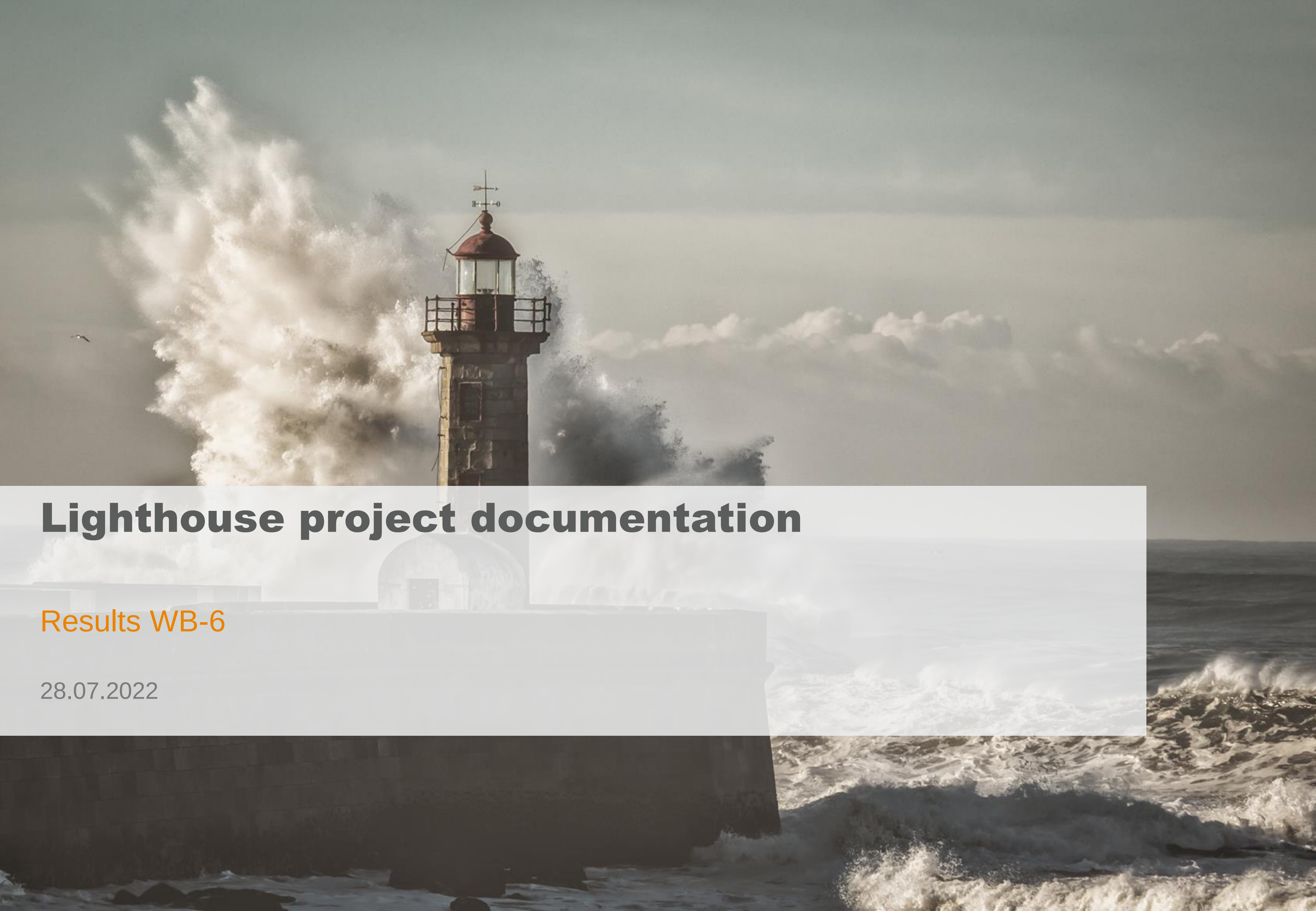


Lighthouse project documentation

Results WB-6

28.07.2022

Contents

Conclusions

Conclusions for WB-6 region – I

Power market decarbonisation by 2045 is possible and cost efficient	• A decarbonisation of the power sector by 2045 is possible while saving costs. The energy transition scenarios cut cumulated CO2 emissions by half (46-51%) while reducing overall generation costs by ~3-15% (compared to the baseline scenario). Security of supply is ensured in the energy transition scenarios.
Fossil gas is a dead end	• Baseline and gas lock-in invest heavily into natural gas, which proves as a dead end in the long-term, leading to overall higher costs. If investments are executed hydrogen-ready and efficient storage technologies are deployed, cumulated gas demand can be reduced by 50% while reducing overall costs by 12% (smart transition vs. gas lock-in • It should be noted, that a strategy which relies heavily on fossil gas to later switch to hydrogen increases exposure to hydrogen prices. A sensitivity of the gas heavy scenario with higher H2 prices demonstrates cost increases by 11%.
Storage technologies provide flexibility & scalability	• Li-Ion batteries and, where available, pumped storage is deployed in the smart in transition scenario, helping to increase cost efficiency. Storage also helps to switch the RES mix from wind to more easily scalable PV. Further sensitivities demonstrate, that thermal storage at lignite sites as well as redox flow batteries can reach an energy economic breakthrough.

Conclusions for WB-6 region – II

Hydrogen as decarbonisation enabler with low volumes	• Long-term storage is a necessary enabler of deep decarbonisation and to ensure security of supply. Based on the current technological outlook, hydrogen is of key importance here. Combined H2 capacities of the region range in between ~5-9 GW in the energy transition scenarios. • Its role in regards to volumes should not be overstated though: generation shares on demand are limited to ~7-10% (2045-2050) of demand. If hydrogen prices should be higher than assumed in the core scenarios, H2-based generation drops to 3-6% (2045-2050) of demand.
Investments into H2 capacities should be considered carefully	• Other storage technologies like batteries can effectively reduce the need for H2 capacity and generation. Deploying batteries reduces demand for H2 generation by 20% in 2050. Investments into H2 plants should therefore be considered carefully, not to overestimate the future needs given potential technological breakthroughs.

Methodology & scenarios

Overview of scenario design

Three core scenarios were designed and analysed for all countries in the focus region WB-6 (AL, BA, MK, ME, RS, XK). They display the implications of two different decarbonisation pathways compared to a baseline without net-zero target for the power sector. Three sensitivities assess the impact of crucial parameters on the scenario outcome.

SCENARIOS		SENSITIVITIES		
	CORE	H2 COSTS (S2)	REDOX-FLOW BREAKTHROUGH (S3)	THERMAL STORAGE BREAKTHROUGH (S4)
FOSSIL BASELINE	Baseline scenario with current ambition level and no increased	Not relevant	Not relevant	Not relevant
GAS LOCK-IN	Earlier investments into gas plants, late retrofit to H2, no storages	Gas lock-in in a H2 risk scenario (increased H2 price over duration)	Not relevant	Not relevant
SMART TRANSITION	Smart transition with earlier H2-readiness and investments into storage technologies	Smart transition in a H2 risk scenario (increased H2 price over duration)	Smart transition with technological breakthrough of redox-flow batteries	Smart transition with technological breakthrough of thermal storages

Overview of sensitivities

FOCUS OF ANALYSIS

- S2: Higher hydrogen prices to analyse the risks of gas based strategy
- S3: Upsides of technological uncertainty: storage breakthrough can be a game changer
- S4: Site conversion opportunities: Thermal storage as system balancing technology in a post-lignite era

	S2 H2 COSTS	S3 REDOX-FLOW BREAKTHROUGH	S4 THERMAL STORAGE BREAKTHROUGH
FOSSIL GAS PRICES	• Same as in core scenarios.	• Same as in core scenarios.	• Same as in core scenarios.
CO_2 NEUTRAL FUEL PRICES	• Higher level of long term prices for H2 vs. core scenarios		
CAPEX REDOX FLOW BATTERIES	• Same as in core scenarios.	• Lower CAPEX vs. core scenarios	
CAPEX THERMAL STORAGE		• Same as in core scenarios.	• Lower CAPEX vs. core scenarios

Core scenario parameter overview

	Fossil baseline	Gas lock-in	Smart transition
CO_2 targets (power sector)	none	decarbonisation of power sector by 2045	decarbonisation of power sector by 2045
Carbon pricing	In line with -55% 2030 & long term decarbonisation ambition / Phase-in of carbon pricing incl. CBAM in WB-6 region	In line with -55% 2030 & long term decarbonisation ambition / Phase-in of carbon pricing incl. CBAM in WB-6 region	In line with -55% 2030 & long term decarbonisation ambition / Phase-in of carbon pricing incl. CBAM in WB-6 region
Coal-fired capacities	Based on national strategies / NECPs	Based on exogenous phase-out trajectories (EU: 2030, WB-6: 2040)	Based on exogenous phase-out trajectories (EU: 2030, WB-6: 2040)
RES capacities	Based on national strategies / NECPs	Based on power system optimization for 2035, 2040 and 2045.	Based on power system optimization for 2035, 2040 and 2045.
Storage technologies	Based on national strategies / NECPs	Based on power system optimization for 2035, 2040 and 2045.	Based on power system optimization for 2035, 2040 and 2045.
Hydrogen-ready gas capacities	none	Based on power system optimization for 2035, 2040 and 2045.	Based on power system optimization for 2035, 2040 and 2045.
Natural gas-fired capacities	Based on national strategies / NECPs / merchant expansion	Based on national strategies / Decommissioning (age) until 2040	No expansion / Decommissioning (age) until 2040

Key results – WB-6 Cluster

Core scenarios with different policy strategies

Three core scenarios show the implications of two different decarbonisation pathways compared to a baseline without net-zero target for the power sector.

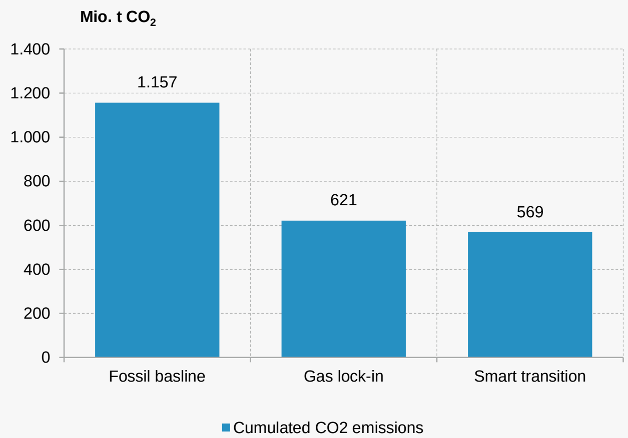
SCENARIOS		SENSITIVITIES		
	CORE	S2 H2 COSTS	S3 REDOX-FLOW BREAKTHROUGH	S4 THERMAL STORAGE BREAKTHROUGH
FOSSIL BASELINE	Baseline scenario with current ambition level and no increased	Not relevant	Not relevant	Not relevant
GAS LOCK-IN	Earlier investments into gas plants, late retrofit to H2, no storages	Gas lock-in in a H2 risk scenario (increased H2 price over duration)	Not relevant	Not relevant
SMART TRANSITION	Smart transition with earlier H2-readiness and investments into storage technologies	Smart transition in a H2 risk scenario (increased H2 price over duration)	Smart transition with technological breakthrough of redox-flow batteries	Smart transition with technological breakthrough of thermal storages

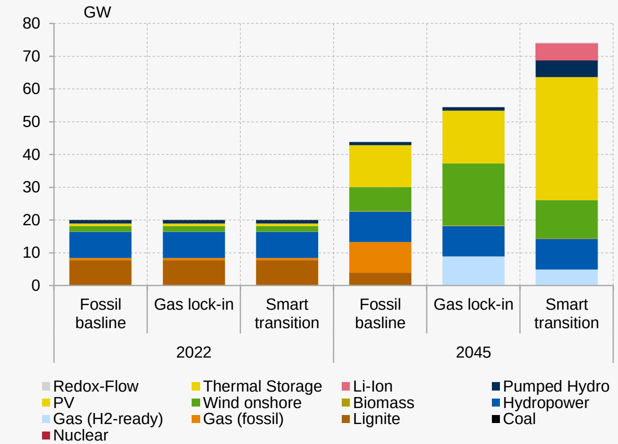
WB-6: overview of core scenario results

Within the set of core scenarios, the smart transition strategy shows a significant reduction in overall generation costs (~15% compared to baseline), driven by savings in OPEX and CO_2 costs.

CO_2 emissions

- Decarbonisation strategies save 46% CO_2 overall compared to baseline
- Smart transition saves additional 5%



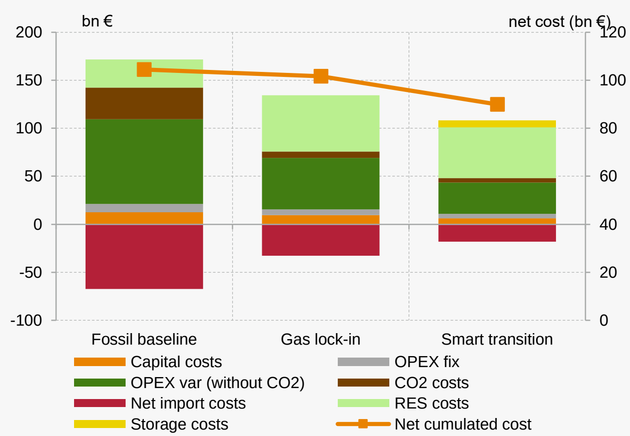


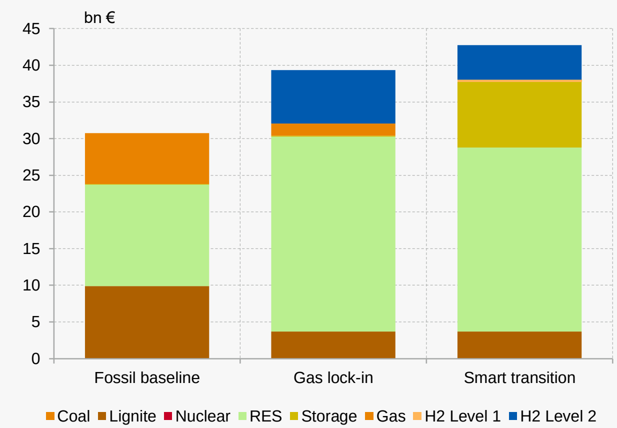
Capacities

- Net-zero scenarios deploy 35-49 GW of RES by 2045
- Storage scenario deploys less H2 capacity and integrates more PV

Incremental generation costs

- Transition scenarios save 3 to 15% vs. baseline even though climate ambition level is much higher
- Main driver is fuel and CO_2 costs





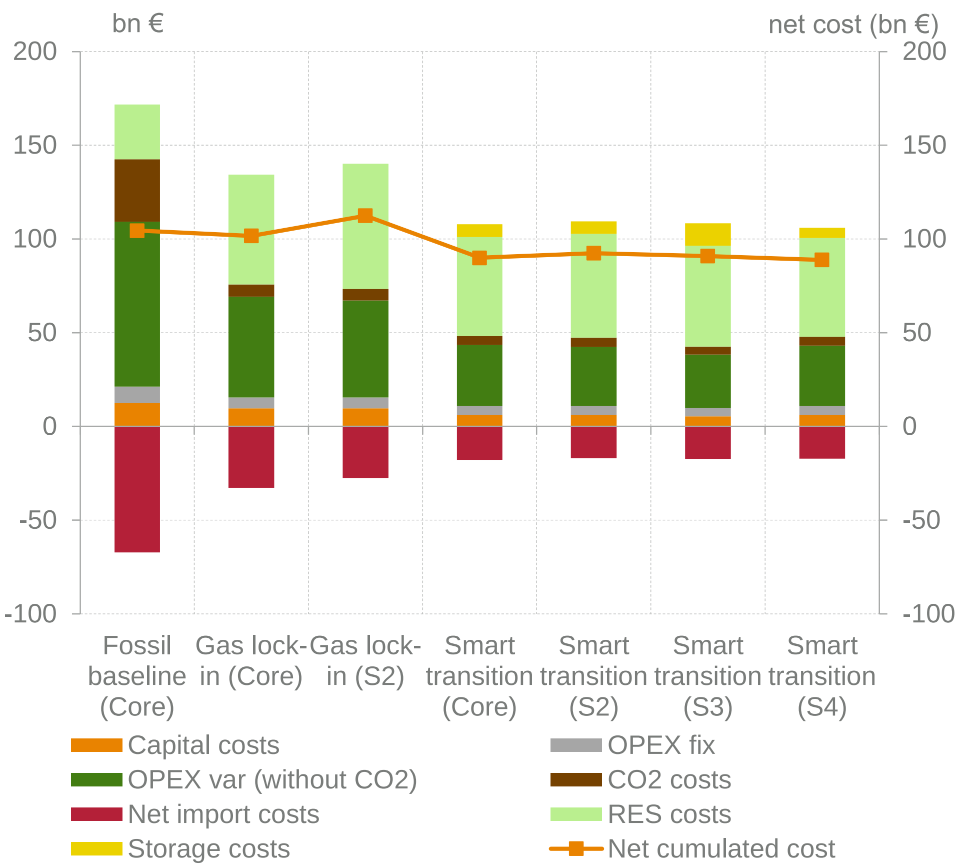
Investment costs

- Baseline investments to a large share go to fossil technology
- Net-zero scenarios strongly invest in RES

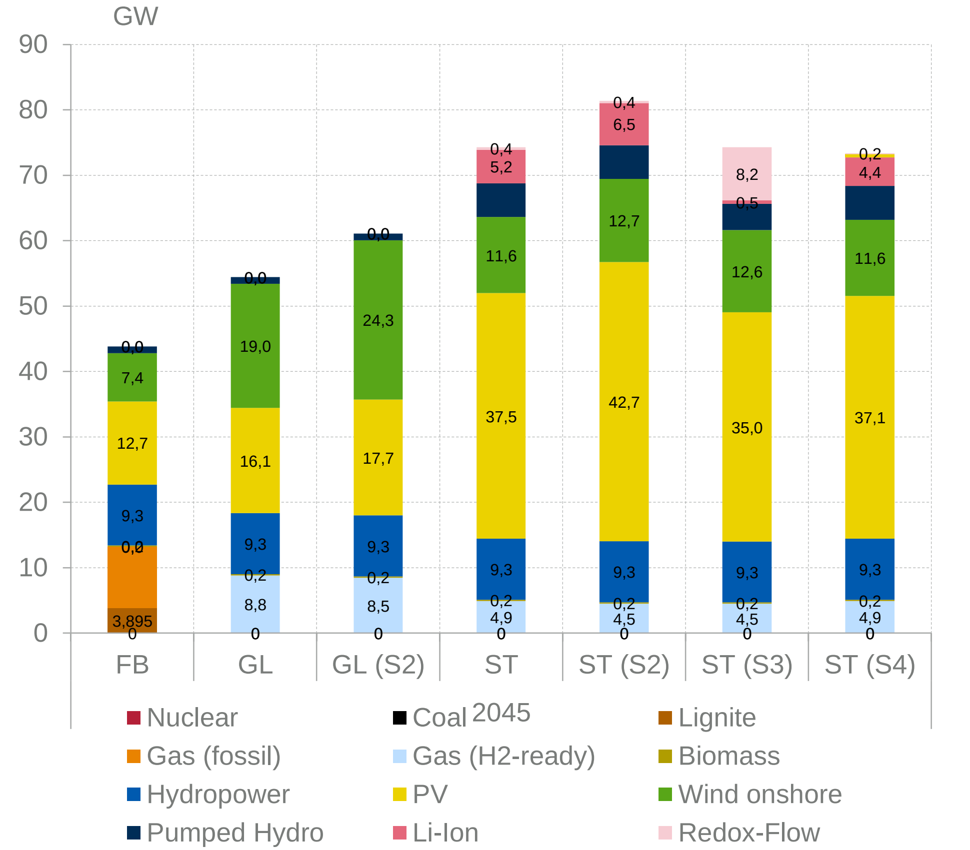
WB-6: overview all scenarios

Incremental generation costs decrease in the gas lock-in (3%) and smart transition (15%) compared to the baseline. High H2 costs increase total costs especially in the gas lock-in. Technology-breakthroughs lead to shifts in the capacity mix but do not yield major cost savings.

Incremental generation costs



Capacities



Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

Gas lock-in under different H2 prices

A gas lock-in policy relies on using (carbon neutral) gas to deliver a decarbonized power sector and is hence vulnerable to uncertainties in fuel cost development.

SCENARIOS		SENSITIVITIES		
	CORE	S2 H2 COSTS	S3 REDOX-FLOW BREAKTHROUGH	S4 THERMAL STORAGE BREAKTHROUGH
FOSSIL BASELINE	Baseline scenario with current ambition level and no increased	Not relevant	Not relevant	Not relevant
GAS LOCK-IN	Earlier investments into gas plants, late retrofit to H2, no storages	Gas lock-in in a H2 risk scenario (increased H2 price over duration)	Not relevant	Not relevant
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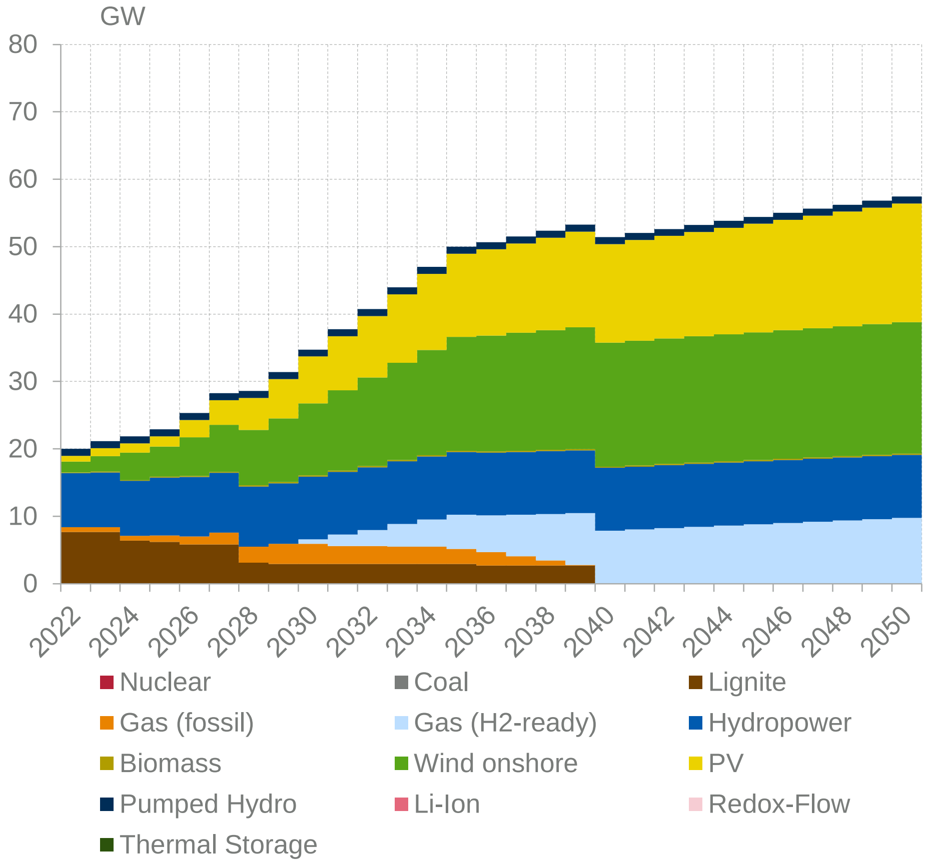
WB-6: capacities in gas lock-in scenarios

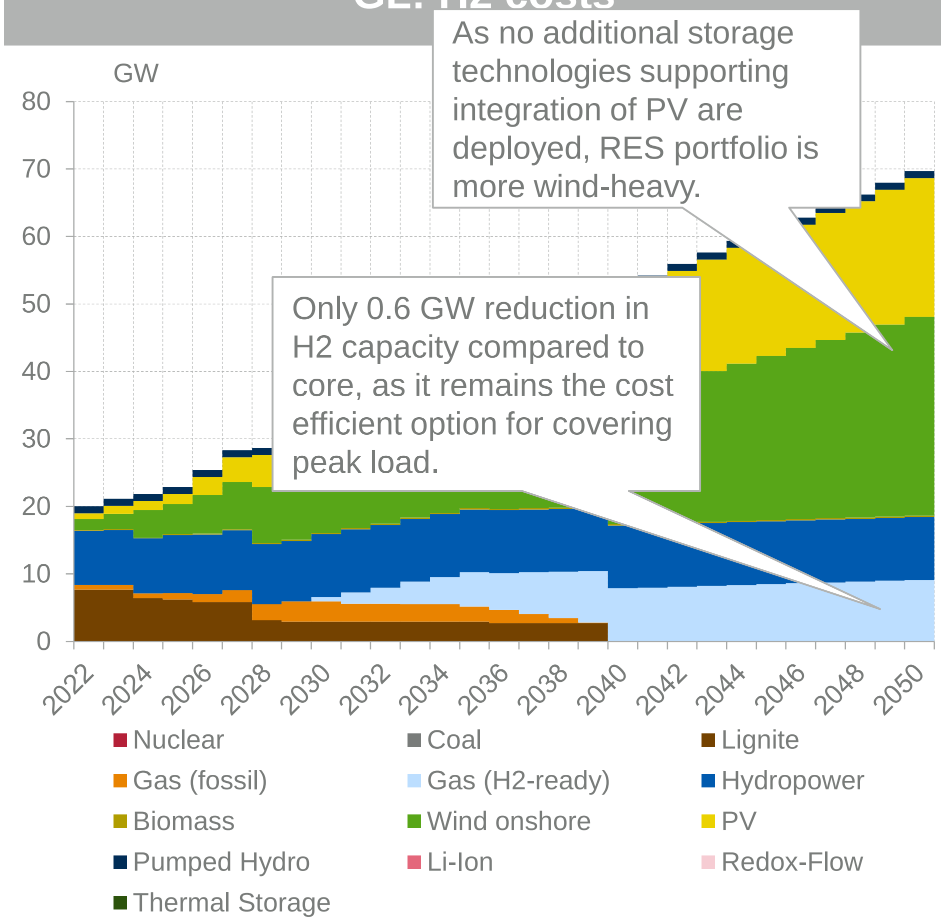
S2

Higher costs of H2 fuel result in higher deployment of onshore wind to substitute generation in the gas lock-in scenario (GL). As peak load contribution of onshore wind is limited, capacity demand for H2 plants remains at similar level as in core scenario.

GL: Core



GL: H2 costs



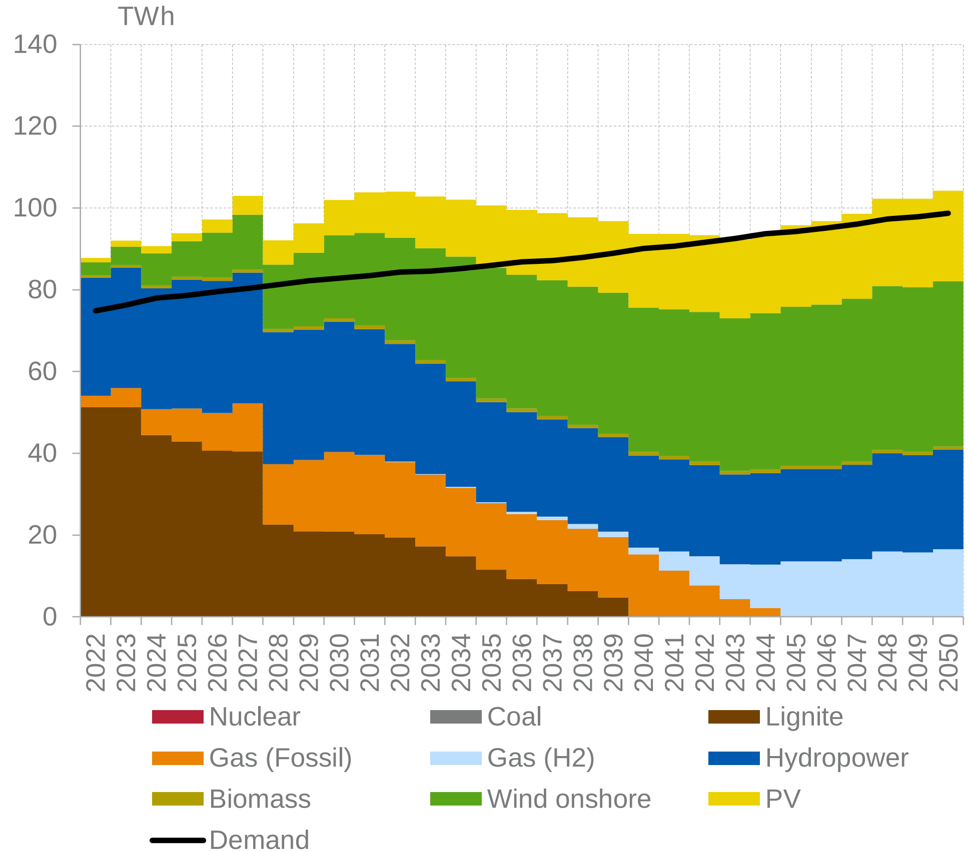
Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

WB-6: generation in gas lock-in scenarios

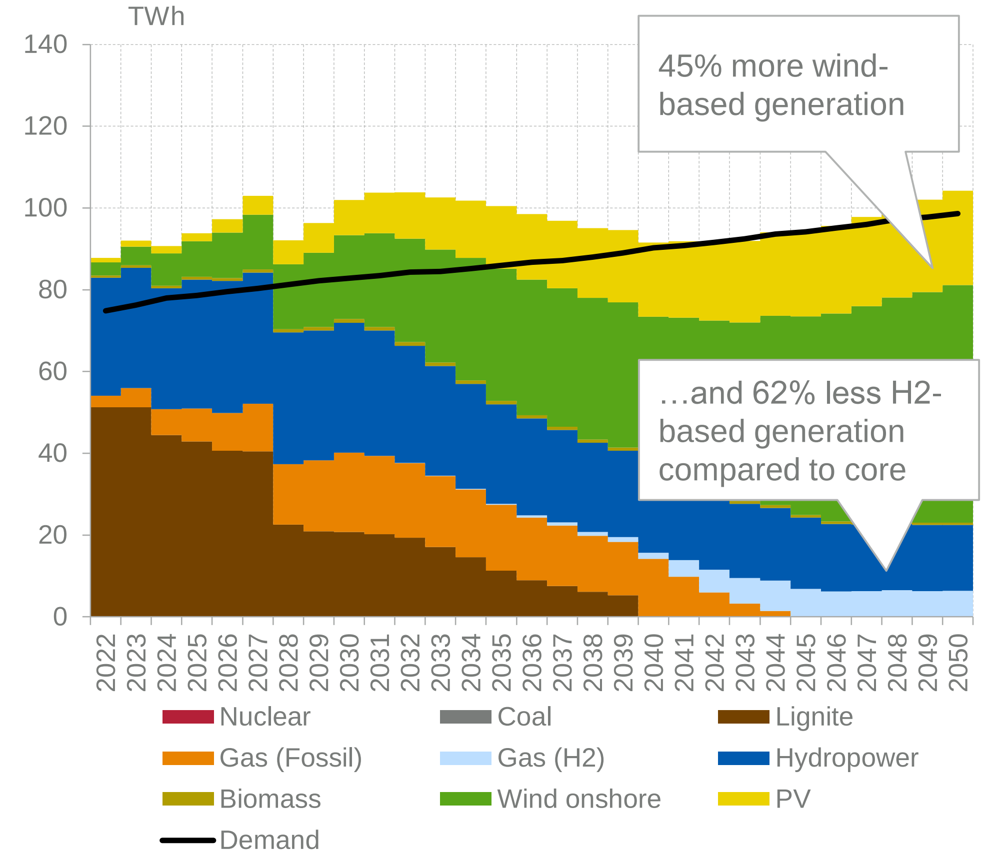
S2

Higher H2 costs cut utilisation of H2-based capacities, reducing the respective generation in the Gas lock-in by 62% compared to the core scenario. Instead, RES generation increases by 45% (wind onshore) and 5% (PV), respectively.

GL: Core



GL: H2 costs



Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

Smart transition under different fuel and storage costs

A smart transition policy utilises a wider portfolio of technologies to deliver a carbon neutral power system.

SCENARIOS		SENSITIVITIES		
	CORE	H2 COSTS (S2)	REDOX-FLOW BREAKTHROUGH (S3)	THERMAL STORAGE BREAKTHROUGH (S4)
FOSSIL BASELINE	Baseline scenario with current ambition level and no increased	Not relevant	Not relevant	Not relevant
GAS LOCK-IN	Earlier investments into gas plants, late retrofit to H2, no storages	Gas lock-in in a H2 risk scenario (increased H2 price over duration)	Not relevant	Not relevant
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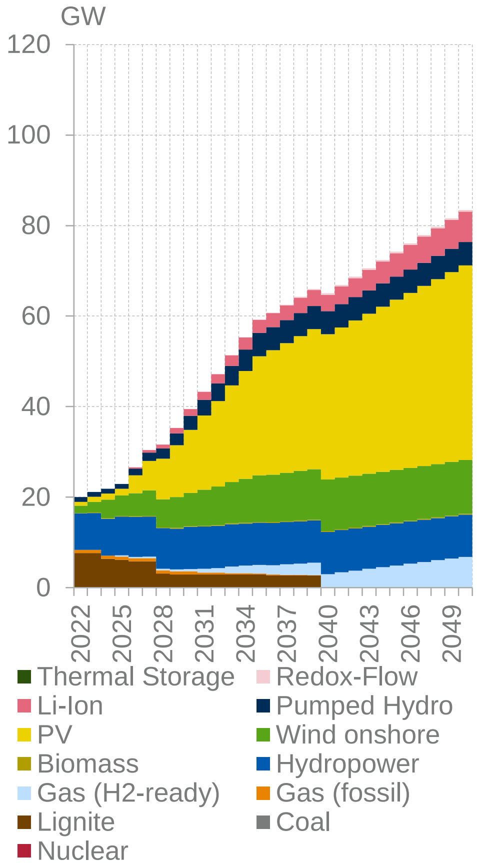
WB-6: capacities in smart transition scenarios

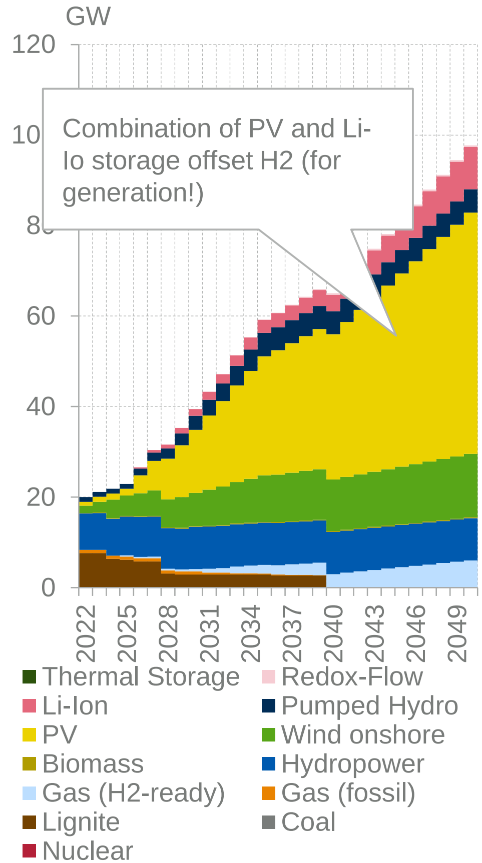
S2 S3 S4

With higher H2 costs, a combination of PV and Li-Ion battery capacities is efficient to substitute H2-generation (S2). Cheaper and longer-term Redox flow batteries reduce overall capacity demand. In a thermal storage cost breakthrough scenario, 0.7 GW thermal storage can replace 1.4 GW Li-Io batteries.

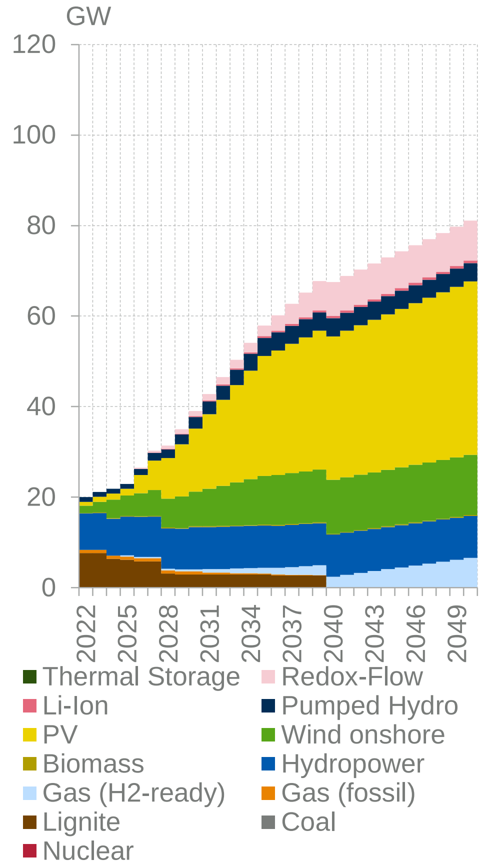
ST: Core



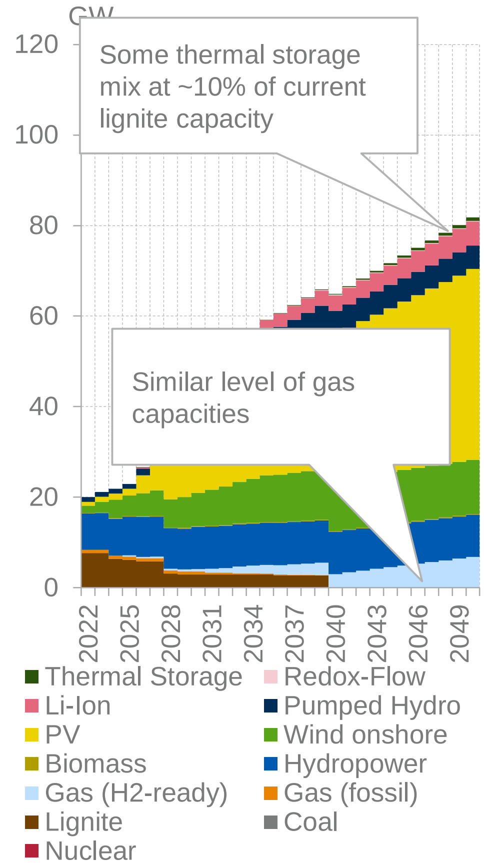
ST: H2 costs



ST: redox-flow breakthrough



ST: thermal storage breakthrough



Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

Detailed results – WB-6 Cluster

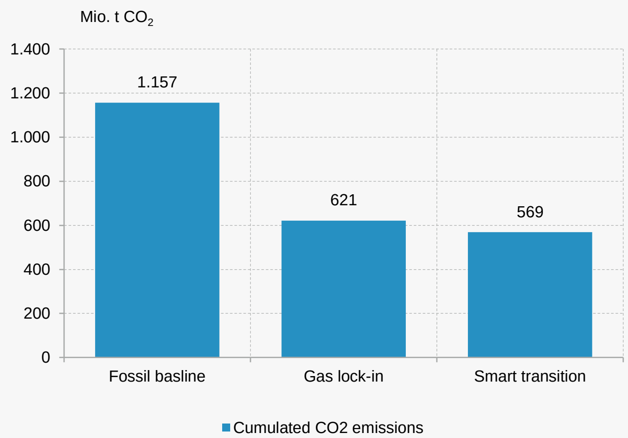
Core scenarios

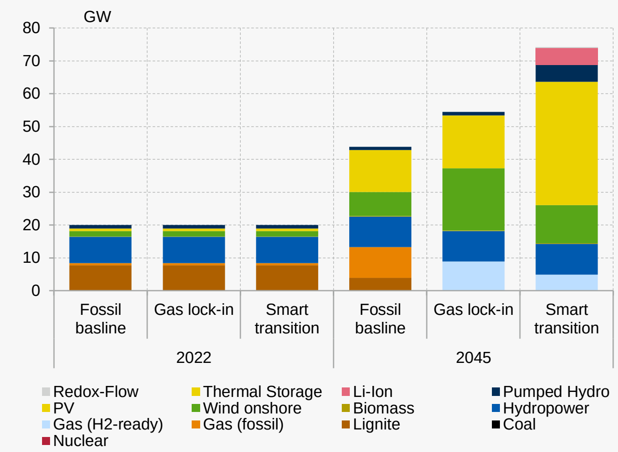
WB-6: overview of core scenario results

Within the core set of scenarios, the smart transition strategy shows potential for significant reduction in overall Incremental generation costs (~15% compared to baseline), driven by savings in OPEX and CO_2 costs.

CO_2 emissions

- Decarbonisation strategies overall save 46% CO_2 compared to baseline
- Smart transition saves additional 5%





Capacities

- Net-zero scenarios deploy 35 GW & 49 GW of RES by 2045
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Incremental generation costs

- Transition scenarios save 3% (15)% vs. baseline even though climate ambition level is much higher
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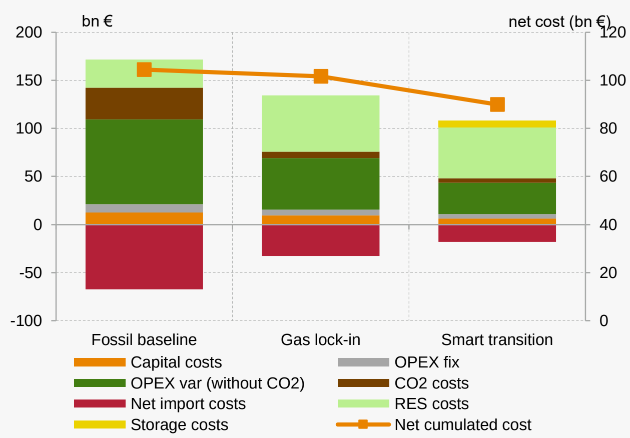

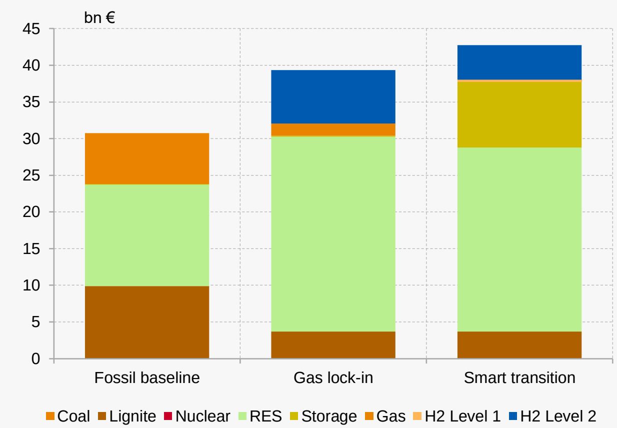

Investment costs

- Baseline investments to a large share go to fossil technology
- Net-zero scenarios strongly invest in RES

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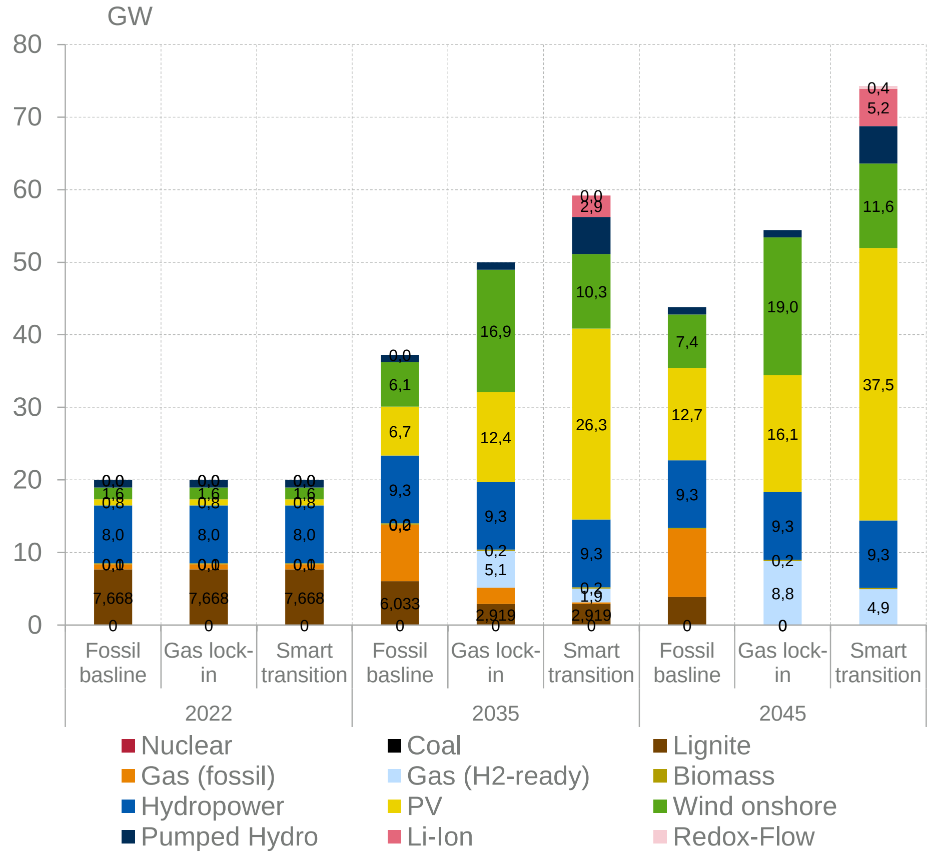
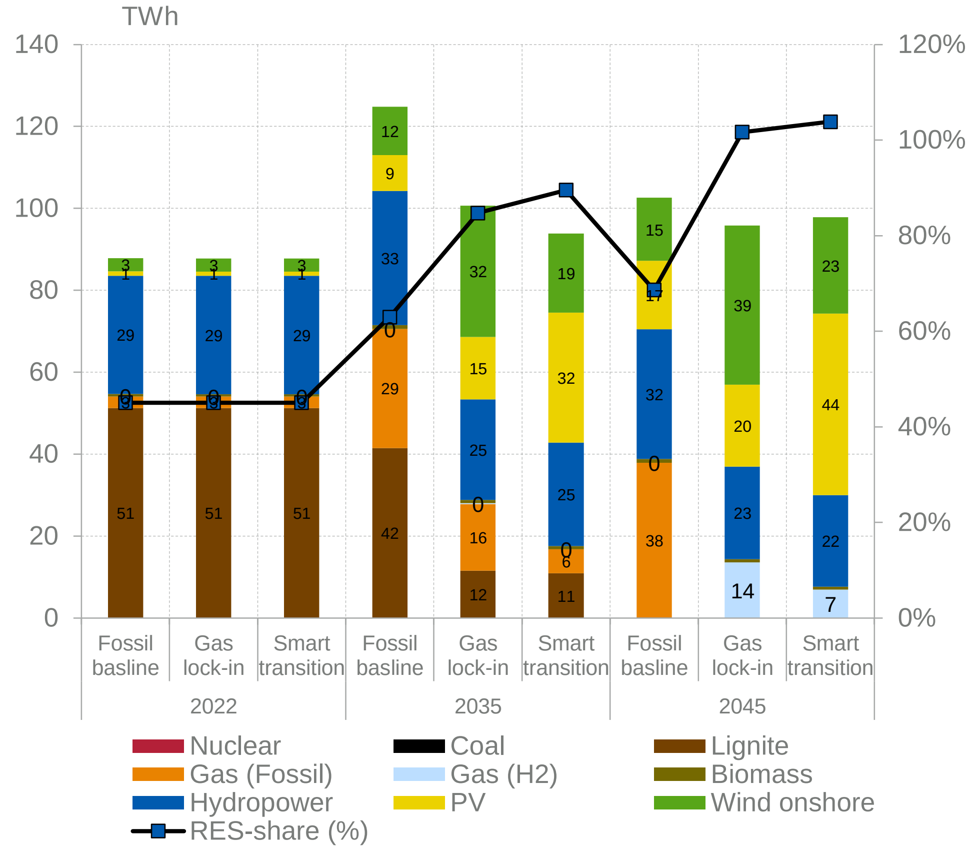
Generation & capacity (WB-6)

The decarbonisation scenarios (GL, ST) see an accelerated reduction of lignite capacities, substituted by RES (& storages in the ST). Gas-based production is reduced significantly in the medium-term (down 45% in GL and 80% in ST by 2035) and replaced by hydrogen. Long-term, investments into storages can reduce H2-demand by 50%.

Capacity



Generation



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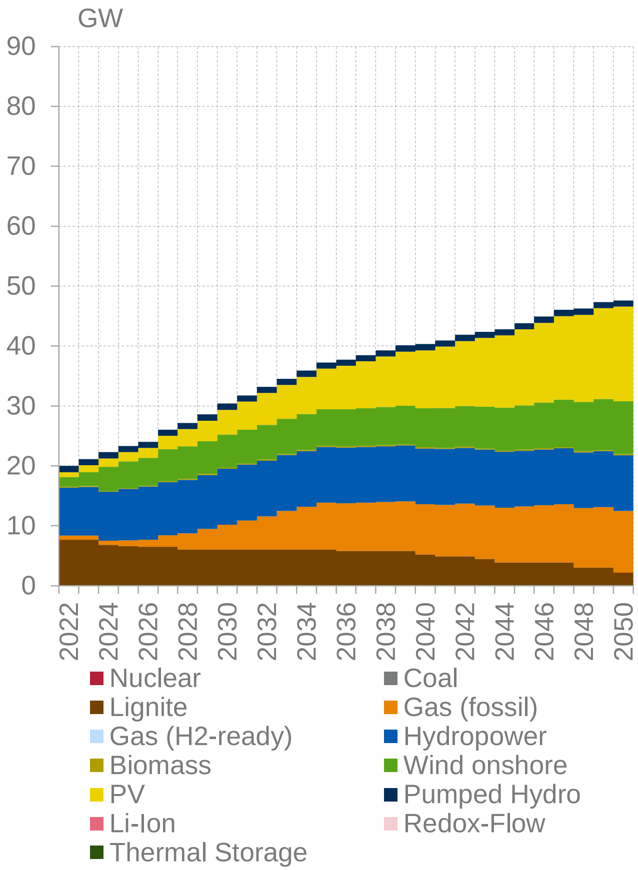
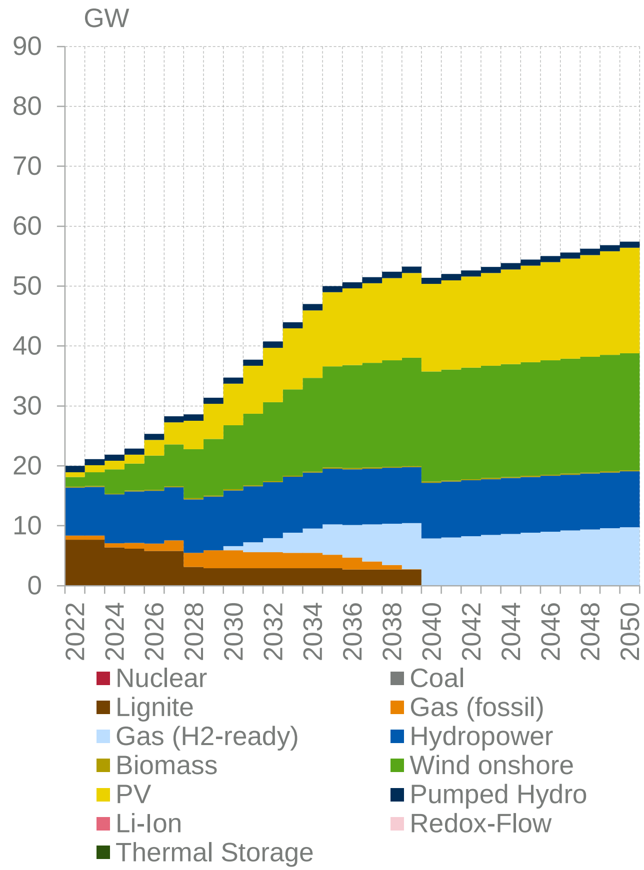
Capacity (WB-6)

In both decarbonisation scenarios, lignite capacities are replaced by increasing RES capacities. In the ST more than double of the GL PV capacities, complementary to storage expansion, are built in the long-term. Pumped hydro potential is fully utilised, while additional 6.7 GW of Li-Ion batteries are deployed.

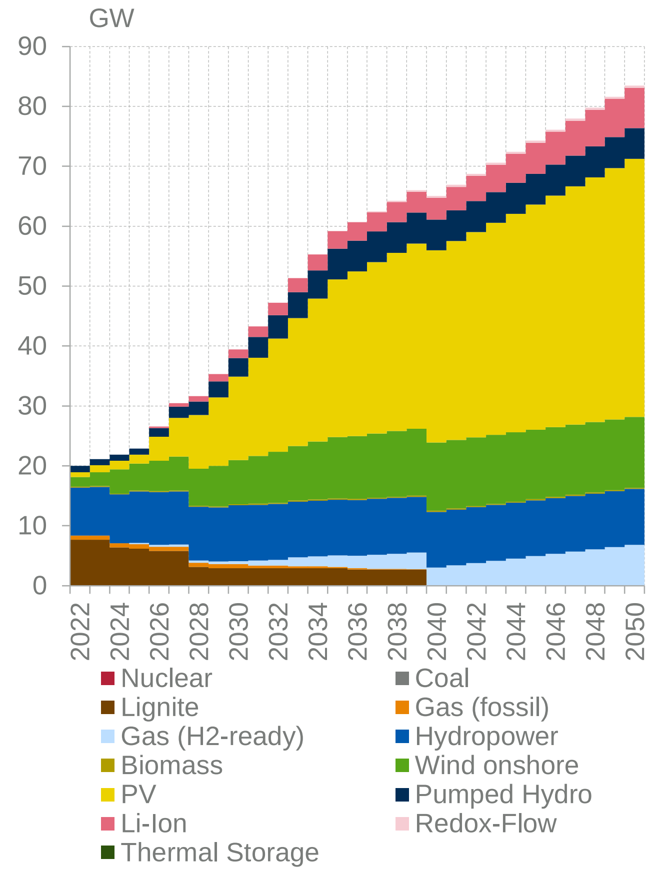
Fossil baseline



Gas lock-in



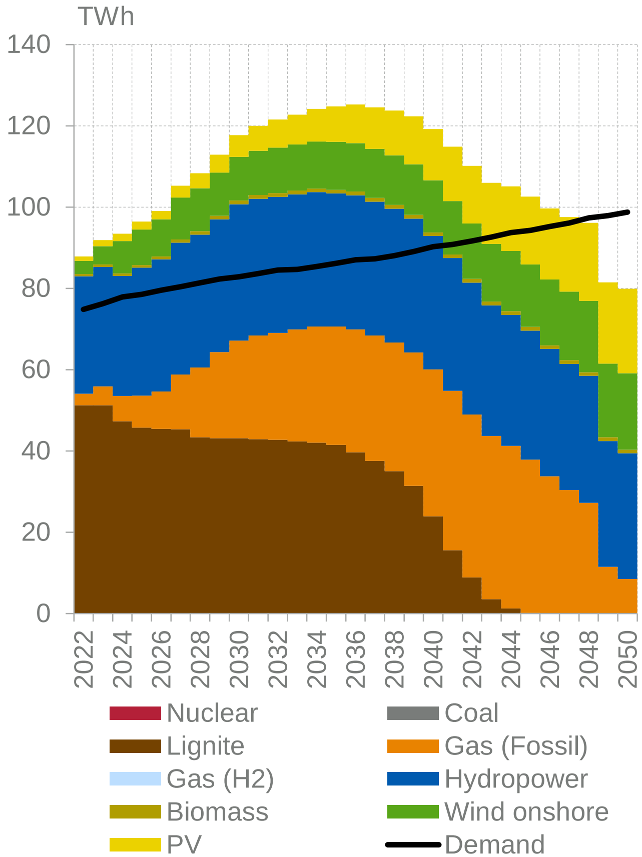
Smart transition



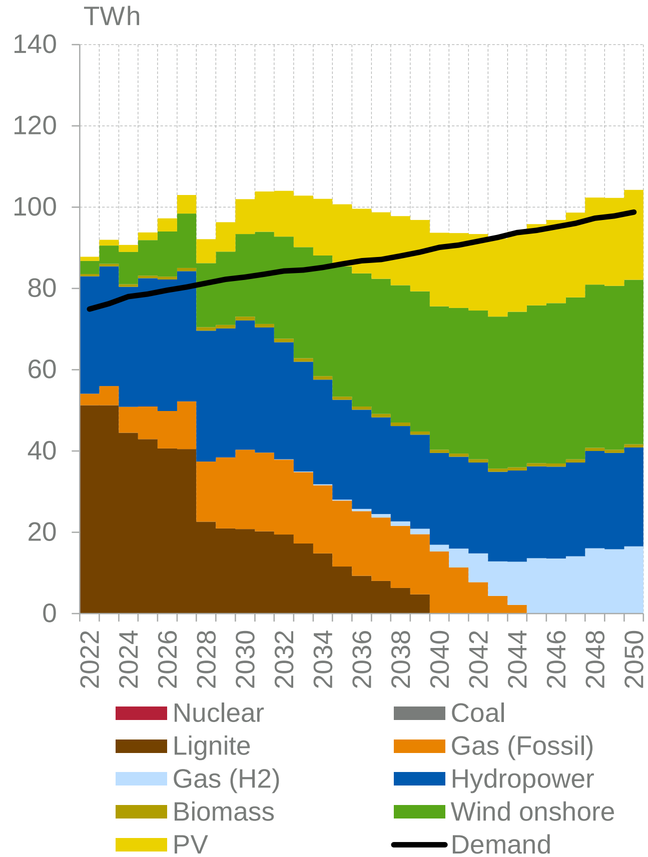
Generation (WB-6)

Earlier decomissioning and lower utilisation of lignite plants decreases exported power and is compensated by renewables and higher gas utilisation, especially in the medium-term.

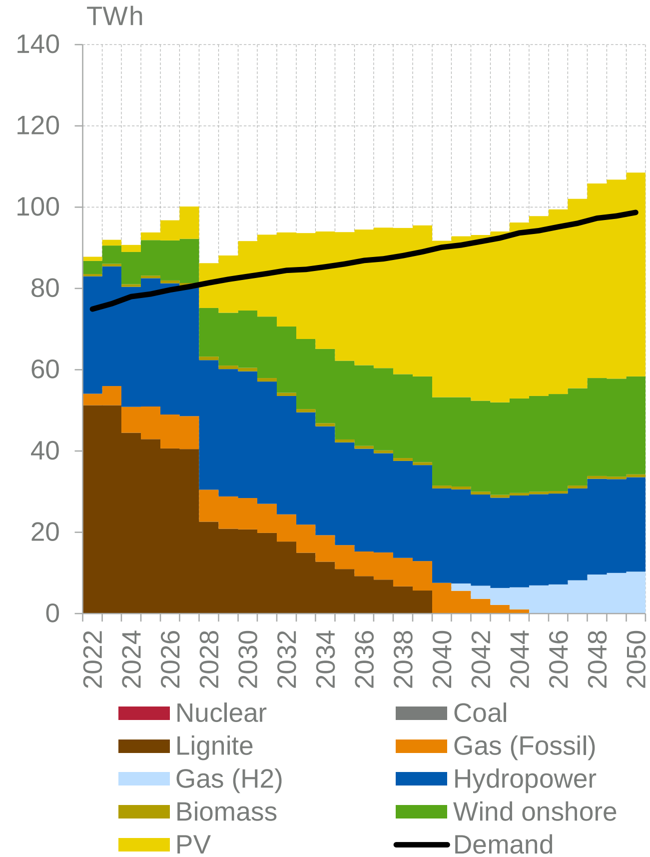
Fossil baseline



Gas lock-in



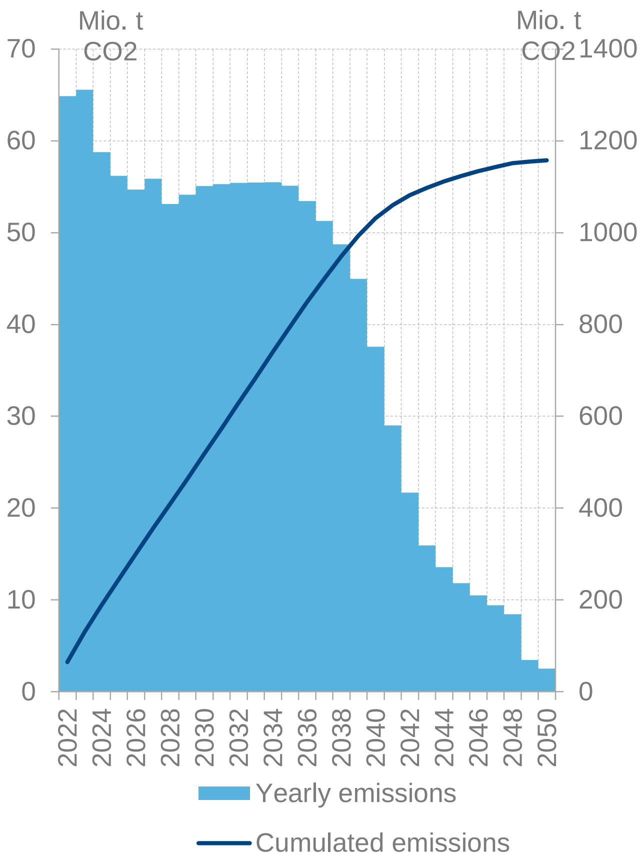
Smart transition



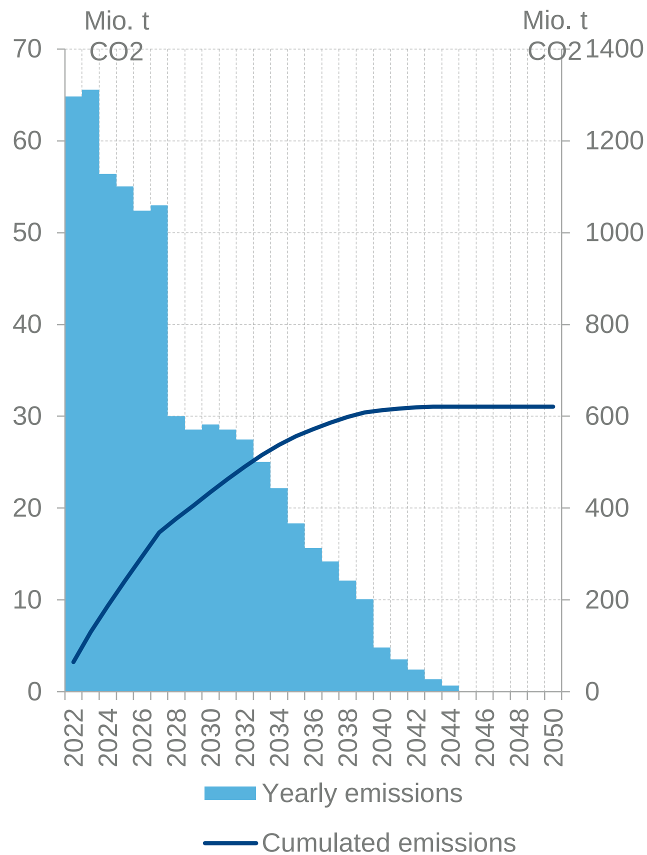
Emissions (WB-6)

Long-term cumulated emissions until 2050 are reduced by 46% in the GL and an additional 5% in the ST. The high-gradient decrease in the late 2020s in mainly driven by decomissioning of ~50%of lignite capacity in the respective timeframe. A complete decarbonisation of the power sector is achieved until 2045.

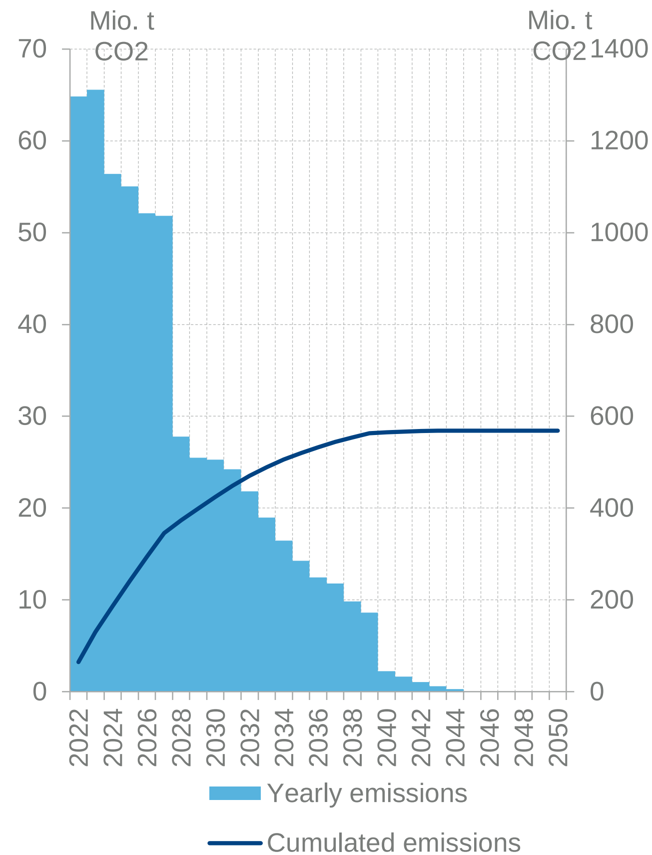
Fossil baseline



Gas lock-in



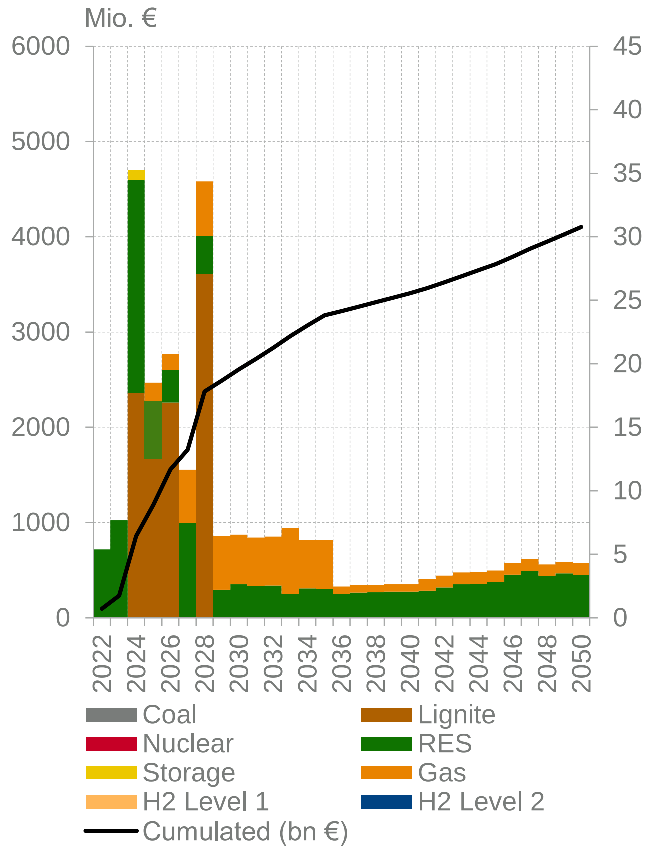
Smart transition



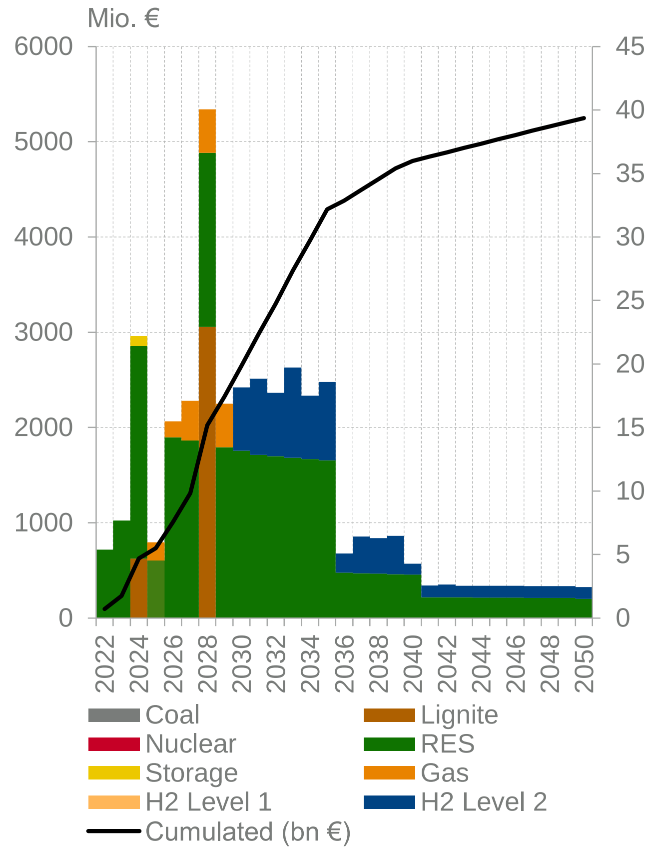
Investment costs (WB-6)

Required additional investments in the WB-6 accumulate to 8.6 bn € or ~28% (GT) and 12.0 bn € or ~39% (ST) until 2050 compared to baseline. Additional investments are mainly channelled towards onshore wind and PV assets (GT and ST). A smart transition mitigates costs for H2-readiness retrofits, but increases investment needs for storages.

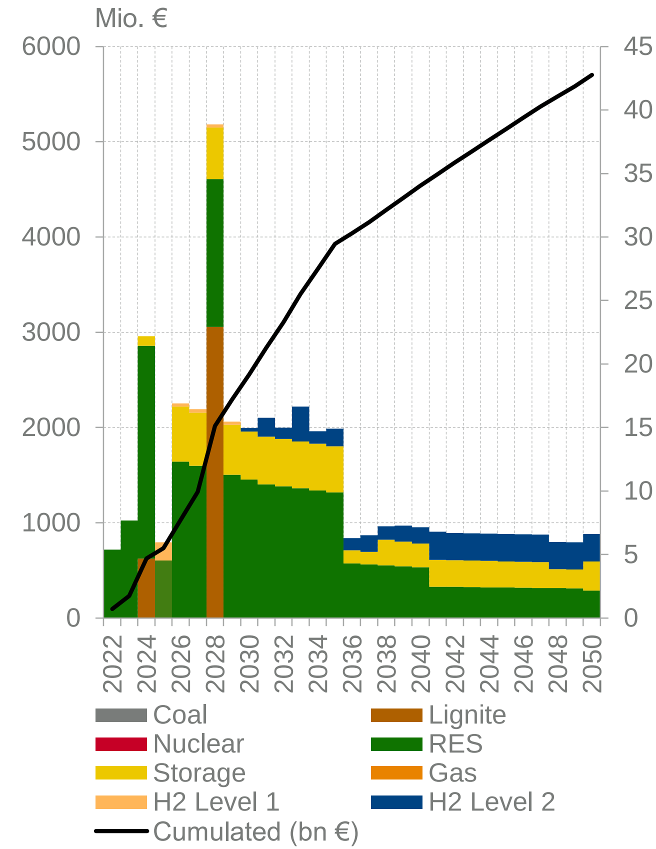
Fossil baseline



Gas lock-in



Smart transition



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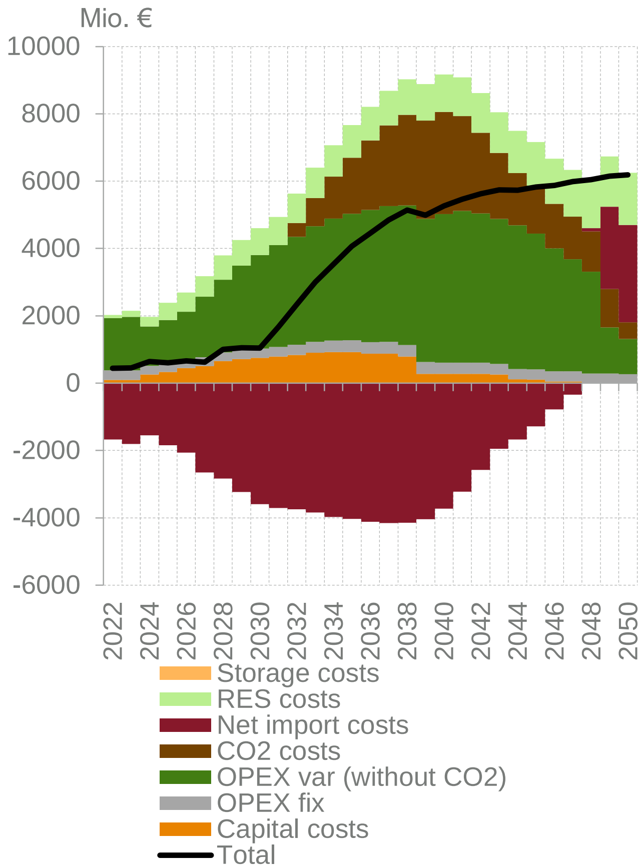
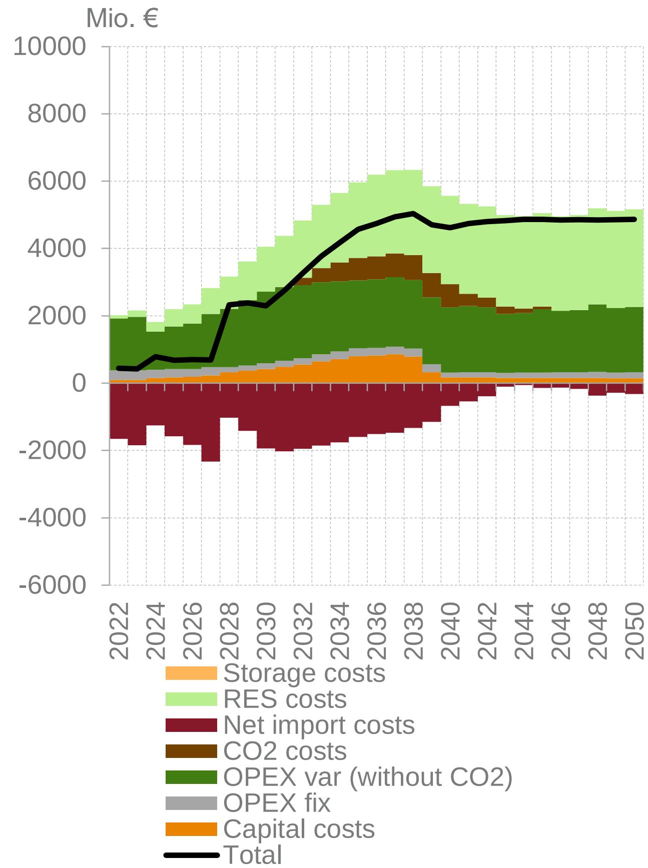
Incremental generation costs (WB-6)

In total, cumulated incremental generation costs until 2050 decrease in the decarbonisation scenarios (3% for GL and 15% for ST). While import revenues decrease due to reduced lignite capacity & utilisation, savings in OPEX and CO_2 cost (due to lower lignite and gas-based production) are realised.

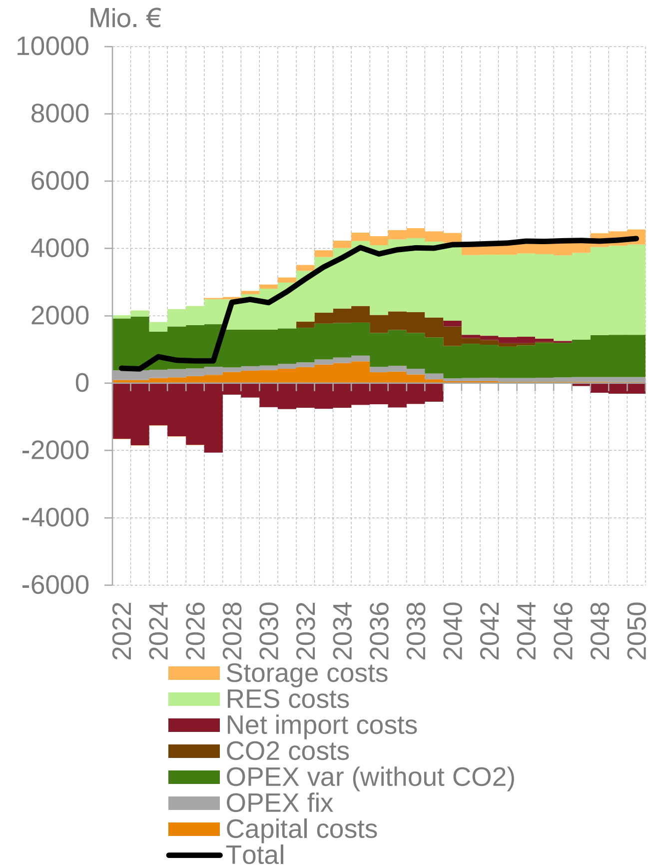
Fossil baseline



Gas lock-in



Smart transition

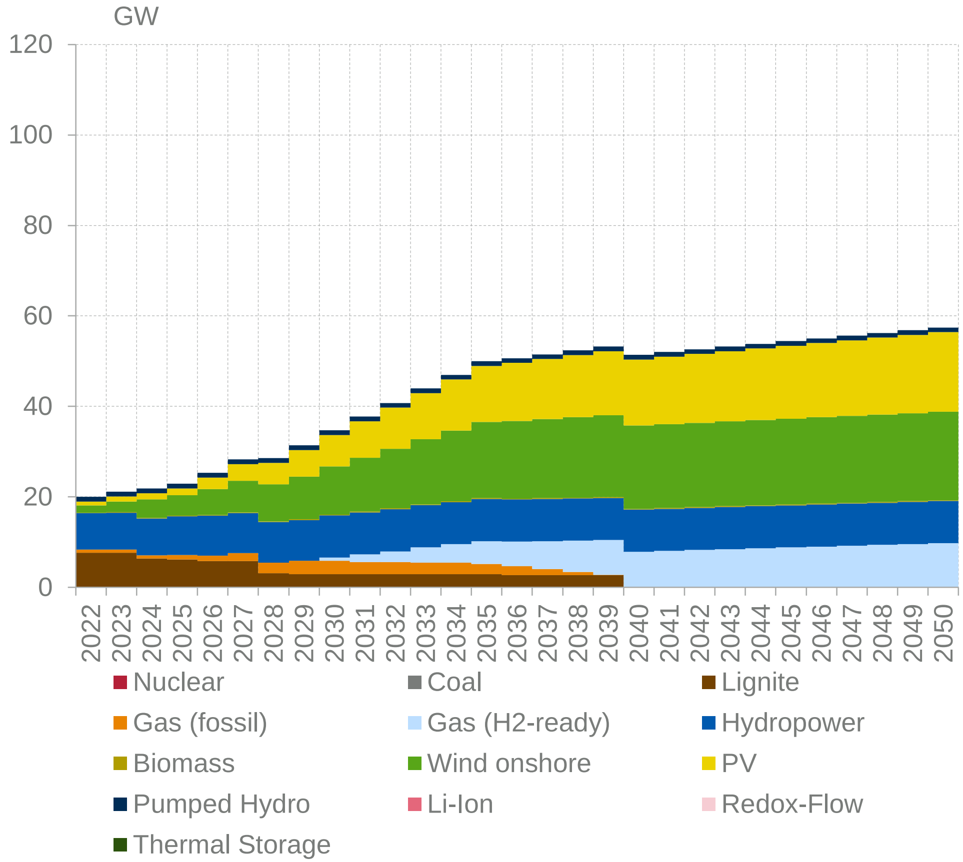


Sensitivity 2: H2 costs

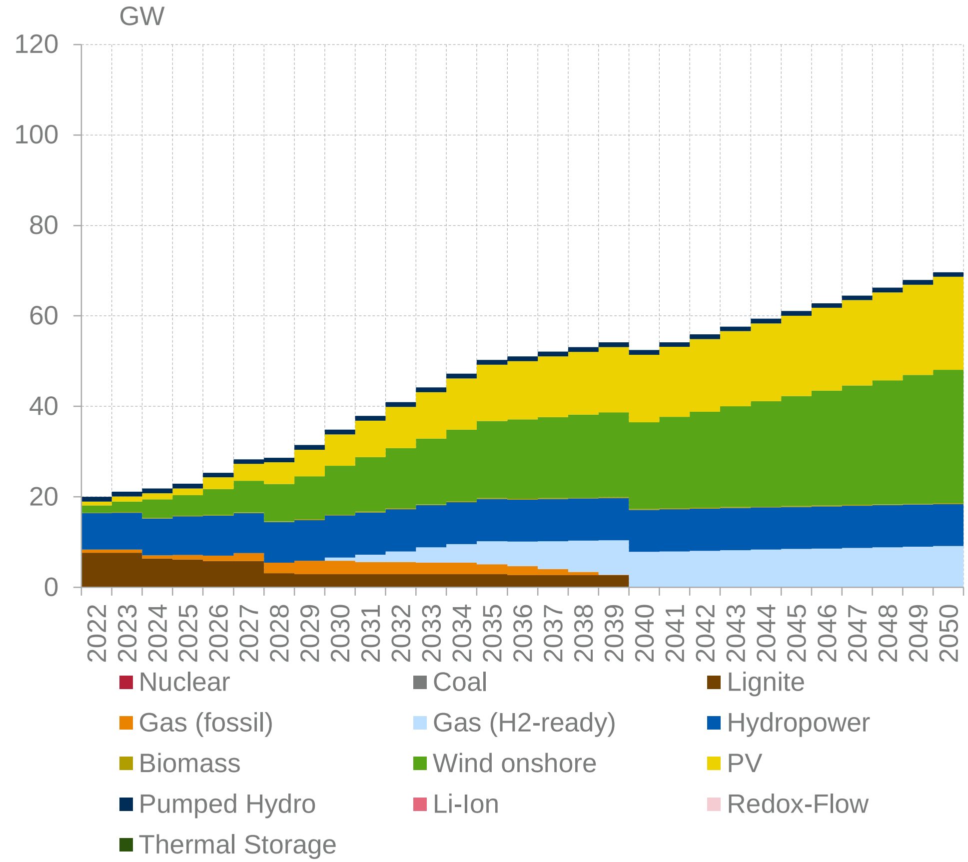
WB-6: capacities in gas lock-in (core vs. S2)

Higher H2 costs result in higher deployment of onshore wind to substitute generation in the gas lock-in scenario (GL). As peak load covering contribution of onshore is limited, capacity demand from (green) gas-based plants remains at similar level as in core scenario.

GL: Core



GL: S2

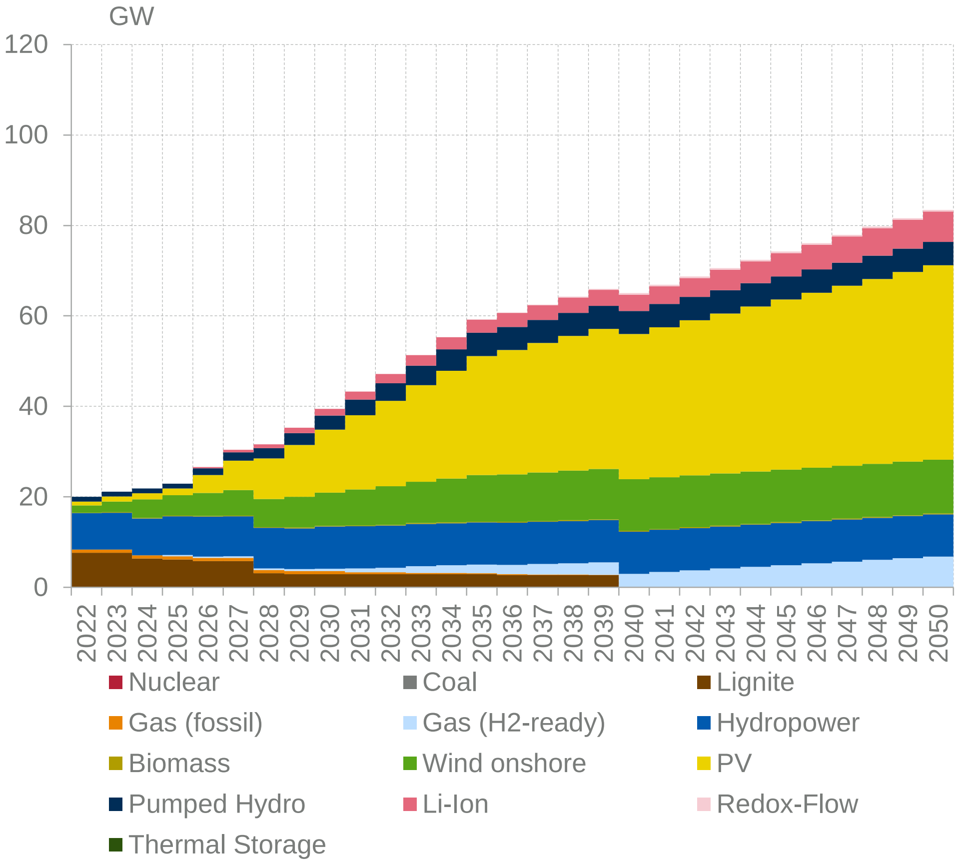


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

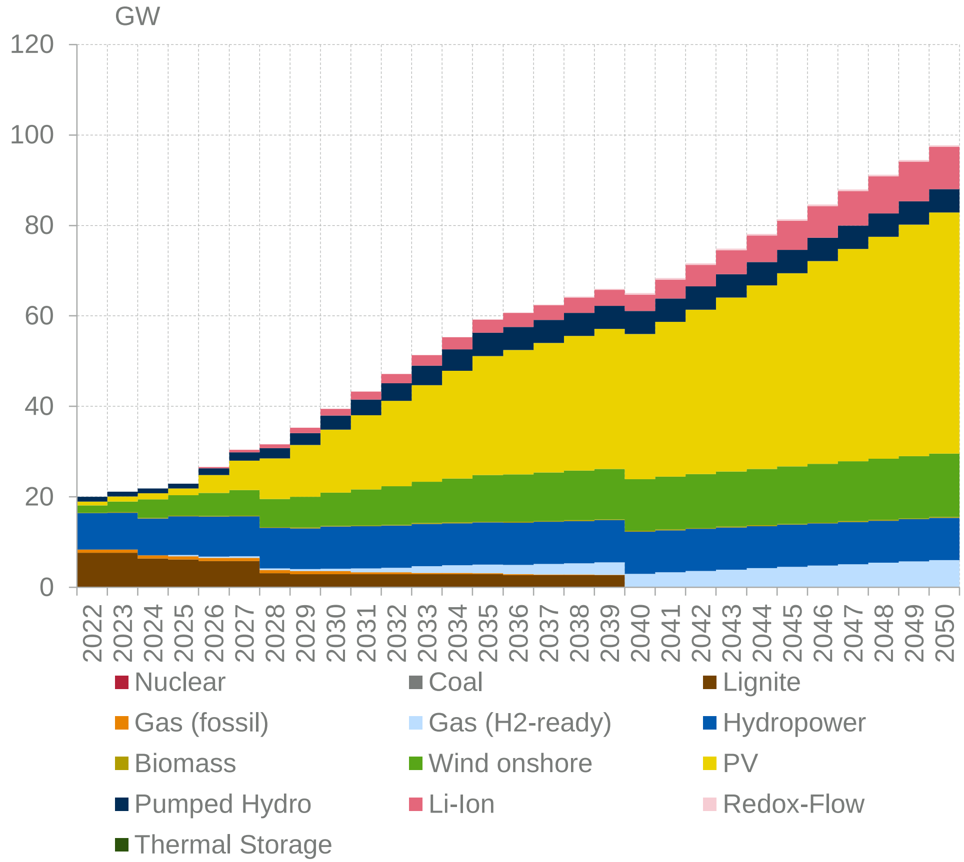
WB-6: capacities in smart transition (core vs. S2)

With higher H2 costs, a combination of PV and Li-Ion battery capacities is efficient to substitute H2-generation (S2). Until 2050, 10 GW of additional PV and 3 GW of additional batteries are built.

ST: Core



ST: S2

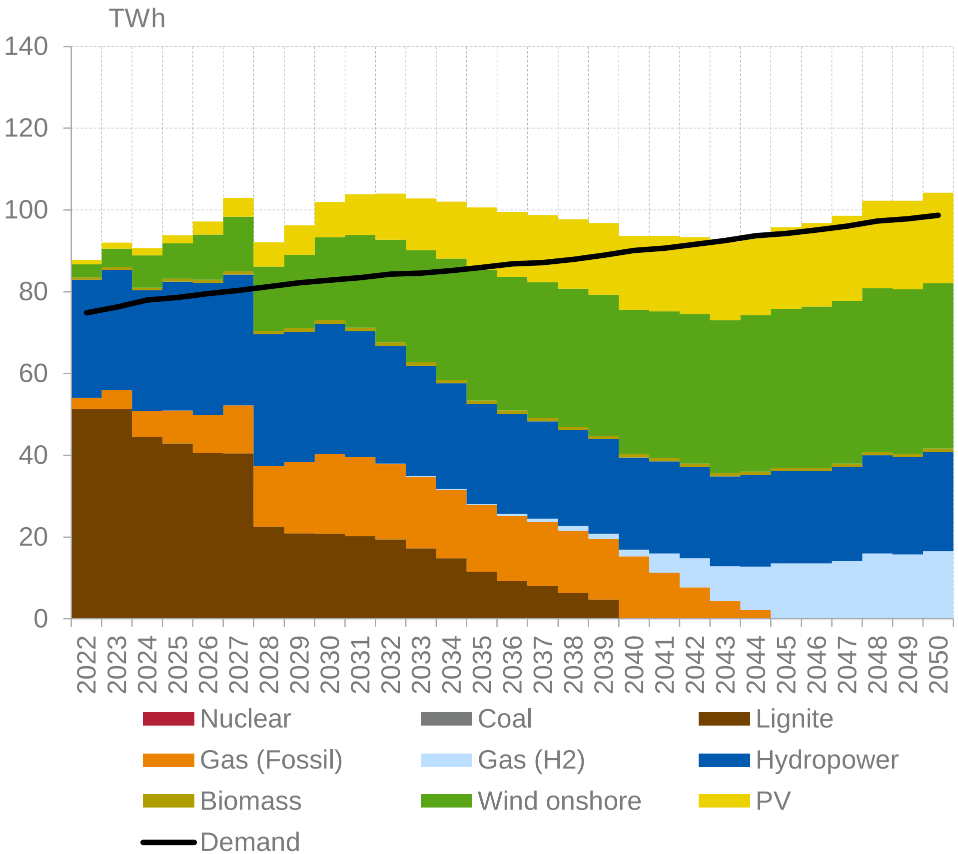


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

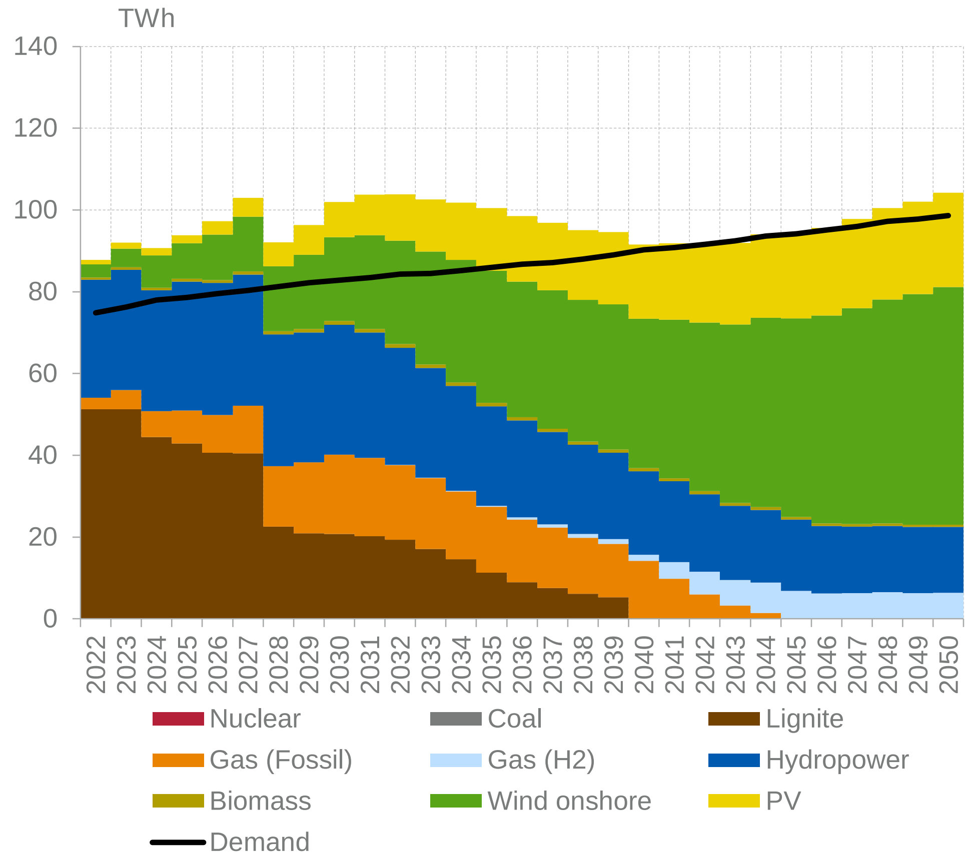
WB-6: generation in gas lock-in (core vs. S2)

Higher H2 costs cut utilisation of H2-based capacities, reducing the respective generation in the Gas lock-in by 62% compared to the core scenario. Instead, RES generation increases by 45% (wind onshore) and 5% (PV), respectively.

GL: Core



GL: S2

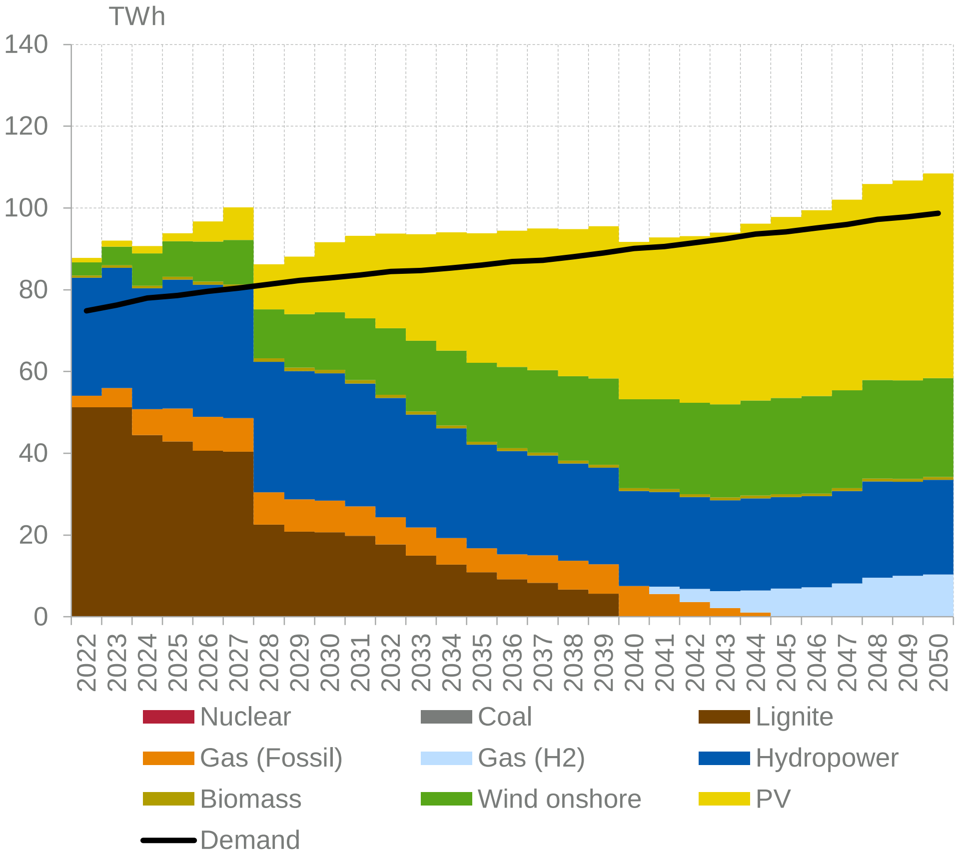


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

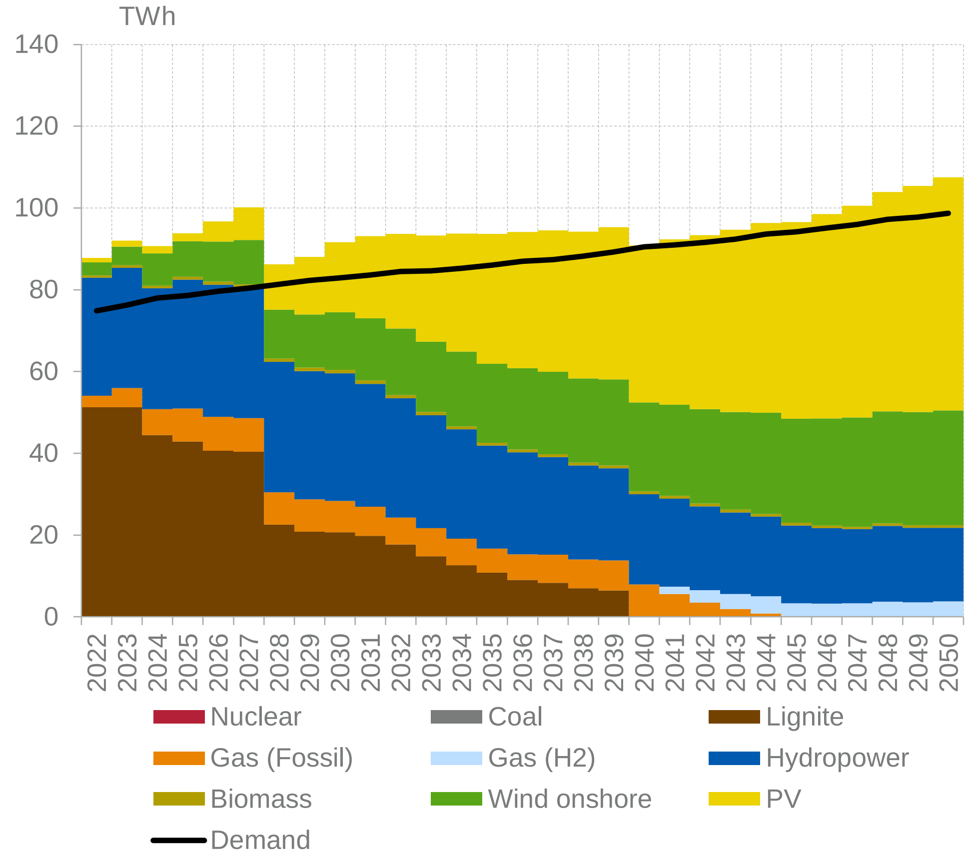
WB-6: generation in smart transition (core vs. S2)

Higher H2 costs cut utilisation of H2-based capacities, reducing the respective generation in the smart transition scenario by 63% compared to the core scenario. Instead, RES generation increases by 16% (wind onshore) and 14% (PV), respectively.

ST: Core



ST: S2

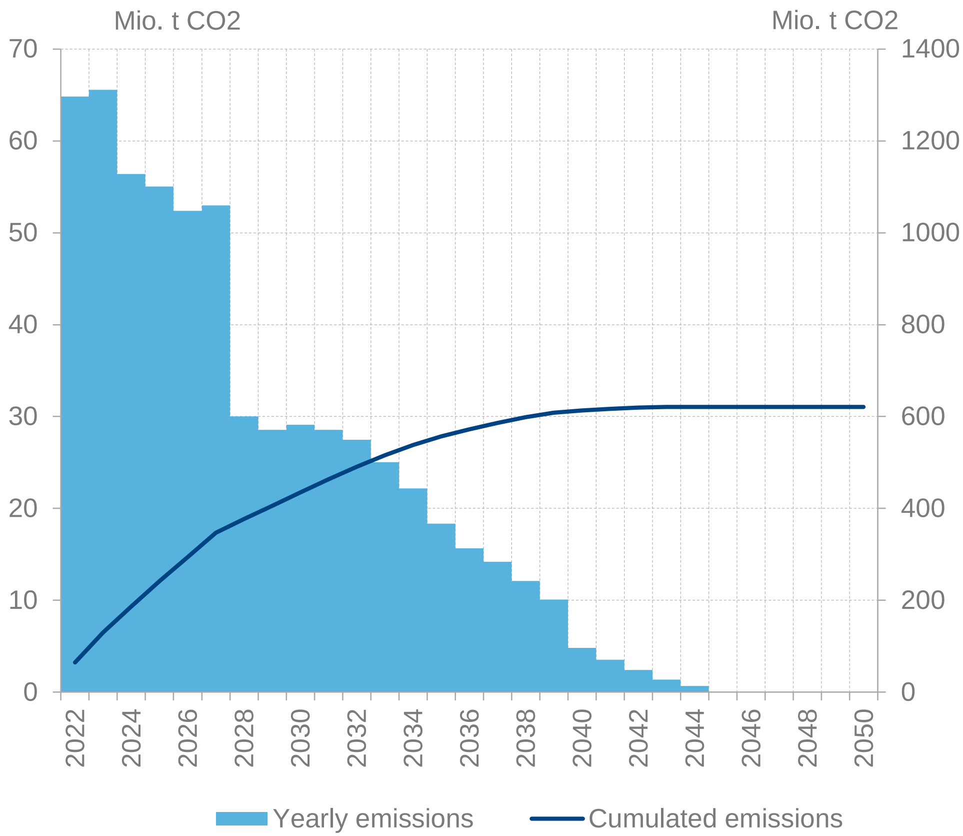


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

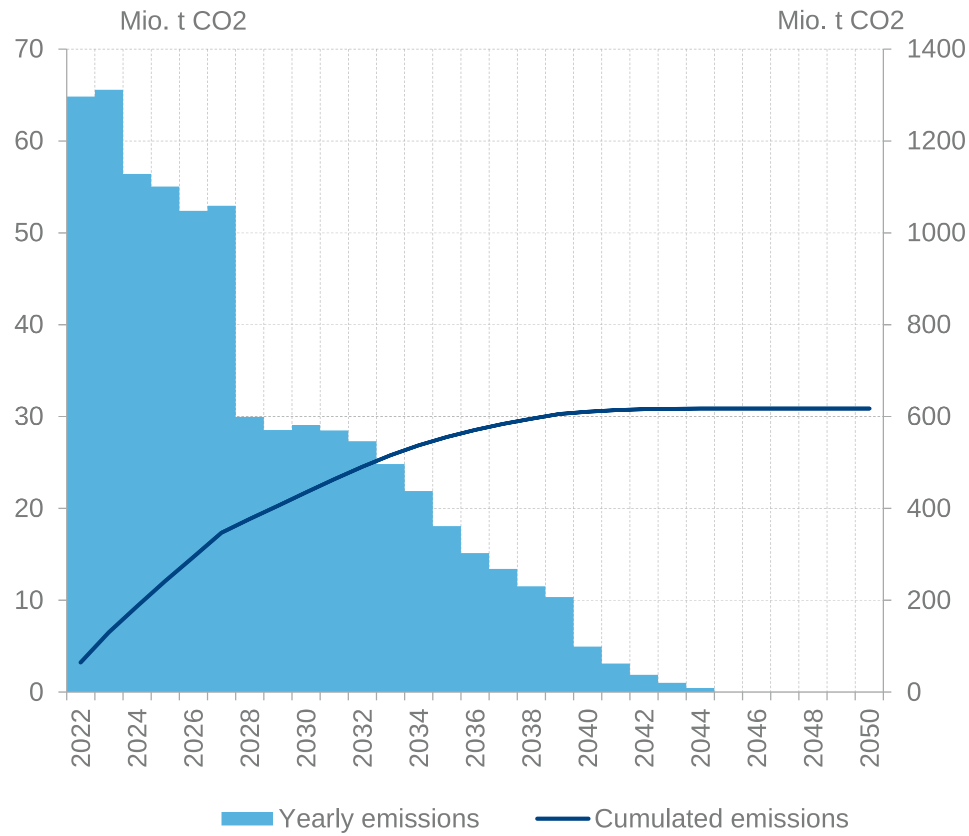
WB-6: emissions in gas lock-in (core vs. S2)

A higher H2-price has no significant impact on the overall CO2 emissions, since H2-based generation is mainly substituted by RES.

GL: Core



GL: S2

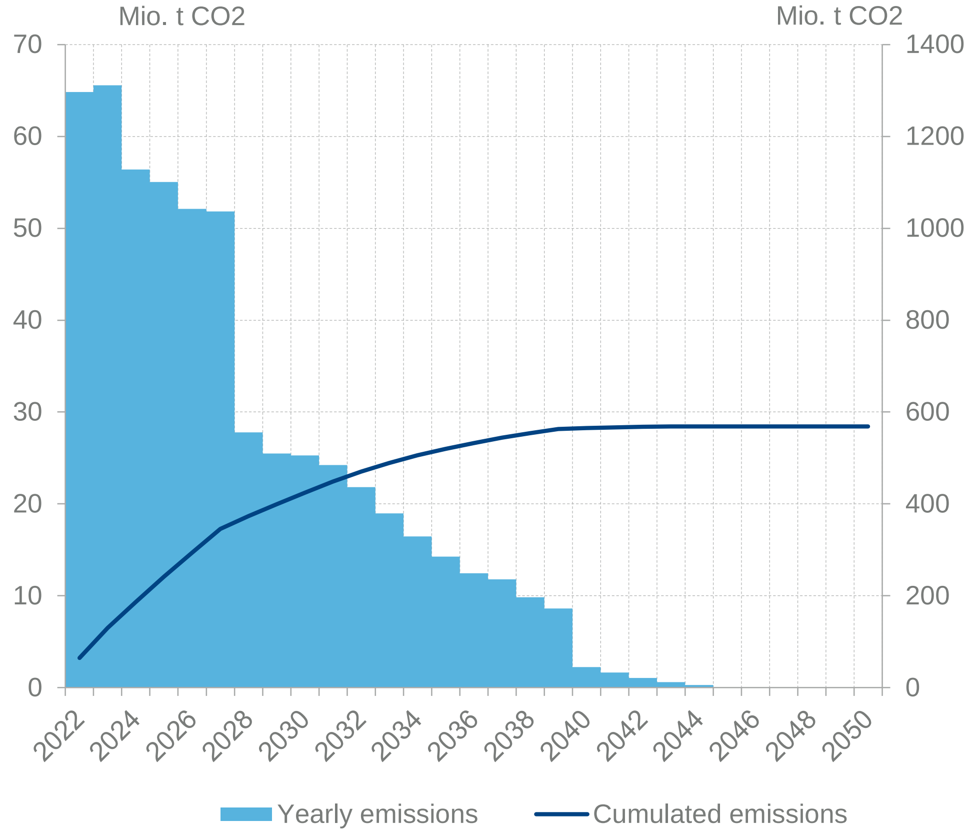


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

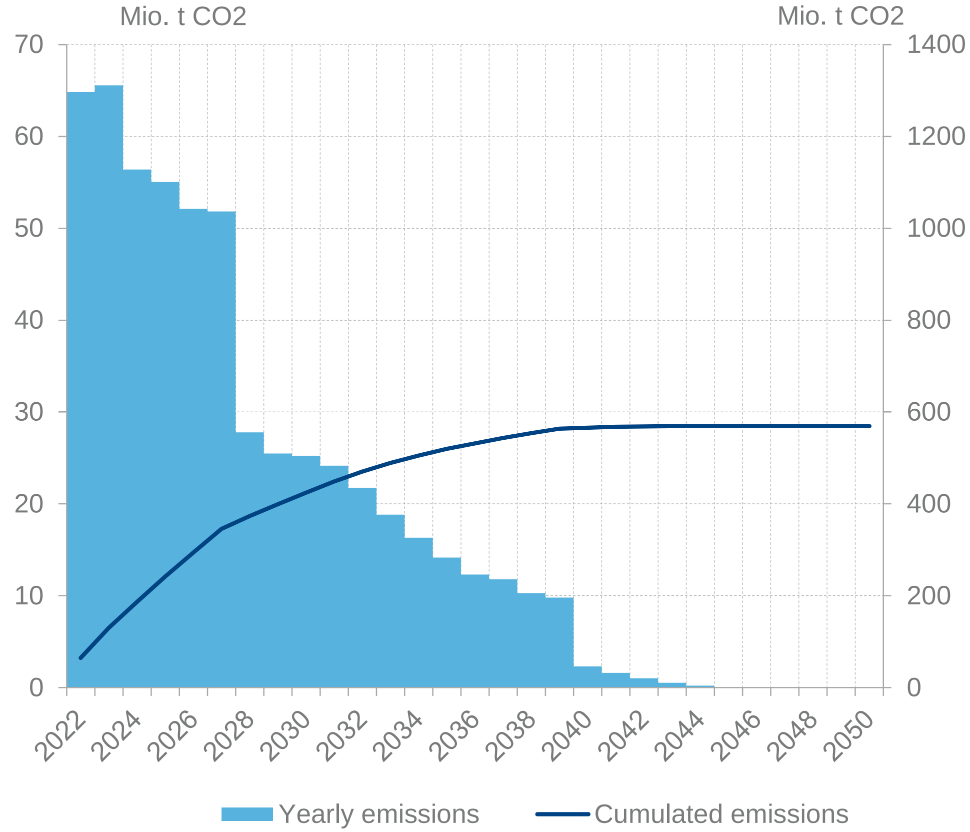
WB-6: emissions in smart transition (core vs. S2)

H2-price likewise has no significant impact on the overall CO_2 emission mitigation in the smart transition scenario.

ST: Core



ST: S2

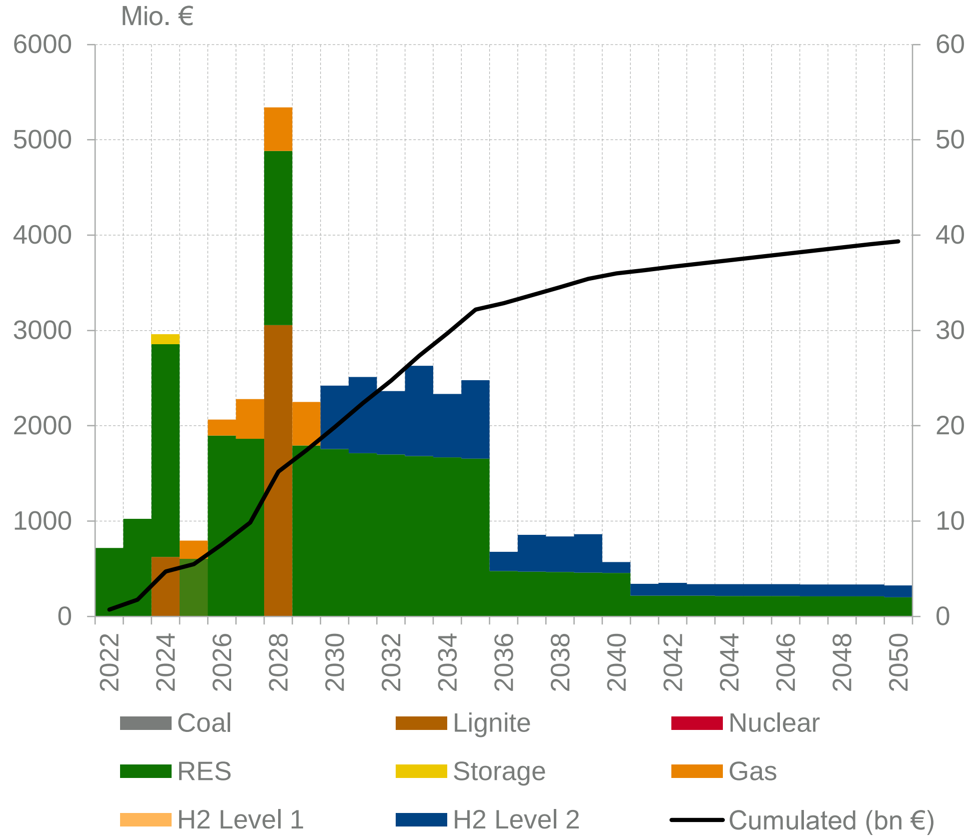


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

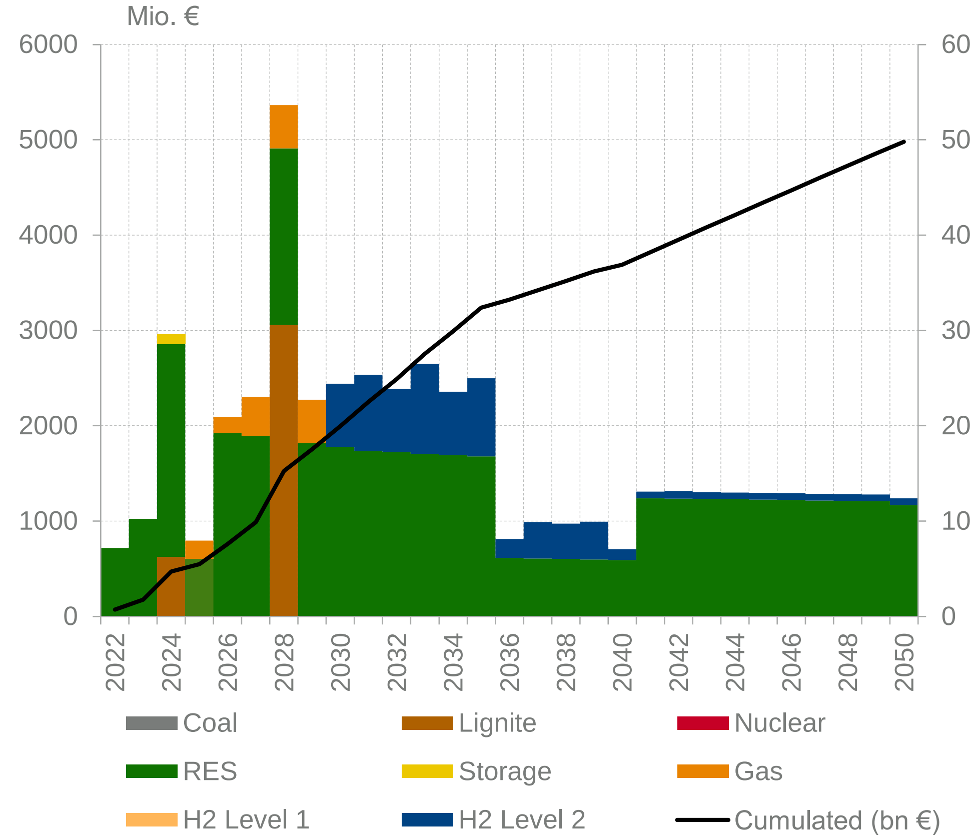
WB-6: investment costs in gas lock-in (core vs. S2)

The H2-risk sensitivity highlights that required investment volumes for reaching a deep decarbonisation of the power sector in a gas lock-in scenario increase significantly (~26%), especially in the late 2030s and throughout the 2040s. This increase is mainly driven by additional RES capacities.

GL: Core



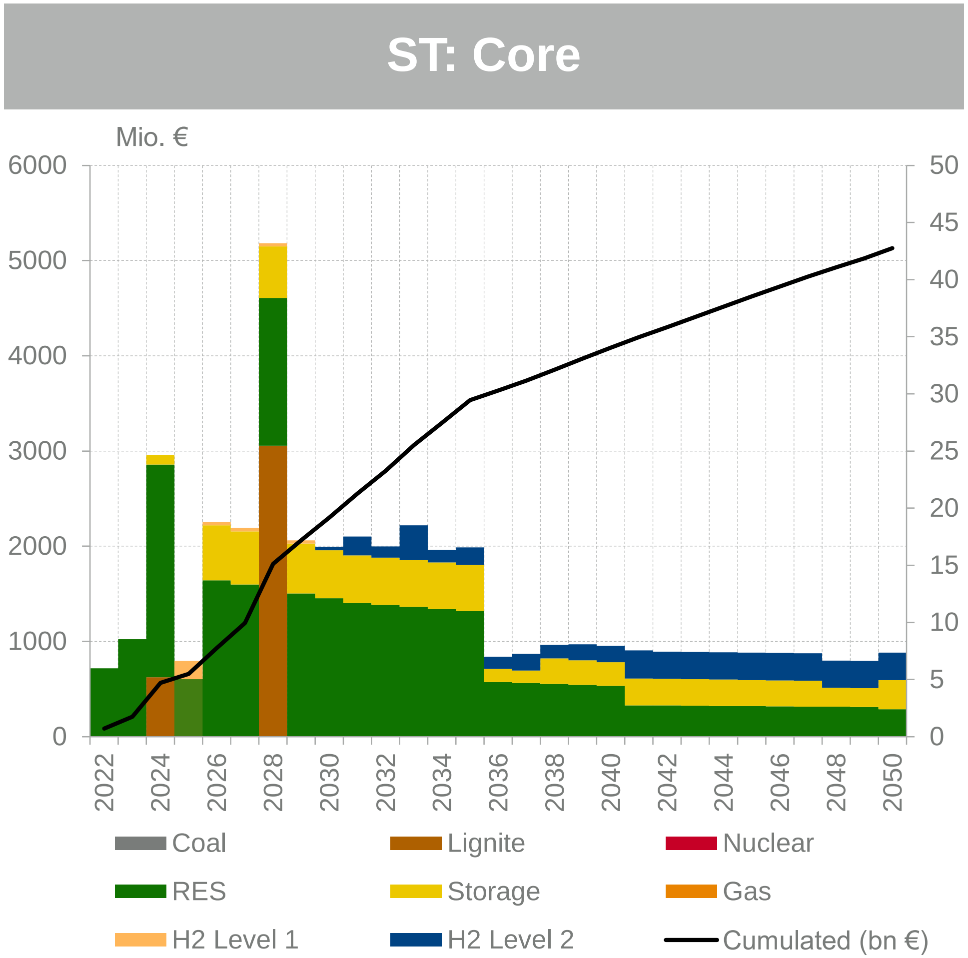
GL: S2

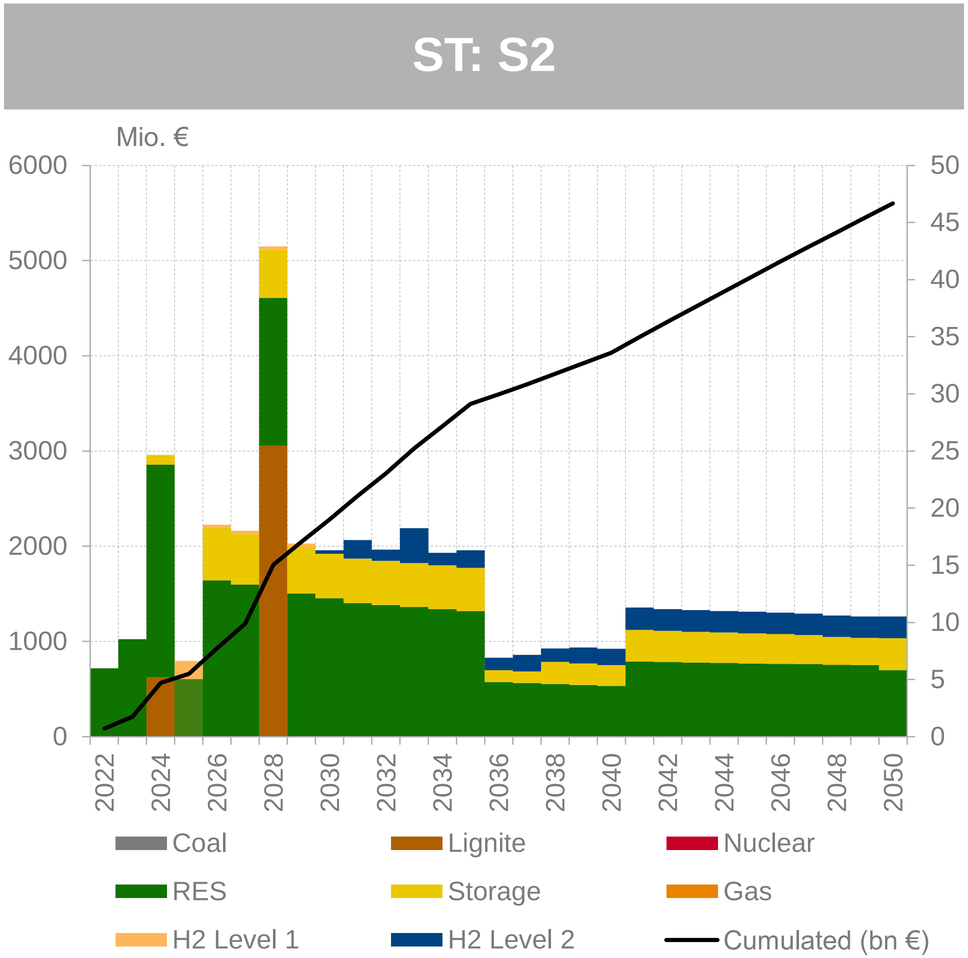


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

WB-6: investment costs in smart transition (core vs. S2)

In comparison, a smart transition is substantially less sensitive to global H2 costs, increasing cumulated investment needs by only ~8% (compared to ~26% in gas lock-in).



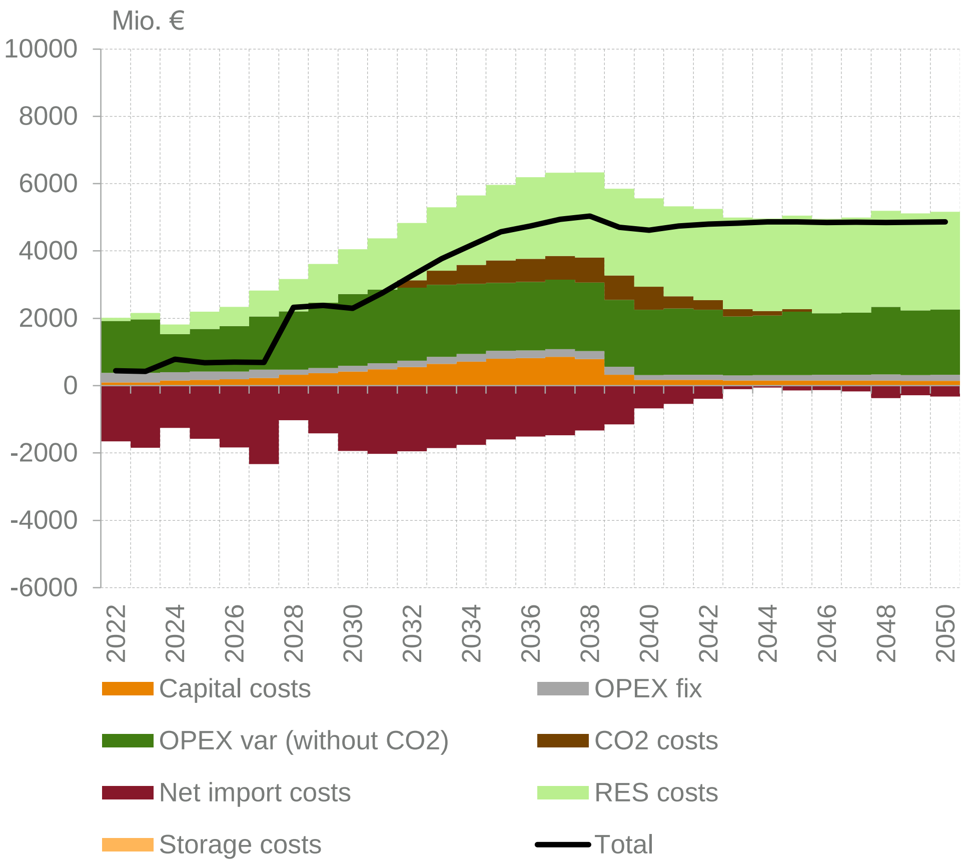


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

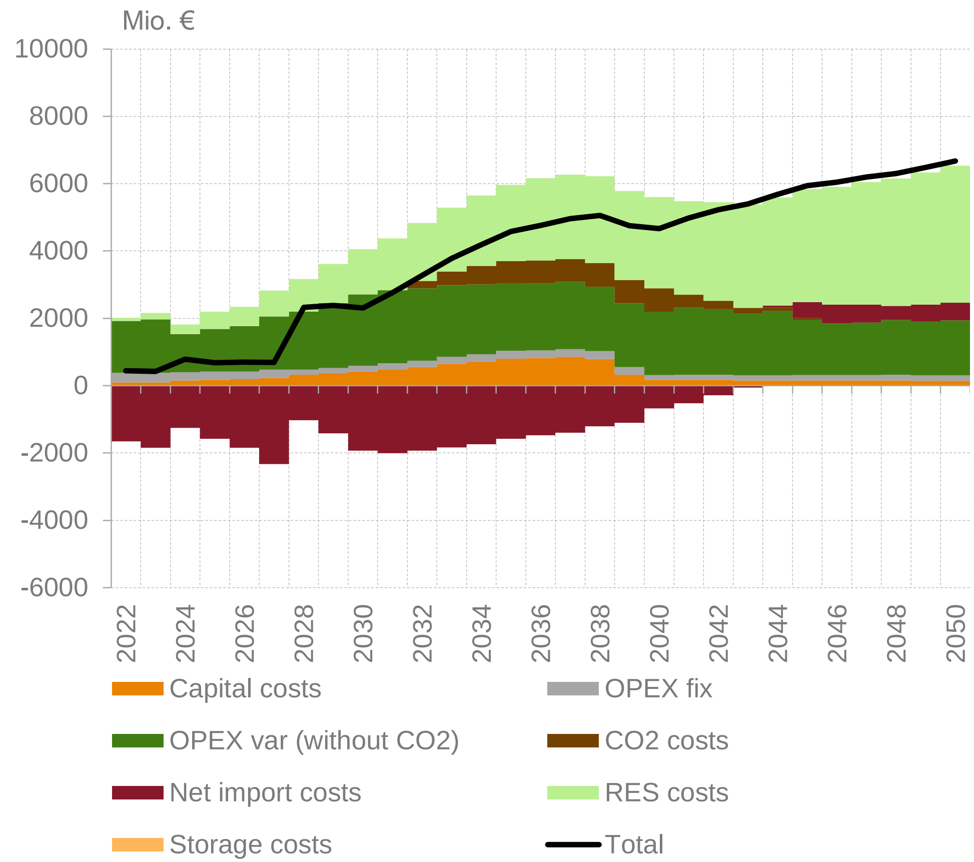
WB-6: incremental generation costs in gas lock-in (core vs. S2)

Incremental generation cost increase in the 2040s are mainly driven by increased RES investments required for decarbonisation. Simultaneously, OPEX decrease due to lower fuel consumption and net import costs increase due to decreased flexibility from gas/H2-plants.

GL: Core



GL: S2

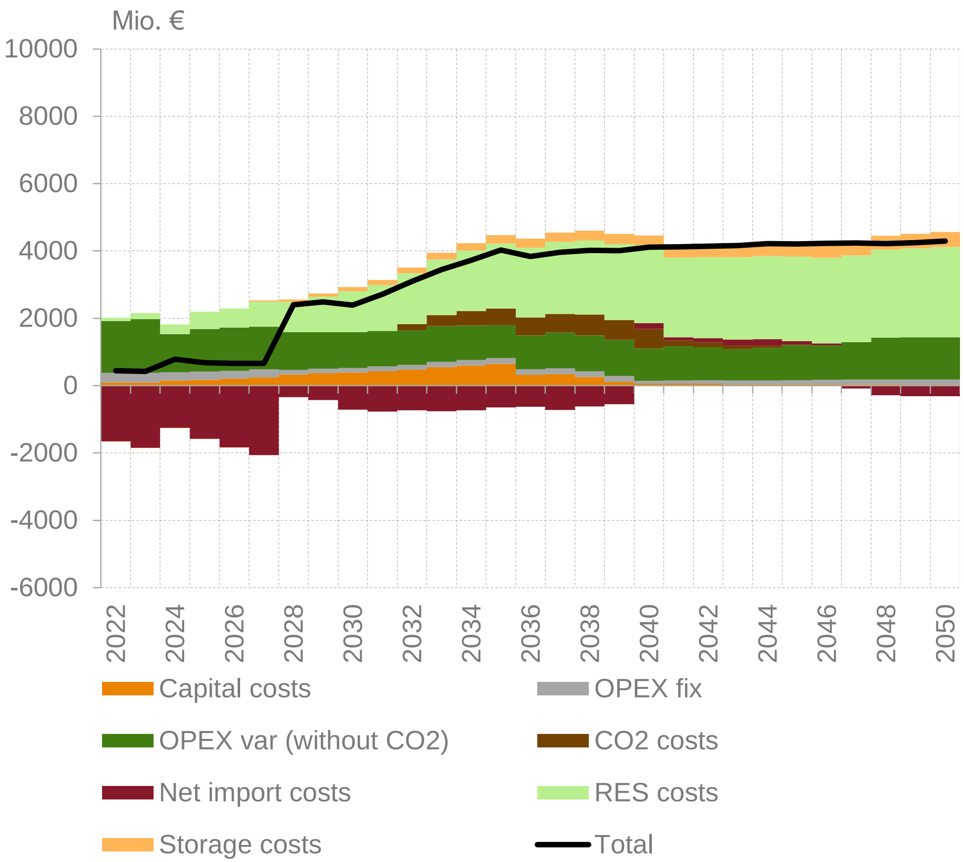


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

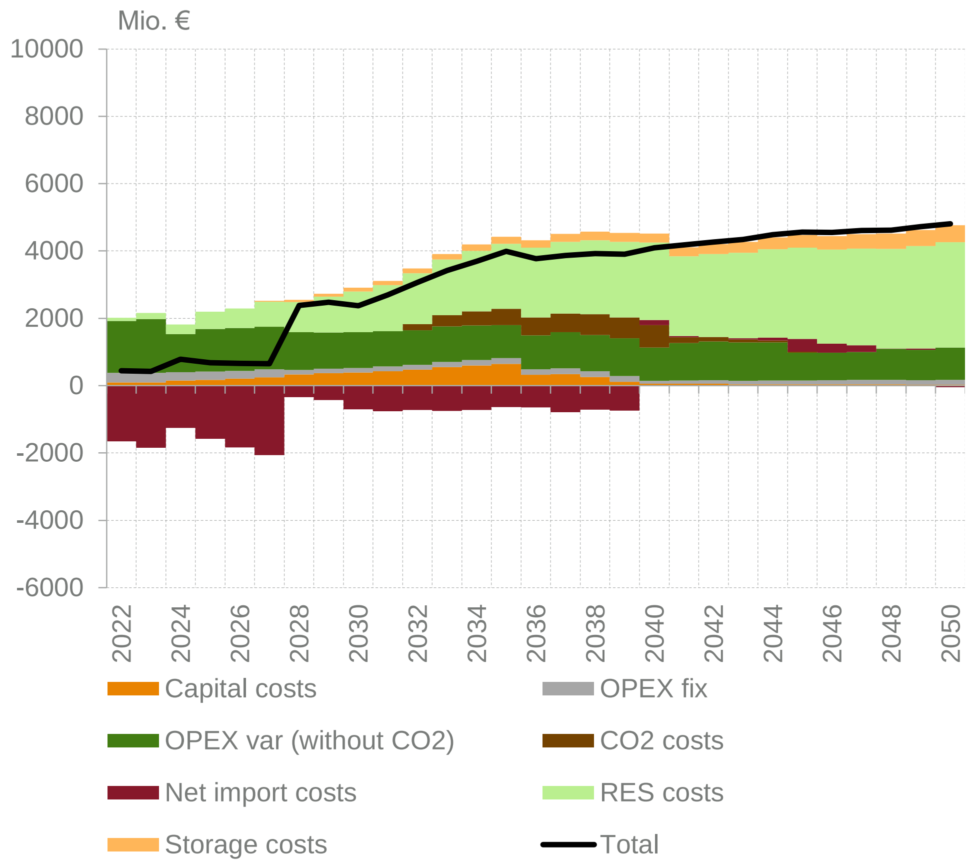
WB-6: incremental generation costs in smart transition (core vs. S2)

In comparison, generation costs in the smart transition increase to a lesser extent, highlighting a lower sensitivity to H2-price related risks.

ST: Core



ST: S2



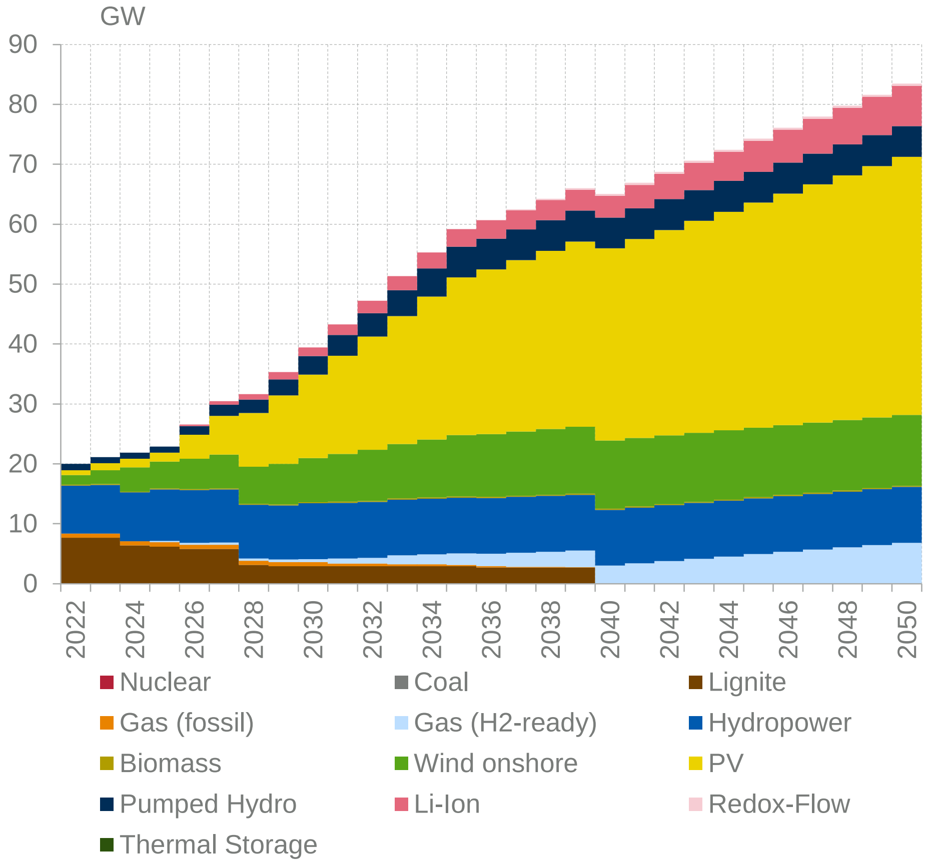
Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

Sensitivity 3: Redox-flow breakthrough

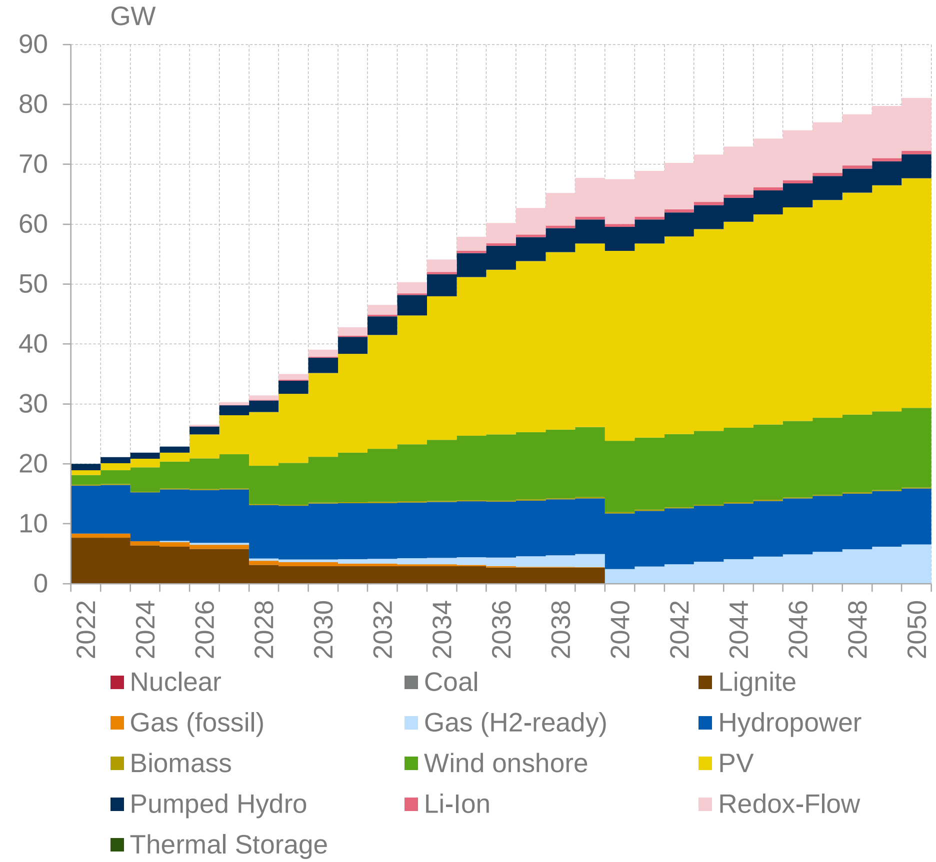
WB-6: capacities in smart transition (core vs. S3)

Cheaper and longer-term redox flow batteries reduce overall capacity demand and lead to a shift from Li-Ion storage to redox flow batteries. PV capacity is reduced (by ~5 GW) in favor of additional wind capacity (~2 GW).

ST: Core



ST: S3

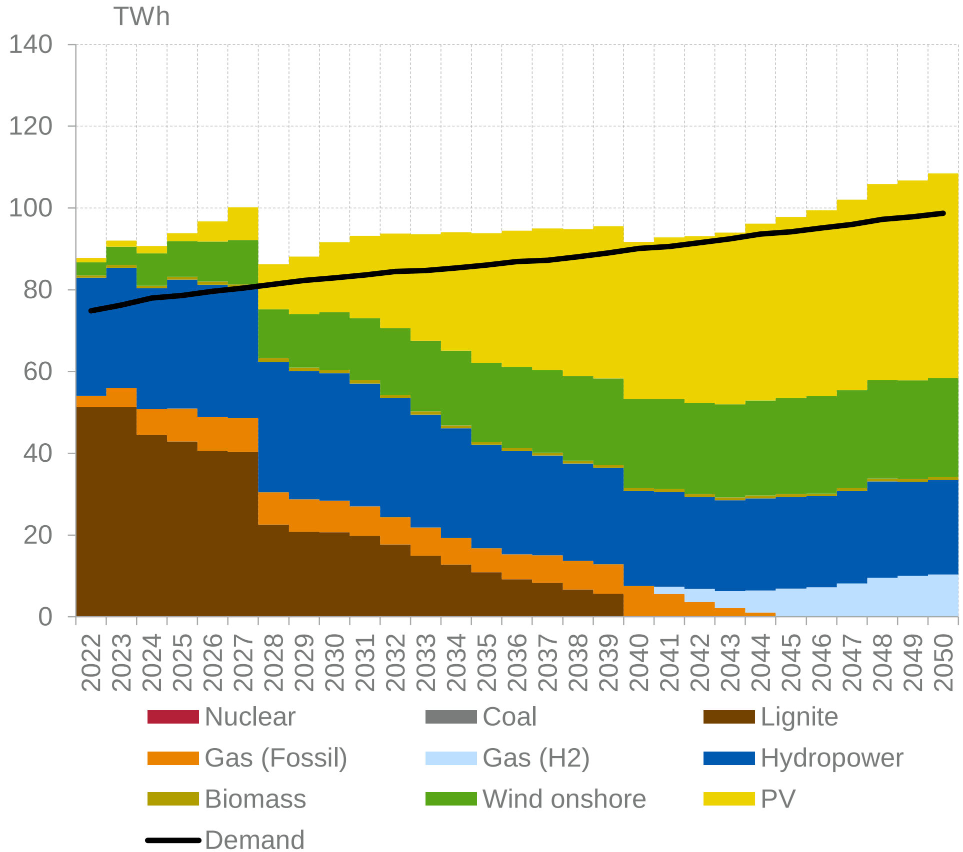


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

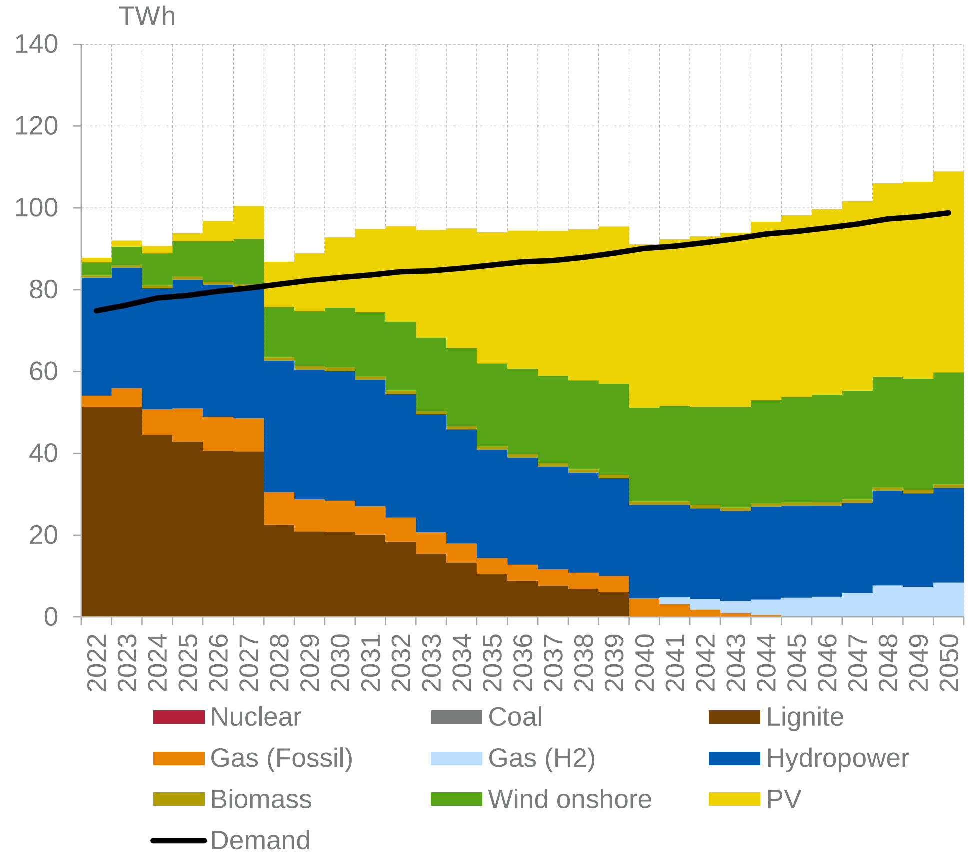
WB-6: generation in smart transition (core vs. S3)

Increased flexibility through storages reduces gas and later on H2 demand (~ minus 30% for gas in 2035 and and ~ minus 20% for H2 in 2050). RES generation, according to capacity development, increases for wind onshore and slightly decreases for PV.

ST: Core



ST: S3

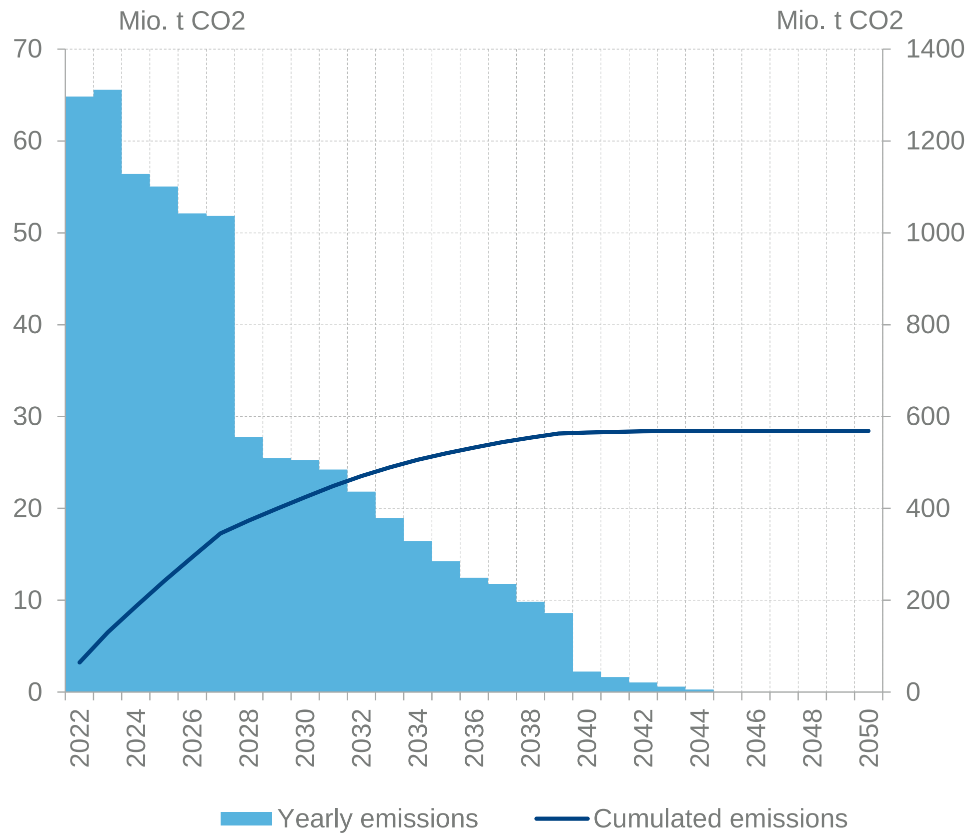


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

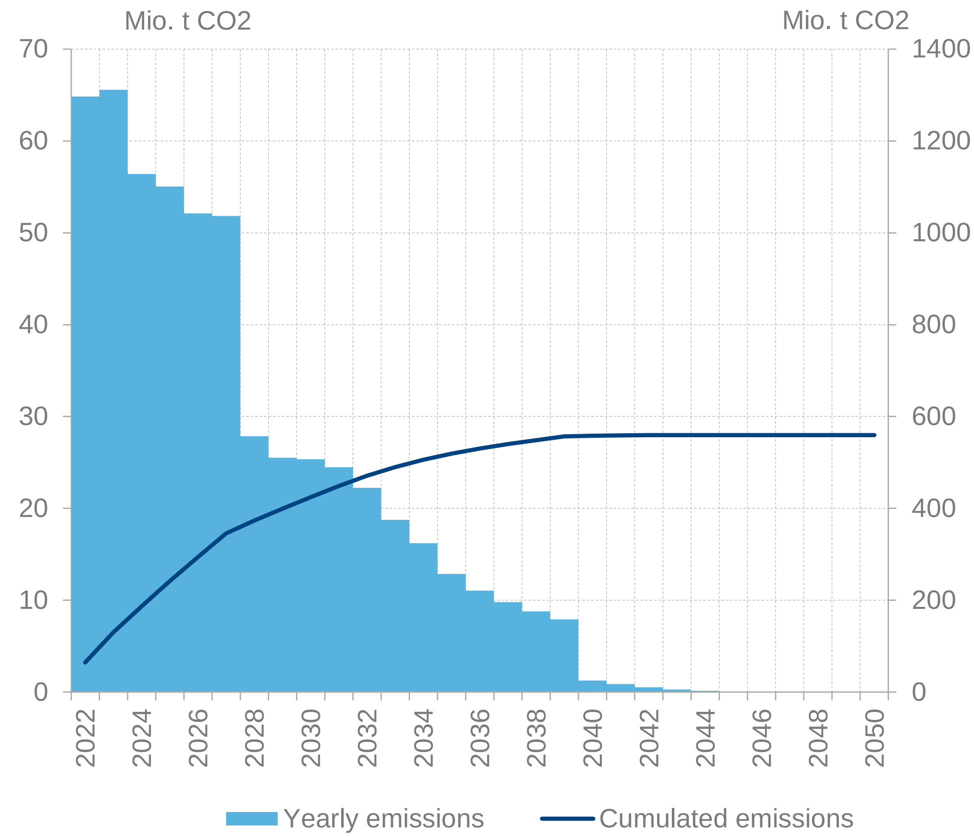
WB-6: emissions in smart transition (core vs. S3)

A redox-flow breakthrough has no significant impact on the total CO2 emission mitigation, though reduction of gas-based production in the 2030s decreases yearly emissions by about 10%.

ST: Core



ST: S3

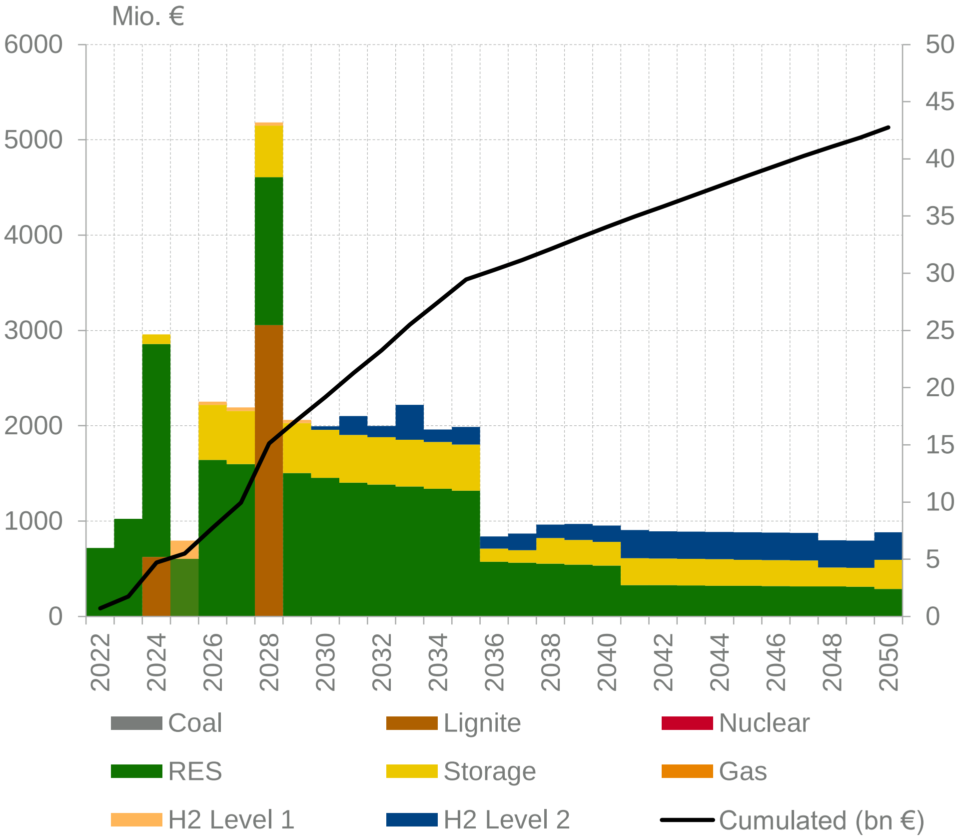


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

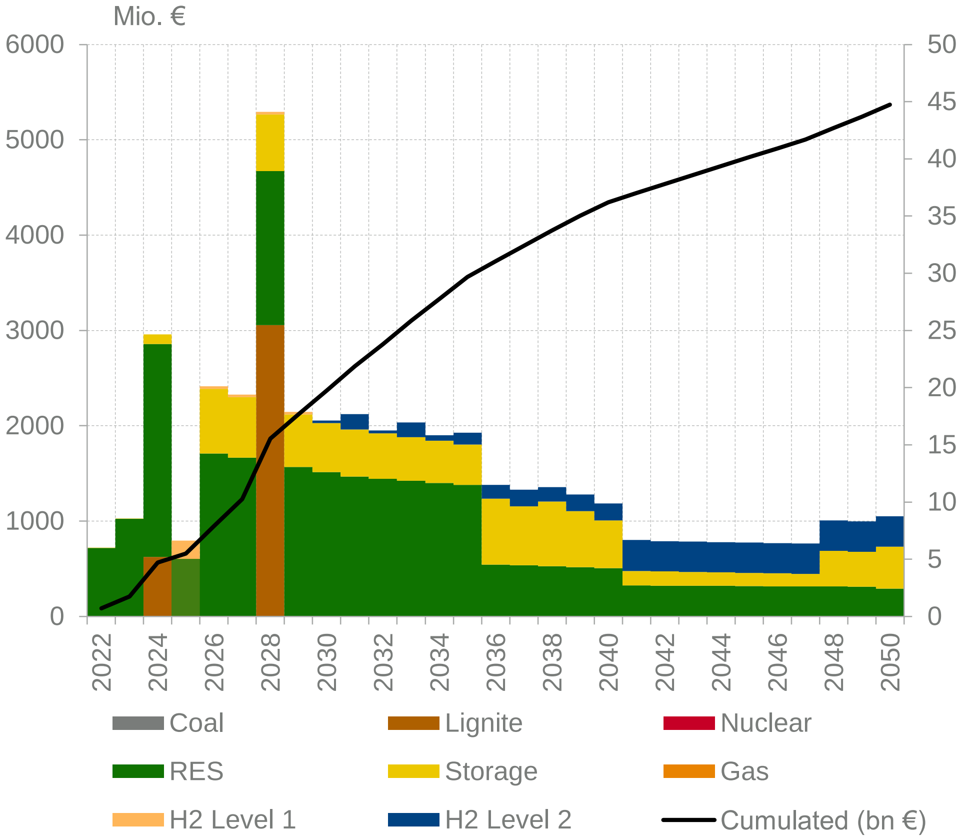
WB-6: investment costs in smart transition (core vs. S3)

Total cumulated investment volumes increase by about 5% in the sensitivity scenario. This is mainly driven by a shift and increase in total storage cost investment and to a lesser extend by additional RES capacities.

ST: Core



ST: S3

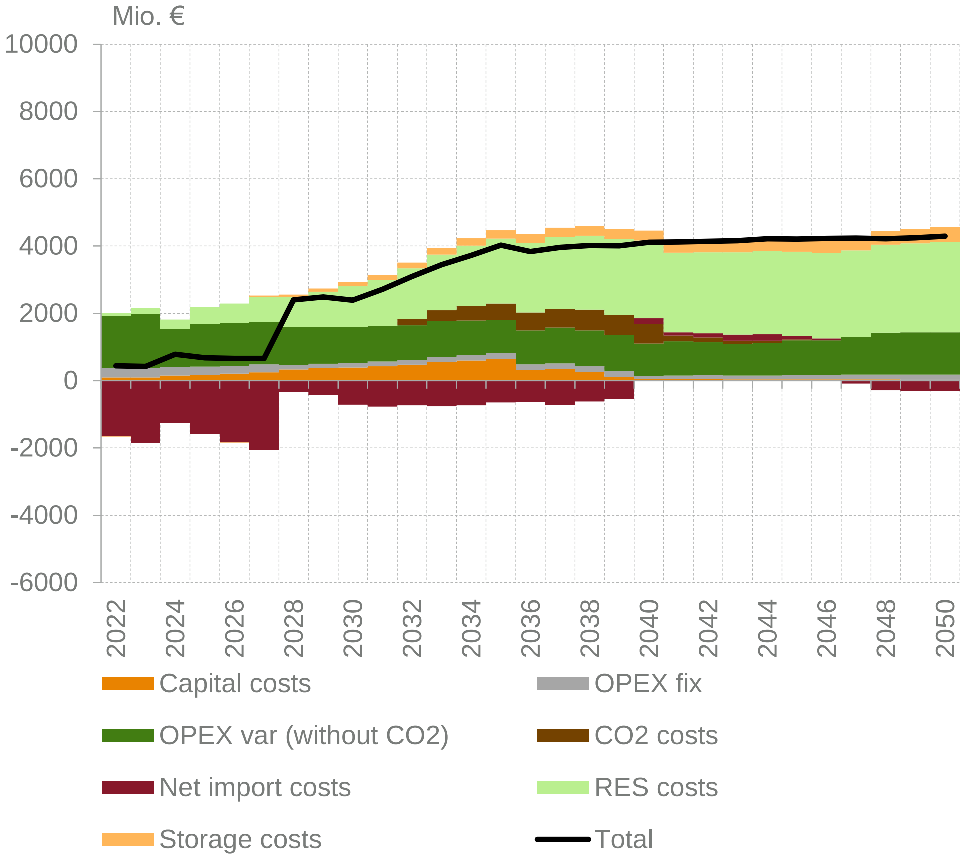


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

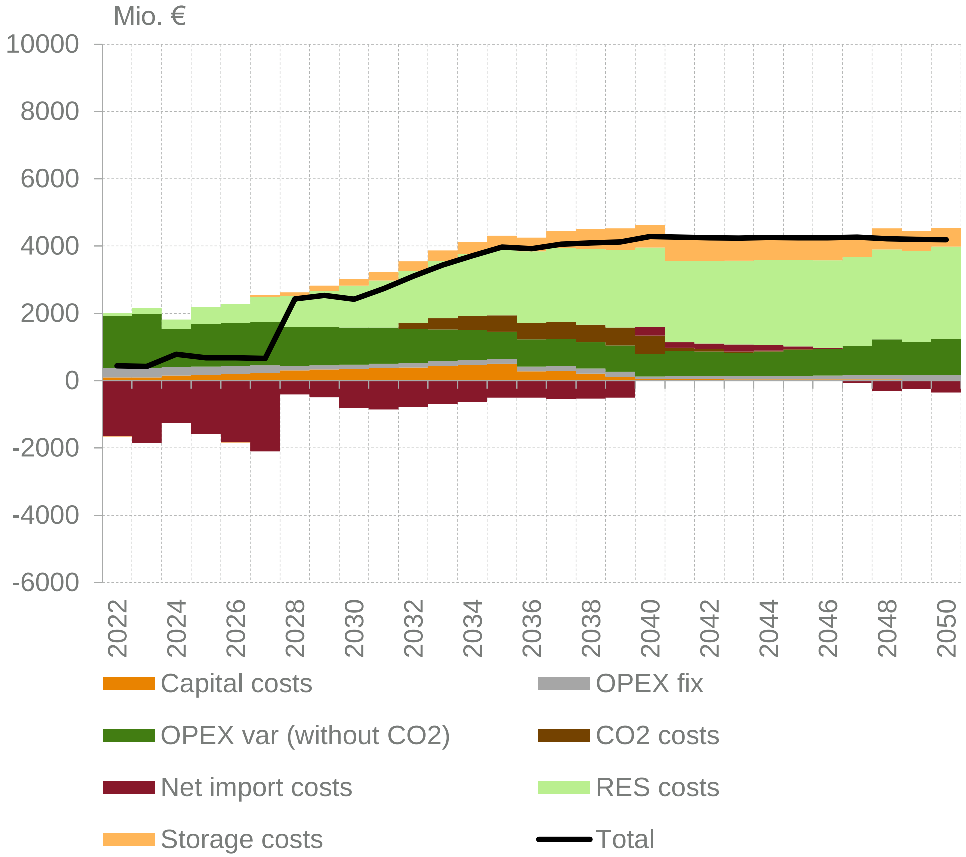
WB-6: incremental generation costs in smart transition (core vs. S3)

Total incremental generation costs are not significantly impacted and remain largely unchanged, since additional RES and storage expenditures are compensated by savings in CO2 and fuel costs.

ST: Core



ST: S3



Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

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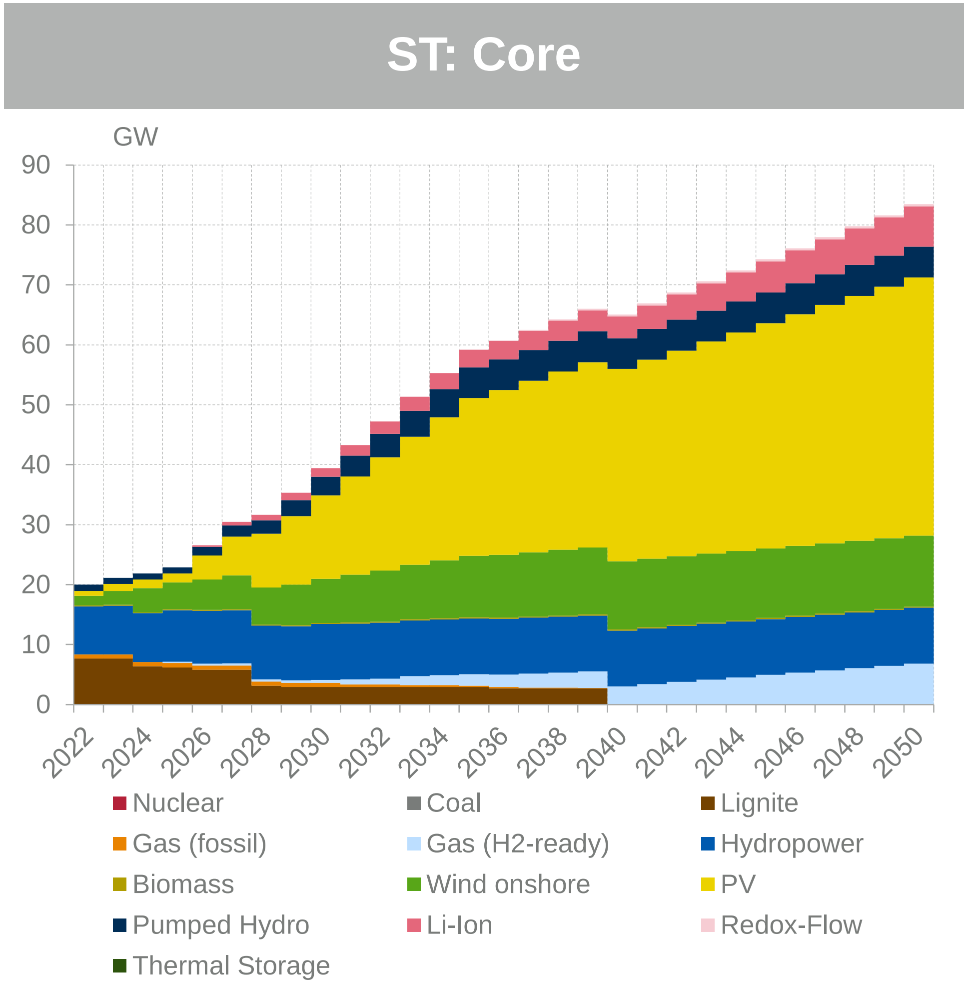
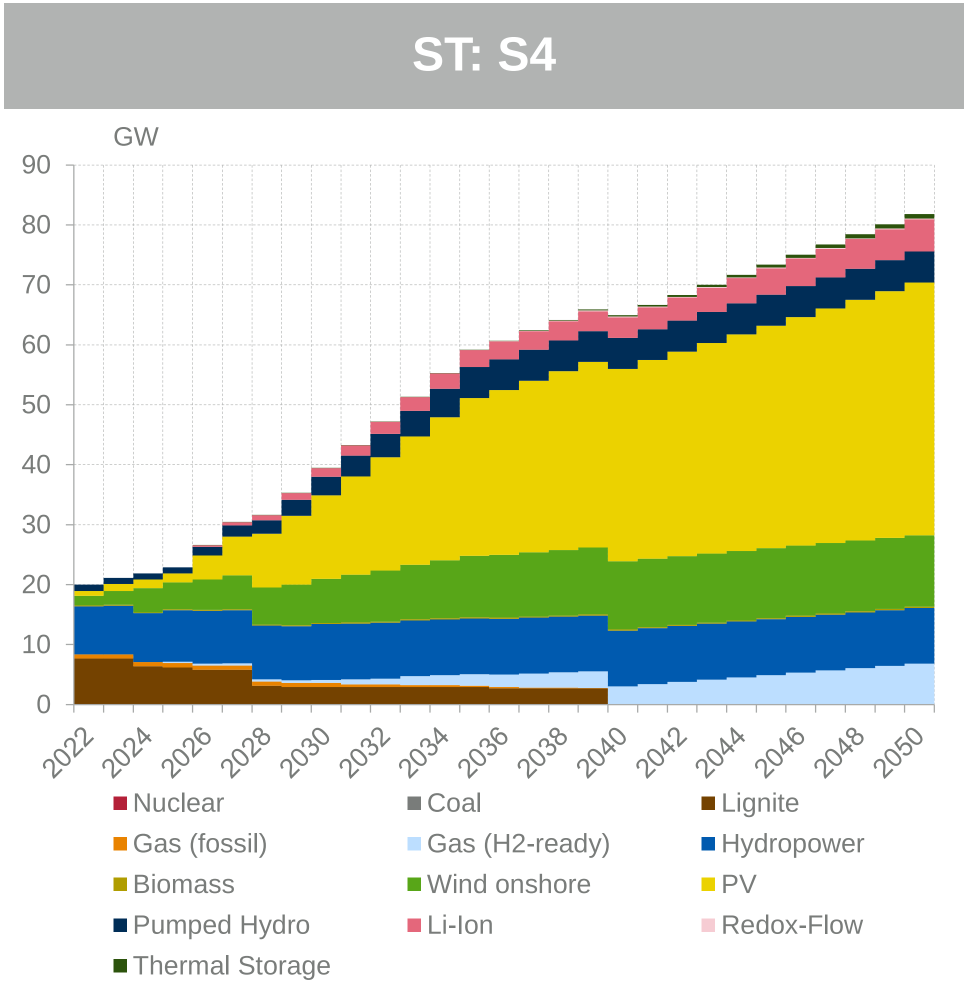
Sensitivity 4: Storage breakthrough (Thermal)

WB-6: capacities in smart transition (core vs. S4)

In a thermal storage cost breakthrough scenario, 0.7 GW thermal storage can replace 1.4 GW Li-Io batteries. This has no significant impact on the rest of the capacity mix.

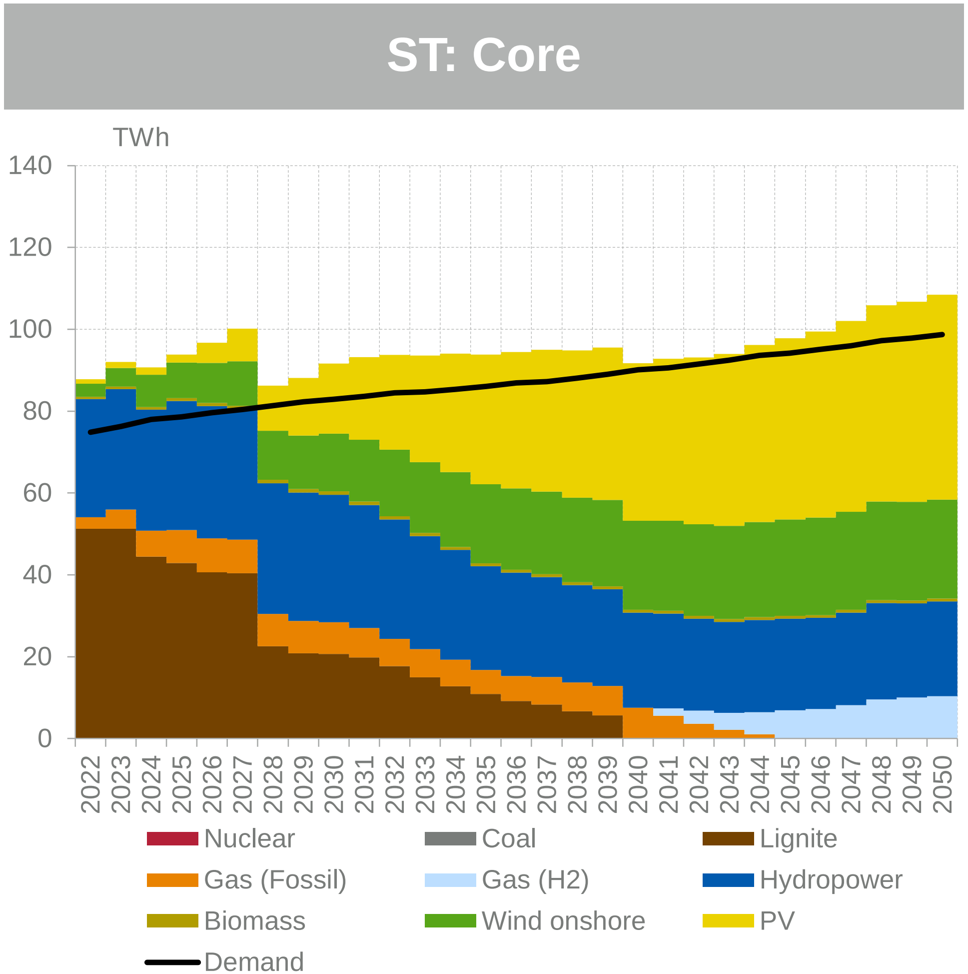


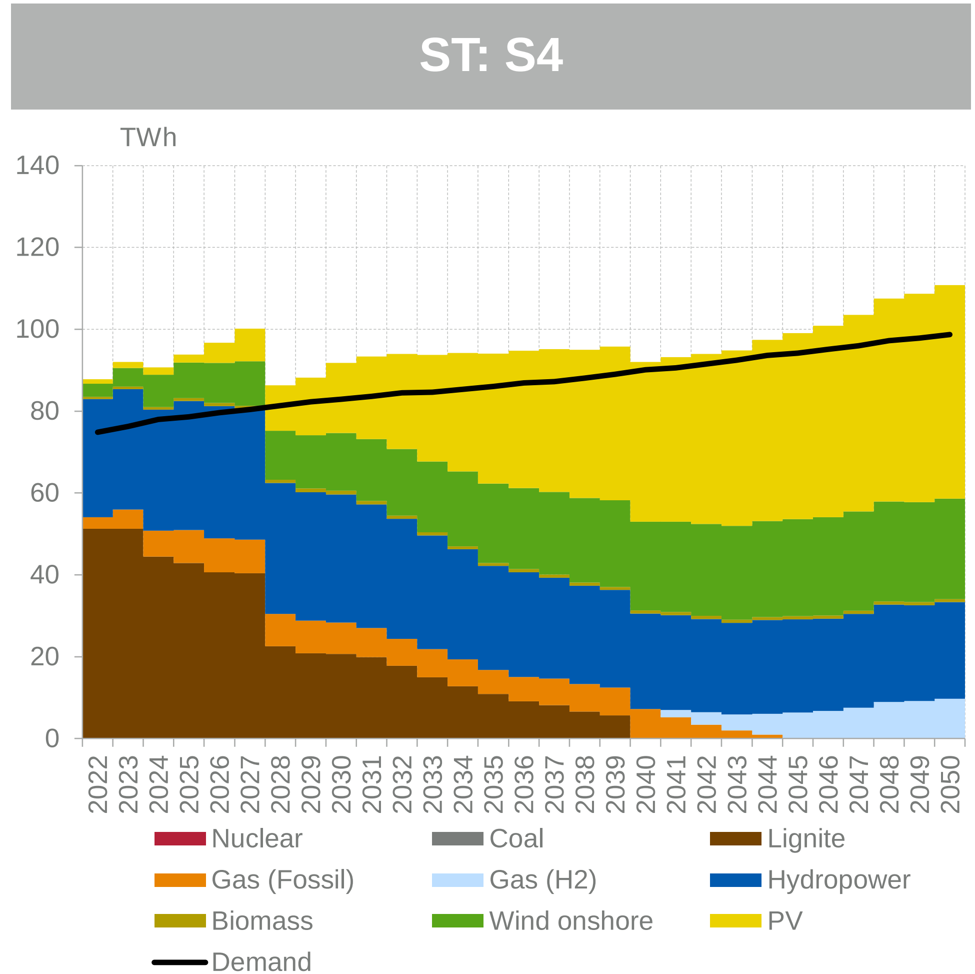


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

WB-6: generation in smart transition (core vs. S4)

In a thermal storage cost breakthrough scenario, the generation mix remains largely unchanged.



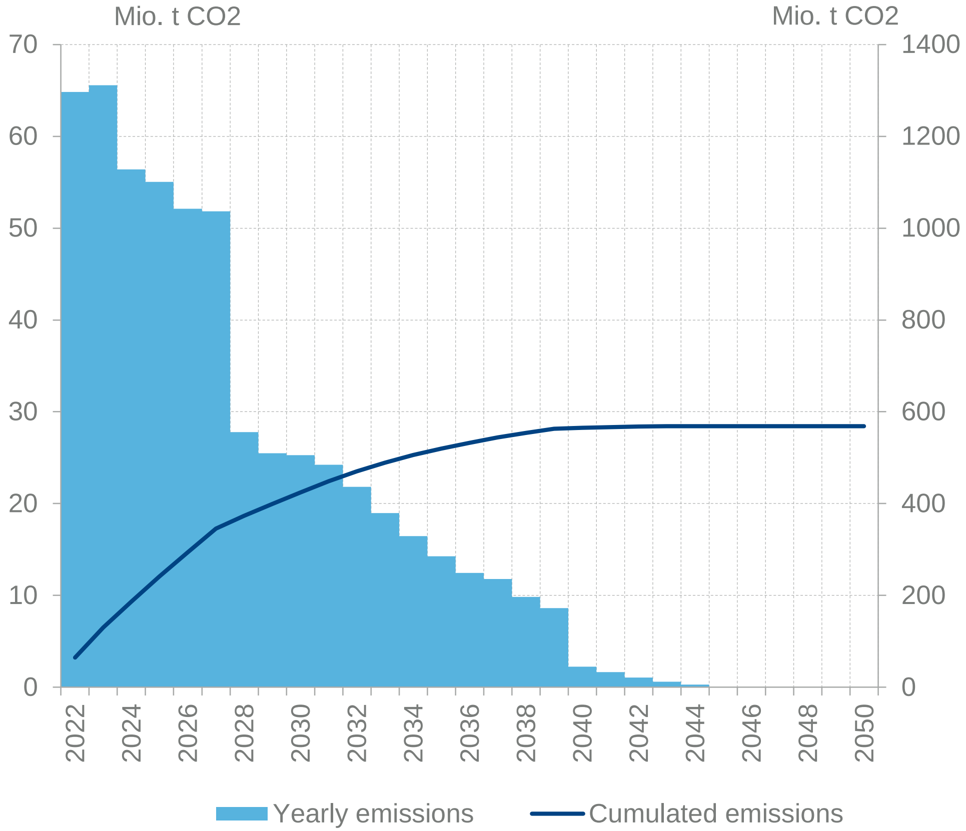


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

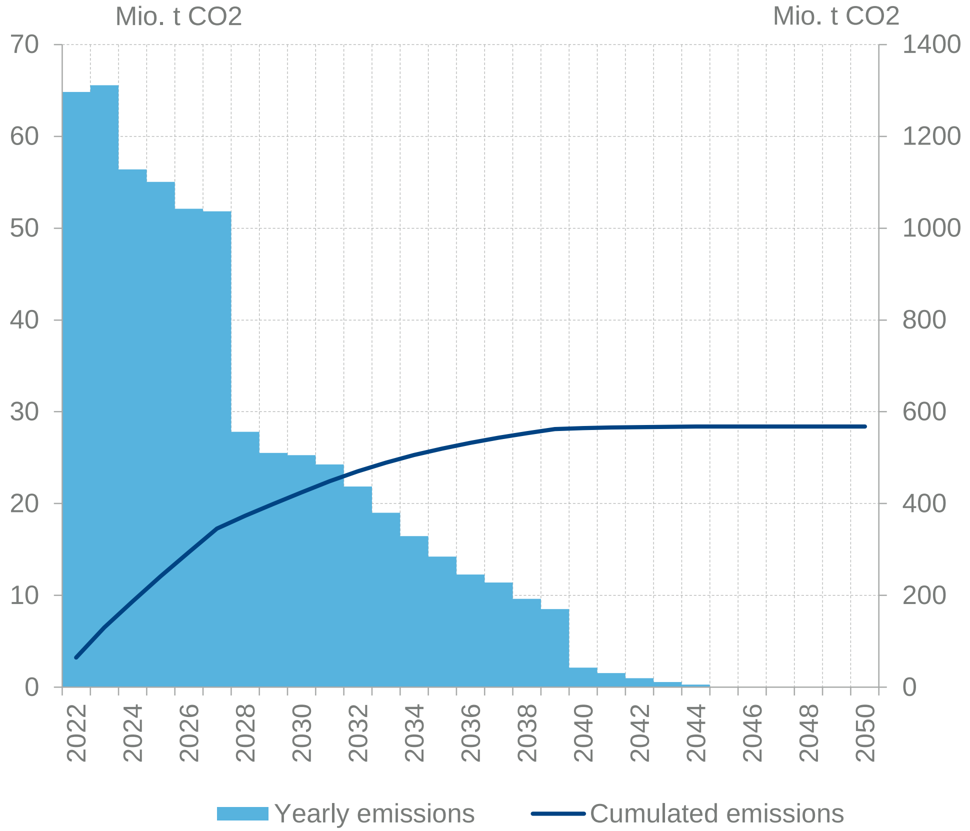
WB-6: emissions in smart transition (core vs. S4)

A thermal storage breakthrough therefore has no significant impact on the total CO2 emission mitigation.

ST: Core



ST: S4

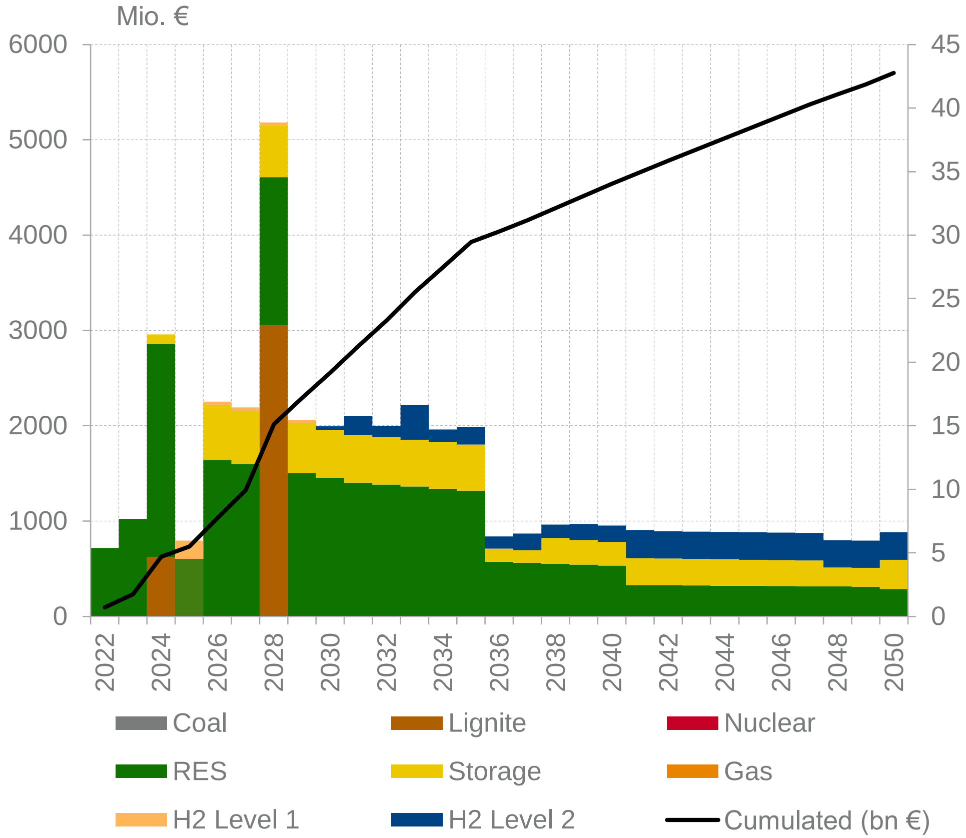


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

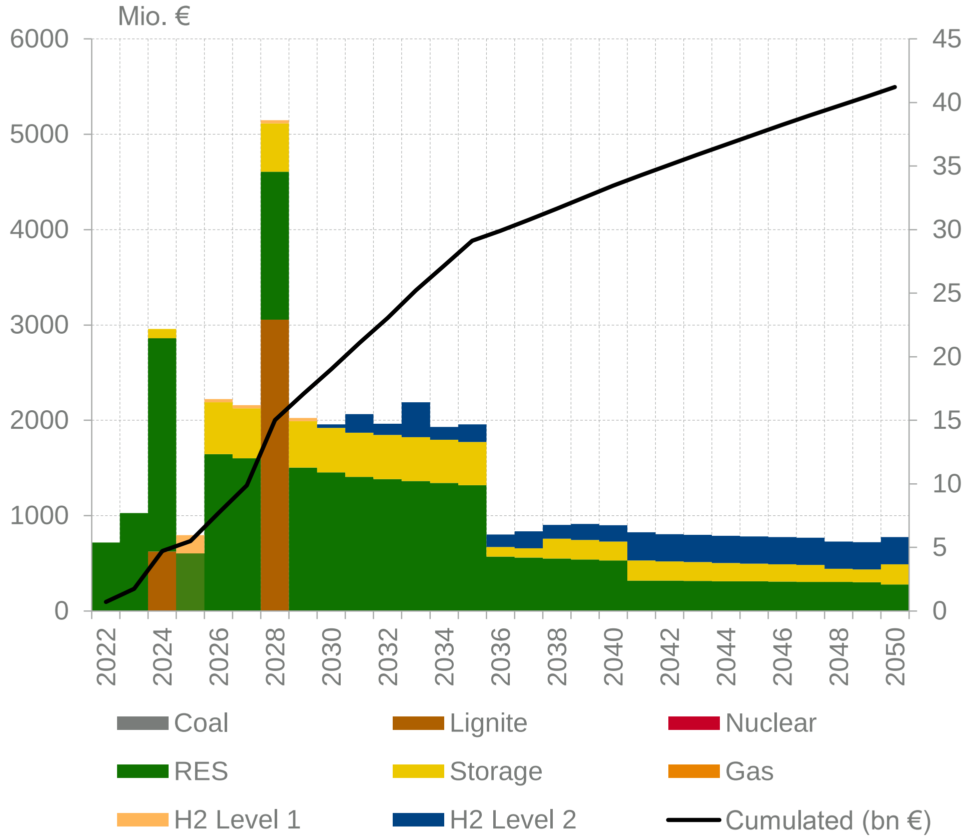
WB-6: investment costs in smart transition (core vs. S4)

Cumulated investment decrease by ~1% (cumulated by 2050).

ST: Core



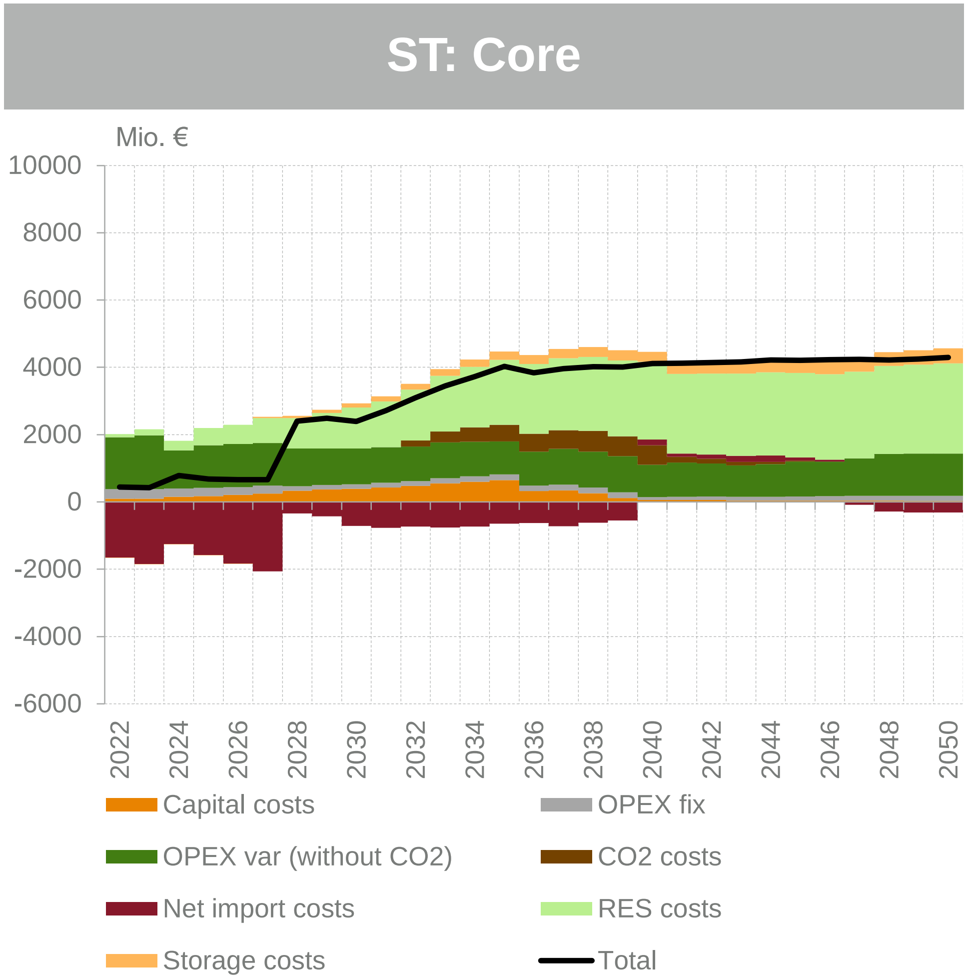
ST: S4

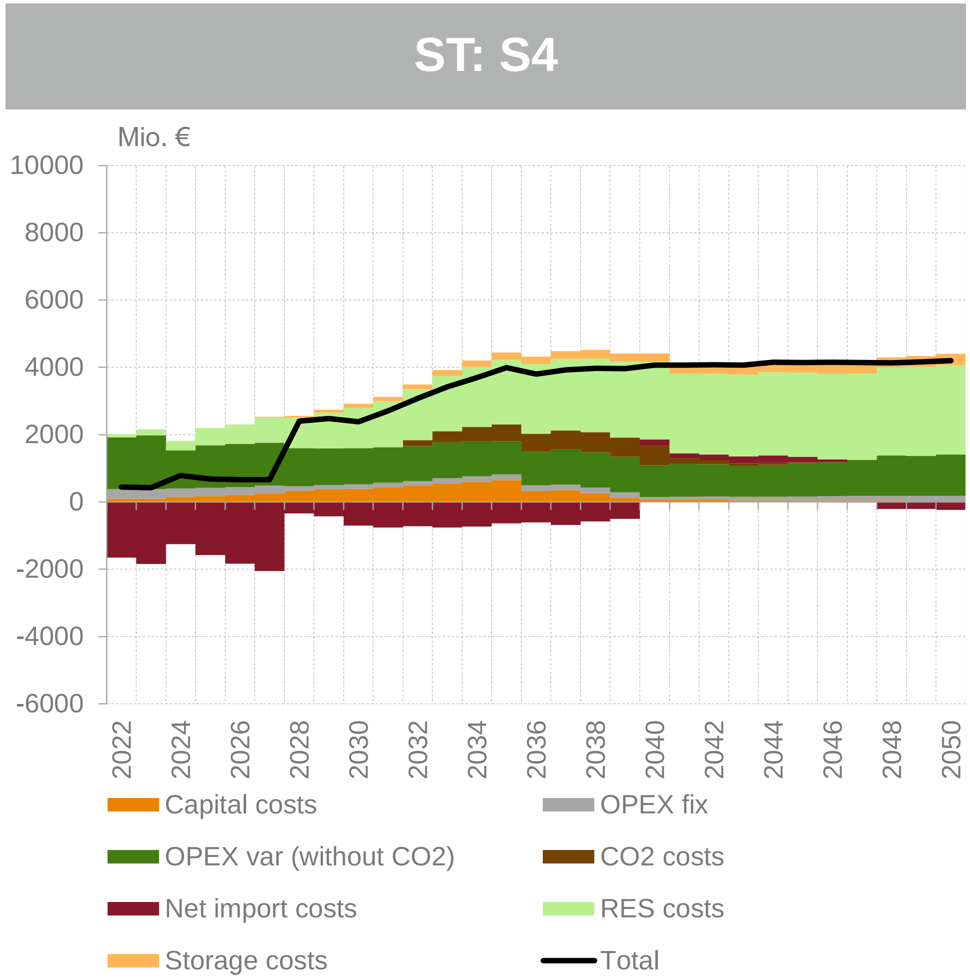


Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

WB-6: incremental generation costs in smart transition (core vs. S4)

Total incremental generation costs are slightly reduced but do not significantly impact the overall cost level & composition.





Core/S1: core policy scenarios, S2: H2 costs, S3: redox-flow battery breakthrough, S4: thermal storage breakthrough

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