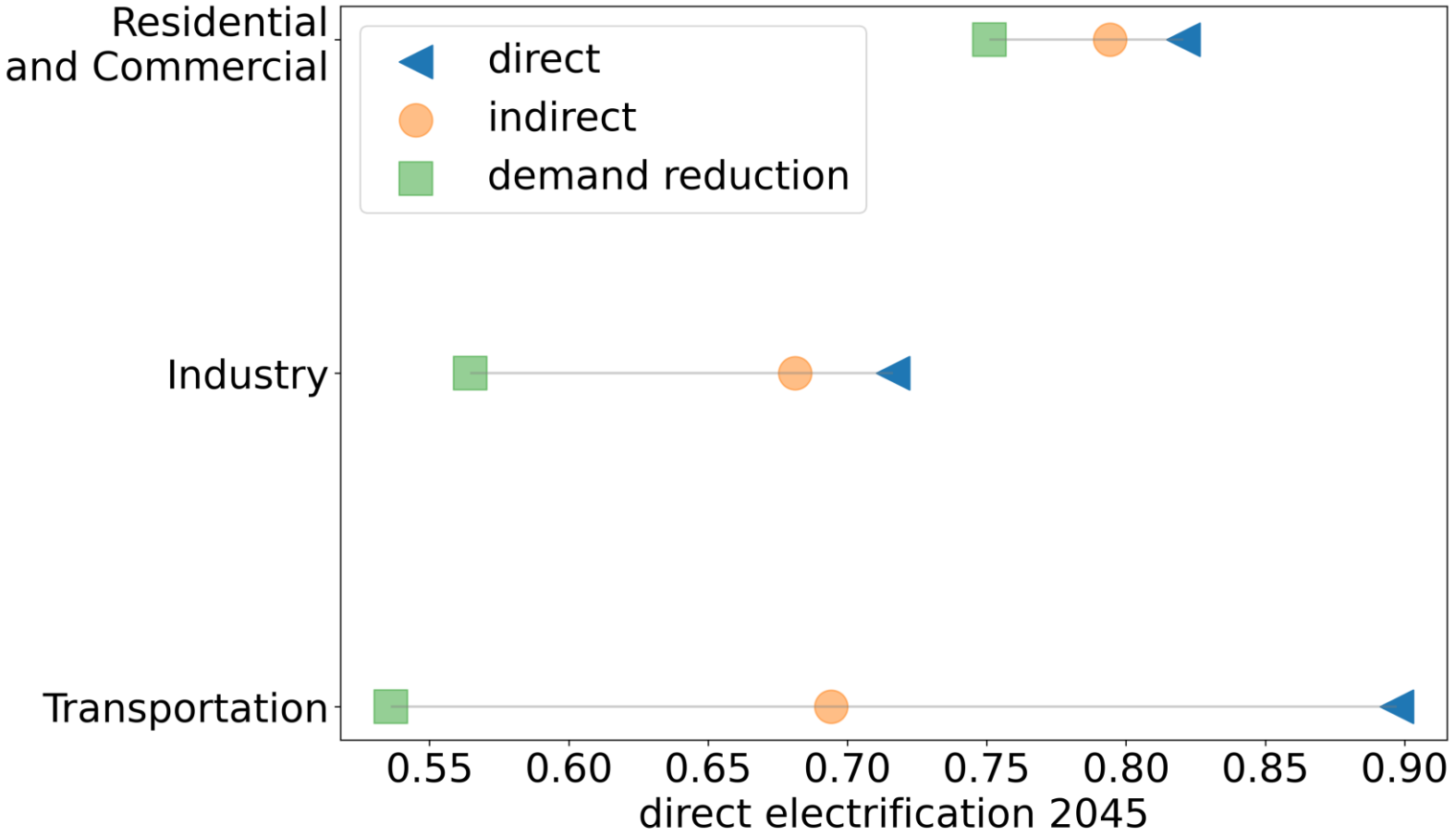
# Pathways to a GHG-neutral German industry: Assessing the role of direct and indirect electrification and demand reduction

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**eceee**
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# Research Questions

1. In a sector-coupled energy system model, how does the **cost-optimal transformation of the industry sector** look like in scenarios between **direct- and indirect electrification and demand reduction**?

2. Which **impacts** do different transformation pathways between **direct- and indirect electrification and demand reduction** have **on the rest of the energy system**?



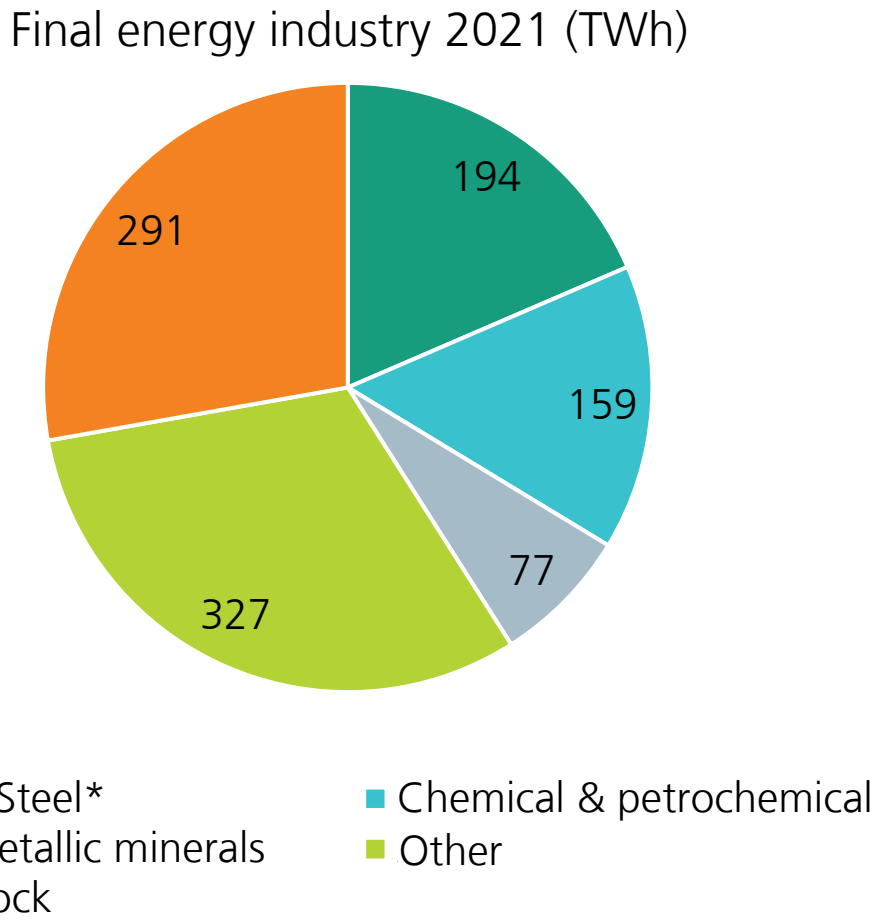



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# German industry sector has final energy demand of ~1000 TWh in 2021

## Motivation




- Final energy demand in the industry 2021: 757 TWh + 291 TWh feedstocks
- 57% (69% incl. feedstocks) by iron & steel, chemical & petrochemical and non-metallic minerals

- 27% of EU27-steel production[1]
- 19% of EU27-cement production[2]


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*incl. Coke oven and blast furnaces
Eurostat, 2021: https://ec.europa.eu/eurostat/de/web/energy/database/additional-data#Energiebilanzen
1 EUROFER (2023): European steel in figures 2023.
2 https://www.cembureau.eu/media/fe4ojlpq/main-world-producers-table.pdf

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# Energy system model REMod

## Methods

### Energy and demand sectors

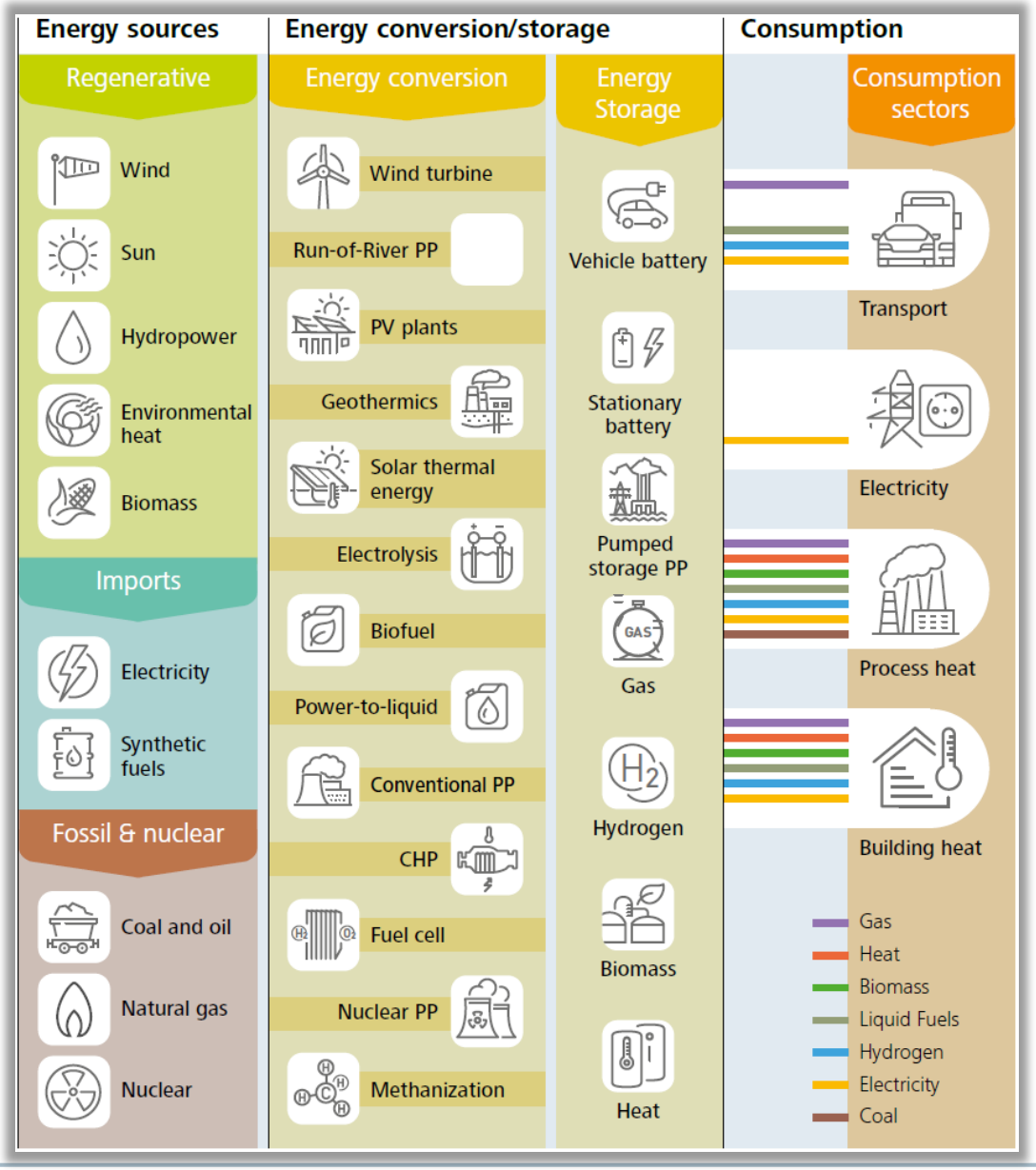
- All demand sectors (buildings, industry, transport) and energy sector covered
- Simultaneous optimization of technologies in all sectors in one model
- Detailed implementation of sector coupling

### Optimization

- Minimization of total costs of the transformation
- Yearly simulation-based optimization

### Resolution

- Technology: ~100 technologies
- Time: Hourly simulation of the operation
- Space: Germany as a one-node model



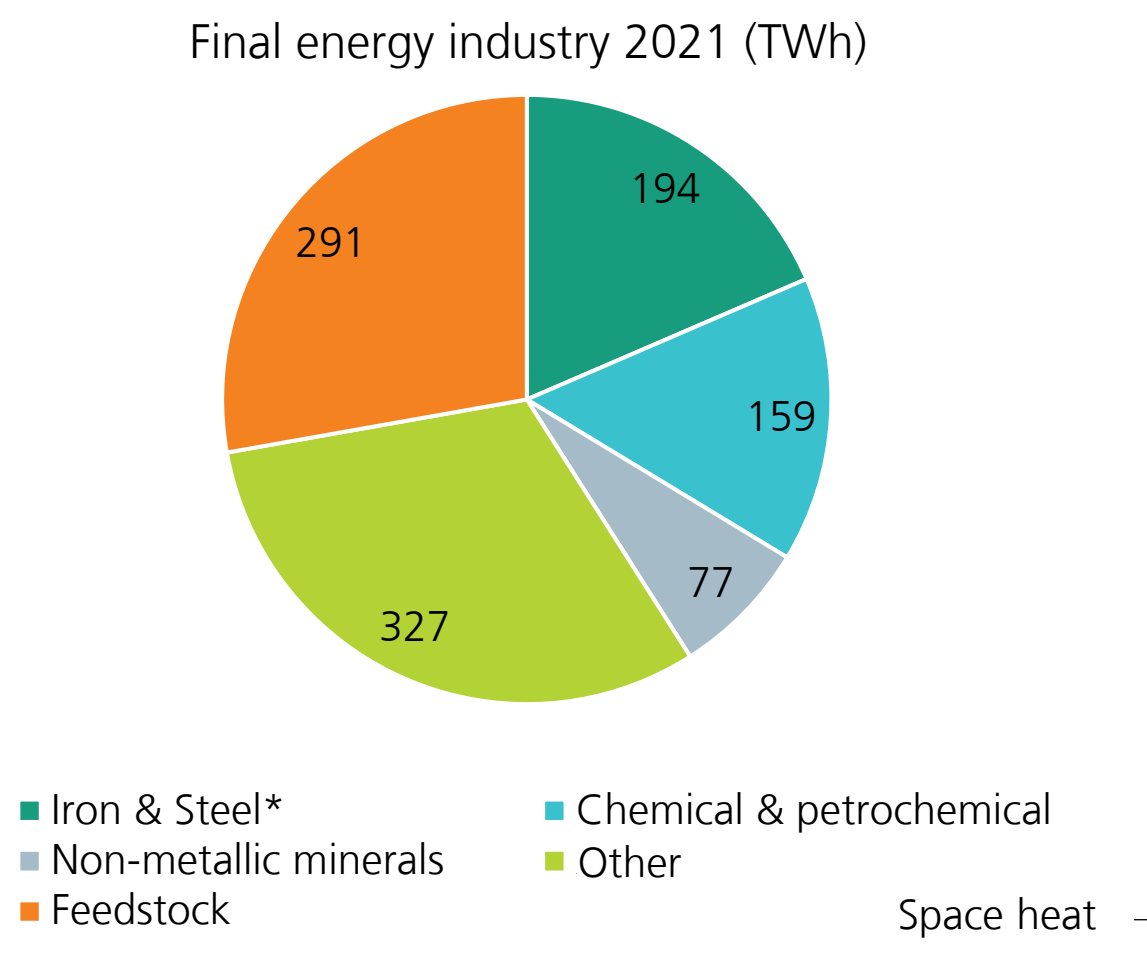


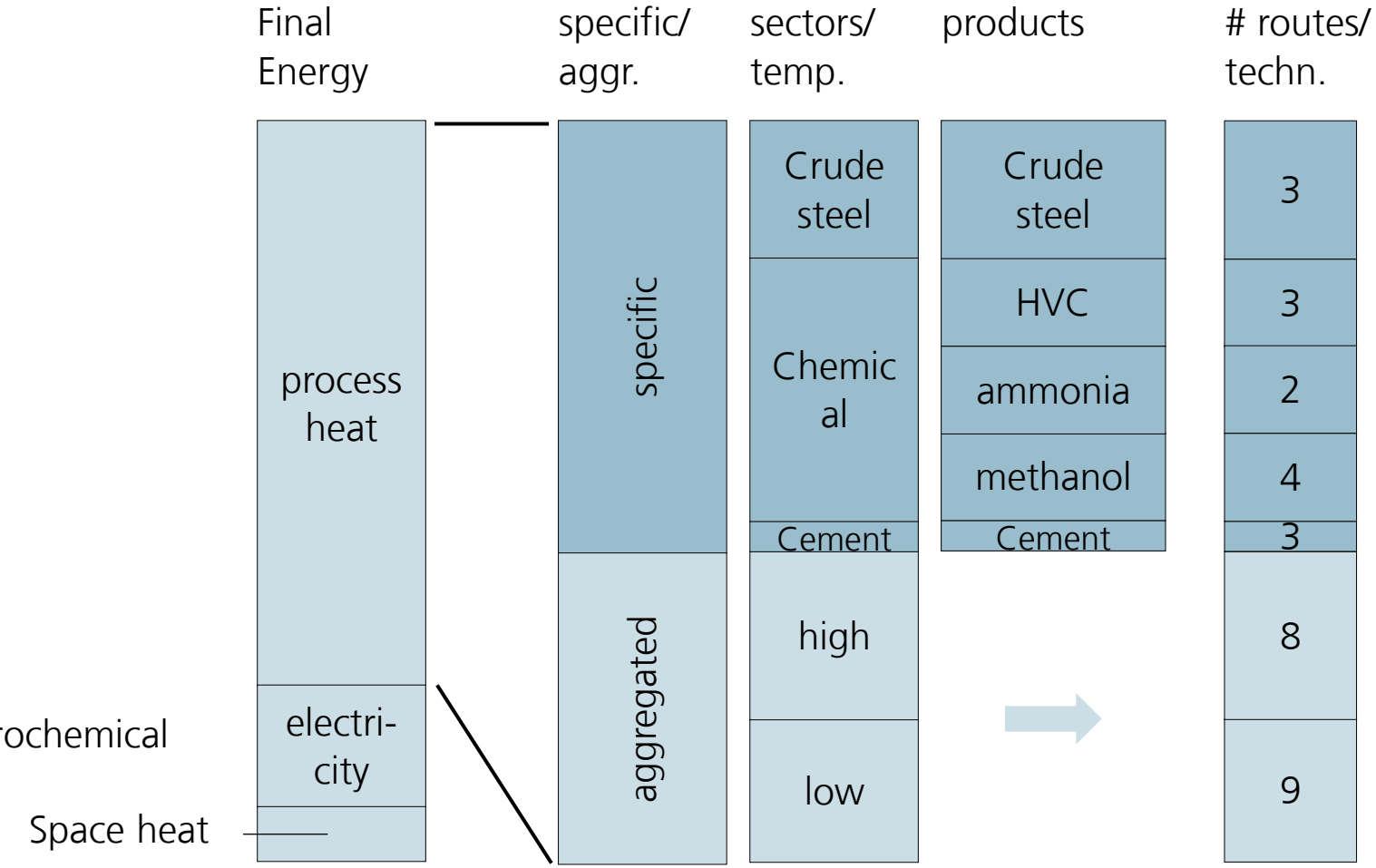

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# Implementation of industrial production routes in a sector-coupled ESM

## Methods




*incl. Coke oven and blast furnaces

Eurostat, 2021: https://ec.europa.eu/eurostat/de/web/energy/database/additional-data#Energiebilanzen



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# Scenarios: direct vs. indirect electrification and demand reduction

## Methods

| Indicator | Direct | Indirect | Demand reduction |
|---|---|---|---|
| GHG-Reduction | -65% 2030 and -100% 2045 (wrt 1990) | | |
| Technological development electricity | + | o | + |
| Technological development PtX | o | + | + |
| PtX import availability | 225 TWh 2045 | 450 TWh 2045 | 125 TWh 2045 |
| PtX import prices (here H2) | 128€/MWh 2045 | 112€/MWh 2045 | 112€/MWh 2045 |
| Demand (production, transport, living area) | constant | constant | reduced[1] |

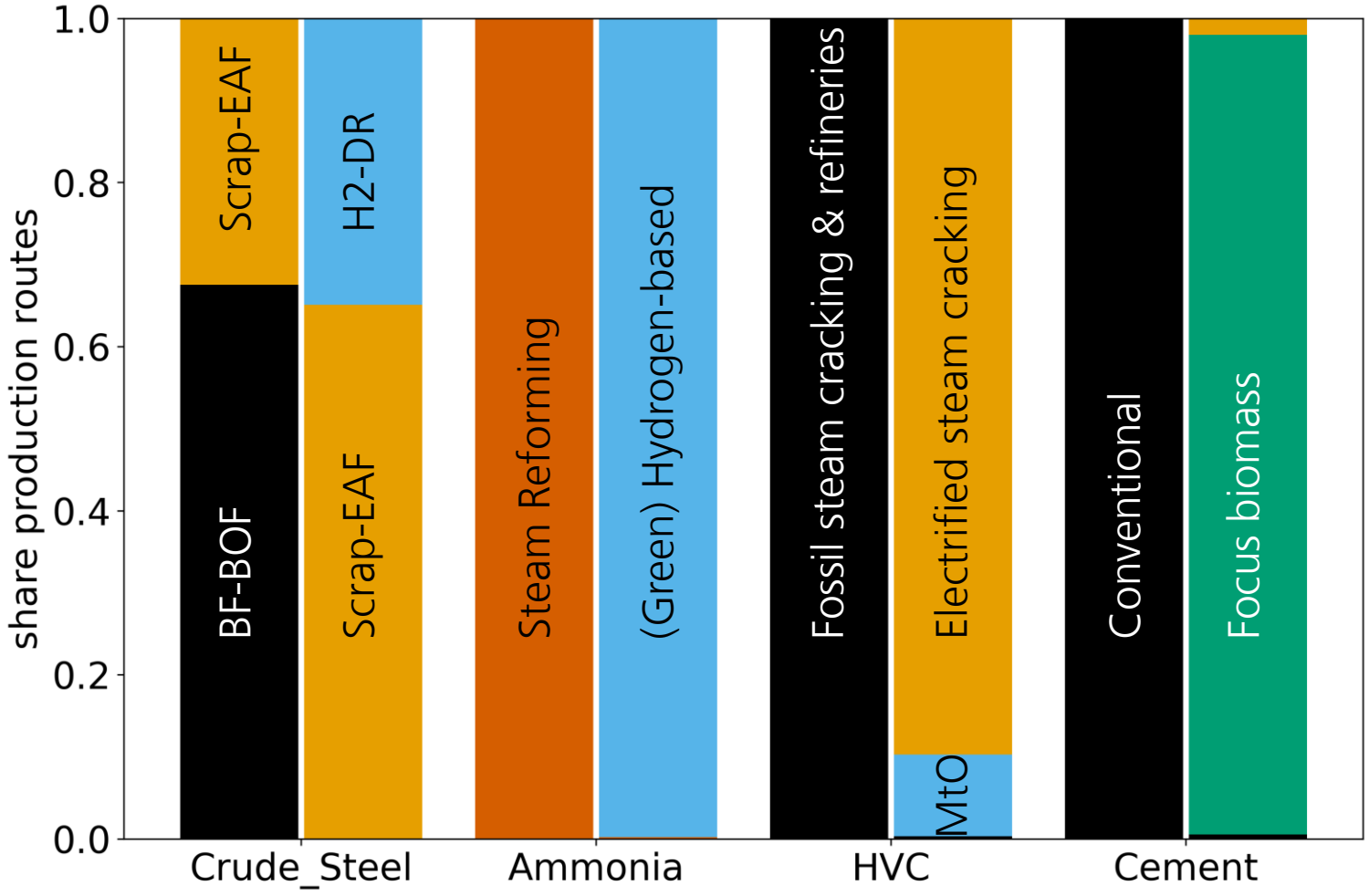
1 based on GreenSupreme scenario in Umweltbundesamt (publisher) 2019: Wege in eine ressourcenschonende Treibhausgasneutralität – RESCUE: Langfassung. https://www.umweltbundesamt.de/rescue


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# Production routes in the basic materials industry: direct electrification

## Results: industry

- Crude steel: Increase of secondary production assumed (to 65%)
- Ammonia: 100% based on green hydrogen
- HVC: Electrification of steam-cracking very important (90%)
- Cement: focus-biomass, direct electrification hardly plays a role (<2%)






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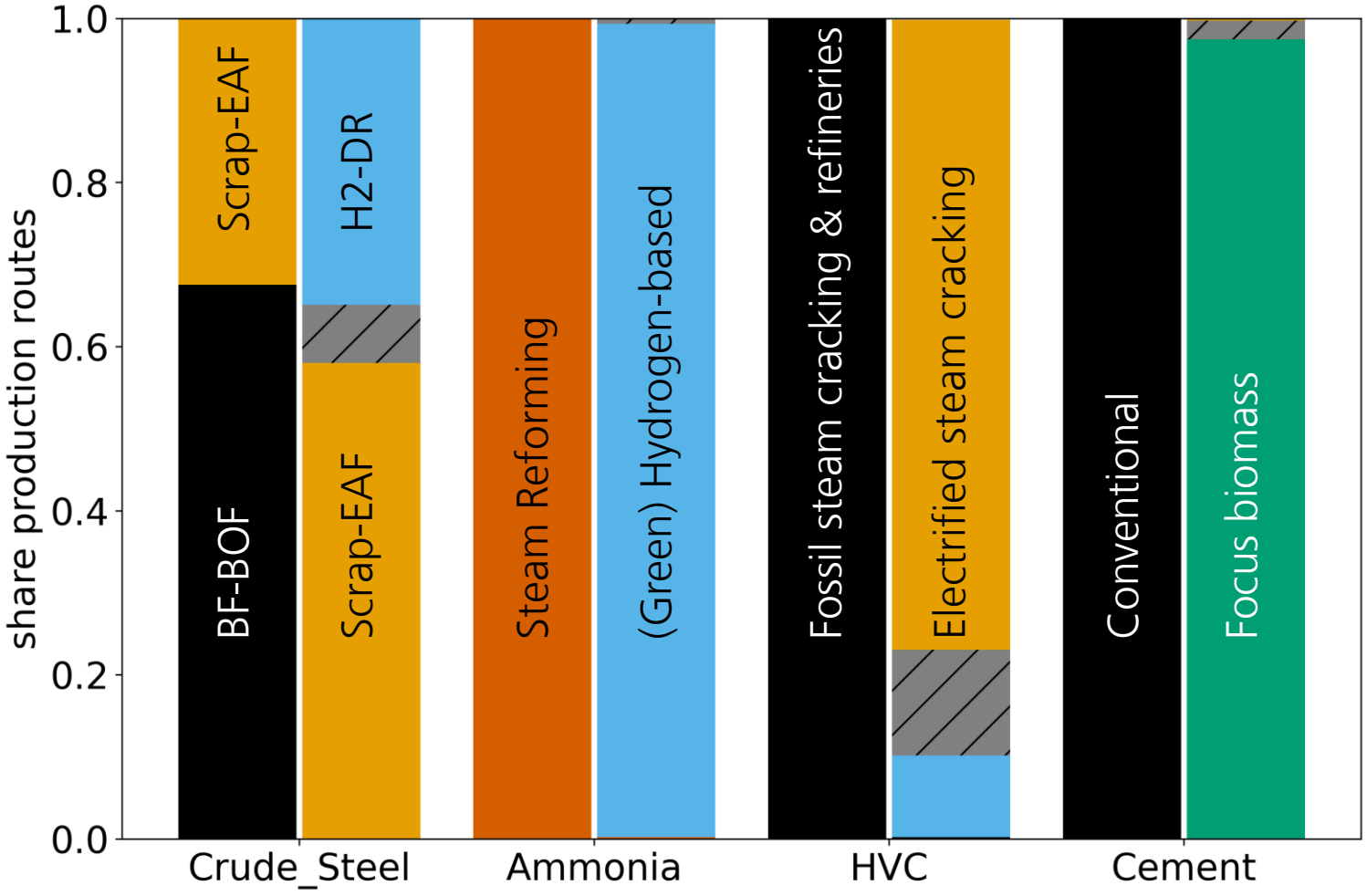
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# Production routes: comparison direct vs indirect electrification

## Results: industry

- Crude steel: Increase of secondary production assumed (to 58%)
- Ammonia: 100% based on green hydrogen
- HVC: Methanol-based route more attractive in indirect scenario (23%)
- Cement: only focus-biomass, no electrification

- Cost-optimal solution shows small differences between scenarios
- Highly dependent on assumed age structure





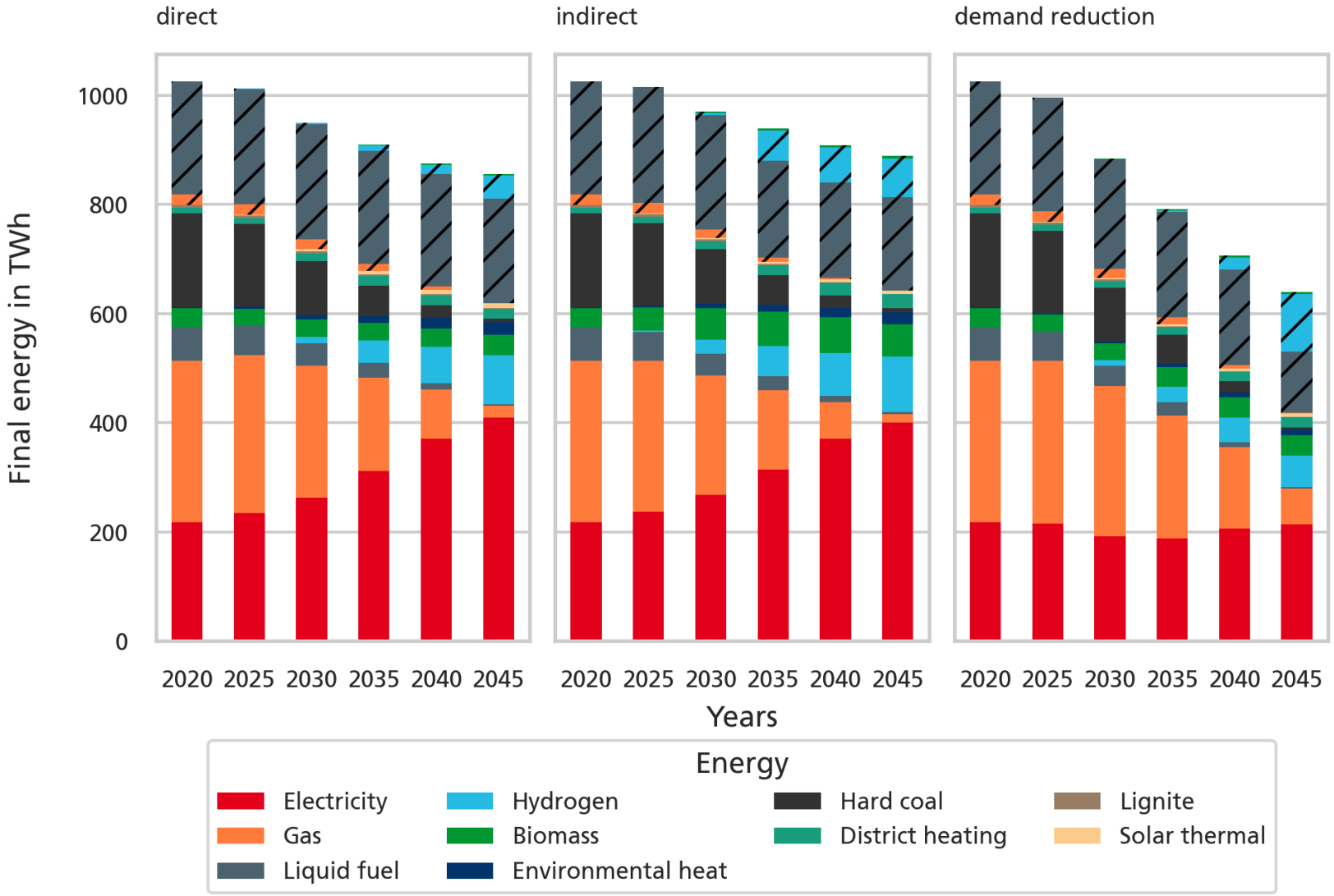

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# Decarbonization of the industry: green electricity and hydrogen are key

## Results: industry

- **Final energy demand reduces** by 18% (direct), 15% (indirect), 39% (demand reduction)
- **Electricity demand** reaches 400 TWh 2045 (direct and indirect), stays constant in demand reduction
- **H2 demand** between 130 TWh (direct) and 170 TWh (indirect)
- Green electricity and hydrogen are key for a decarbonized industry






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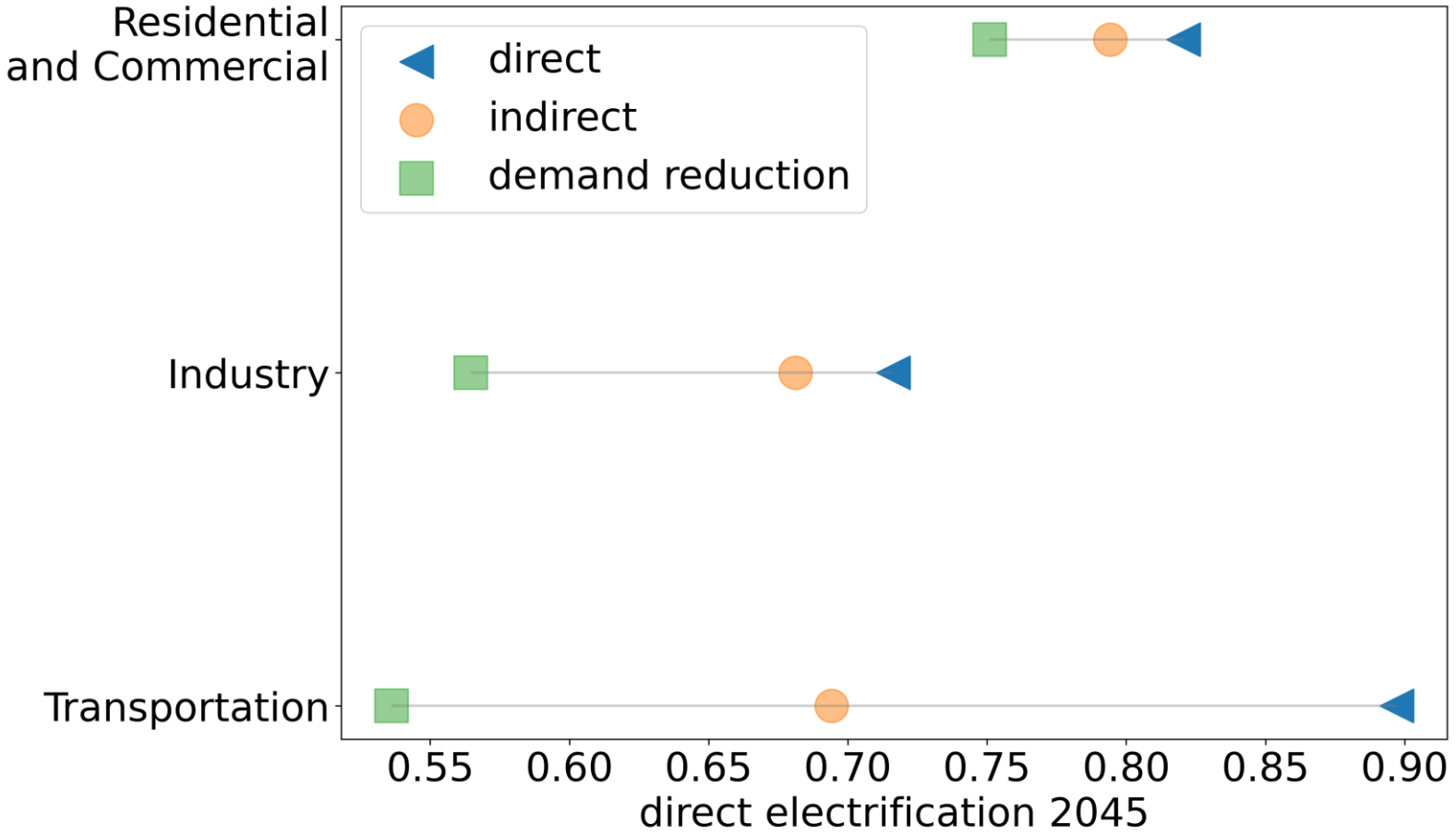
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# Electrification across sectors

## Results: rest of the energy system

- **Residential and Commercial**: between 75% (demand reduction) and 82% (direct)
- **Industry**: between 51% (demand reduction) and 66% (direct)
- **Transportation**: between 54% (demand reduction) and 90% (direct)

- Small sensitivity of electrification in the industry wrt assumptions direct vs indirect
- Demand reduction leads to a largely reduced electrification






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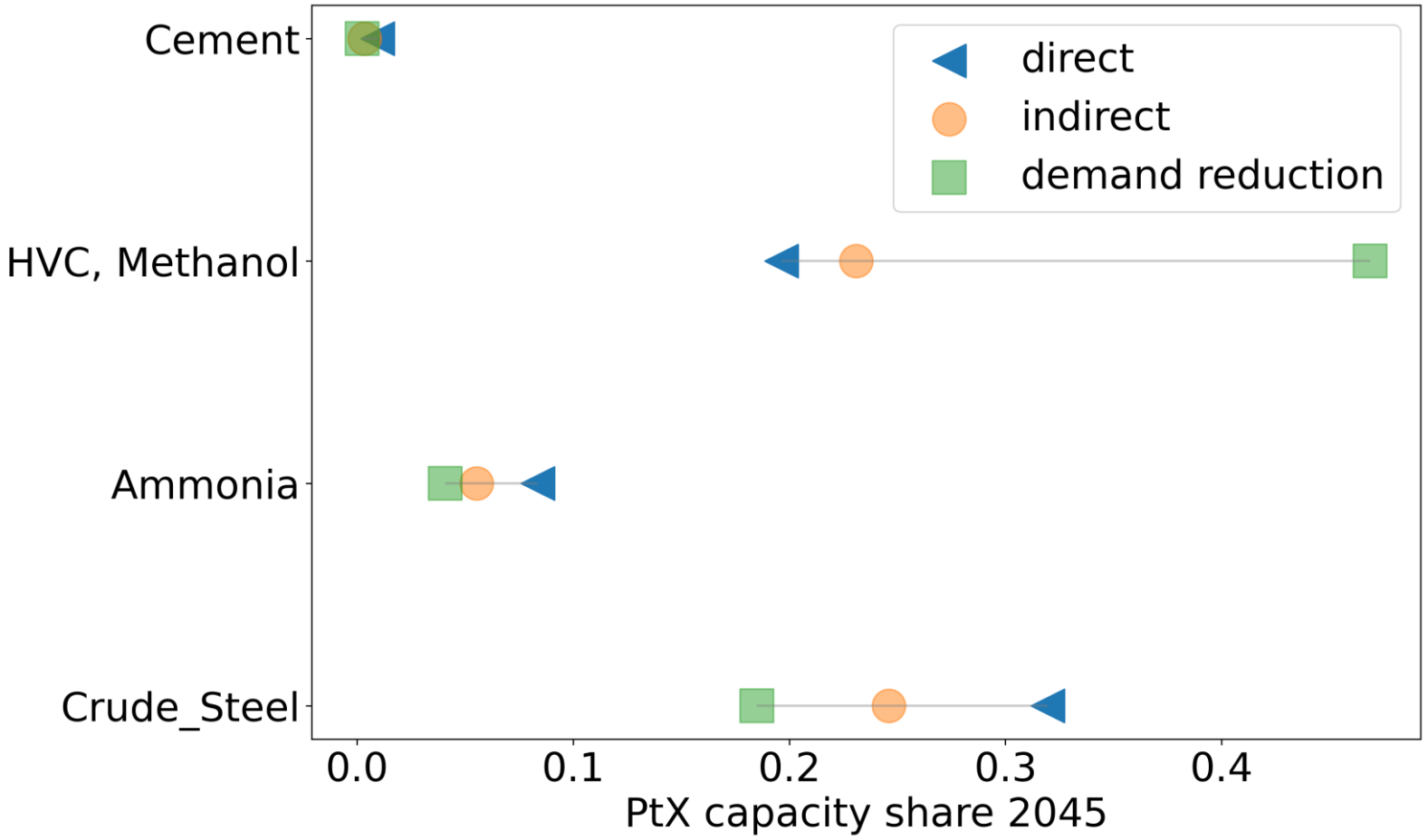
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# Basic materials industry requires >50% of domestic PtX capacities

## Results: rest of the energy system

- All products together: 54% (indirect) to 70% (demand reduction)
- HVC and methanol: 20% (direct) to 49% (demand reduction)
- Crude steel: 18% (demand reduction) to 32% (direct)

- Basic materials industry highly relevant for PtX expansion, especially in scenario demand reduction






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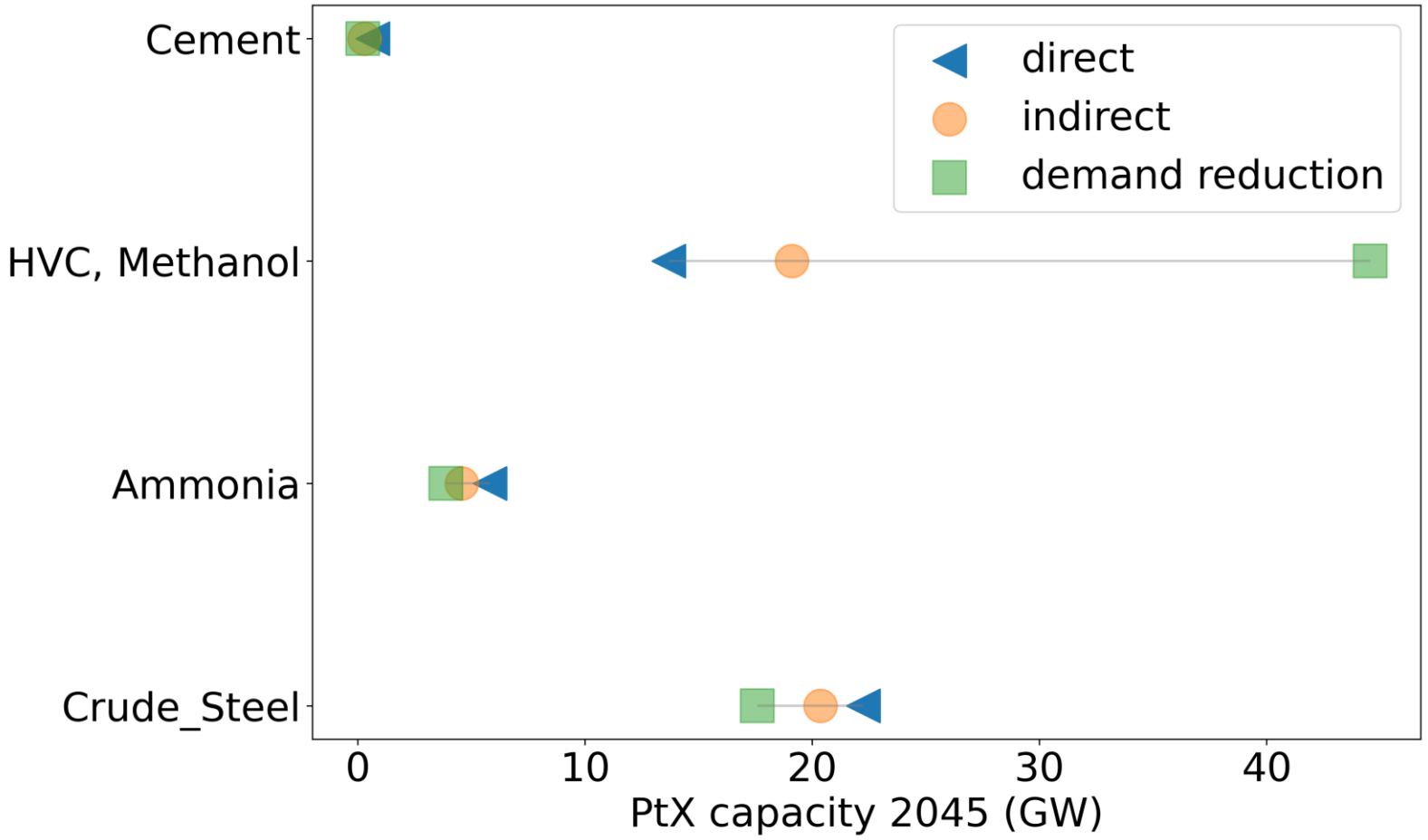
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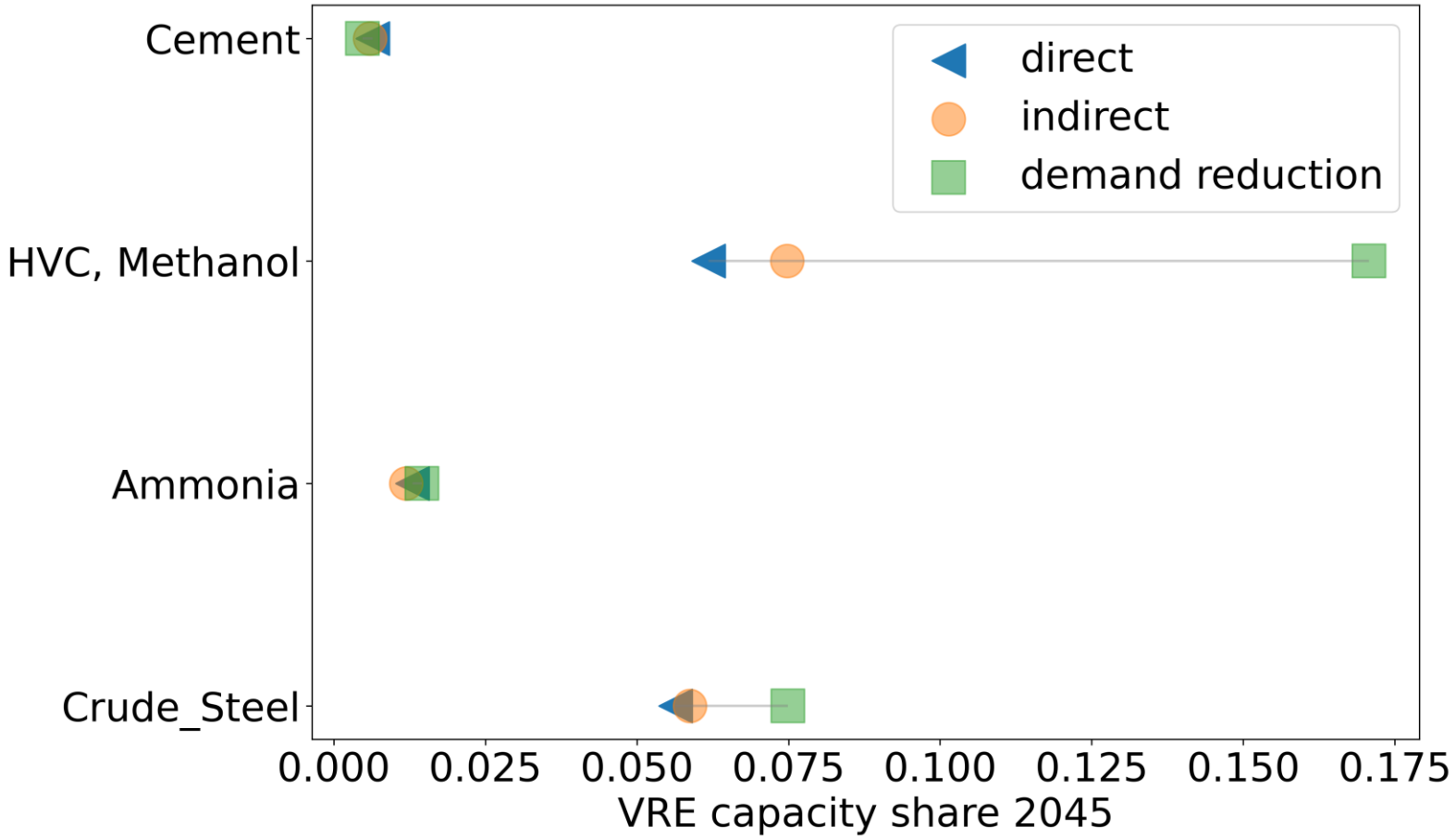
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# VRE capacities required for basic materials industry

## Results: rest of the energy system

- All products together require 14% (direct) to 26% (demand reduction) of VRE capacities
- HVC and methanol require 6% (direct) to 17% (demand reduction)
- Crude steel requires 6% (in/direct) to 7% (demand reduction)

- Basic materials industry highly relevant for VRE expansion, especially in scenario demand reduction






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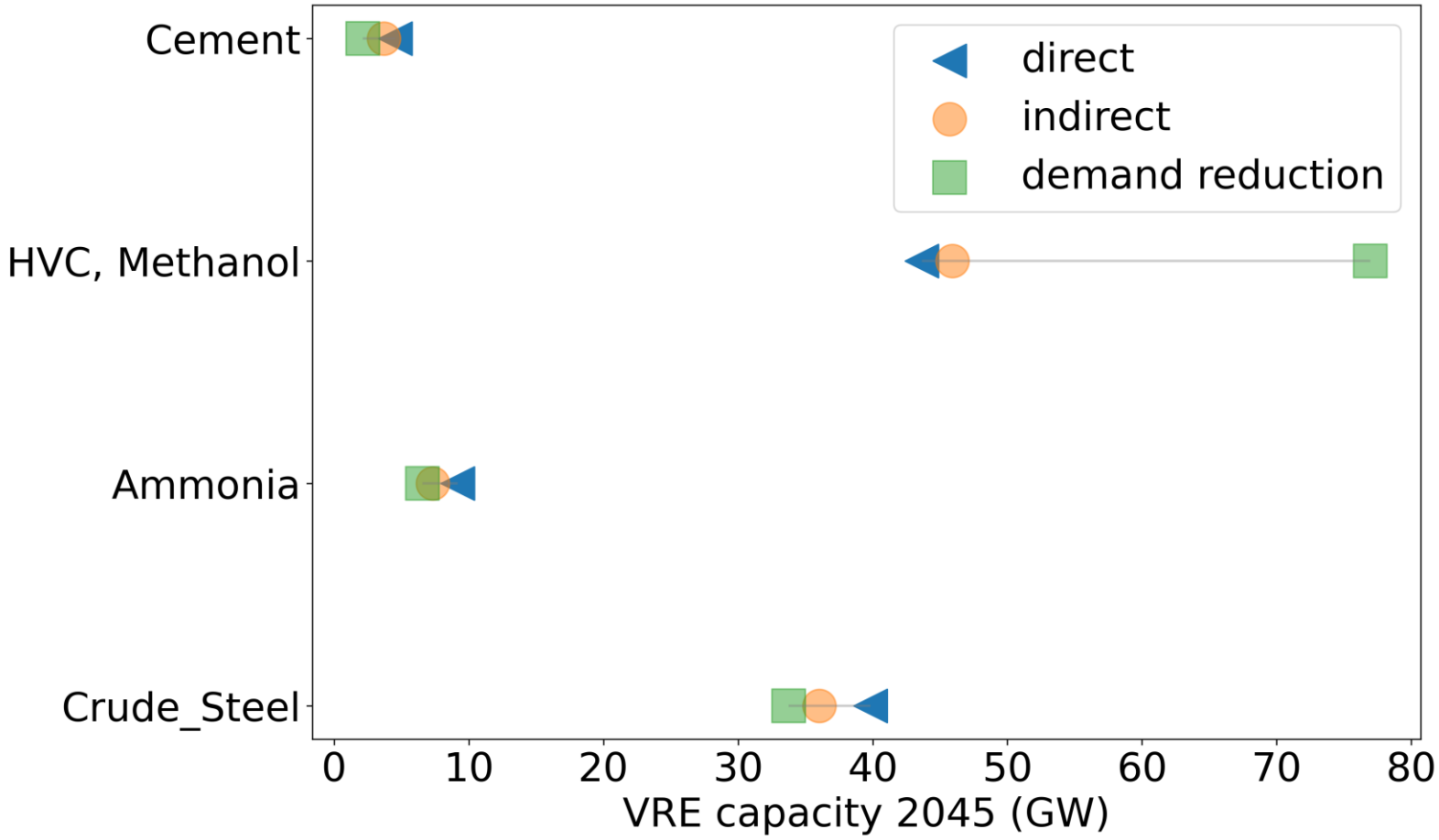
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# Summary

1. In a sector-coupled energy system model, how does the **cost-optimal transformation of the industry sector** look like in scenarios between **direct- and indirect electrification and demand reduction**?

- Capacity shares of production routes are not highly sensitive to assumptions in scenario direct vs. indirect electrification
- Ammonia green H2-based, HVC largely by electrified steam cracking, cement largely by CC and increased use of biomass

2. Which **impacts** do different transformation pathways between **direct- and indirect electrification and demand reduction** have **on the rest of the energy system**?

- Electrification varies most in the transport sector (36% difference), industry less sensitive (15% difference)
- Basic materials industry highly relevant for PtX- and VRE expansion in all scenarios
- Demand reduction with reduced import dependency has similar demand of domestic VRE- and PtX-capacities


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# Thank You for Your Attention!

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