Quantifying EE1st | Trade-offs between end-use energy efficiency and supply-side options to decarbonize buildings

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enefirst.

Agenda

01 | Background
The need for model-based assessments in the scope of the EE1st principle

02 | Methodology
Scenarios, models, and conceptual aspects

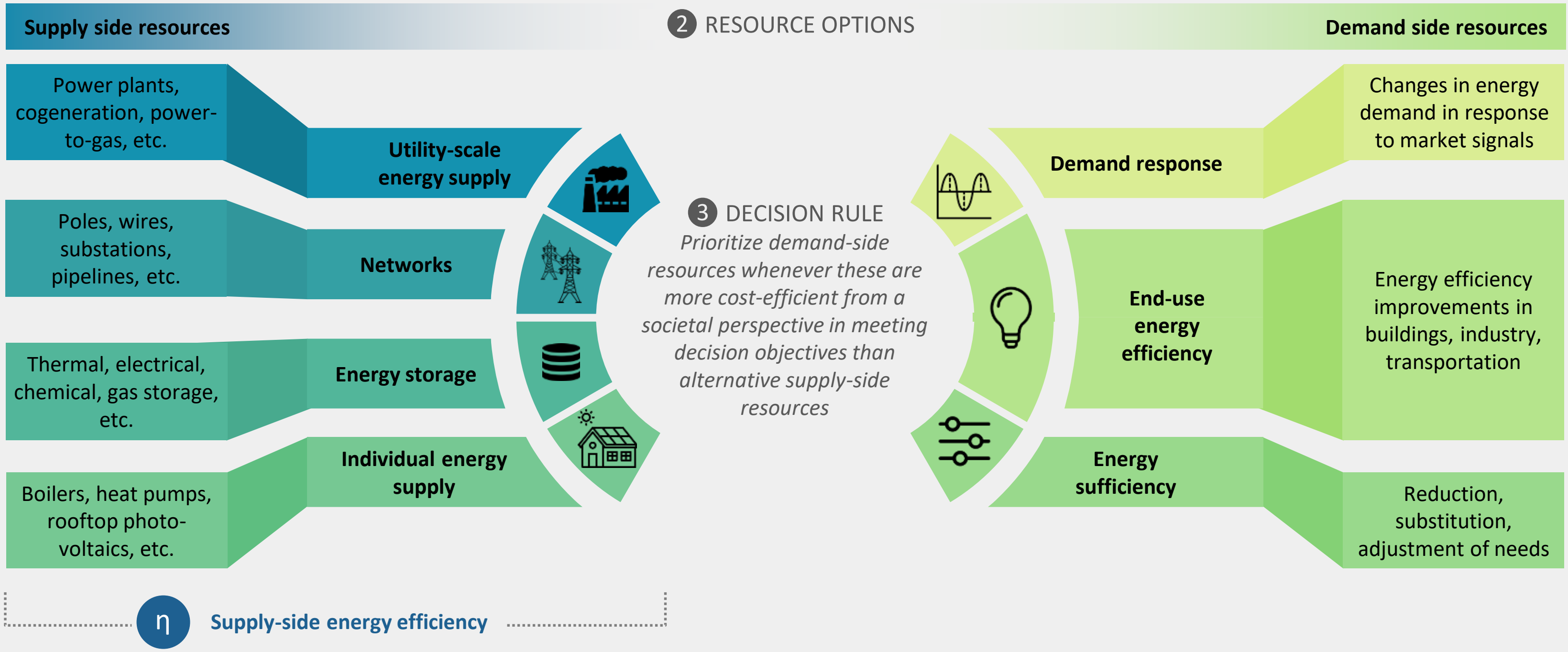
03 | Results
Trade-offs between saving and supplying energy in reaching net-zero emissions by 2050

04 | Discussion & conclusions
End-use energy efficiency in buildings is key with a view to climate-neutrality

Background

The Energy efficiency first (EE1st) principle can be conceptualized as follows

1 DECISION OBJECTIVES: *Meet energy service demand and policy objectives*



Investigating Energy Efficiency First in the EU building sector

Objective

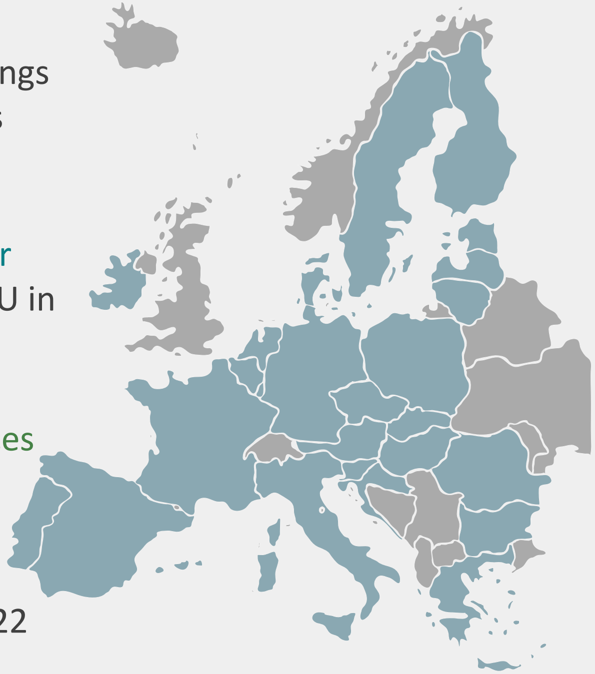
To provide quantitative evidence on effects of EE1st in buildings and energy supply in a transition towards net-zero emissions

Question

What level of end-use energy efficiency in the building sector would provide the greatest benefit – or least cost – for the EU in achieving net-zero GHG emissions by 2050?

Key properties of the analysis

- Integrated appraisal of demand- and supply-side resources
- Common objective: net-zero GHG emissions by 2050
- Societal perspective (ambition)
- No consideration of spike in energy prices as of 2021-2022



Meet the modelling team of *enefirst*

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Methodology

We investigate three scenarios for the EU building sector and energy supply

SCENARIOS

		Low efficiency in buildings (LowEff)	Medium efficiency in buildings (MediumEff)	High efficiency in buildings (HighEff)
	Decision objectives	**2020 to 2050** Meet energy service demand	**2030** ▪ ≥55% reduction GHG emissions (1990) ▪ ≥32% share for renewable energy ▪ ≥32.5% improvement in energy efficiency	**2050** Net-zero GHG emissions according to European Climate Law
BUILDINGS	Thermal efficiency	Moderate component requirements and renovation rates	Enhanced component requirements and renovation rates	Ambitious component requirements and renovation rates
	Appliance efficiency	Moderate minimum energy performance standards	Enhanced minimum energy performance standards	Ambitious minimum energy performance standards
	Individual heat supply	Optimized capacity expansion & operation | Balanced deployment of solar thermal, heat pumps, etc.		
	Energy sufficiency	Equal indoor temperatures, floor space, technology ownership, appliance use intensity, etc.		
ENERGY SUPPLY	Fuel prices	Fuel prices for crude oil, natural gas, hard coal according to *Sustainable Development* scenario (IEA World Energy Outlook 2019)		
	Other energy demand	Energy demand in industry & transportation according to *1.5TECH* scenario (Clean Planet for All study)		
	Electricity supply	Optimized capacity expansion & operation | No CCS, coal phase-outs, declining biomass, power transmission based on TYNDP-2018		
	District heating supply	Optimized capacity expansion & operation | Limited potential for solar thermal, geothermal, biomass		
	Hydrogen supply	Optimized capacity expansion & operation | 20% share of hydrogen & synthetic methane in building gas demand in 2050; high import prices		

See also: ENEFIRST (2021): Concept development for a model-based assessment of the E1st Principle. Deliverable D3.2 of the ENEFIRST project.

Energy system cost is the central performance indicator in the analysis

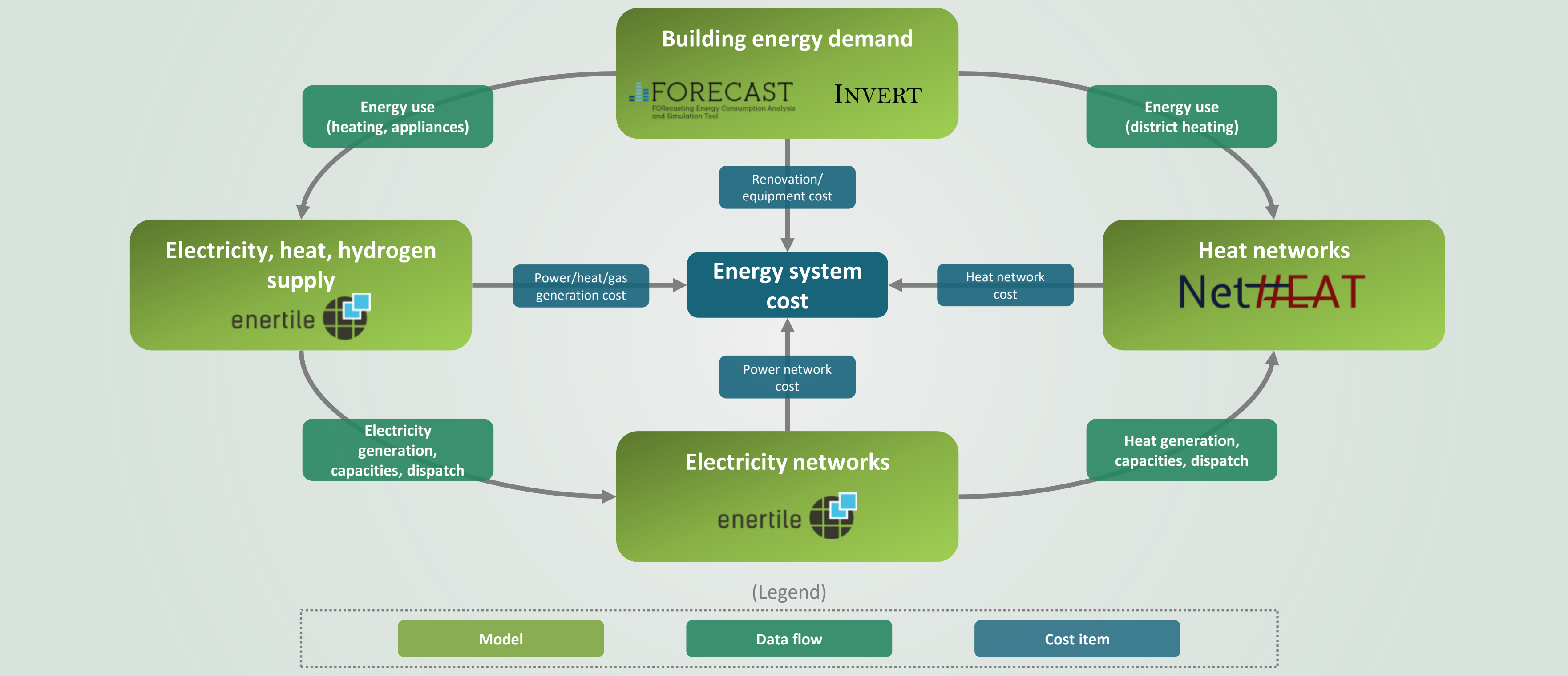
Σ ENERGY SYSTEM COST (EUR_{2018})

	Capital costs [1]	Fuel costs [2]	O&M costs	Other costs
Buildings	▪ Building renovation ▪ Heating equipment ▪ Electrical appliances & lighting equipment	▪ Wholesale costs for natural gas, fuel oil, coal, biomass	▪ Maintenance costs for heating systems	-
Electricity supply	▪ Generation plants ▪ Electricity storage facilities ▪ Electricity networks	▪ All relevant fuel costs (wholesale)	▪ Import/export cost ▪ Fixed & variable O&M costs of supply assets (incl. ancillary services)	▪ EU emissions allowance costs (ETS)
District heating supply	▪ Boilers & cogeneration plants ▪ Heat storage facilities ▪ Heat networks	▪ All relevant fuel costs (wholesale)	▪ Fixed & variable O&M costs of supply assets	▪ EU emissions allowance costs (ETS)
Hydrogen supply	▪ Hydrogen electrolysers ▪ Methanation facilities	-	▪ Import/export cost ▪ Fixed & variable O&M costs of supply assets	-

[1] 2% discount rate for transforming capital expenditures into annual capital costs (“annuities”)

[2] Excl. taxes (valued added tax, environmental taxes, renewable taxes, nuclear taxes, etc.)

Four models are coupled to assess energy system cost and other variables



Results


Morris Charts
Line Chart
Area Chart
Bar Chart
Donut Chart
Sparkline Charts
Line Chart
Bar Chart
Pie Chart
Easy Pie Charts
25%
50%
75%
100%
Sales
Orders
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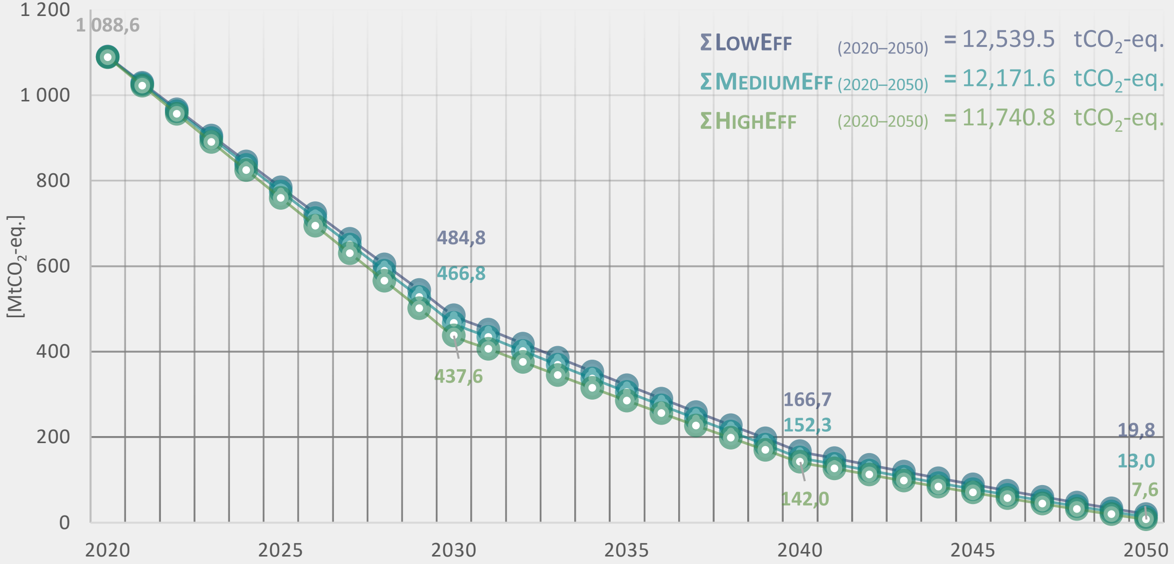
Direct greenhouse gas emissions



Direct greenhouse gas emissions from buildings and energy supply in EU-27 (2020–2050)

Emissions in buildings comprise direct combustion of fuels. Emissions from electricity and heat supply are total emissions for final use across all end-use sectors (buildings, industry, transportation)

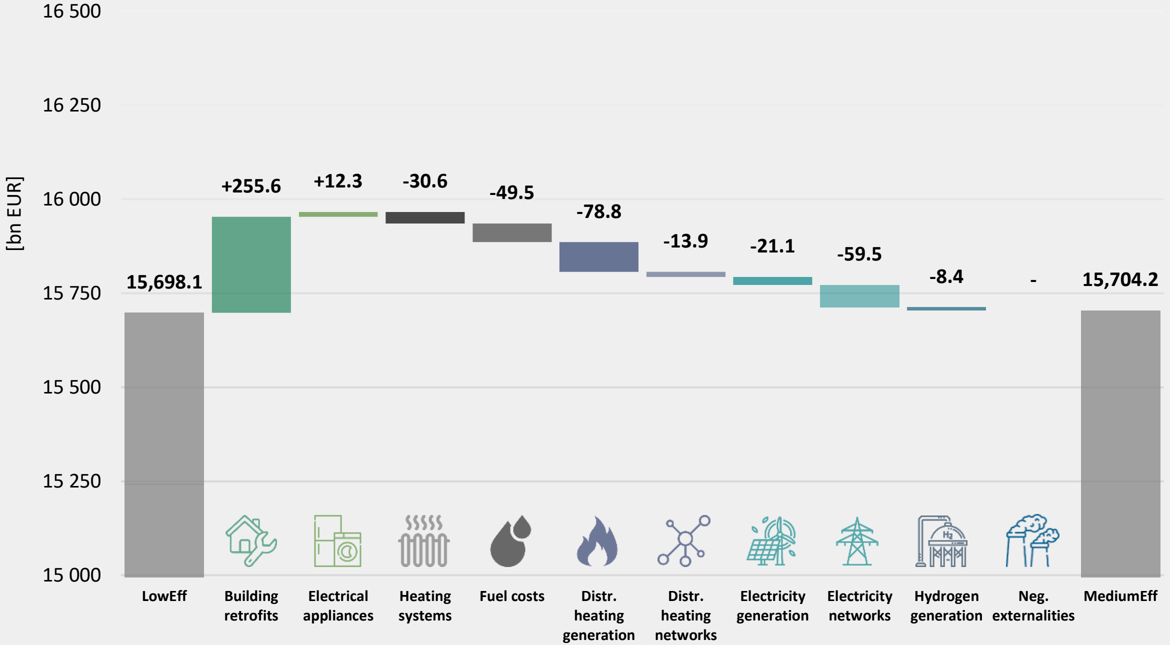
Results

- Reduction by 98.2% (LowEff), 98.8% (MediumEff), and 99.3% (HighEff) vs. 2020 levels
- Carbon budget (2020-2050): minor deviations of -2.9% (MediumEff) and -6.4% (HighEff) compared to LowEff

Key message

There are different technically viable pathways to reach net-zero emission levels. These involve different levels of energy demand and supply as well as energy system cost.

Energy system cost: LOWEFF vs. MEDIUMEFF



Cumulative differential energy system cost in MEDIUMEFF compared to LOWEFF scenario for EU-27 by cost item (2020–2050) [bn EUR]

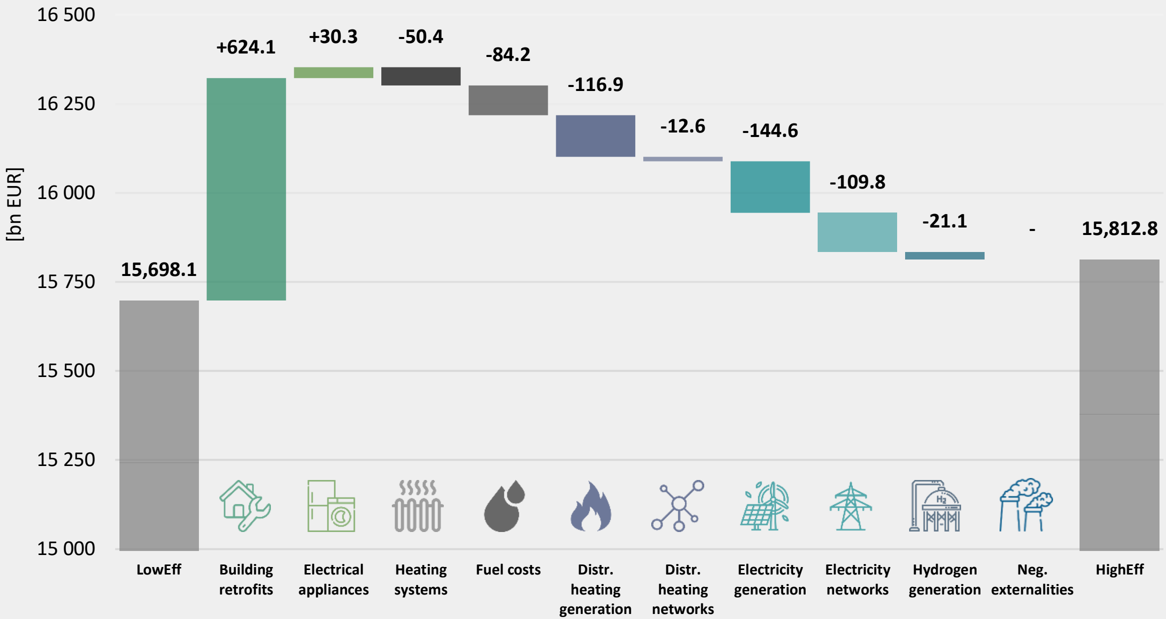
Results

- Close similarity in aggregate energy system cost (0.04%)
- Additional energy system cost in MEDIUMEFF of +6.0 bn EUR over the period 2020-2050
- Cost-benefit ratio = 97.7%

Key message

Enhanced energy efficiency standards in buildings are equivalent in energy system cost to a scenario with ambitious performance requirements

Energy system cost: LowEff vs. HighEff



Cumulative differential energy system cost in HIGHEFF compared to LowEff scenario for EU-27 by cost item (2020–2050) [bn EUR]

Results

- Similarity in aggregate energy system cost (0.73%)
- Additional energy system cost in MediumEff of +114.7 bn EUR over the period 2020-2050
- Cost-benefit ratio = 82.5%

Key message

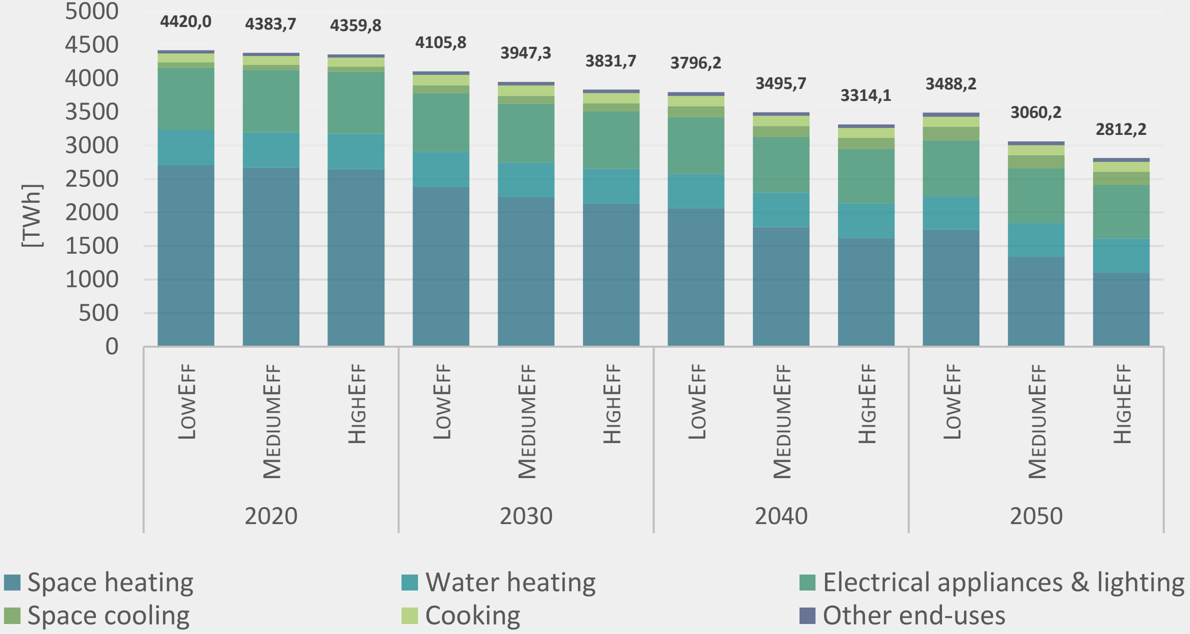
Highly ambitious performance standards for building efficiency does not fully pay off in terms of energy system cost

Key results in the scenarios

	LowEff	MediumEff	HighEff
Building energy demand in 2050 in [TWh]	3,488.2	3,060.2	2,812.2
• of which heating & cooling [TWh]	2,498.4	2,099.5	1,865.4
• of which electrical appliances [TWh]	989.7	960.7	946.8
Total energy savings compared to 2020 [%]	-21.1%	-30.2%	-35.5%
Building renovation rate (2050-2020) [%/a]	0.7%	1.4%	1.7%

Buildings

Final energy demand by end-use



Final energy demand by end-use in EU-27 [TWh]

Results

- Reduction by -21.1% (LowEff), -30.2% (MediumEff), -35.5% (HighEff) until 2050 vs. 2020
- PRIMES 2020: -10.4% reduction in 2050 vs. 2020
- Space heating remains biggest end-use in 2050 (39-50%)

Key message

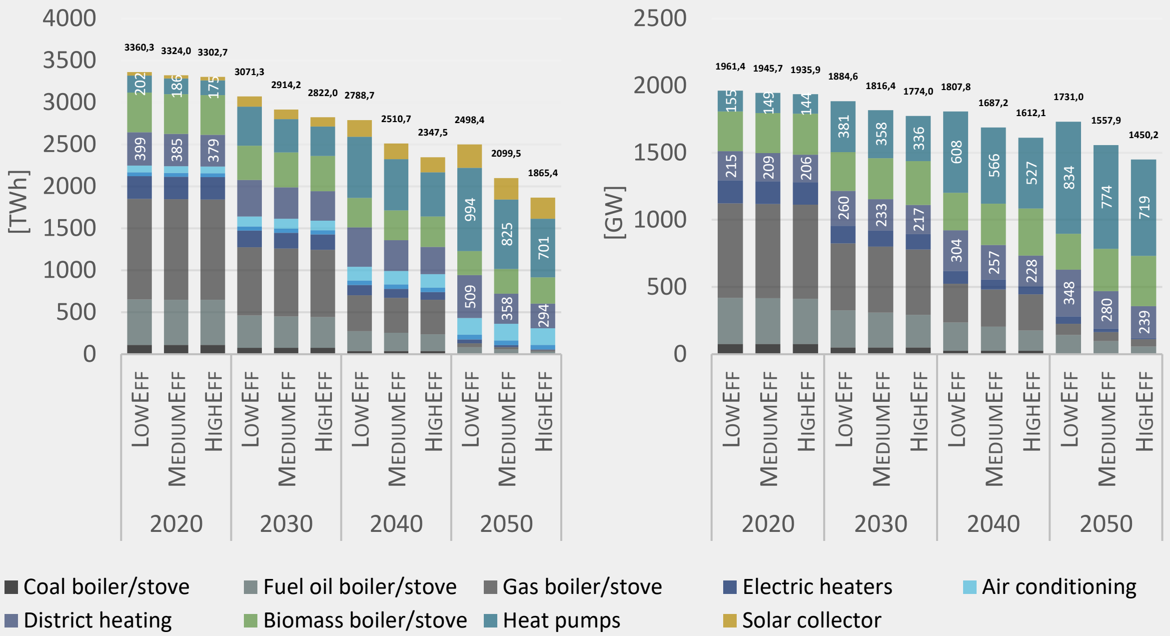
Even in the LowEff scenario, substantial energy demand reductions are needed to contribute to net-zero emission levels by 2050.

Possible energy efficiency targets in the Energy Efficiency Directive

		PRIMES-2007 baseline [d]	PRIMES-2020 baseline [e]
		Targeted/projected level of final energy consumption in year 2030 | % difference to baseline	
Energy efficiency target for final energy consumption			
EED-2018 [a]	846 Mtoe	1,253 Mtoe | -32.5%	864 Mtoe | -2.1%
EED-2021 [b]	787 Mtoe	1,253 Mtoe | -37.2%	864 Mtoe | -9.0%
ENEFIRST scenarios [c]			
LowEff	800 Mtoe	1,253 Mtoe | -34.8%	864 Mtoe | -5.5%
MediumEff	792 Mtoe	1,253 Mtoe | -35.5%	864 Mtoe | -6.5%
HighEff	786 Mtoe	1,253 Mtoe | -36.0%	864 Mtoe | -7.2%

(a) Based on amended Energy Efficiency Directive (European Union 2018a, Art. 3), excluding United Kingdom (European Union 2019) | (b) Based on Commission proposal for recast of Energy Efficiency Directive (European Commission 2021d, Art. 4) | (c) Projections for residential and tertiary sectors based on ENEFIRST project; industry and transportation sectors based on REG_MAX scenario in Impact Assessment accompanying recast of the Energy Efficiency Directive (European Commission 2021c) | (d) EU Reference Scenario 2007 (Capros et al. 2007) | (e) EU Reference Scenario 2020 (Capros et al. 2021)

Heating & cooling technologies in buildings



Final energy demand for heating and cooling technologies in EU-27 [TWh]

Nominal capacities of heating technologies in EU-27 [GW]

Results

- Substantial reduction in energy demand for heating
- 38-40% share of heat pumps in heat demand in 2050
- Heating demand reflects in technology capacities

Key message

Ambitious building performance levels result in substantial reductions in final energy demand for heating.

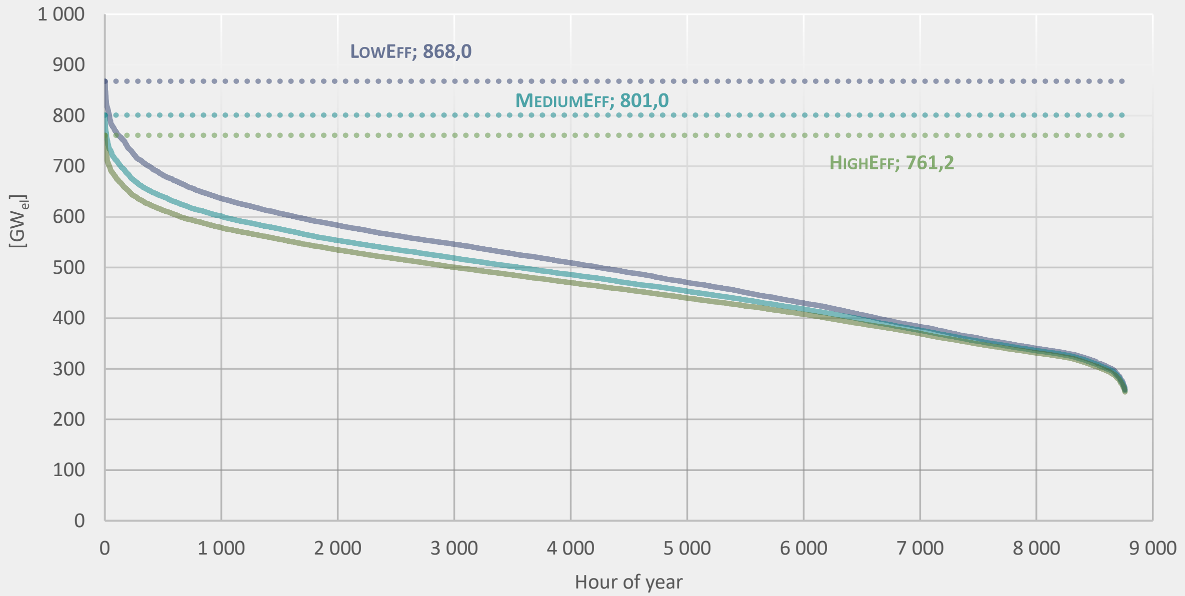
Note: Heat pump energy use includes electricity plus ambient heat

Key results in the scenarios

	LowEff	MediumEff	HighEff
Gross electricity generation in 2050 [TWh]	6,151.4	5,978.5	5,865.0
Installed generation capacities in 2050 [GW]	**2,711.8**	**2,613.1**	**2,535.2**
Cross-border transmission network capacity in 2050 [GW]	722.1	686.9	674.7
Cumulative cost (2020–2050) [bn EUR_{2018}]	5,939.8	5,859.1	5,685.4
Total cost difference compared to LowEff [%]	-	-1.6%	-4.6%

Electricity supply

Load duration curve



Electrical load duration curve in EU-27 in 2050

Electrical load for entire EU power system, including buildings, transportation, industry, and other loads (e.g. electrolysers)

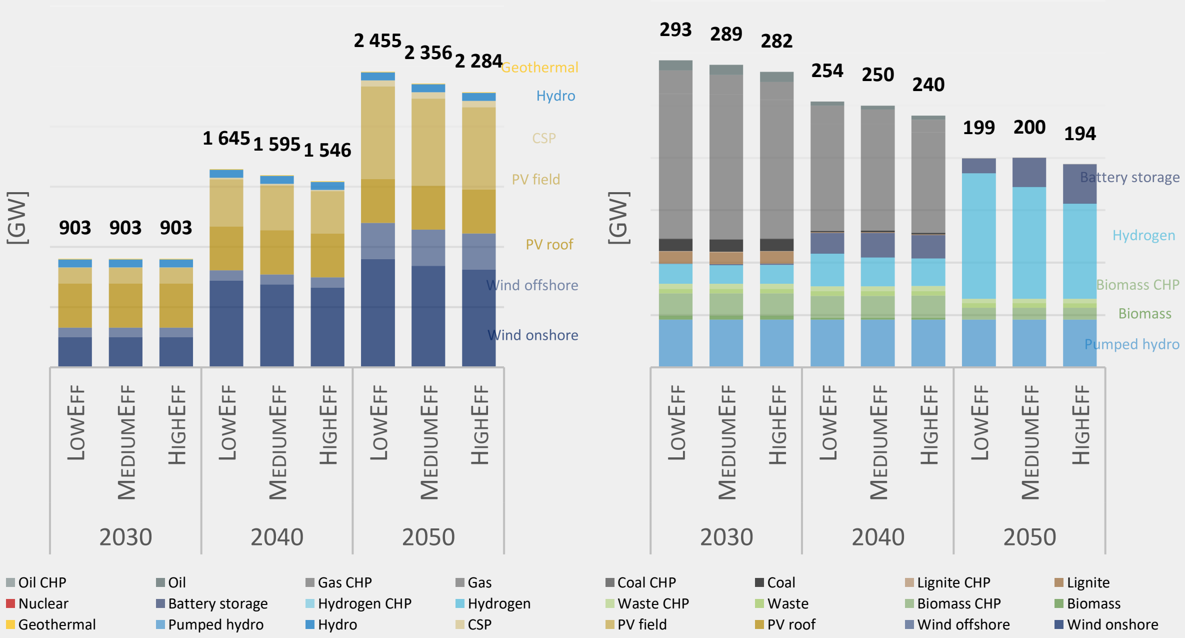
Results

- Peak electrical load in 2050 reduces by -7.7% (MediumEff) and -12.3% (HighEff) compared to LowEff
- Note that chart represents entire electrical load in the power system

Key message

End-use energy efficiency is an effective power system resource in that it leads to consistent reductions in electrical load

Electricity generation capacities



Installed electricity generation capacity by technology in EU-27 [GW]

Results

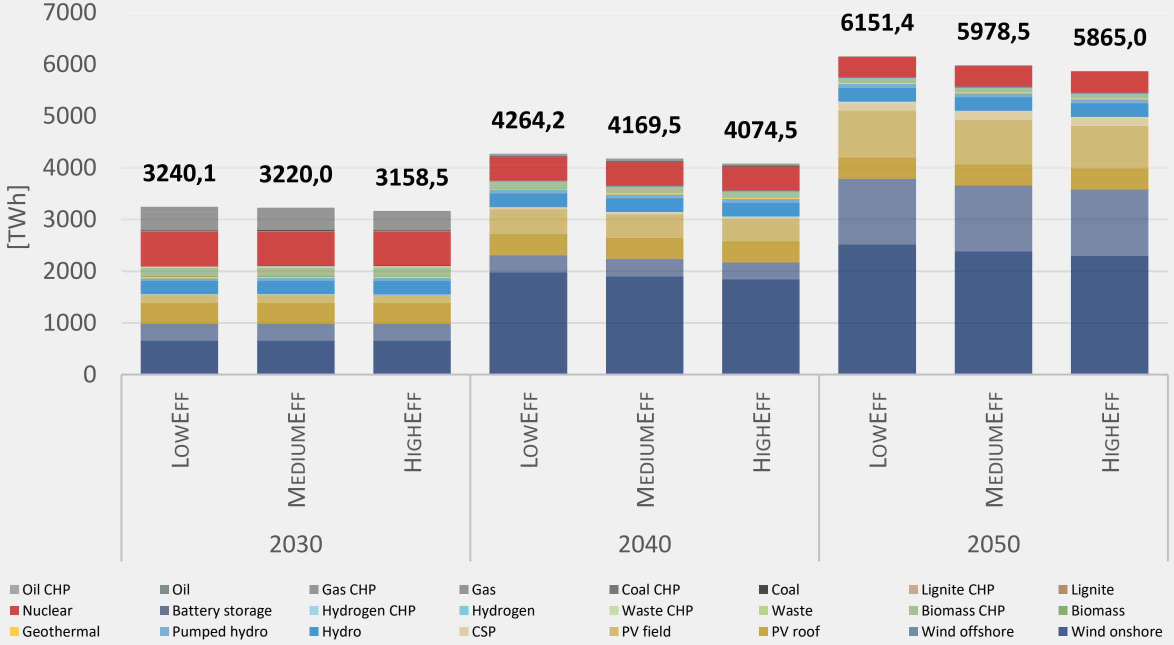
- Building sector energy efficiency corresponds to lower installed capacities (especially for wind onshore, PV roof, hydrogen)
- Dispatchable generators needed to deal with variable renewables

Key message

Wind & solar are the backbone of electricity supply by 2050. Lower demand clearly reduces the need for generation capacity.

Note: Nuclear not shown

Electricity generation



Gross electricity generation by technology in EU-27 [TWh]

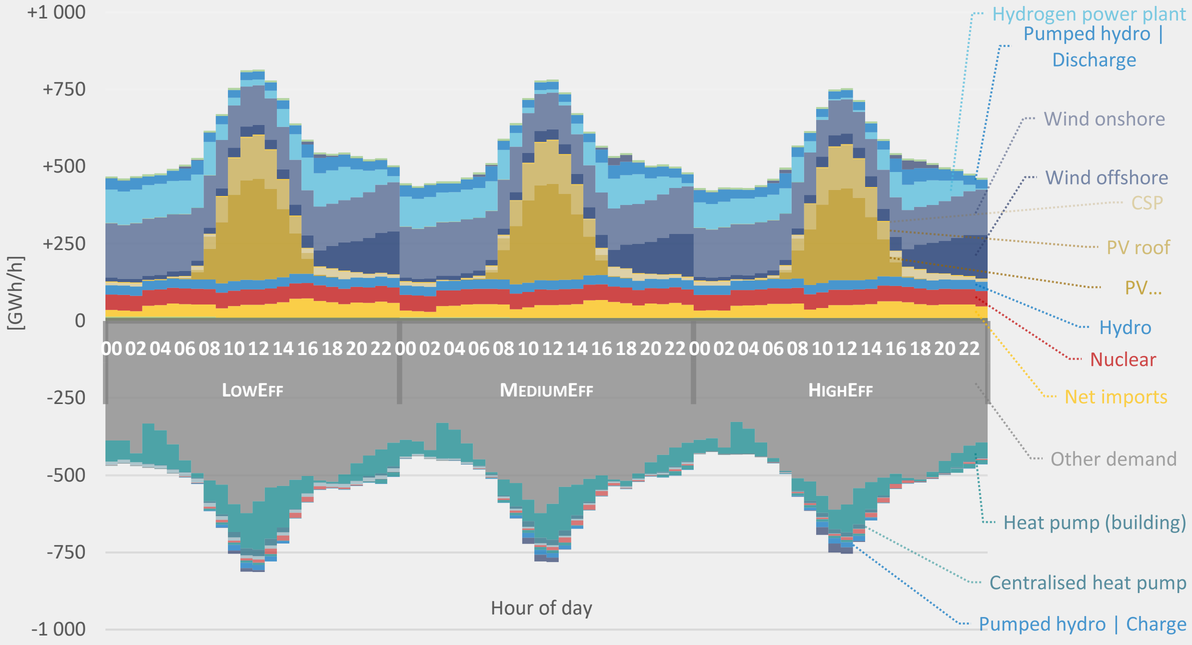
Results

- Electricity generation dominated by variable renewable energies in 2050 (90-93%)
- -286 TWh (-5%) in HIGHEFF in 2050 vs. LOWEFF
- Note: No CCS; fixed nuclear; fixed hydro

Key message

Electricity supply for net-zero emissions requires massive generation from variable renewables

Power system operation for winter day on 15 Feb 2050



Hourly operation of electrical generators and loads for EU-27 in 2050

Other demand including all other loads in buildings, transportation and industry

Results

- Heat pumps (centralised/decentralised) are significant load in power system
- Pumped hydro storage provides flexibility
- Hydrogen power plants as key backup generators

Key message

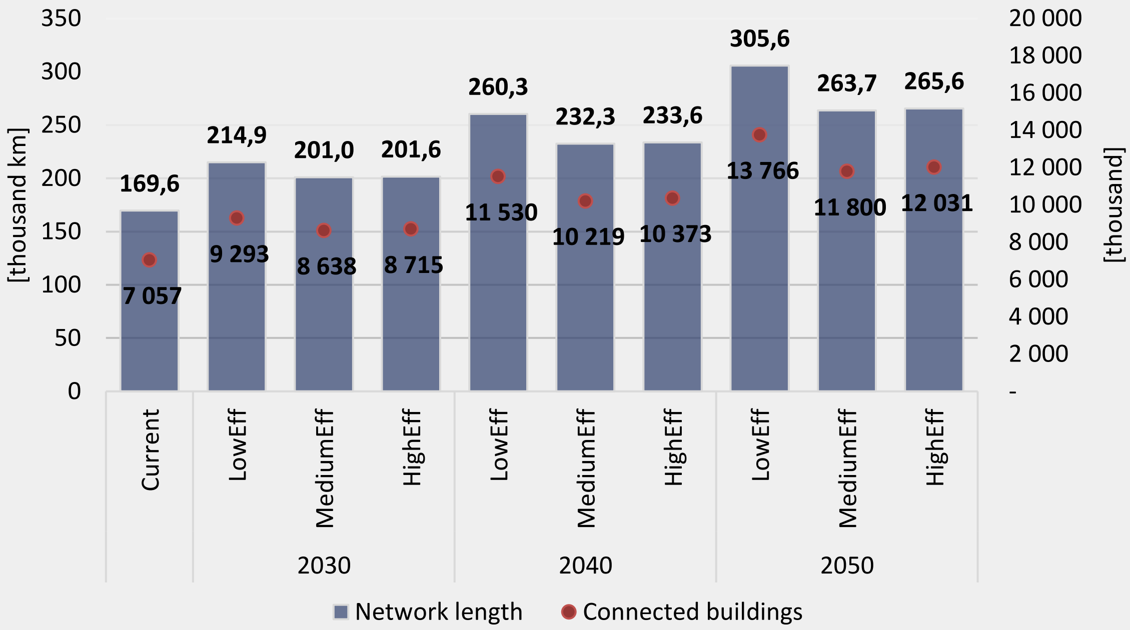
End-use energy efficiency in buildings has notable ramifications for power system operation

Key results in the scenarios

	LowEff	MediumEff	HighEff
Heat generation in 2050 [TWh]	562.7	395.8	324.7
Installed generation capacities in 2050 [GW]	293.6	207.8	172.6
Heat network length 2050 [thousand km]	305.6	263.7	265.6
Cumulative cost (2020–2050) [bn EUR_{2018}]	758.0	665.4	628.5
Cost difference compared to LowEff [%]	-	-12.2%	-17.1%

District heating supply

District heating network length and number of connected buildings



Network length in EU-27 [thousand km] and number of connected buildings

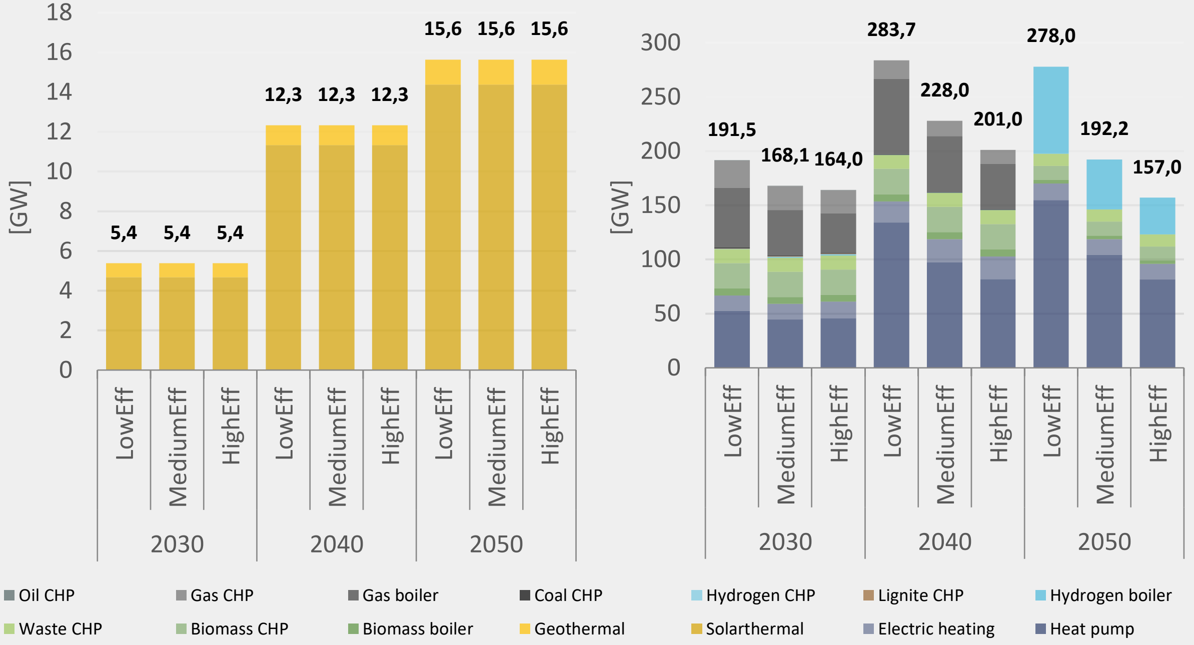
Results

- Network length increase between 56.6% (HIGHEFF) and 80.2% (LOWEFF) by 2050 vs. 2020
- Linear heat densities between 1.84 (LOWEFF) to 1.22 (HIGHEFF) MWh/(m*year) in 2050

Key message

Improved building efficiency affects the boundaries of the economic viability of the DH networks

District heating generation capacities



Installed district heating generation capacity by technology in EU-27 [GW]

Note: Capacity figures excluding heat storage

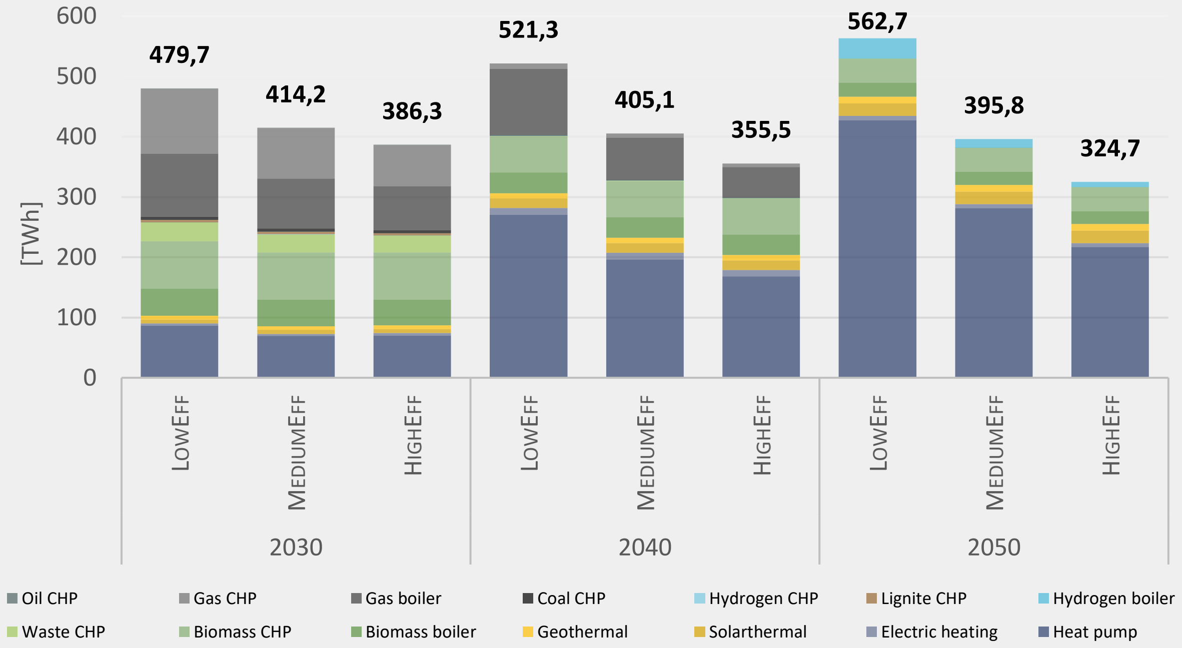
Results

- Max. potential for solar thermal and geothermal exhausted
- 2050 systems rely on heat pumps, but require backup hydrogen, biomass and waste
- Capacity -86 GW (MEDIUMEFF) and -121 GW (HIGHEFF)

Key message

Reduced energy demand for district heating lowers the need for underutilized generation capacities.

District heating generation



District heating generation by technology in EU-27 [TWh]

Results

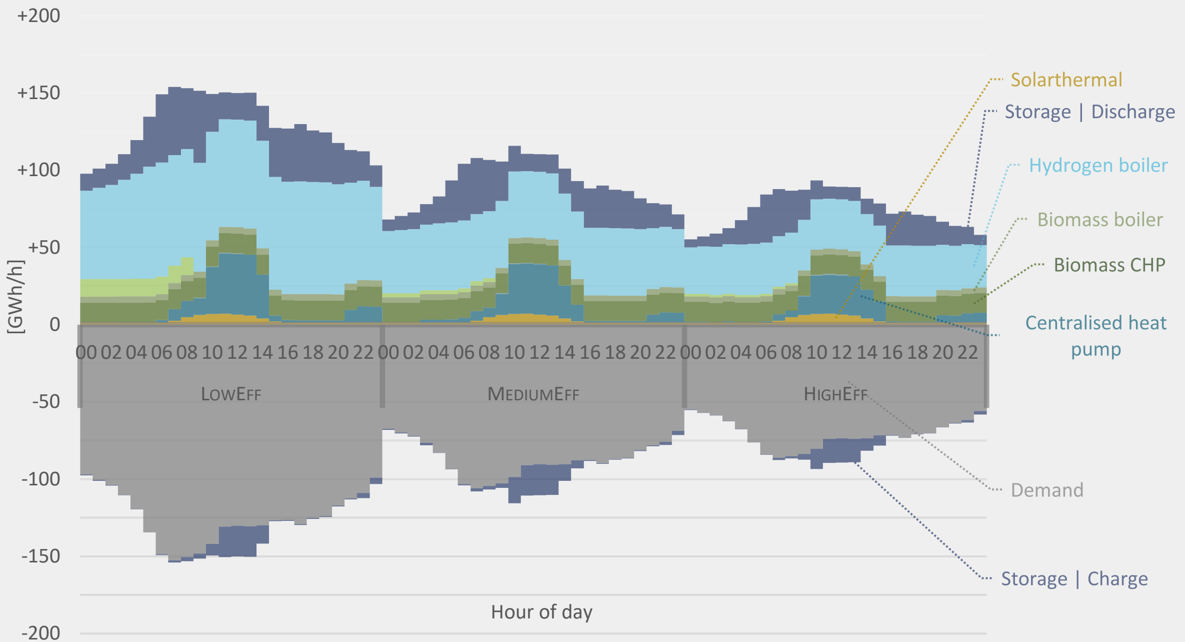
- Heat generation in 2050 -30% (MEDIUMEFF) and -42% (HIGHEFF)
- Heat generation dominated by heat pumps (67-76% in 2050)
- Load peaks covered by hydrogen boilers (34-80 TWh in 2050)

Key message

Energy efficiency in buildings reduces the need for district heating generation. Heat pumps are a key technology across all scenarios.

Note: Generation figures excluding heat storage

District heating system operation for winter day on 15 Feb 2050



District heating generation by technology in EU-27 [TWh]

Results

- Solar thermal systems complemented by centralised heat pumps and biomass
- Hydrogen boilers are key technology to serve high thermal load

Key message

End-use energy efficiency in buildings has significant ramifications for district heating system operation

Note: Generation figures excluding heat storage

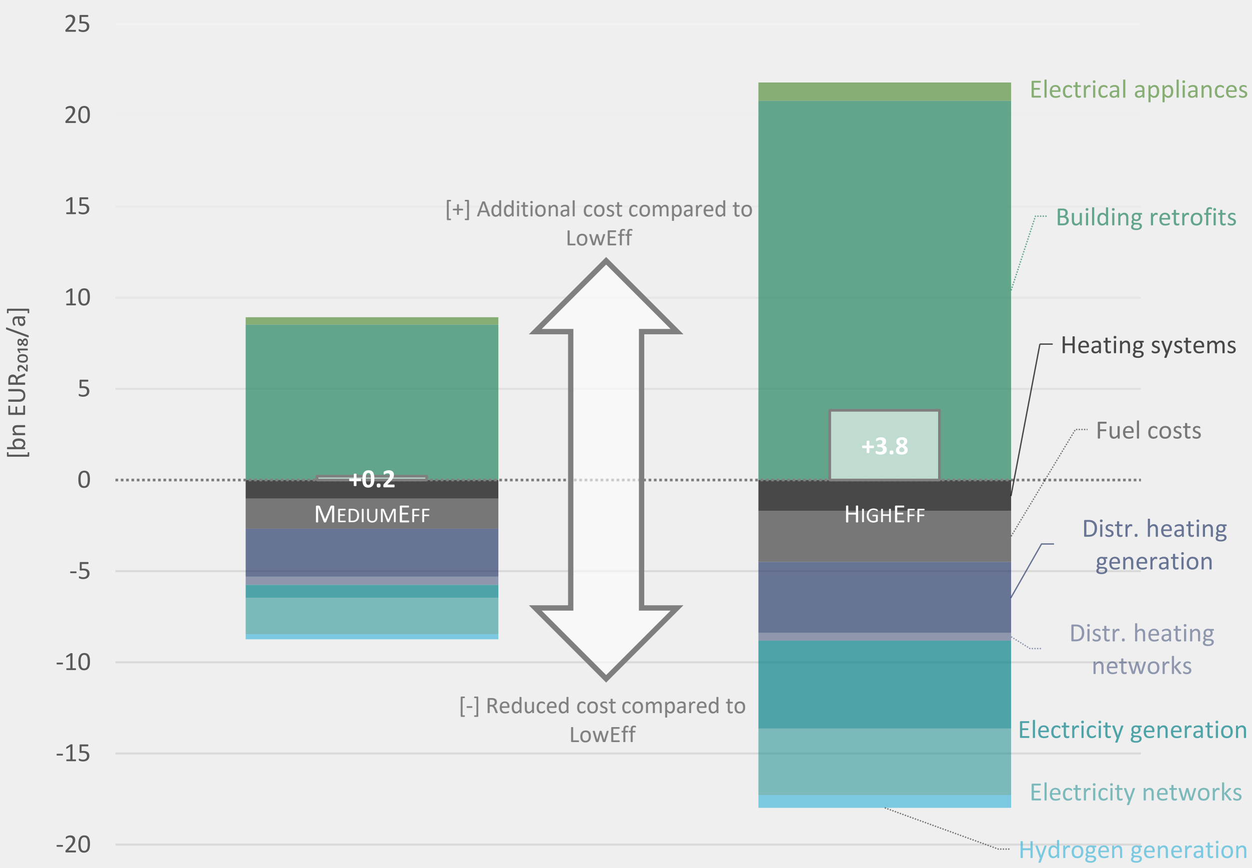
Key results in the scenarios

	LowEff	MediumEff	HighEff
Hydrogen generation in 2050 [TWh]	636.7	610.4	597.7
Electrolyzer capacity in 2050 [GW]	**303.4**	**290.2**	**281.7**
Methane generation in 2050 [TWh]	703.3	698.9	695.5
Cumulative cost (2020–2050) [bn EUR_{2018}]	455.7	447.3	434.6
Cost difference compared to LowEff [%]	-	-1.8%	-4.6%

Hydrogen supply

Discussion & conclusions

Recap of key results



Average annual differential cost compared to LowEff scenario for EU-27 (2020–2050) by cost item [billion EUR_{2018}/a]

Fuel costs in buildings including natural gas, coal, oil, biomass for direct combustion

Conclusions

- **End-use energy efficiency in buildings is critical for an economically cost-efficient transition to net-zero emissions**. Given the close similarity in energy system cost between LowEff and MediumEff, it can be inferred that ambition levels for energy efficiency *below* LowEff are likely to result in *additional* energy system cost that, ultimately, would have to be borne by consumers.

- **The ongoing debate around EE1st provides significant added value in that the principle makes explicit the trade-offs between supply- and demand-side resources for reaching the same decision objectives**. As demonstrated by the scenarios in this study, end-use energy efficiency in buildings clearly reduces the need for electricity, district heating and hydrogen infrastructures on the supply side in transitioning to net-zero GHG emissions.

- **There is ample reason to support ambition levels for energy efficiency beyond the LowEff scenario**. The differences in energy system cost appear minor and arguable when put into perspective. To illustrate, additional cost in HighEff vs. LowEff for the entire EU-27 comes down to +3.8 bn EUR per year. For the year 2020, this corresponds to less than 0.03% of the EU's gross domestic product, 1.4% of the net-import value of fossil fuels, 2.5% of the EU budget, or EUR 8.54 per EU citizen and year.

- **While the modelling techniques used in this study do not allow for detailed analysis by policy measure, it is evident that the transitions set out in the scenarios of this study require a highly ambitious and comprehensive package of strategies, planning and policy instruments across sectors.**

Three reasons why the results should be interpreted with caution

Parameter uncertainties

- Learning rates & technology cost
- Fuel prices
- Climate conditions
- ...

Model capabilities & scope

- Power & gas network modelling
- Economy-wide rebound effects
- Role demand response & energy sufficiency
- What if *Energy Efficiency last*?

Conceptual issues

What defines costs and benefits from a societal/economic perspective?

What multiple impacts have to be taken into account?

What defines costs and benefits from a societal viewpoint

	[-] Costs to society	[+] Benefits to society
Buildings	• CAPEX/OPEX for building renovation, heating systems, electrical appliances • Search and information cost • External costs from upstream production chain	• Health & well being • Workforce productivity • Poverty alleviation ...
Electricity supply District heating supply Hydrogen supply	• CAPEX/OPEX for generation and storage assets • CAPEX/OPEX for networks • OPEX for retail (trading, metering, etc.) • CAPEX/OPEX for power-to-gas facilities • CAPEX/OPEX for hydrogen/gas networks • External costs from fuel combustion (GHG emissions, air pollution) • External costs from renewables (land use, water use, aesthetics, noise, etc.) • External costs from power networks (exposure to electrostatic fields) • External costs from upstream production chain	• Macroeconomic impacts / employment • Energy security ...

(Legend)

- included in analysis
- partly included in analysis
- not included in analysis

Coming up in eηefirst: Report on multiple impacts in the scope of the EE1st principle

- Conceptual background | Why taking the EE1st principle seriously means acknowledging multiple impacts
- Decision-support with Multiple Impacts | How different impacts can be aggregated to inform decisions in different venues
- Multiple impacts in practice | How the inclusion of impacts alters the outcome of cost-benefit analysis

Thank you

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