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A plant-specific approach to model future hydrogen demands in energy-intensive industries

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Marius Neuwirth, Tobias Fleiter

Industrial Site Database

For energy-intensive industries in Europe

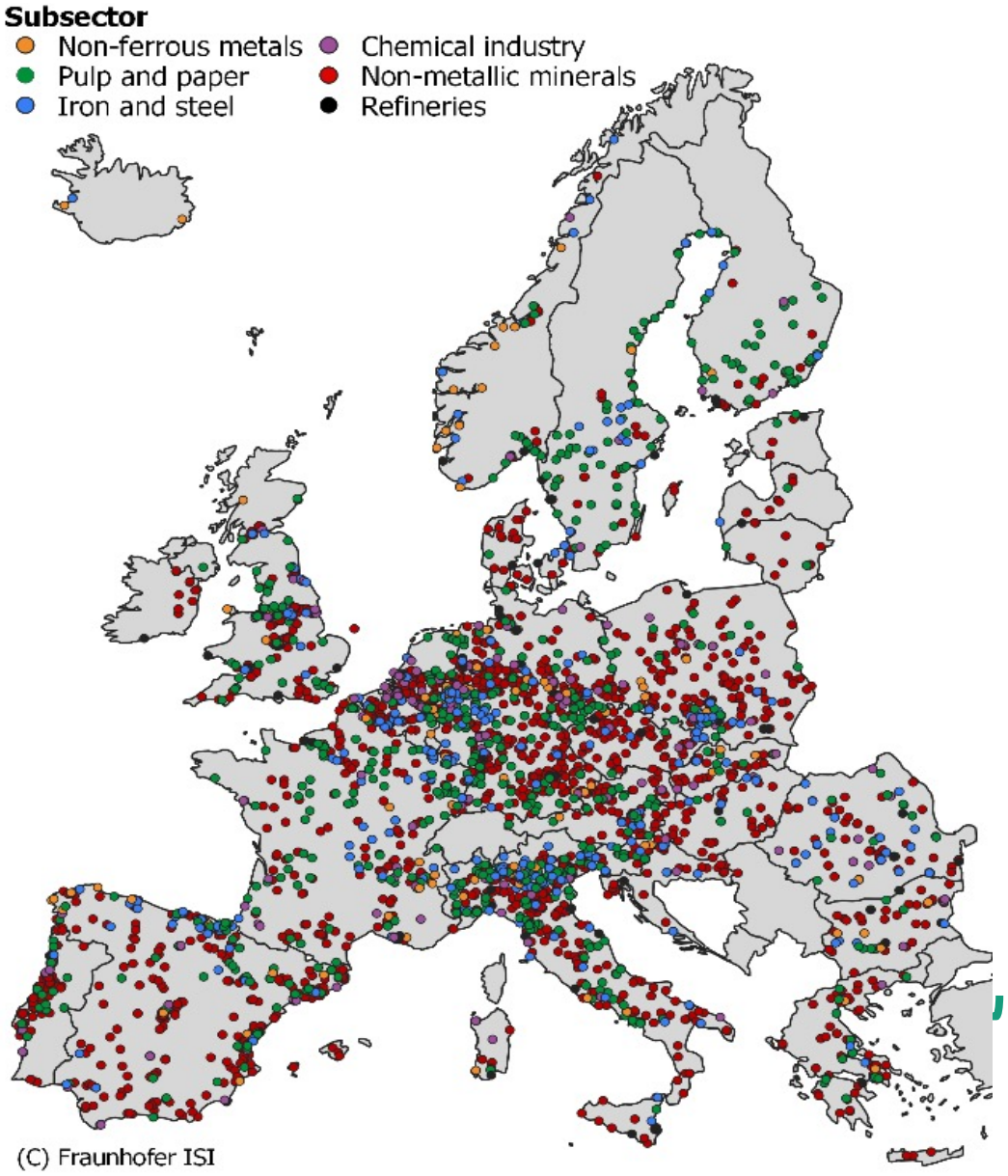
Industrial Site Database

Energy-intensive industry sites

- Iron and Steel
- Non-metallic Minerals
- (Basic) Chemicals
- Non-ferrous Metals
- Pulp and Paper
- Refineries

- Region (ID, Name)
- Geocoordinates (Lat., Long.)
- Processes status quo
- Plant Age (Year)
- Products
- Emissions (ETS) (tCO_2/year)
- Companies (ID, Name)
- Capacities (t/year)
- Others...

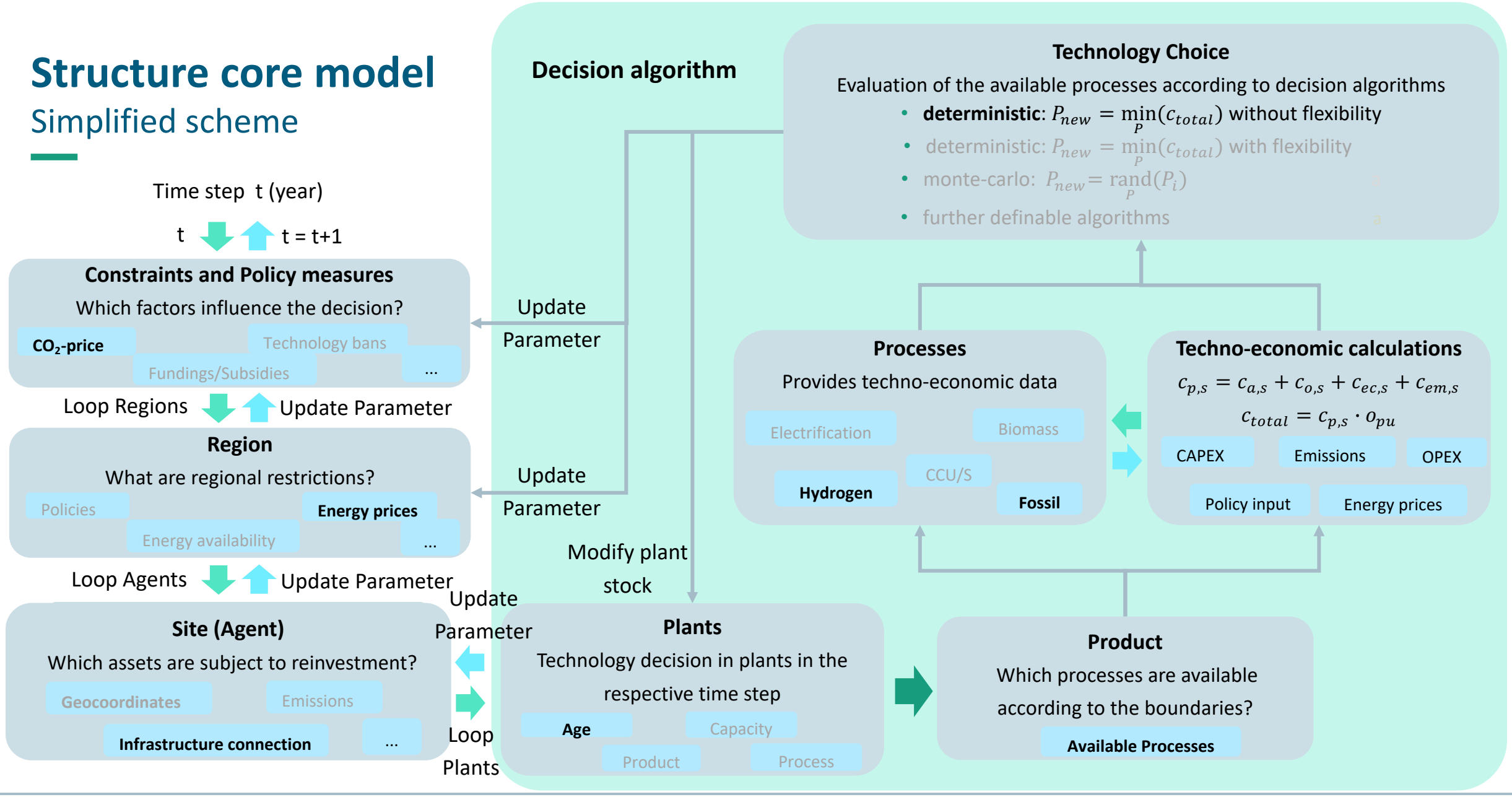
Georeferenced model input v



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Structure core model

Simplified scheme

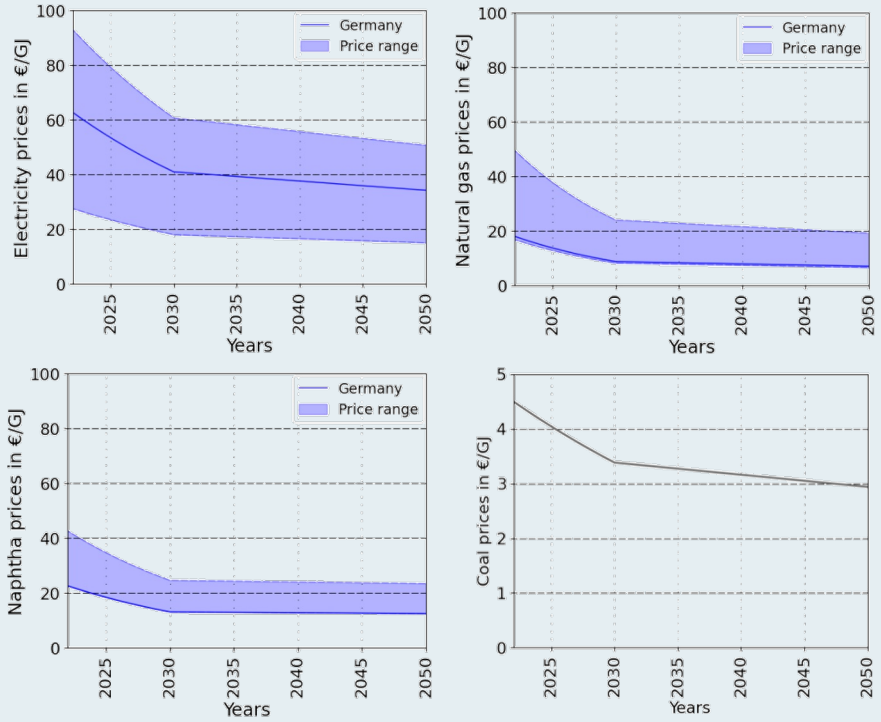


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Main drivers for the scenario results and transformation development

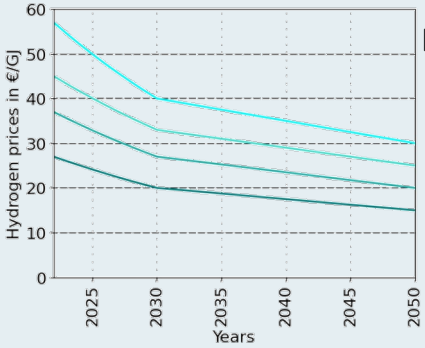
Energy prices, sensitivities and reinvestment cycles

Energy prices [€/GJ]

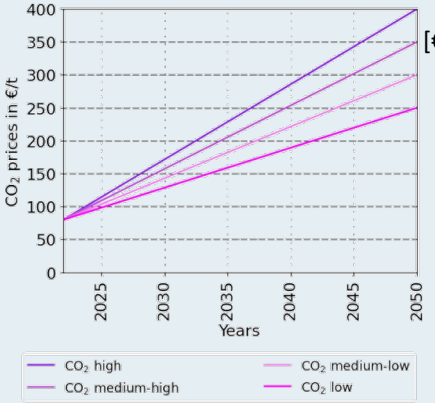


- Adjusted price assumptions to current situation
- Prices decline until 2030, but remain > pre-crisis
- Strong decline of H_2-prices until 2030

Variation of H_2 and CO_2 prices to calculate the sensitivity of the industry's response to these price signals

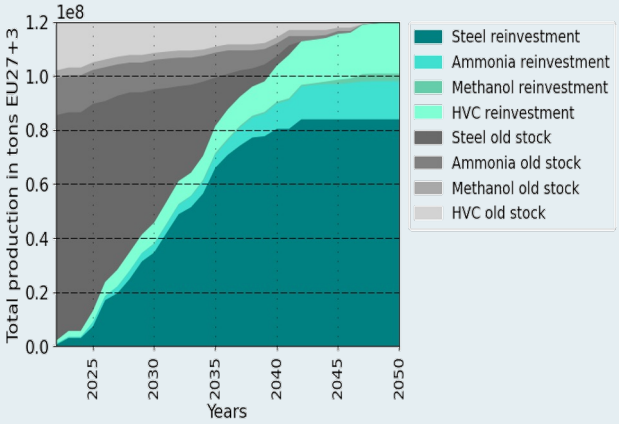


[€/GJ]	2022 – 2030 – 2050
1.	57 – 40 – 30
2.	47 – 34 – 25
3.	37 – 27 – 20
4.	27 – 20 – 15



[€/tCO$_2$]	2022 – 2030 – 2050
1.	80 – 130 – 250
2.	80 – 150 – 300
3.	80 – 160 – 350
4.	80 – 175 – 400

Reinvestment cycles



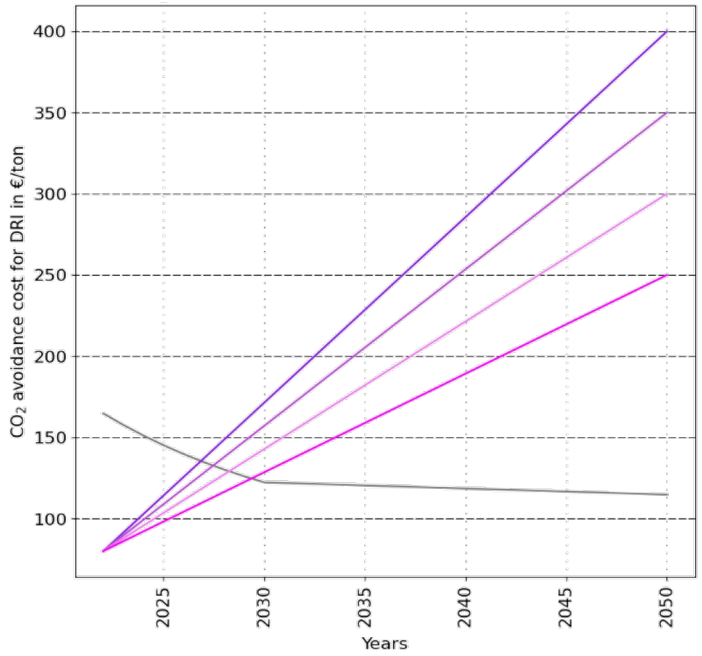
- **Lifetimes**
  - Blast Furnace: 20 a
  - Direct Reduction: 25 a
  - Ammonia SMR: 25 a
  - Methanol SMR: 25 a
  - Steam Cracker: 25-50 a

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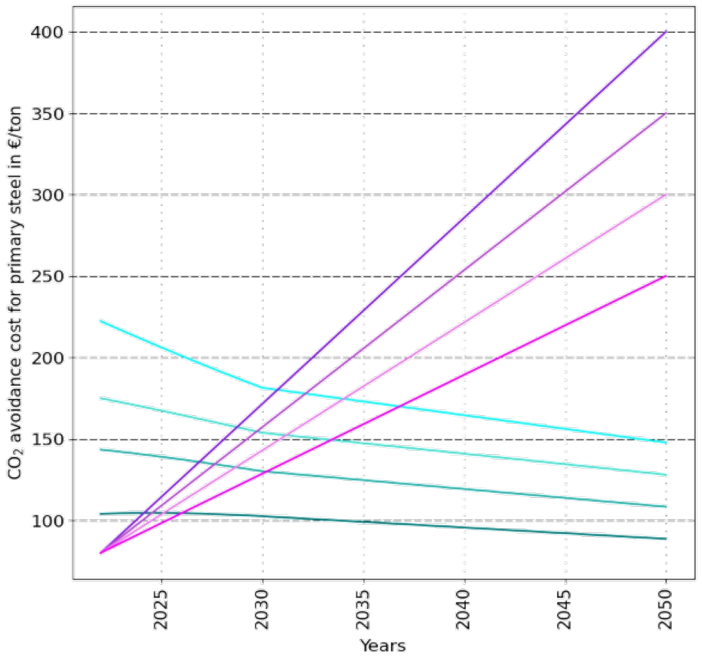
CO_2-avoidance costs according to H_2-price variations

Avoidance costs for primary steel comparison with CO_2-prices – Example Germany

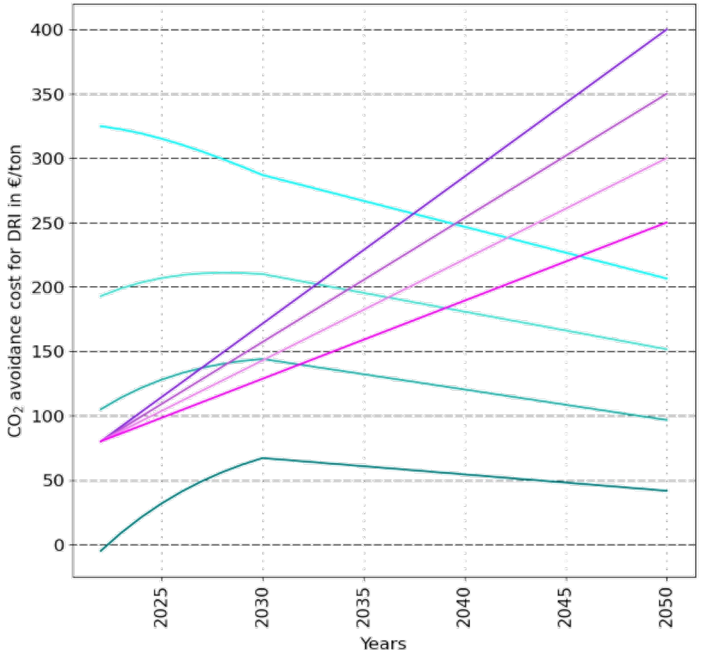
Blast furnace vs. NG-DRI



Blast furnace vs. H2-DRI



NG-DRI vs. H2-DRI



Relatively low dependence on the CO_2-prices

- Relatively low CO_2 avoidance costs of 120 to 130 €/tCO_2
- Economic viability for all CO_2 sensitivities before 2030

Dependence on H_2-price and CO_2-price

- Economic viability given very early on with low H_2-prices (100 €/tCO_2)
- Higher H_2-prices lead to stronger dependence on CO_2-prices (up to 180 €/tCO_2)

Dependence on CO_2-price at higher H_2-prices

- H2-DRI gets economically viable until 2050
  - Even for high H_2 prices (at 200 to 260 €/tCO_2)
- Lower H_2-prices lead to very low CO_2 avoidance costs (70 €/tCO_2)

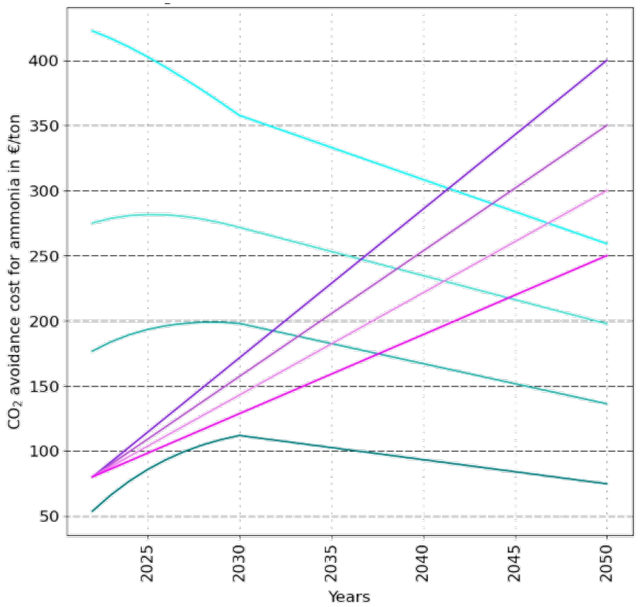
CO_2 avoidance cost for coal and natural gas price case
CO_2 avoidance cost in high hydrogen price case
CO_2 avoidance cost in medium-high hydrogen price case
CO_2 avoidance cost in medium-low hydrogen price case
CO_2 avoidance cost in low hydrogen price case
CO_2 high
CO_2 medium-high
CO_2 medium-low
CO_2 low

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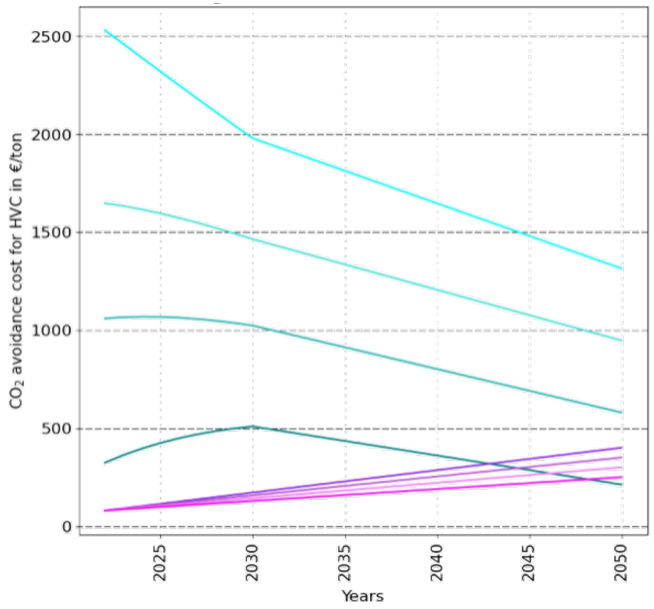
CO_2-avoidance costs according to H_2-price variations

Avoidance costs for basic chemicals and comparison with CO_2-price assumptions

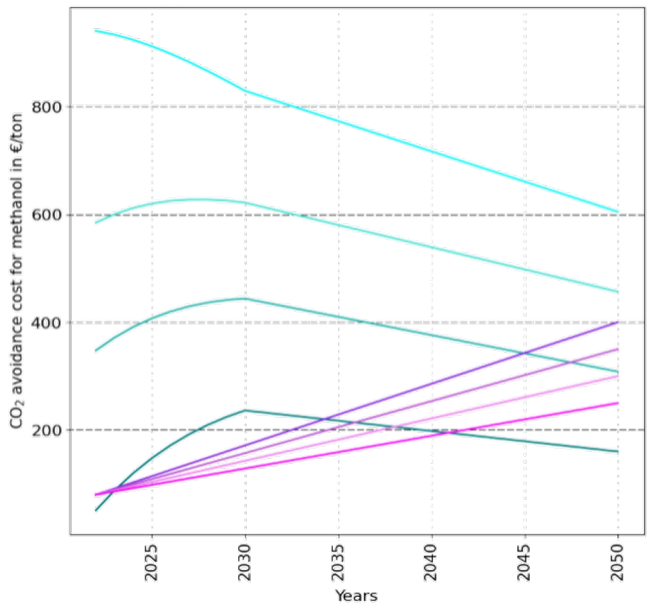
Ammonia SMR vs. Ammonia H2



Steam Cracker vs. MtO



Methanol SMR vs. Methanol H2



Relatively strong dependence on CO_2-price

- Strong dependence on both H_2 and CO_2-prices
- Very sensitive price reactions
  -> Low H_2-prices needed to avoid Lock-ins
- Switch driven by price difference H_2 vs. NG

Very low effects of CO_2-prices

- Very high avoidance costs
  - Only scope 1 emissions are covered (20%)
    -> Naphtha as feedstock not affected
- Just for low H_2-prices late competitiveness

High avoidance costs depending on H_2-prices

- High dependence on H_2-prices due to relatively low CO_2-emissions (partly embedded in the product)
- Low H_2-prices needed – leading to strong sensitivity on CO_2-prices

CO_2 avoidance cost in high hydrogen price case
CO_2 avoidance cost in medium-high hydrogen price case
CO_2 avoidance cost in medium-low hydrogen price case
CO_2 avoidance cost in low hydrogen price case
CO_2 high
CO_2 medium-high
CO_2 medium-low
CO_2 low

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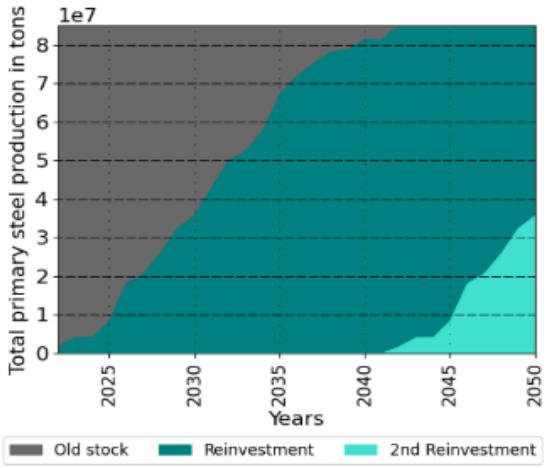
Age structure an theoretical reinvestments per product

At least one re-investment decision until 2050 for each plant considered (theoretical “full replacement”)

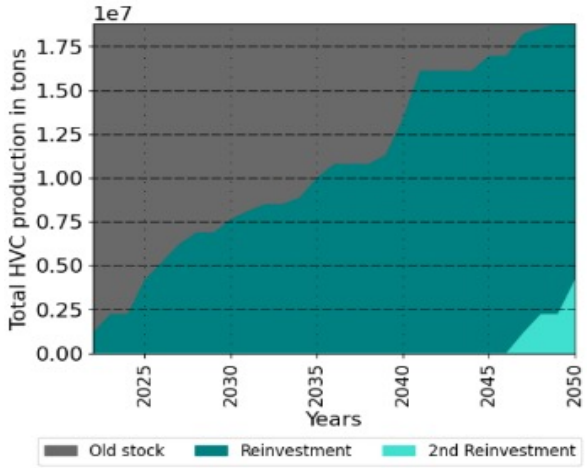
- Blast furnaces in operation are relatively old: 42% require reinvestment by 2030
- Steam crackers (HVC production) are old: 39% of possible reinvestments by 2030
- SMR units for Methanol production: 51% possible reinvestments by 2030
- SMR units for ammonia production: only 22% possible reinvestment by 2030.

➡ **Approach:** Better understanding of the danger of lock-ins by assessing the techno-economic competitiveness in availability of hydrogen infrastructure

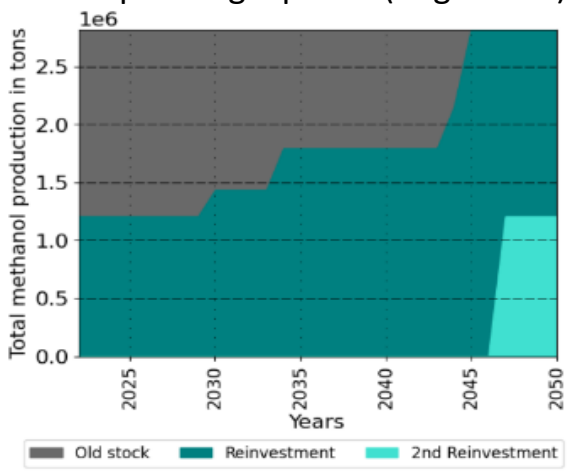
Steel, primary
28 sites operating 58 blast furnaces



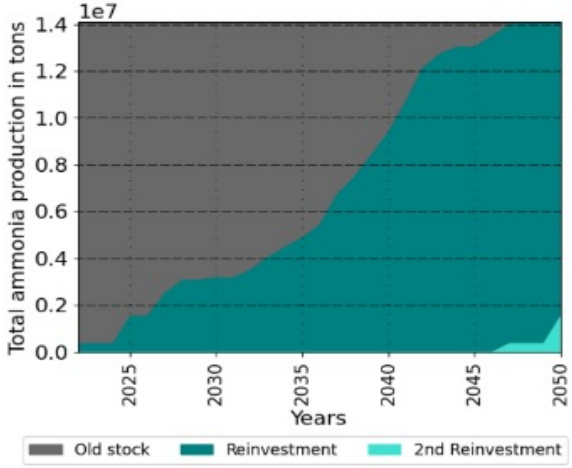
High Value Chemicals
36 sites operating 47 steam crackers



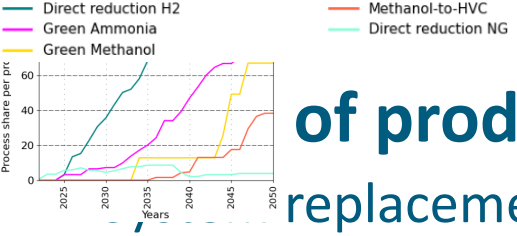
Methanol
6 sites operating 7 plants (large-scale)



Ammonia
31 sites operating 41 plants



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# of production capacity per process

replacement dependent on reinvestment cycles and EHB

Primary steel:

- Relatively low CO_2-prices sufficient for phase-out of blast furnaces
  - With high H_2-prices, late substitution of natural gas utilisation in DRI
  - Replacement of natural gas with higher CO_2-prices only from 2040
- Medium H_2-prices lead to early replacement of natural gas utilisation
- Early higher CO_2-prices or lower H_2-prices reduce fossil reinvestments

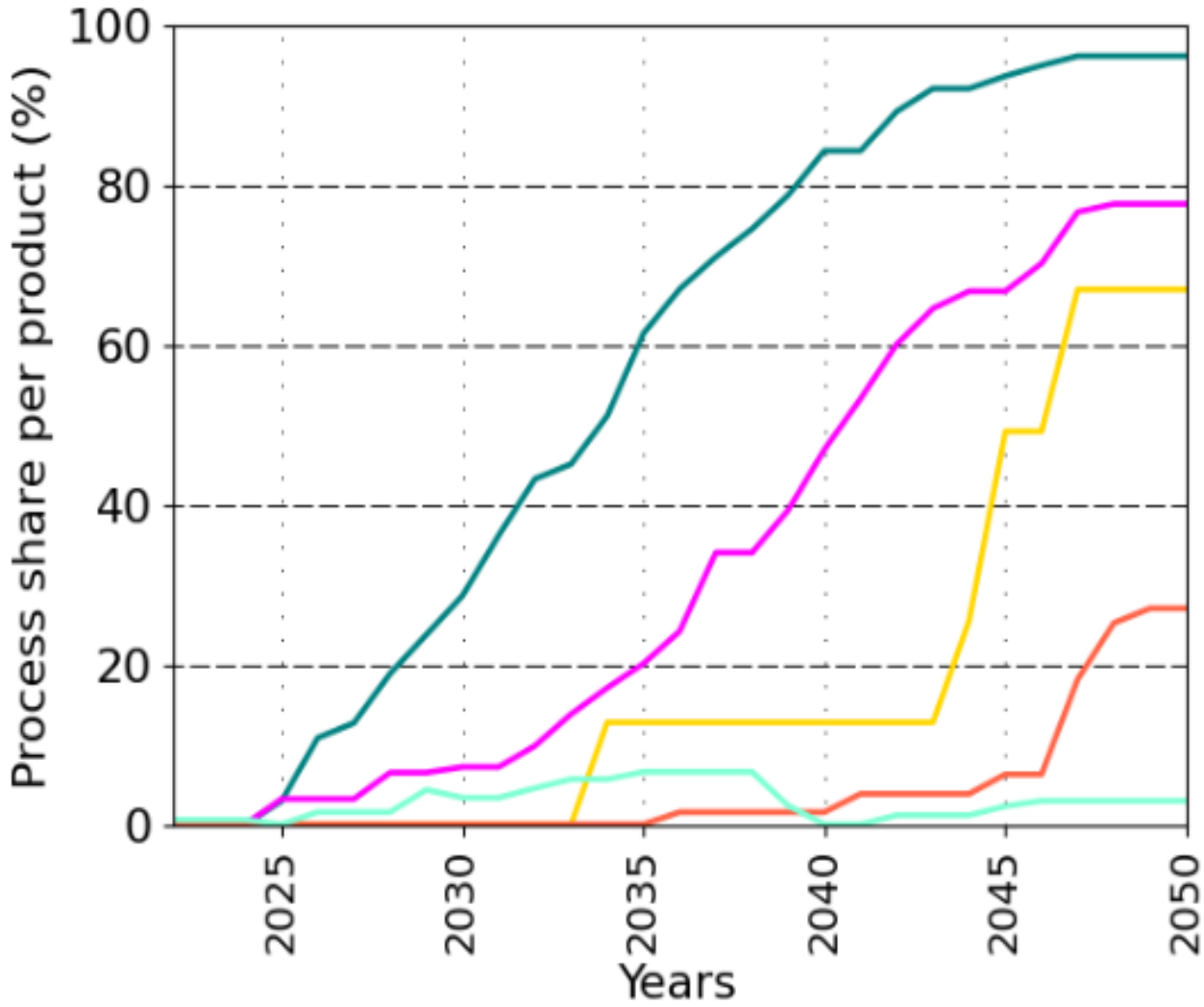
Ammonia:

- Diffusion towards hydrogen accelerates with higher CO_2 prices
  - Up to 50% of European capacity for high H_2 prices
  - UP to 80% of European capacity for low H_2 prices

HVC and methanol:

- Conversion of HVC and methanol capacity only at extremely low H_2 prices
  - Huge lock-ins through steam cracker and SMR reinvestments

➡ Late economic viability of H_2-based production in all sensitivities



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Investigation on two sensitivities with different H_2 prices

Investment decisions based on plant age, reinvestment cycles and price signals

How to read the figure?

- Area plots: total production shares in tons per process
- Bar charts: newly added investment per year in tons per process

Sensitivity 5

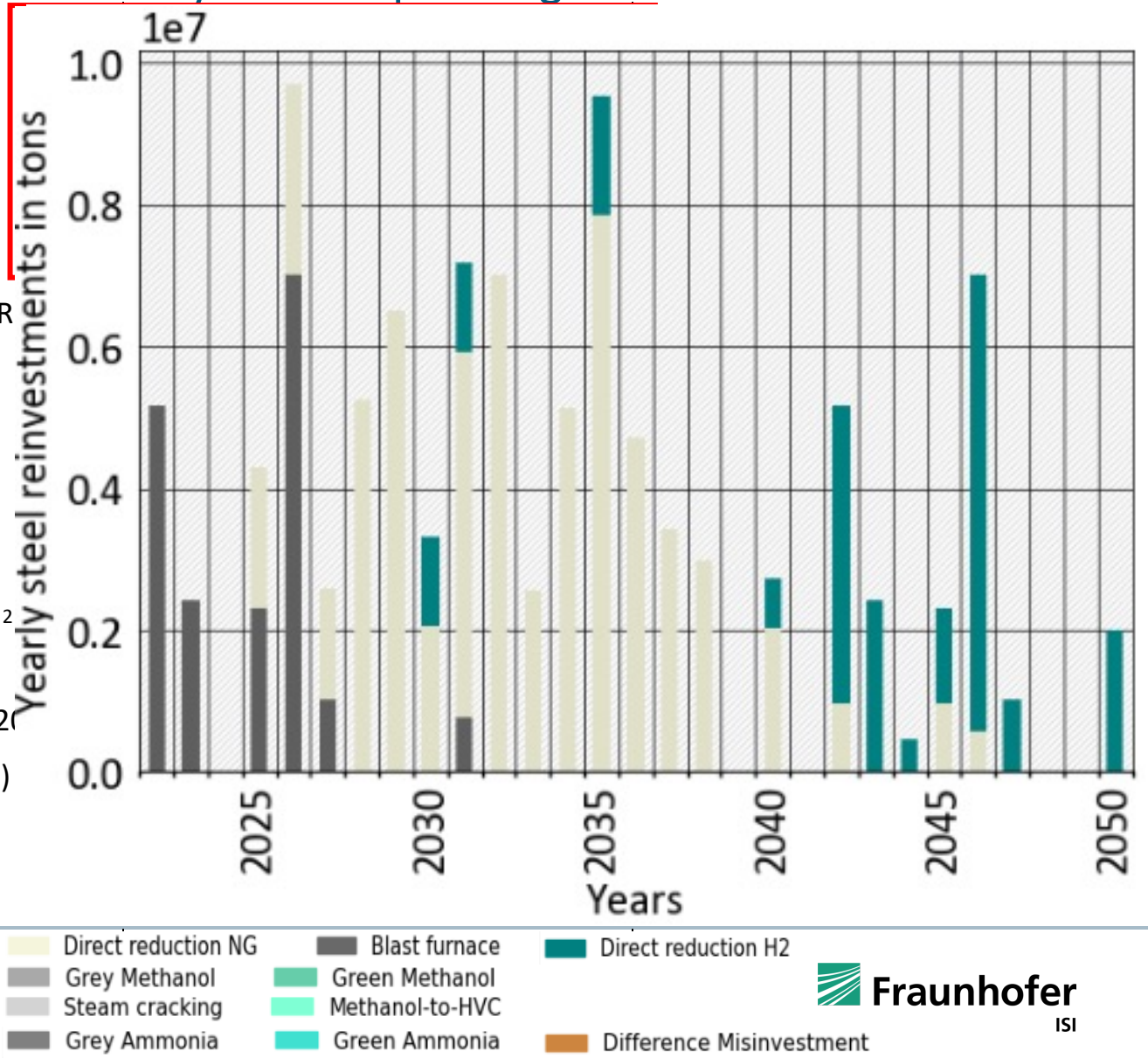
- Steel: Fossil reinvestments in the beginning and huge share of NG-DR
- Ammonia: Fossil reinvestments and late diffusion of hydrogen
- HVC: Fossil reinvestments, no competitiveness for hydrogen
- Methanol: Fossil reinvestments, no competitiveness for hydrogen

Sensitivity 8

- Steel: Less fossil reinvestments in the beginning and huge share of H_2
- Ammonia: Earlier competitiveness and larger share of H_2 (77%)
- HVC: Fossil reinvestments dominating, few hydrogen basically from 2
- Methanol: Less fossil reinvestments, late diffusion of hydrogen (60%)

Effects of early reinvestments in fossil processes

- Fossil reinvestments still operating in 2050 lead to lock-in



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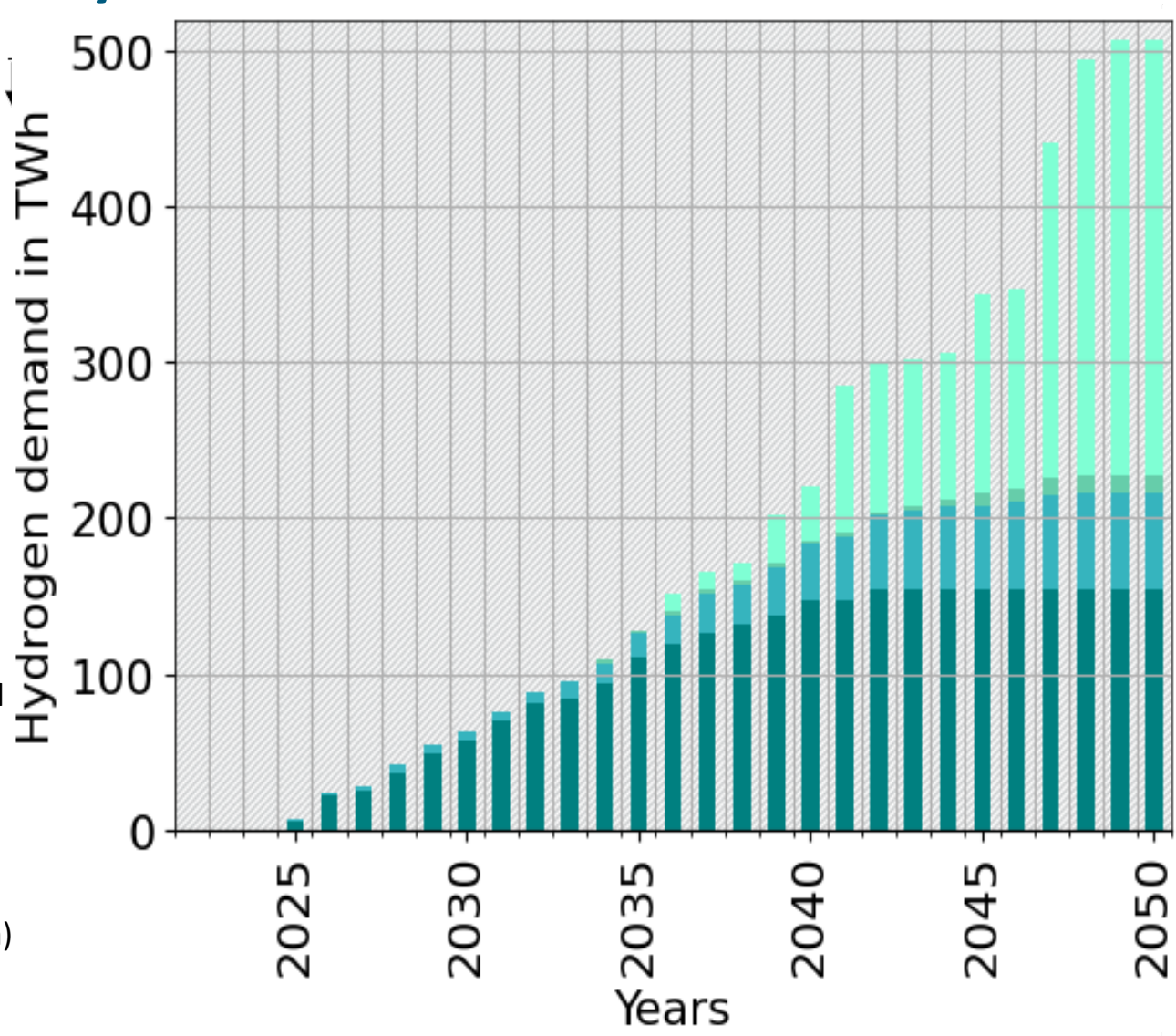
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Hydrogen demand ramp up per sensitivity

Dependence on reinvestment cycles and EHB

Development of the hydrogen demand

- Generally expected demand development of the sensitivities
  - Lower H_2-demand for lower CO_2- and higher H_2-prices
  - Surprisingly (?) low hydrogen demand of 64 TWh in the lowest case
- Very sensitive tipping points at high H_2-prices due to the CO_2-prices
  - Driven by flexible change towards H_2 for DRI
- Roughly linear increase in H_2 demand until 2040 for low H_2 prices
  - Ca. 200 TWh H_2 demand in long term for ammonia and primary steel
- Extreme increase in H_2 demand to 500 TWh with conversion of HVC
  - Although only 20 of 47 Steam Cracker get replaced!
  - Potential at complete replacements significantly higher (~ 1000 TWh)

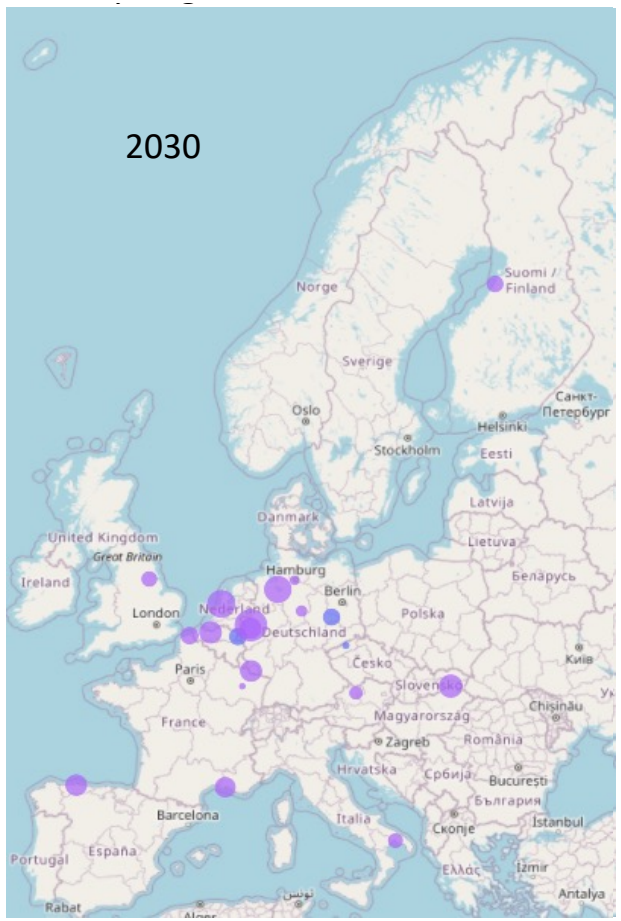


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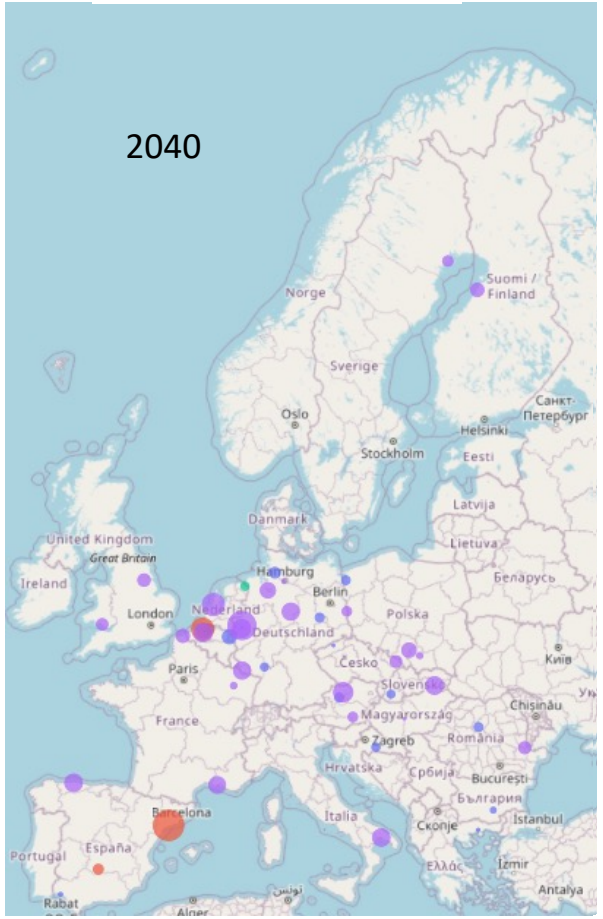
Development of hydrogen demand in most supporting sensitivity

Spatial distribution: Replacement based on reinvestment cycles and EHB plans

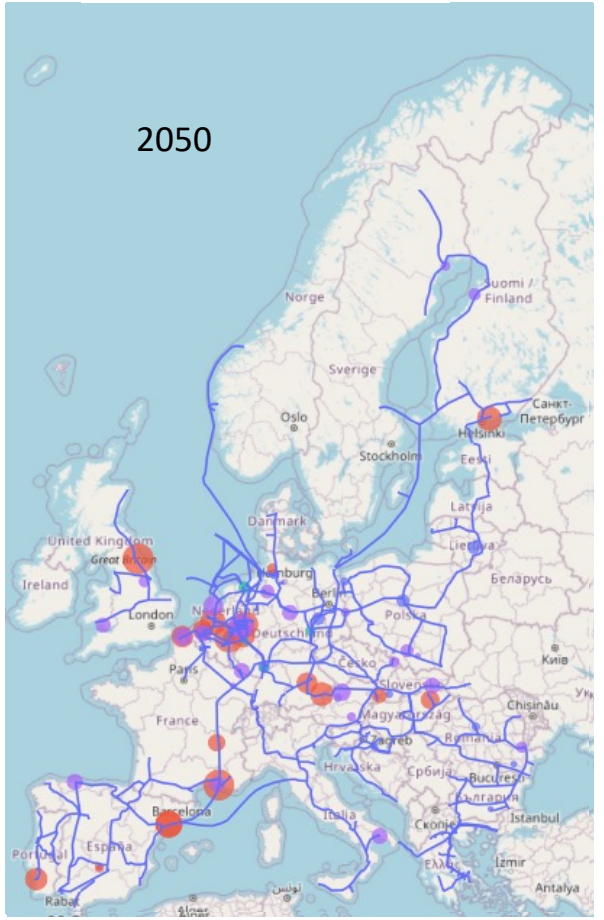
Hydrogen demand 2030



Hydrogen demand 2040



Hydrogen demand 2050



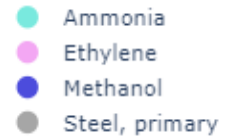
- Ammonia
- Ethylene
- Methanol
- Steel, primary

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Difference of hydrogen demand

Replacement differences by considering EHB plans and without considering EHB plans







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Summary and Conclusions

1. Industry is seen as main hydrogen consumer, but substantial uncertainties about dynamics and concrete pathways still exist.
2. Full market diffusion of (H_2-based) alternatives until 2050 is unlikely.
3. Early reinvestment needs show high danger for lock-ins (as there is also scarcity for supplying large-scale investments).
4. Competitiveness of climate-neutral processes depends on energy prices (especially hydrogen).
5. Economic viability varies strongly between the products and processes (as seen from avoidance costs).
6. Especially HVC and methanol require very low H_2 prices and are not economically viable in medium-tem.
7. Impact of CO_2 pricing particularly weak due to fossil carbon being embedded in the basic chemical products.
8. Plant lifetimes more strictly for steel while chemical plants don´t have those strict lifetimes.

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Thank you very much for your attention!

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