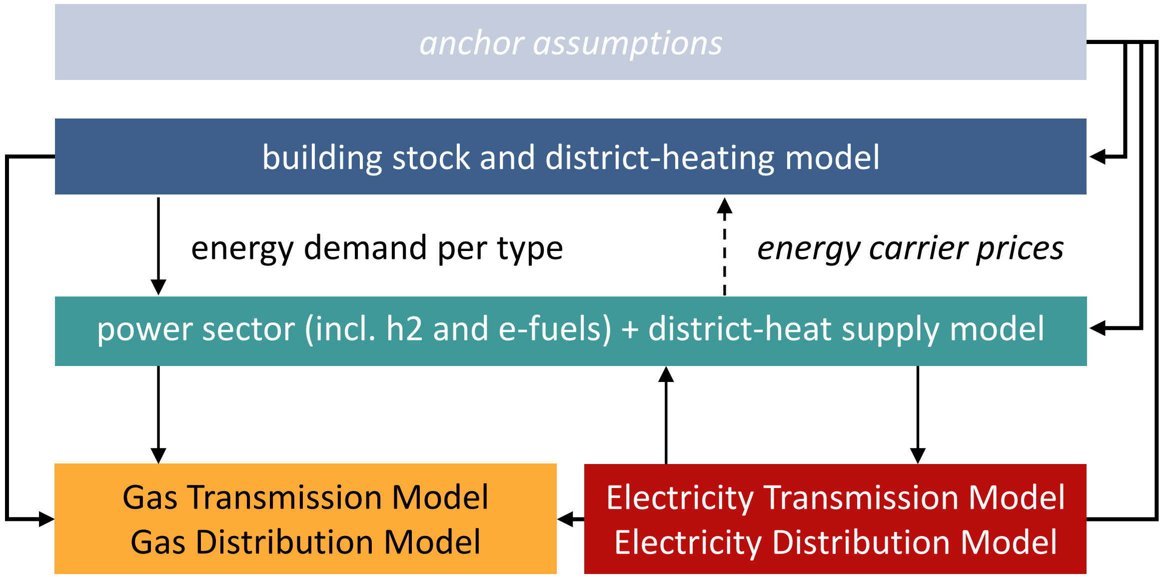
space heating

power and district heat sector, infrastructure
→ optimised for for each scenario

other sectors
→ fixed

12 technology scenarios:
- *Elec_30,…. Elec_80*
- *H2_20,… H2_80*
- *E-fuel_20,… E-fuel_80*

overview on modelling approach



anchor assumptions

building stock and district-heating model

energy demand per type

energy carrier prices

power sector (incl. h2 and e-fuels) + district-heat supply model

Gas Transmission Model
Gas Distribution Model

Electricity Transmission Model
Electricity Distribution Model

Building sector – modelling

Modelling approach

- Building stock modelling based on building archetypes (Invert/Opt)
- Cost-minimal combination of building envelope measures and heating / hot water systems
- Setting technology and potential constraints to frame the technology scenarios

Key inputs and assumptions

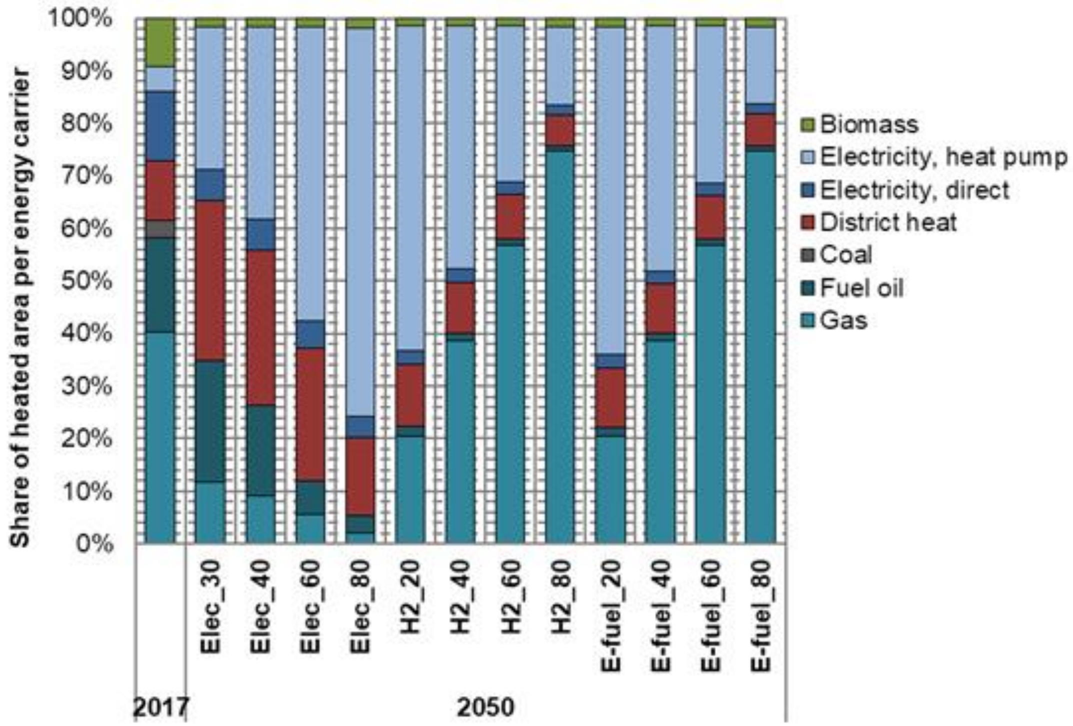
- Reference scenario: key drivers based on 2020 PRIMES reference scenario
- No growth of solid biomass use
- Country specific constraints on the upper limit of heated floor area by energy carrier/technology
- COP of heat pumps determined depending on the heating system's supply temperature

Main output / results

- Merit order of energy carriers / heating technologies: Heat pumps and district heating (where heat densities are sufficiently high) are economically viable. Liquid and gaseous energy carriers (H2 and e-methane) are expensive.
- If e-fuels must be used, they should be combined with solar heat and increased renovation measures.
- High levels of building renovation and related energy savings is part of the economic optimum in the largest part of the building stock

Results technology scenarios – building sector

share of heated area by energy carrier, technology scenarios, EU-27

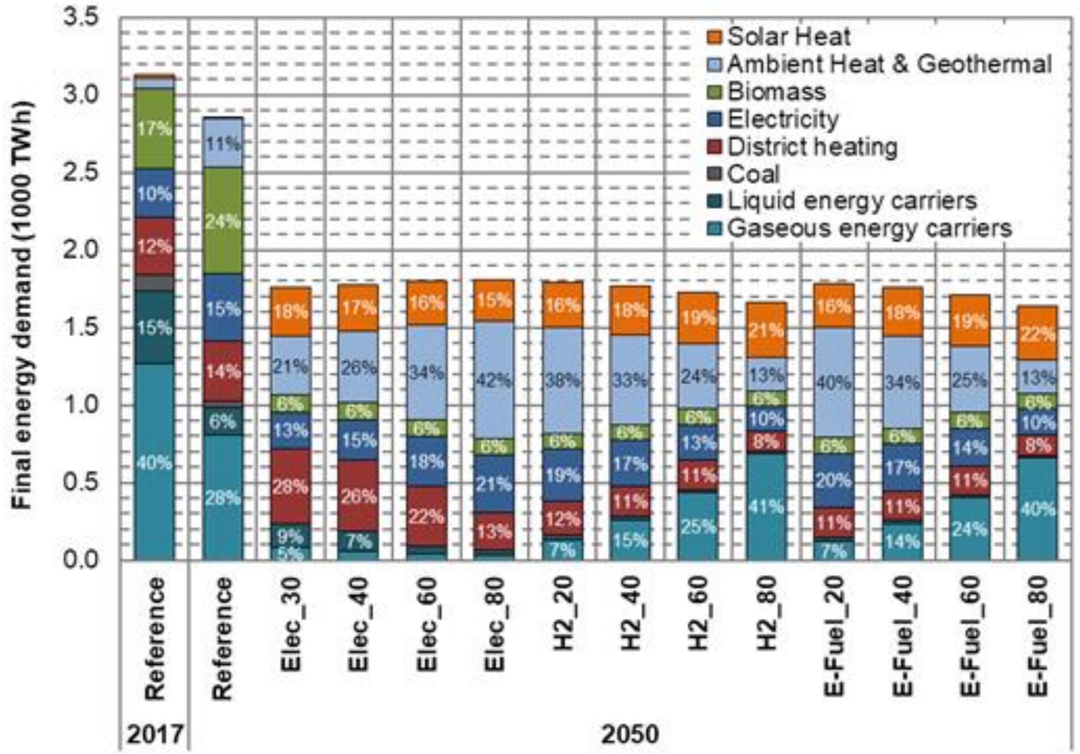


Key results

- Elec_80: remainder of the building stock is mainly supplied by district heating.
- E-fuel_80/H2_80: remainder of the building stock is mainly supplied by heat pumps.
- Model constraints lead to not fully achieving the 80% targets.
- E-Fuel_20/H2_20: high shares of heat pumps (and increased district heating)
- Elec_30: high district heating and e-liquids (competition mainly between DH and gas, in favour of DH, remainder cannot be filled by heat pumps, thus liquids)
- Solar heat is not included in the graph, to avoid double counting (solar heat is understood as secondary system to a “main” heating system).

Results technology scenarios – building sector

final energy demand space and water heating, technology scenarios, EU-27



Key results

- Share of electricity and ambient heat in the 80%-electrification scenario by 2050: 63%
- Share of gas in the 80% e-fuel and H2 scenario by 2050: 40-41%
- Each of the scenarios results in a strong decrease of direct electric resistance heaters.
- Biomass for space and water heating is mainly reduced due to the assumed resource constraints.

Conclusions

- This difference is due to high variable costs of e-fuels and H2. Thus, if applying e-fuels and H2 at all, it is most economic in combination with solar energy and in most efficient buildings.
- Higher e-fuels and H2 shares in the optimisation model lead to higher renovation activities (due to high variable energy costs).

Energy supply sector – modelling

Modelling approach

- Energy system optimization (system cost minimization) with Enertile
- Supply of electricity, district heat, hydrogen and synthetic fuels/gases
- High spatial (Europe in 6.4*6.4 km tiles) and temporal (hourly 2030, 2040, 2050) resolution, including real weather data → demand has to be met in each modelled hour
- Calculation of potentials for each RES technology, including cost per level of expansion
- Sector coupling and transmission infrastructure is taken into account

Key inputs and assumptions

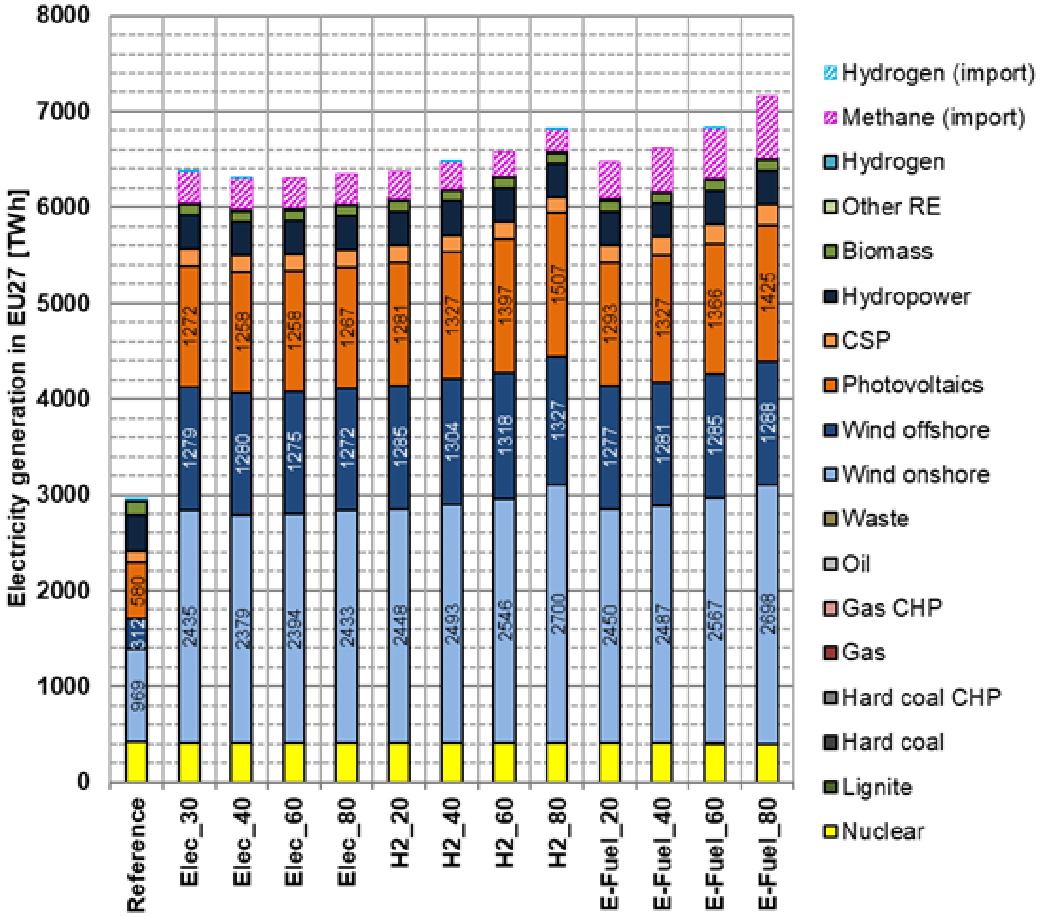
- European optimization under recognition of national targets where existent
- Demand data from Invert (space heating) and anchor assumptions
- Hydrogen and synthetic fuels/gases can be produced locally in the EU at corresponding (calculated) cost or be imported at assumed prices
- Under the chosen modelling setup (Invert, Enertile) the resulting changes across scenarios are induced by changes in the space heating sector

Main output / results

- electricity generation mix and heat generation mix in district heat grids per country
    - installed capacities (including storage)
    - hourly dispatch
- supply of electricity-based energy carriers (hydrogen, e-fuels)
    - including supply of demand for such energy carriers for electricity and heat generation
- high spatial resolution data on use of potentials for RES-E production
- expansion and utilization of infrastructure for cross-border electricity exchange

Results technology scenarios – energy supply sector

power sector – results: electricity generation by technology & import of hydrogen and methane in 2050

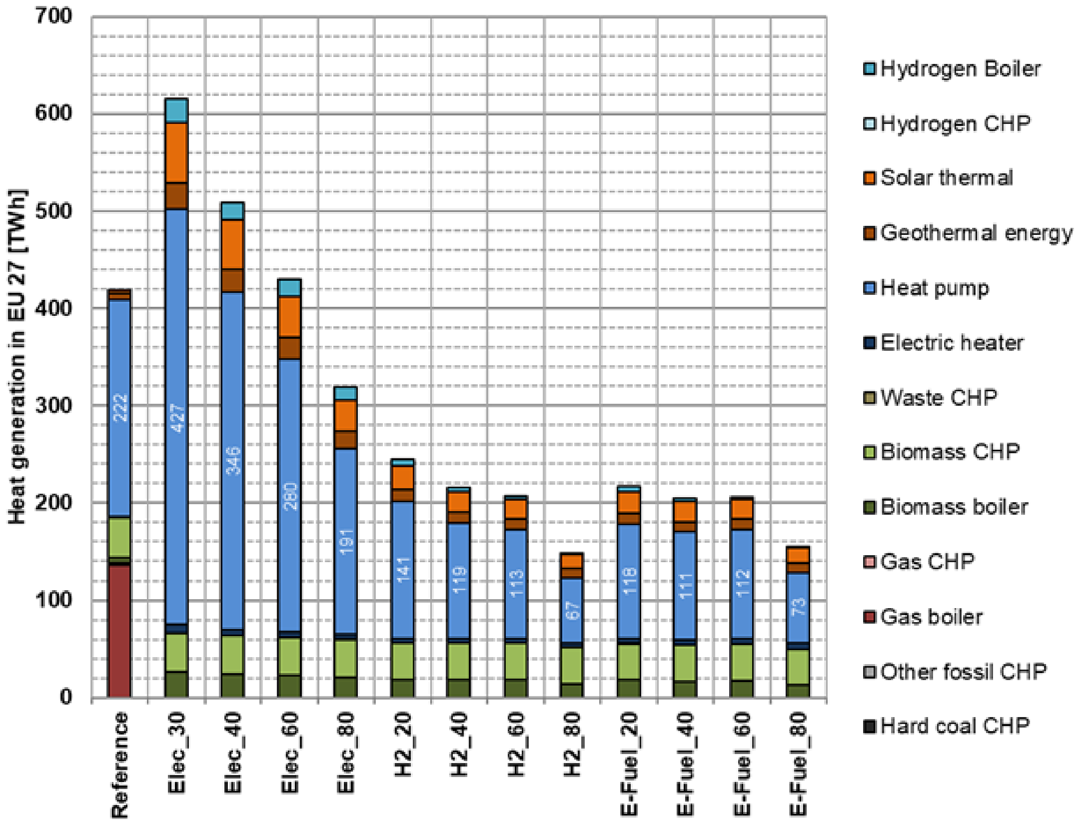


Key results

- Highest overall electricity generation in E-Fuel_80 followed by H2_80 and E-Fule_60 (> 6.800 TWh)
- Lowest electricity generation in Elec_40 and Elec_60
- EU-Imports of synth. methane high in all scenarios (highest in E-fuel_scenarios)
- Hydrogen imports are very small or negligible (EU production). Hydrogen reconversion for electricity generation is also negligible
- Elec_scenarios require a lower generation than H2_- and E-fuel_scenarios
- Within the H2_- and E-fuel_scenarios, the 80% scenarios require the most energy, the 20% scenarios the least (not in Elec_scenarios)
- Phase-out of fossil fuels and high share of wind energy and photovoltaics
- No significant variation in the mix between scenarios, changes are most pronounced in onshore wind and PV
- System balancing by CSP, nuclear power, existing hydropower, existing pump storage as well as cross-regional exchange

Results technology scenarios – energy supply sector

district heat sector – results: heat generation in heat grids by technology in 2050



Key results

- Significant variation in district heat-generation across scenarios due to different demand levels (exogenous / taken from Invert)
- Highest share of district heating and thus highest generation in Elec_30
- Lowest share of district heating and thus lowest generation in H2_80- and E-Fuel_80-scenario
- High share of large-scale heat pumps in 2050 in all scenarios
- Heat pumps “cover” most of the variation in overall generation
- Hydrogen boiler for peak demands
- Phase-out of fossil fuels

Energy supply sector – overall results

Main conclusions

Electricity

- Higher generation and imports in 2050 in E-fuels- and H2-scenarios is due to overall higher energy needs (i.e., energy carrier conversion losses). And in these scenarios, the generation is higher in the 80% scenarios than in the 20% scenarios.
- In 2050, the electricity system is vastly dominated by fluctuating renewables (i.e., wind and photovoltaics) in all scenarios and the system is balanced by CSP, nuclear power, existing hydropower, existing pump storage as well as cross-regional exchange
- Increases in electricity generation throughout time are vastly met by onshore wind and PV expansion

District heating

- Heat pumps are the dominating generation technology in all technology scenarios in 2050, followed by biomass (boiler and CHP) and solar thermal
- 30% electrification scenario shows highest generation in 2050 in heat grids - electrification is shift from decentral to central (because heat generation with heat pumps is cheapest)

Electricity transmission system – modelling

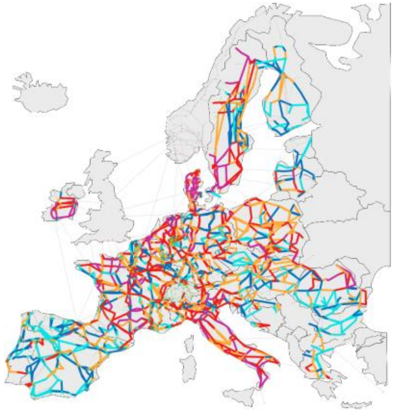
Modelling approach

- **simplified grid model** as part of the energy supply model
  - transport limitations between member states
  - expansion costs differ per border and increase the more capacity is built
  - model parameters iteratively validated in detailed grid model (see below)

→ cost-optimal expansion of grid infrastructure and dispatch limitations resulting from grid infrastructure are an integral part of the energy supply model

- **detailed model of the European electricity transmission** grid
  - load-flow contingency analysis for all 8,760 hours modelled in the energy supply model for each scenario (and year)
  - line overloadings identified lead to grid expansion

→ necessary grid expansion to cope with demand for cross-regional electricity exchange



exemplary result from full-year load-flow analysis (color indicates maximum overload throughout the year)

Key inputs and assumptions

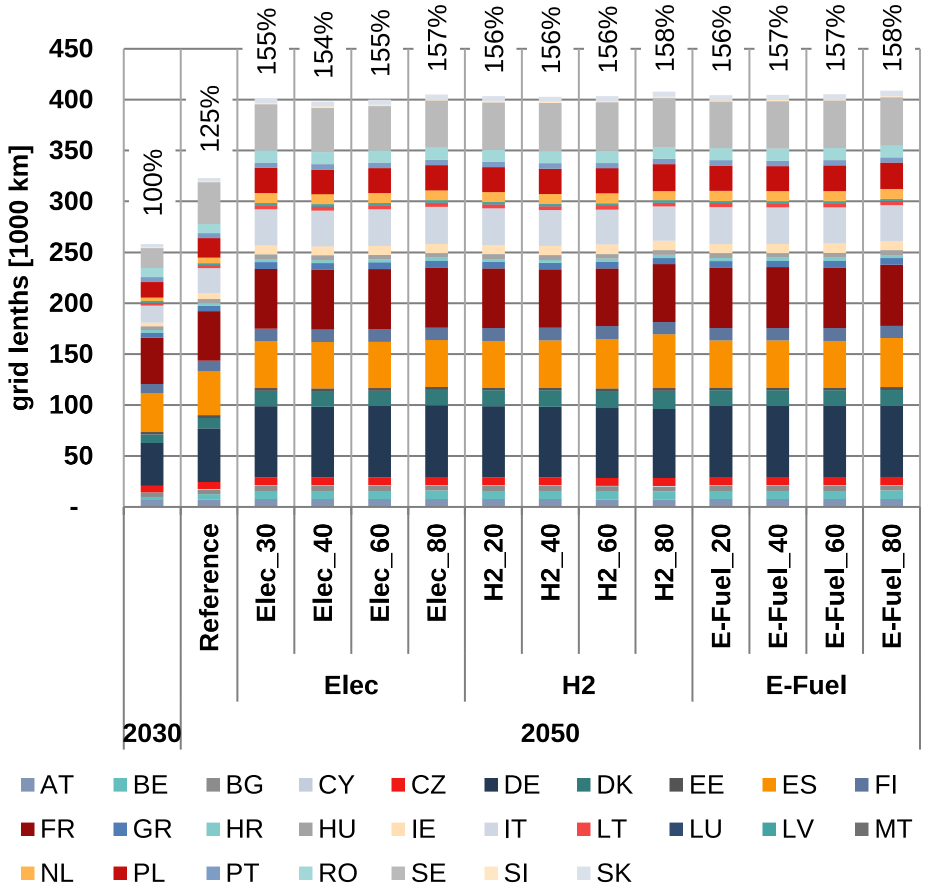
- starting point: current grid + planned expansion acc. to TYNDP
- spatial allocation of electricity load and generation and its dispatch directed aligned with the according scenario results from the energy supply model
- standard costs assumptions for grid equipment (lines, etc.)

Main output / results

- necessary expansion of transmission lines in kilometers
  - upgraded lines (switch in voltage level, other technologies)
  - new lines
- investments needs and developments of annualized grid costs

Results technology scenarios – electricity transmission system

total length of electricity transmission grid infrastructure in EU 27 (scenario comparison)



Key results

- Grid length increases by >50% and is more or less similar for all technology scenarios (~400.000 km)
- no major differences in regional distribution of expansion needs between scenario
- annuity of EU 27 transmission grids increases from 12 bn. EUR/a (2030) to approx. 30 bn. EUR/a in the technology scenarios (2050)

Conclusions

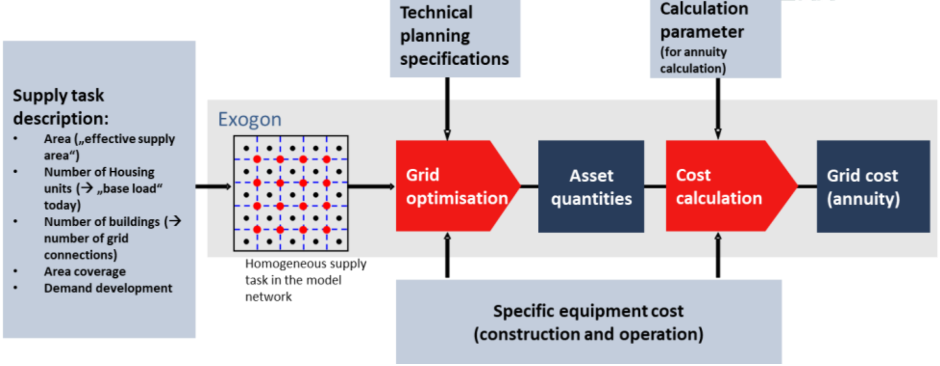
- A *cost-efficient* decarbonised energy system requires substantial transmission infrastructure expansion
- Decarbonisation strategy for space heating does not significantly influences amount of necessary transmission infrastructure
- Flexible loads can reduce the additional infrastructure needs in a cost-efficient manner, if the dispatched accordingly

Distribution grids (electricity) – modelling

Modelling approach

- basic modelling approach: model grid analysis
- key idea: supply task description in highly abstract form with only a few input variables (homogeneous chessboard-like grid model)

→ essential interrelationships between input and output variables can be easily investigated, detached from case-specific individual influences



Key inputs and assumptions

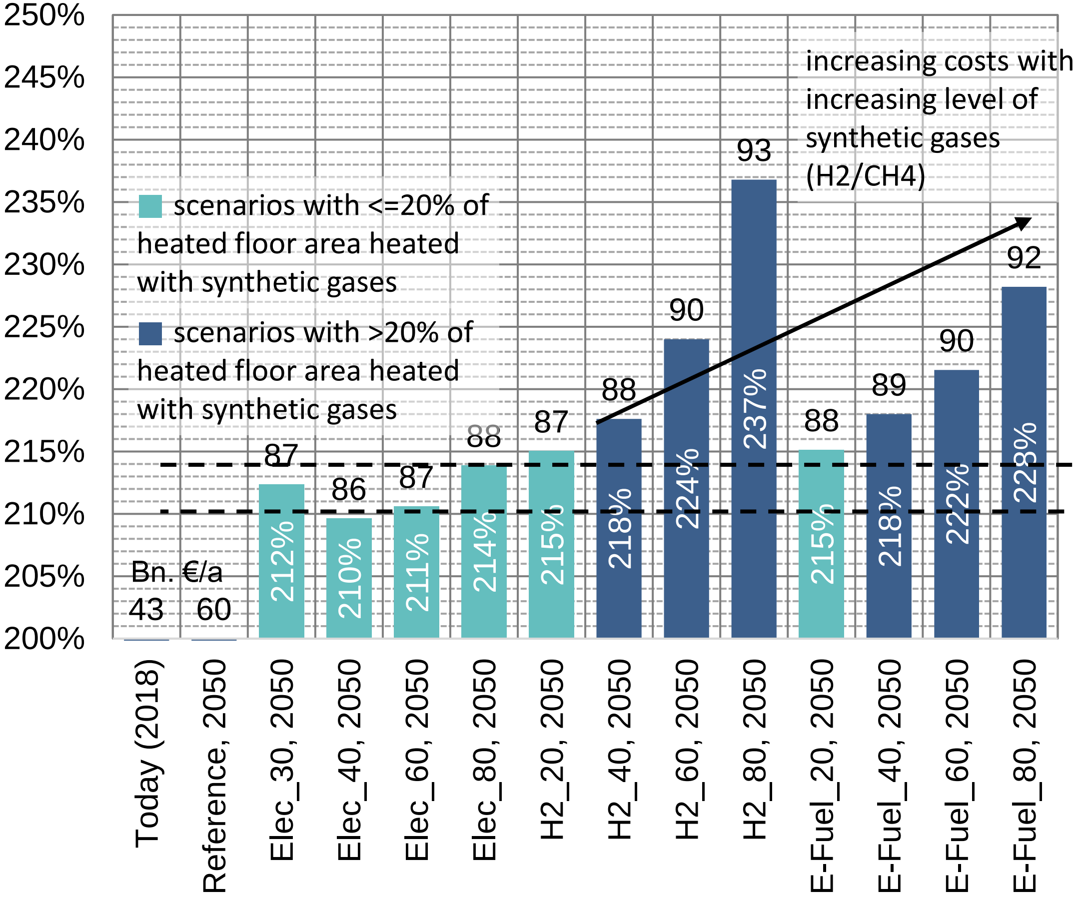
- Key inputs: spatial distribution of grid users, specific demand of consumers, area coverage, output of generation plants, typical specifications for grid design
  - scenario specifics taken from Invert and Enertile
- spatial resolution: NUTS2 (~250 regions for EU27)
- input parameters of model calibrated to current grid quantities

Main output / results

- quantity of the grid elements required to fulfil the supply task
- grid costs (annuity) based on quantity of the grid elements

Results technology scenarios – electricity distribution grids

Annual cost in 2050 including necessary grid expansion from 2030 to 2050 for EU-27 comparing technology scenarios with historic grid (2018)



increasing costs with increasing level of synthetic gases (H2/CH4)

Key results

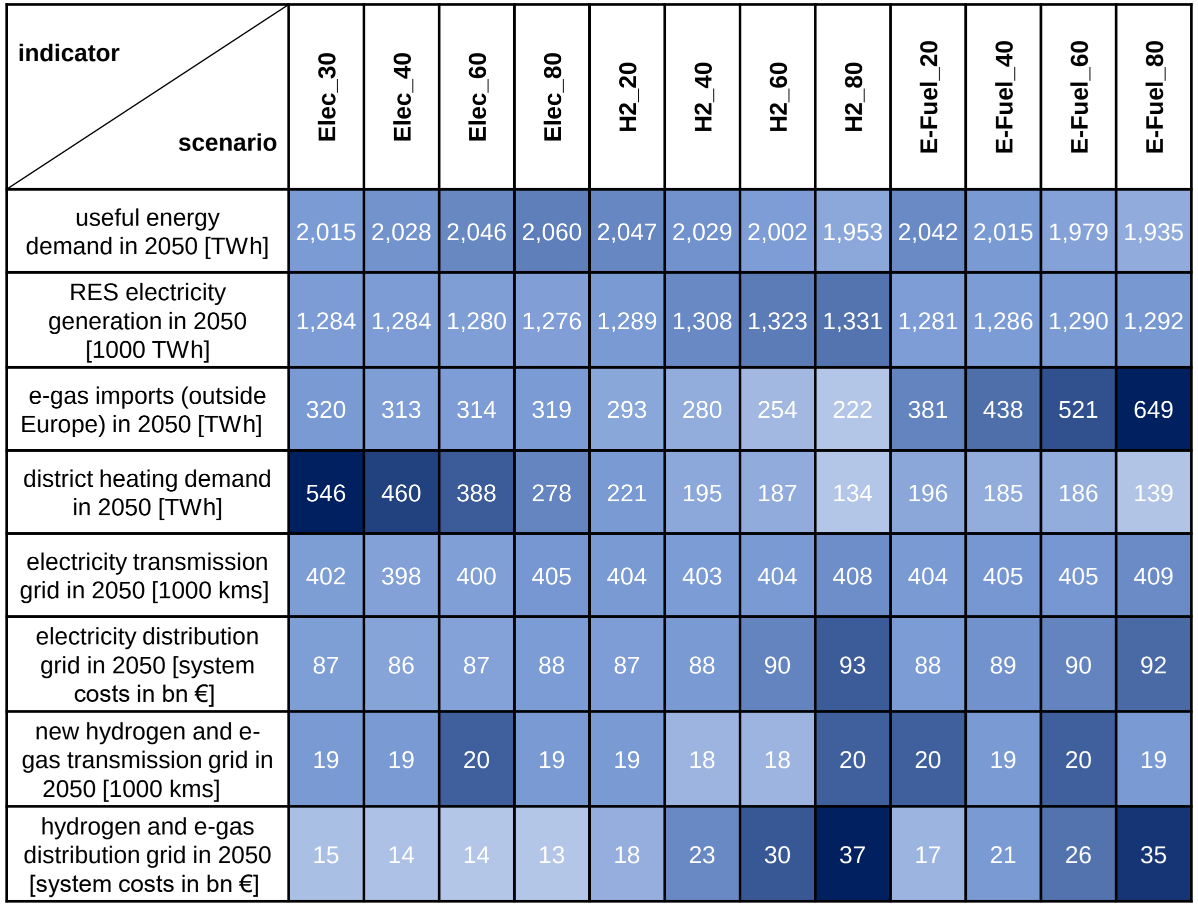
- GHG-neutral technology scenarios' costs of the electricity distribution networks are higher than these costs in the reference scenario
- but even the non-GHG-neutral reference scenario's costs are nearly 50% higher than today's costs
- among the technology scenarios H2_80 shows the highest cost increase
- differences between 20% to 60% penetration scenarios are only small
- even though, system load doubles, RES capacity increased by ~7, grid costs rise far less than the increase of the RES capacity
- regardless of this, cost differences between scenarios seem closely related to RES capacity differences as many grids must be extended due to high RES capacity and load only plays a minor role

Conclusions

- electricity scenarios show lowest cost increases among technology scenarios even though they face the highest load
- only small variations in costs in scenario with low level of synthetic gases

Scenario comparison

further indicators (all model results combined)



indicator / scenario	Elec_30	Elec_40	Elec_60	Elec_80	H2_20	H2_40	H2_60	H2_80	E-Fuel_20	E-Fuel_40	E-Fuel_60	E-Fuel_80
useful energy demand in 2050 [TWh]	2,015	2,028	2,046	2,060	2,047	2,029	2,002	1,953	2,042	2,015	1,979	1,935
RES electricity generation in 2050 [1000 TWh]	1,284	1,284	1,280	1,276	1,289	1,308	1,323	1,331	1,281	1,286	1,290	1,292
e-gas imports (outside Europe) in 2050 [TWh]	320	313	314	319	293	280	254	222	381	438	521	649
district heating demand in 2050 [TWh]	546	460	388	278	221	195	187	134	196	185	186	139
electricity transmission grid in 2050 [1000 kms]	402	398	400	405	404	403	404	408	404	405	405	409
electricity distribution grid in 2050 [system costs in bn €]	87	86	87	88	87	88	90	93	88	89	90	92
new hydrogen and e-gas transmission grid in 2050 [1000 kms]	19	19	20	19	19	18	18	20	20	19	20	19
hydrogen and e-gas distribution grid in 2050 [system costs in bn €]	15	14	14	13	18	23	30	37	17	21	26	35

- There are low differences in the useful energy demand. H2_80 and E-Fuel_80 have a slightly lower useful energy demand compared to Elec_80 → higher renovation is cost-optimal.
- There are low differences in RES electricity generation. Highest values in H2 and E-Fuel scenarios.
- Scenarios with high e-fuel shares have the highest need for e-gas import (from outside Europe).
- Elec scenarios have a higher district heating demand.
- There are low differences with regard to the electricity transmission and distribution grid. H2_80 and E-Fuel_80 have highest costs.
- Hydrogen and e-gas grid expansions are needed mostly in the scenarios with high hydrogen or e-fuels shares.

Scenario comparison

conclusion

- Direct electrification of heat (via heat pumps) shows lower costs when compared to both, hydrogen and e-fuels.
- In the analysis drawn, the Elec_60 scenario features a combination of best results and indicators → high share of the floor area is heated by decentral direct electric heating technologies (mainly heat pumps); the remainder of the floor area is covered by a high share of district heating.
- Building renovation is a no regret option in all scenario. The direct electrification scenarios require slightly lower efforts with regards to building renovation when compared to the hydrogen and e-fuel scenarios.

➢ Directly electrifying a substantial amount of the heating demand (via heat pumps) seems to be beneficial, both in terms of costs but also with regards to infrastructure and import requirements.

Scenario comparison

take aways for the transition

Characteristics of the cost-optimal scenario (Elec_60)

- A high share of the heated floor area is covered by electricity driven heating systems → 60% of decentral direct electrification with around 50% heat pumps and around 10% electric boilers in 2050.
- The remainder of the floor area is covered by a high share of district heating, i.e., around 25% in 2050.
- District heating generation is dominated by central large-scale heat pumps in 2050.
- Hydrogen boilers are used for peak loads in district heating. In decentral heating, hydrogen and e-fuels reach only low shares (below 5%) in 2050.

Developments in all scenarios

- A strong uptake in building renovation, particularly comprising deep retrofitting, is costs-efficient in all scenarios.
- An increase in RES electricity generation is needed in all scenarios.
- A strong increase in electricity transmission grid length and interconnection capacities can be observed in all scenarios.