TRADE-OFFS BETWEEN DIRECT AND INDIRECT ELECTRIFICATION OF GERMAN TRANSPORT SECTOR DEFOSSILIZATION PATHWAYS

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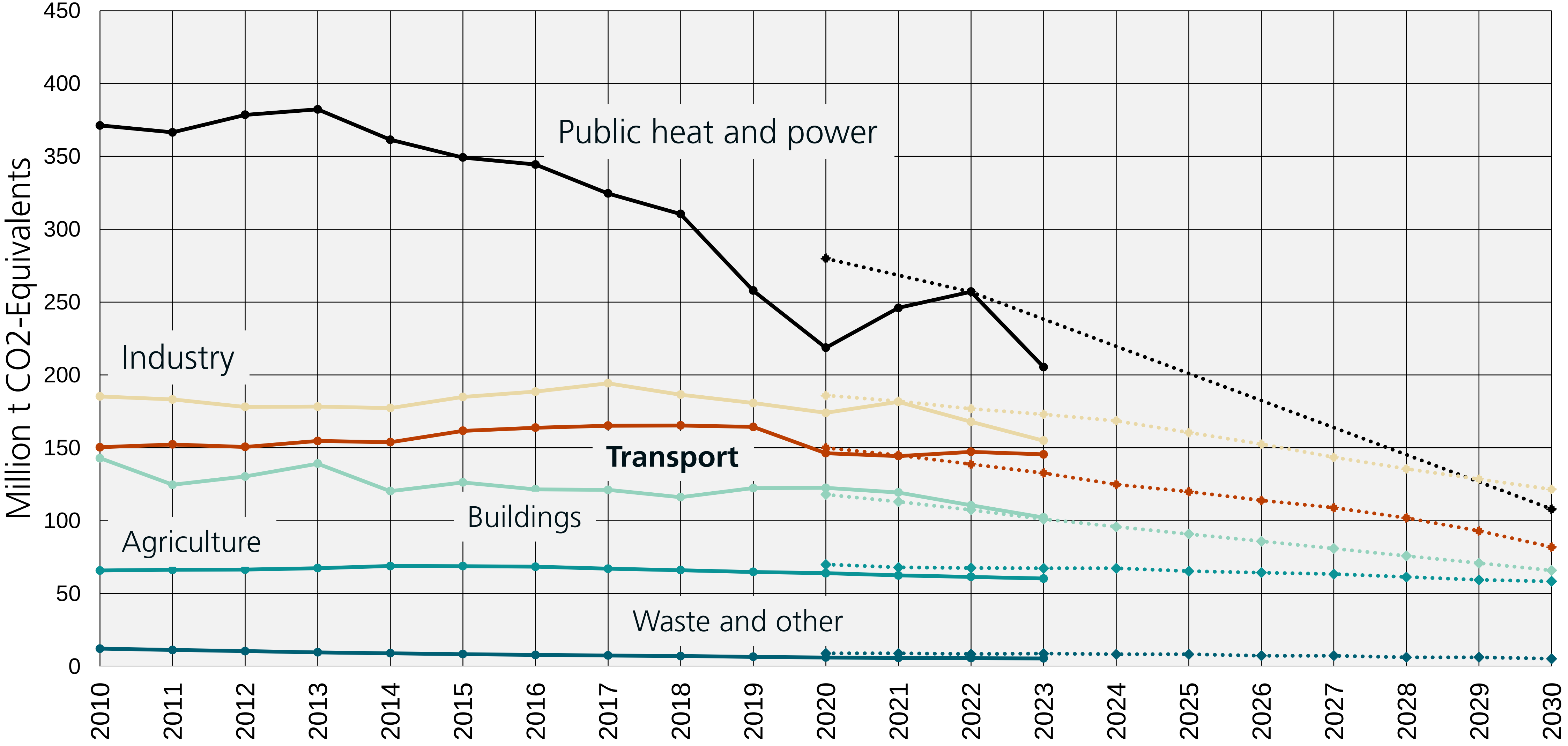
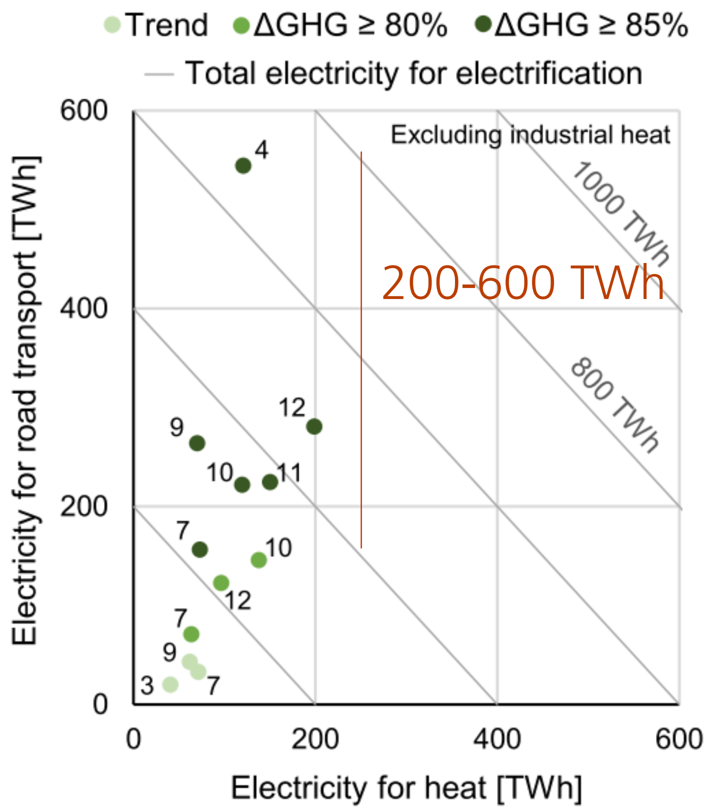
DLR

Motivation – Transport sector is historically harder-to-abate than other sectors in Germany



Introduction and background: What do we know already?

- Large uncertainty in transport sector demand scenario structure between **direct and indirect electrification** [Ruhnau et al. (2019)]
- Considerable differences across GHG neutrality scenarios especially in **final energy demands and biomass usage** [Wiese et al. (2022)]
- Rodrigues et al. (2022) show how defossilization could be achieved in **storyline-driven scenarios**. While electricity does play a major role, it is not dominant in all transport sector scenarios.



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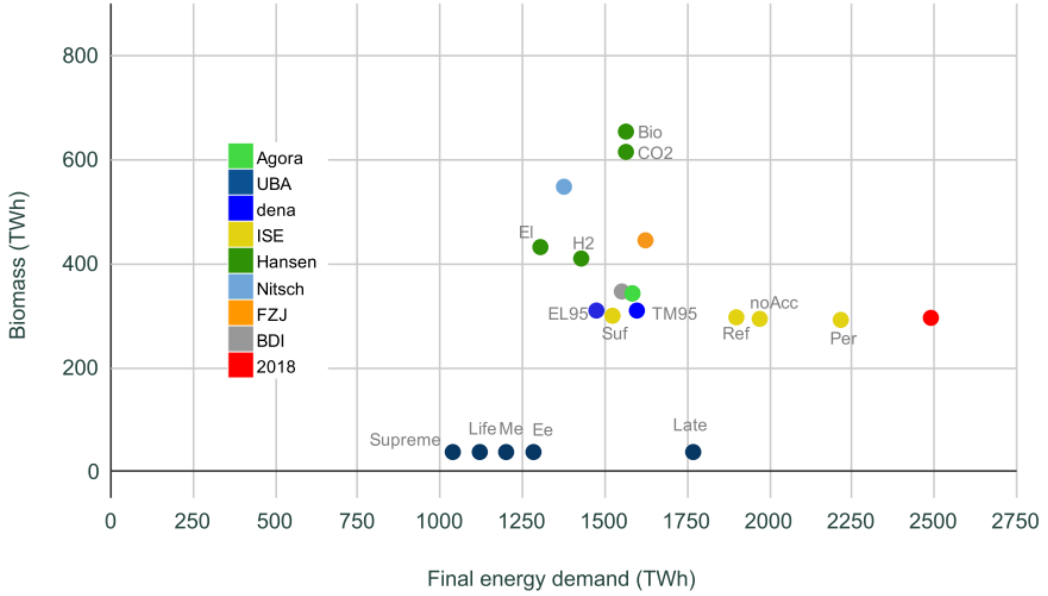

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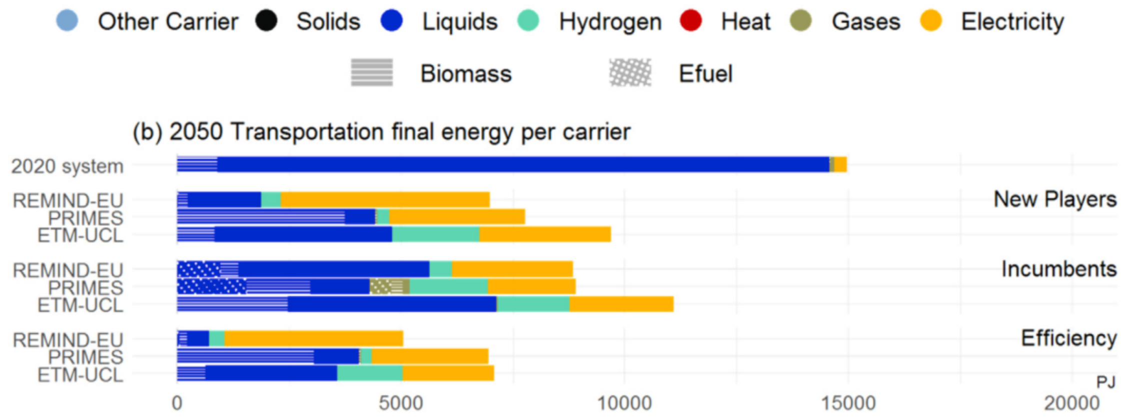
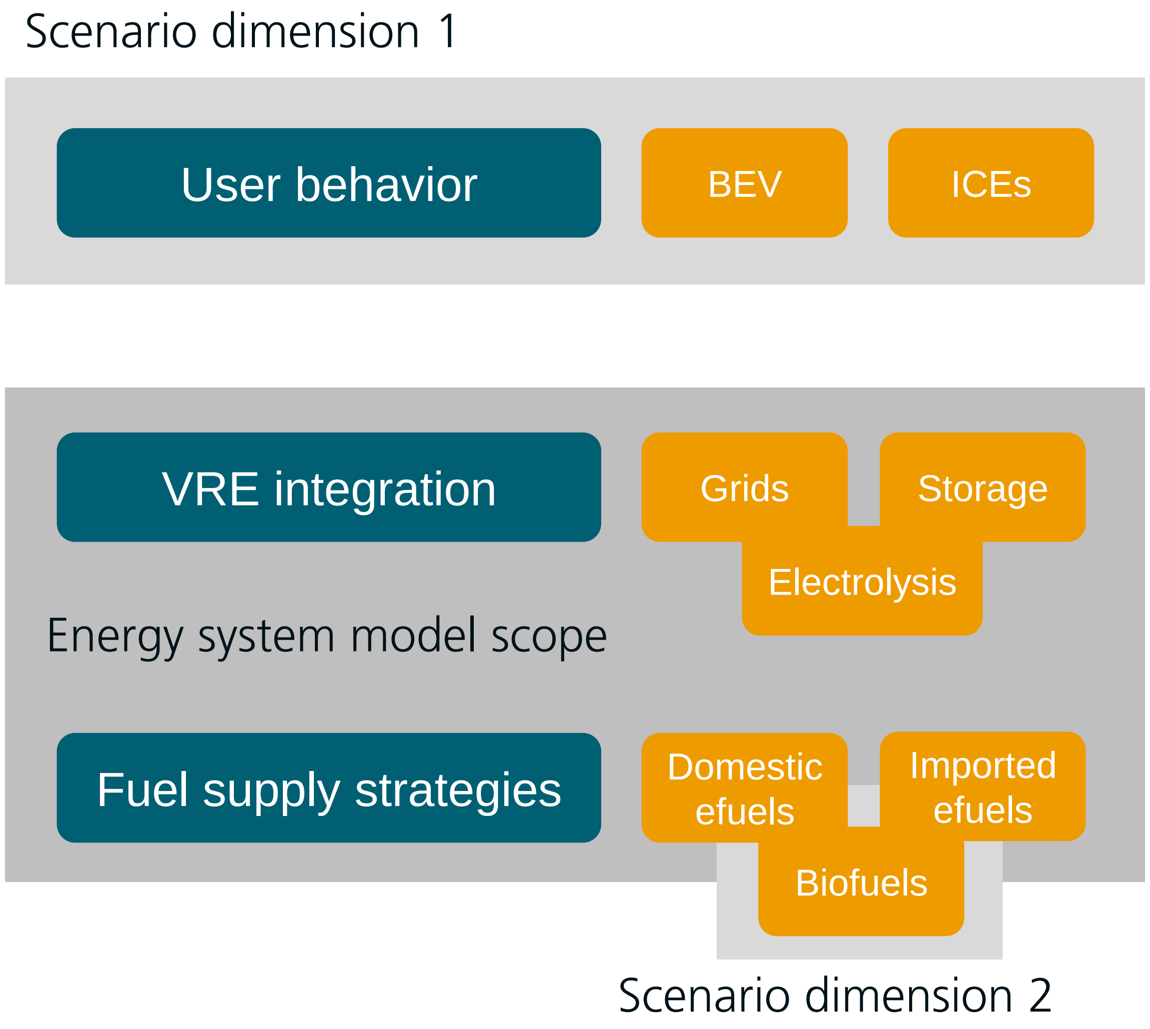


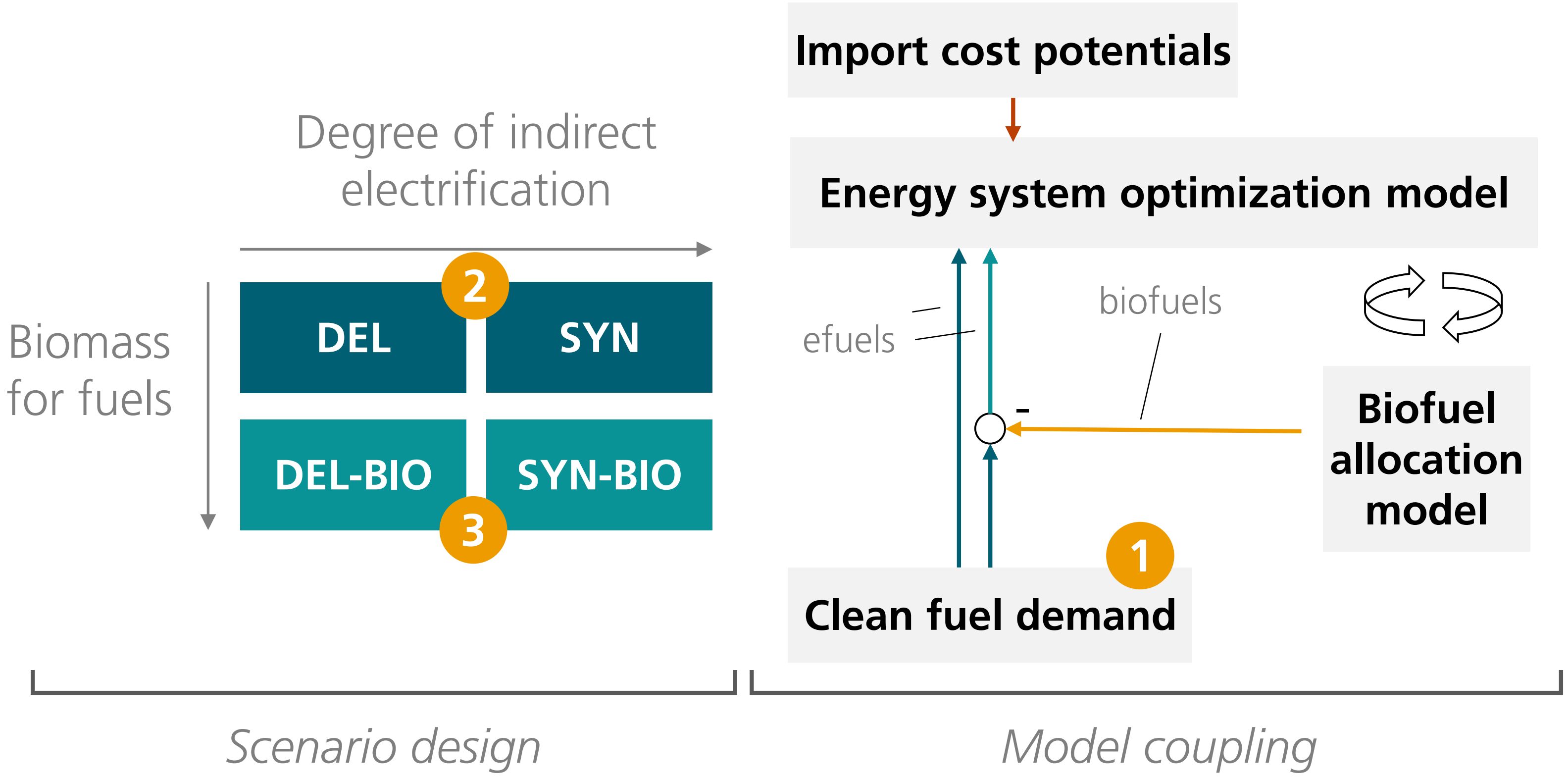
Research questions

What are **energy-planning trade-offs** between direct and indirect electrification of German transport sector defossilization?

- What is the range of **primary energy demands** and their dynamic development for transport sector defossilization?
- How does an **increasing share of indirect electrification** impact energy system transformation scenarios?
- How does lower primary electricity demands through synthetic **fuel substitution through biofuels** impact energy system transformation scenarios?



Scenario design and model coupling

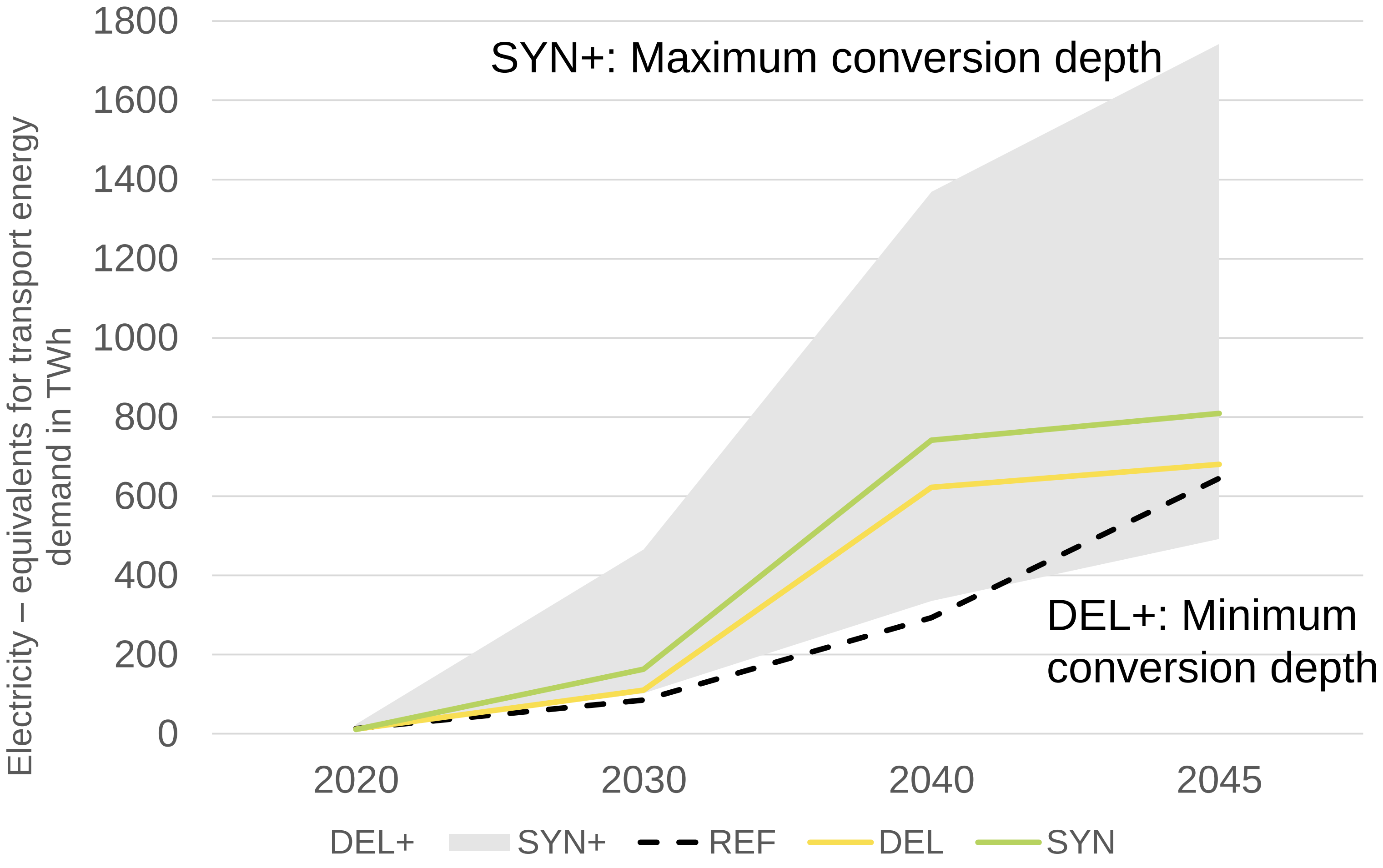


Transport primary demand developments amount to 650-800 TWh/a electricity equivalents

Research Question 1

What is the range of **primary energy demands** and their dynamic development for transport sector defossilization?

- Small differences in 2045 between 5% (DEL) and 25% (SYN) increase of primary energy demand vs. REF
- In HYD, both electricity and eDiesel demand are replaced by H2 compensating each other and marginalizing differences to DEL

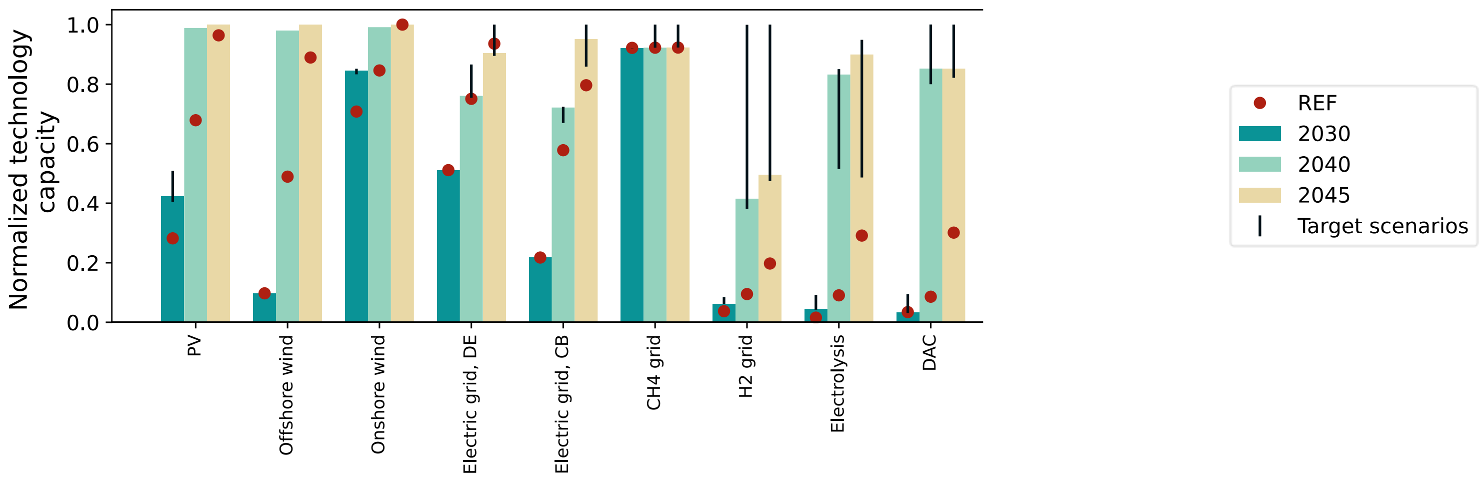


Robust VRE expansion, some influence of conversion indirect electrification on grids, strong influence on H2 infrastructure

Research Question 2

How does an **increasing share of indirect electrification** impact energy system transformation scenarios?

- VRE expansion robust, grids are affected but only minorly, strong differences in H2 grids, electrolysis and refinery capacities
- Increased indirect electrification shows some but minor expansion gradient reduction for VRE and grids. Strong for hydrogen production capacities in the medium term.

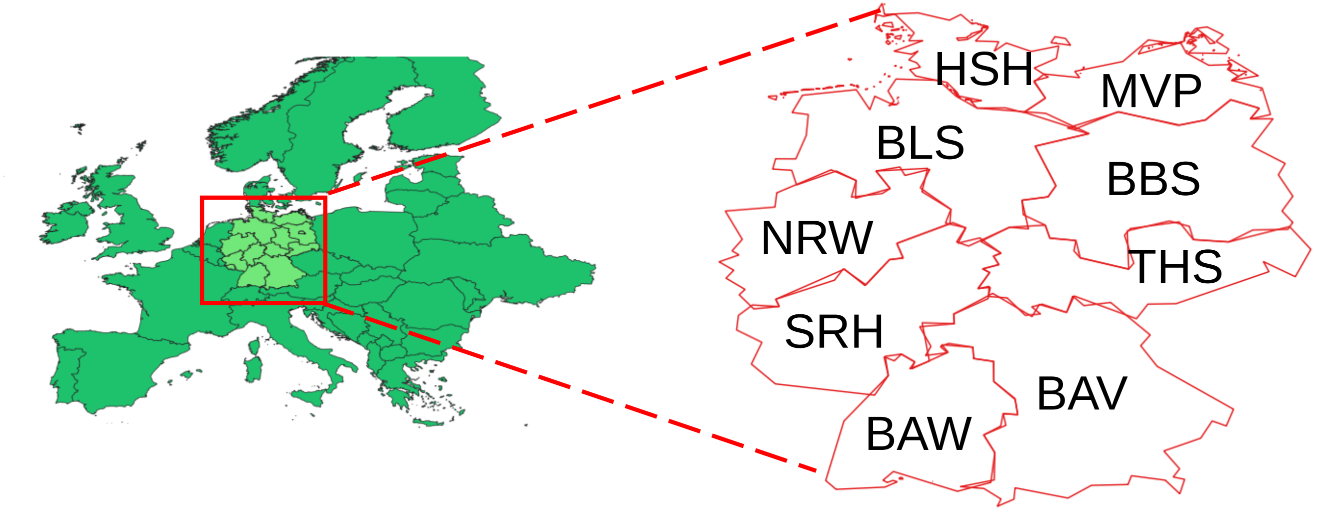


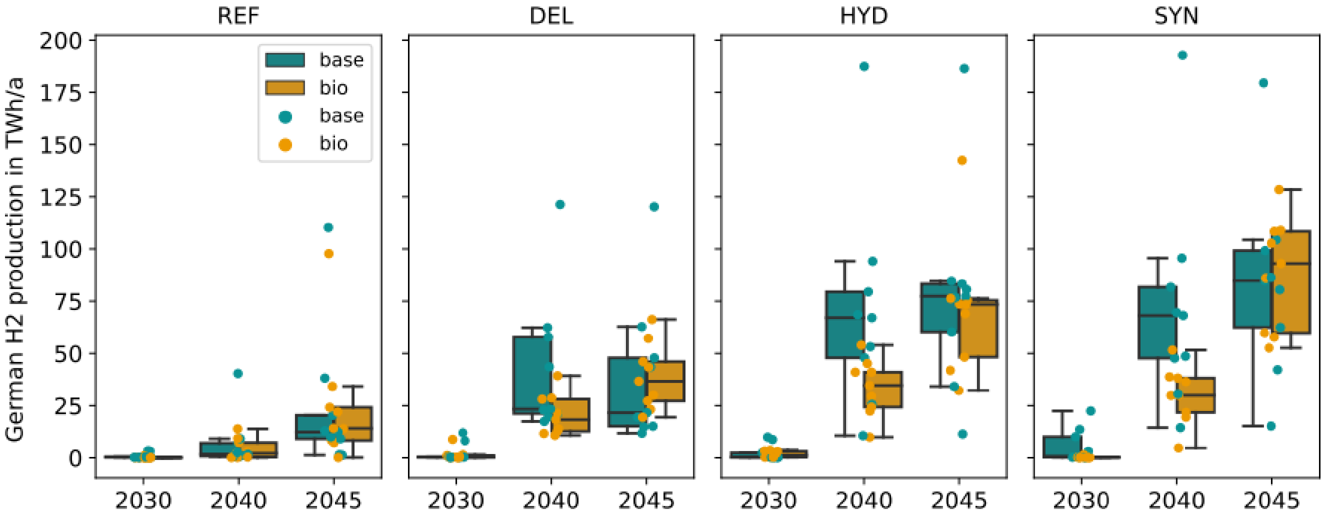
Local H2 production in 2045 strongly varies between 20-200 TWh/a due to demand-supply characteristics

Research Question 2

How does an **increasing share of indirect electrification** impact energy system transformation scenarios?

- H2 production dynamic follows demand dynamic.
- Distribution across German nodes: 20-60 TWh/a (DEL) in most nodes, 10-100 TWh/a (SYN)
- 120 and 190 TWh/a in BLS
- Total electricity needed for electrolysis in SYN 1.8 higher than in DEL



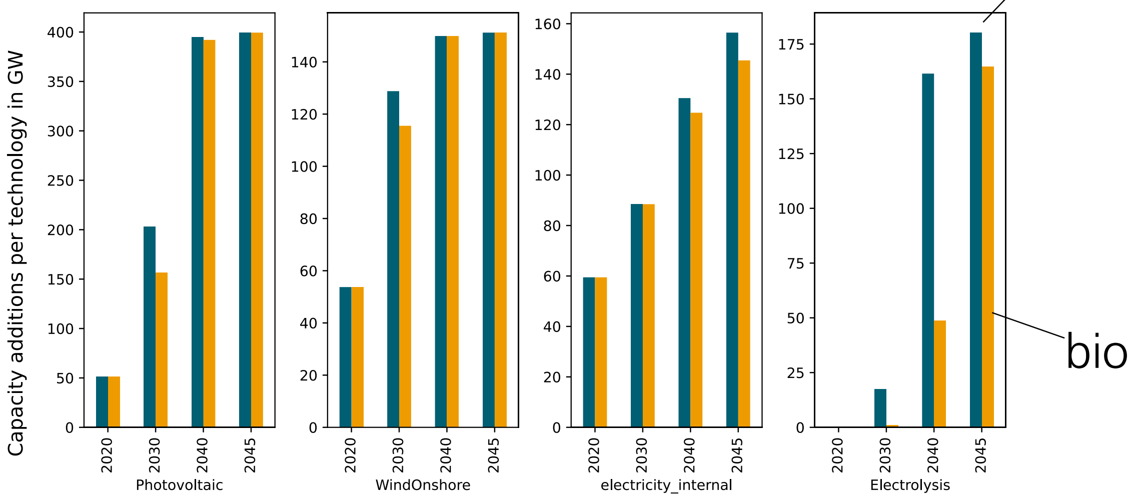


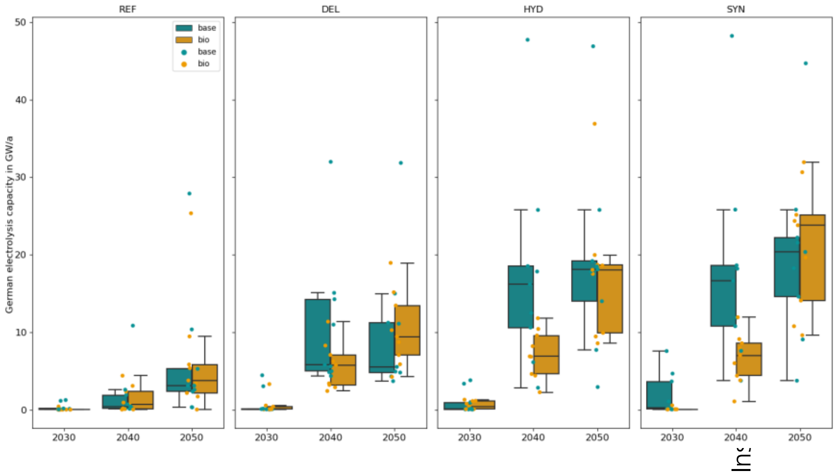
Biofuel may alleviate necessary H2 infrastructure expansion in the medium-term

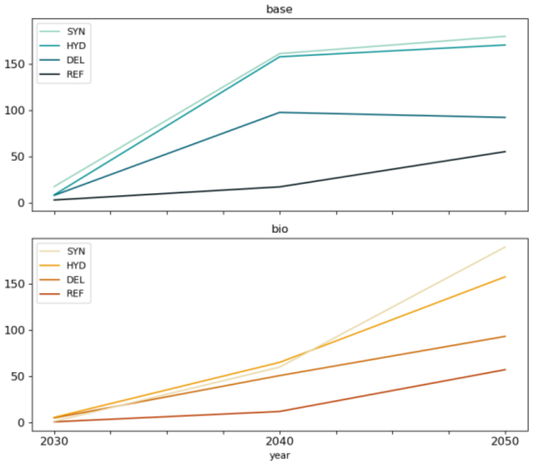
Research Question 3

How does lower primary electricity demands through synthetic **fuel substitution through biofuels** impact energy system transformation scenarios?

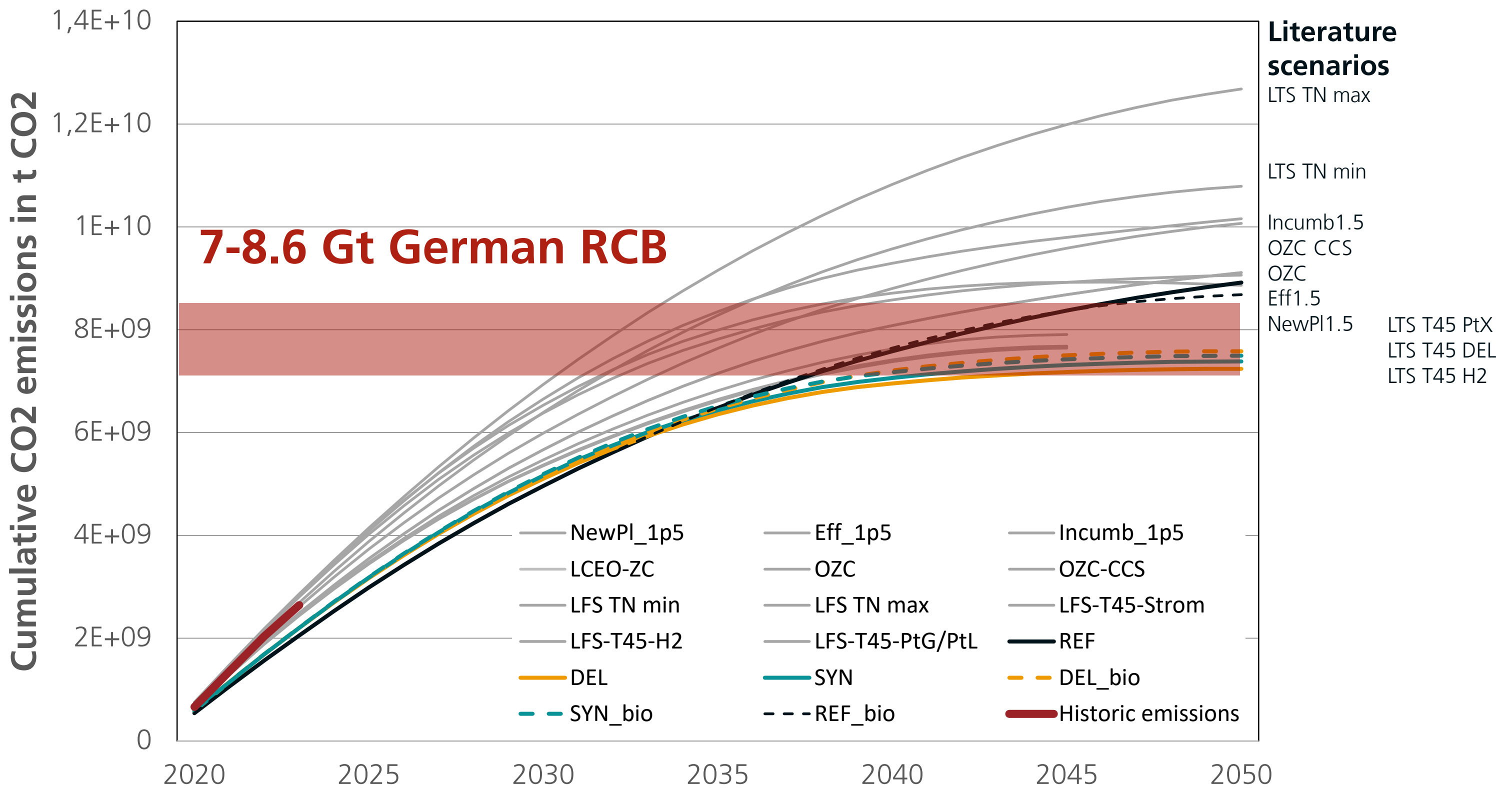
- Reduced electricity demand through synthetic fuel by biofuels substitution does not significantly influence VRE and grid expansion
- However, cost-optimal H2 infrastructure gradients are significantly reduced, especially in the decade 2030-2040







Our scenarios reach 7.2 Gt cumulative emissions from 2020 and thus, are in line with the IEPC-based German RCB (2°C, 67%)



- Range of all ambitious scenarios amounts to between 7.2-12.7 Gt between 2020 and GHG neutrality
- Only the provision of heat, electricity and transport fuels reaches the German RCB but stays within under cost-optimality
- The use of biofuel and related LC emissions do not significantly increase cumulative emissions

Own calculations and literature scenarios harmonized based on [6-10]

Conclusions

We find **primary energy demands of between 650-800 TWh/a** of electricity for transportation. In our scenarios, demands for electricity is especially increased between 2030 and 2040.

Strong VRE expansion up to limits given in the grid development plan is **cost-optimal across all scenarios** and VRE potential is necessary before total GHG neutrality, i.e. until 2040.

Targeting H2 and synthetic fuel mainly increases necessary fuel imports. However, internal and cross-border capacities are moderately affected by the share of indirect electrification.

H2 infrastructure is strongly affected with ~30% higher electrolysis capacities needed in SYN in 2040 than in DEL scenario

Biofuels may alleviate steep gradients in H2 infrastructure expansion and shift expansion to 2040s. This is independent of the share of indirect electrification especially on the medium term. Domestic production of synthetic fuel may additionally be increased. Biofuel usage does not significantly cumulative CO2 emissions.

List of references

[1] Ruhnau, O., Bannik, S., Otten, S., Praktiknjo, A. & Robinius, M. (2019). Direct or indirect electrification? A review of heat generation and road transport decarbonisation scenarios for Germany 2050. In: Energy, 166, pp. 989-999, https://doi.org/10.1016/j.energy.2018.10.114.

[2] Wiese, F., Thema, J. & Cordroch, L. (2022). Strategies for climate neutrality. Lessons from a meta-analysis of German energy scenarios. Renewable and Sustainable Energy Transition, 2, 100015ff. https://doi.org/10.1016/j.rset.2021.100015

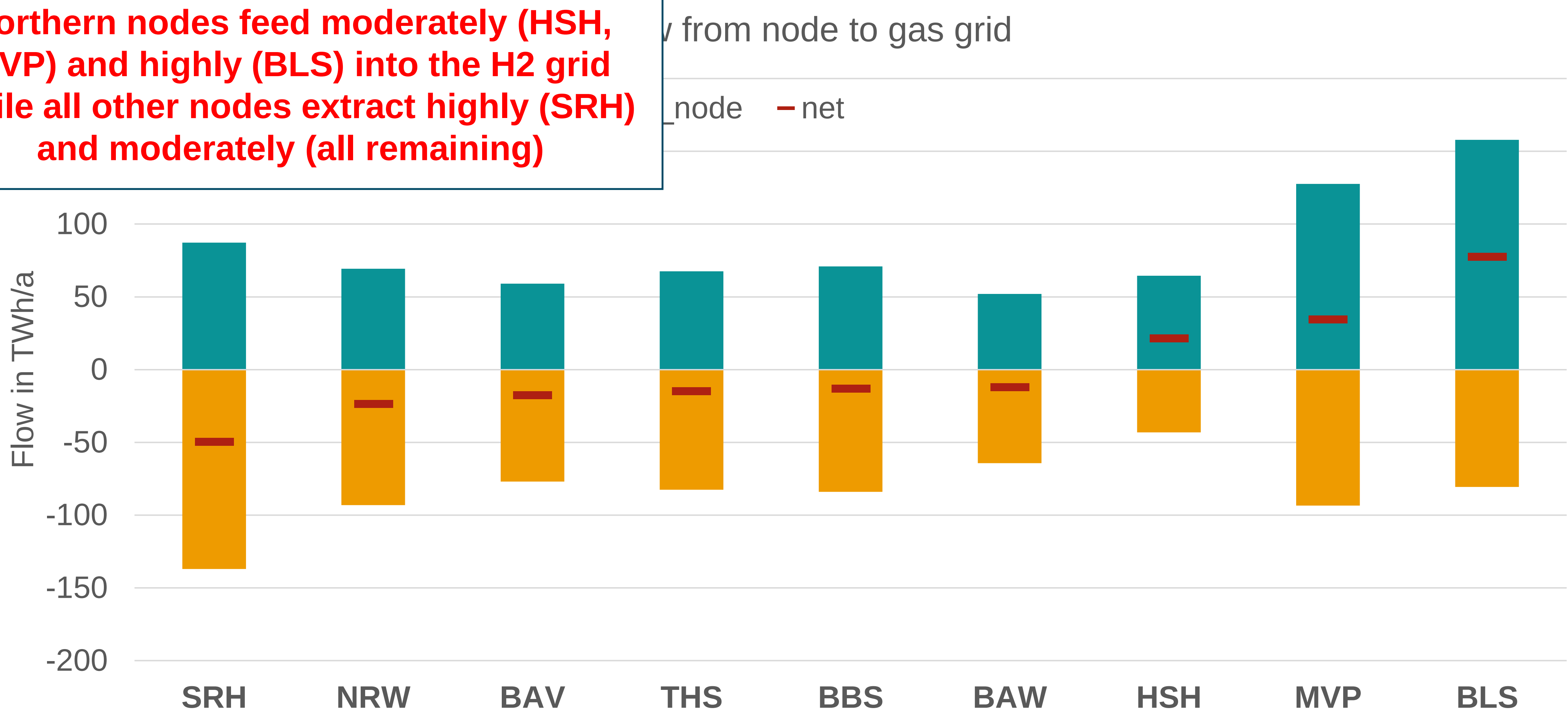
[3] R. Rodrigues, R. Pietzcker, P. Fragkos, J. Price, W. McDowall, P. SIskos, T. Fotious, G. Luderer, P. Capros "Narrative-driven alternative roads to achieve mid-century CO2 net neutrality in Europe" Energy, vol. 239, pp. 121908ff., 2022.

[4] Umweltbundesamt: Presse-Information 11/2023 vom 15.03.2023 - UBA-Prognose: Treibhausgasemissionen sanken 2022 um 1,9 Prozent. Mehr Kohle und Kraftstoff verbraucht. Online: https://www.umweltbundesamt.de/publikationen/treibhausgas-projektionen-2024-fuer-deutschland

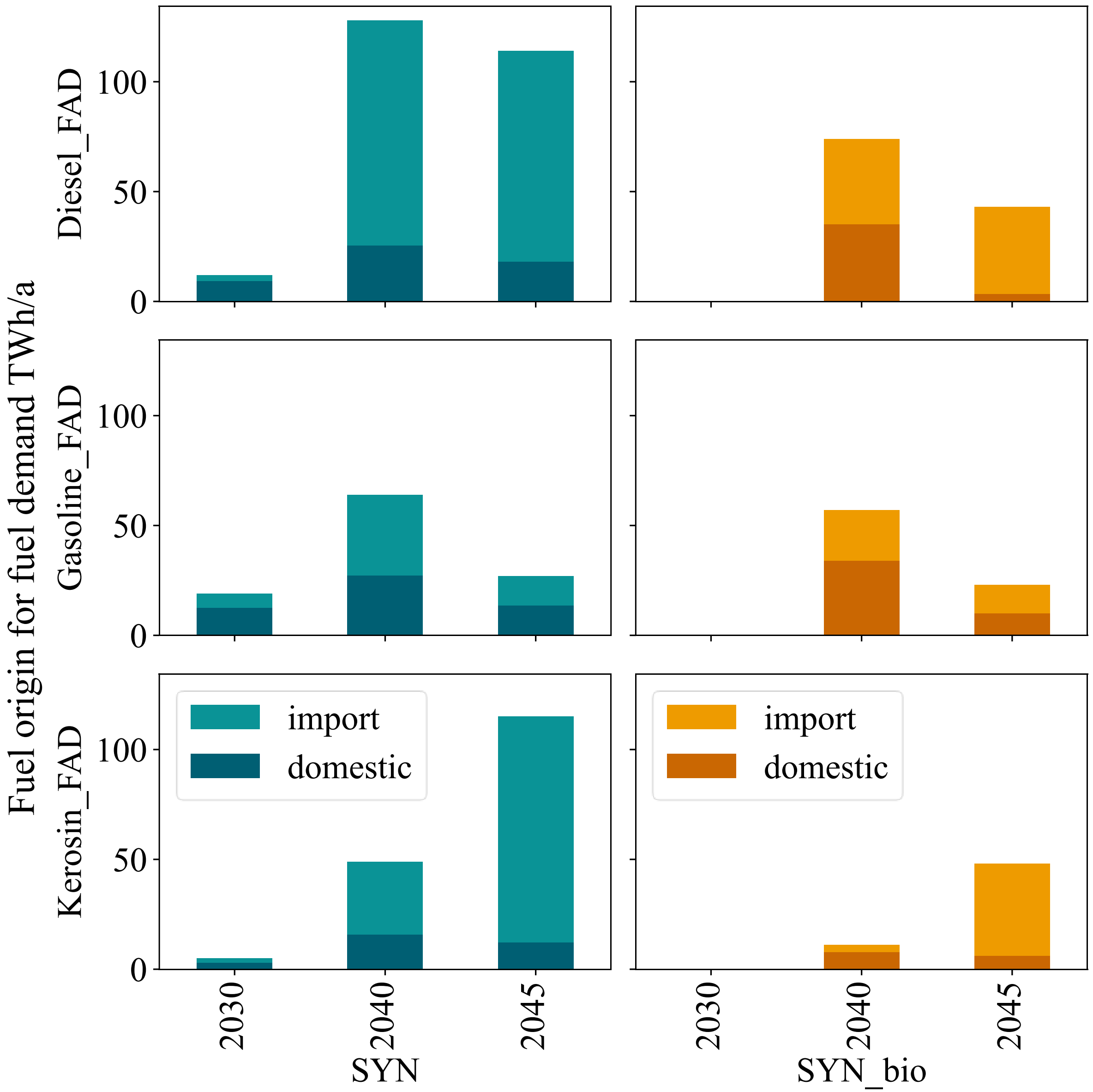
[5] Wulff, N., Esmaeili Aliabadi, D., Hasselwander, S., Pregger, T., Deniz, Ö., Gils, H.C., Kronshage, S., Arellano Ruiz, E.S., Grimme, W., Horst, J., Jochem, P. (submitted). Energy system implications of demand scenarios and supply strategies for renewable transportation fuels. Currently in submission, preprint available upon request.

H2 node to link balance, DEL, 2040

Northern nodes feed moderately (HSH, MVP) and highly (BLS) into the H2 grid while all other nodes extract highly (SRH) and moderately (all remaining)

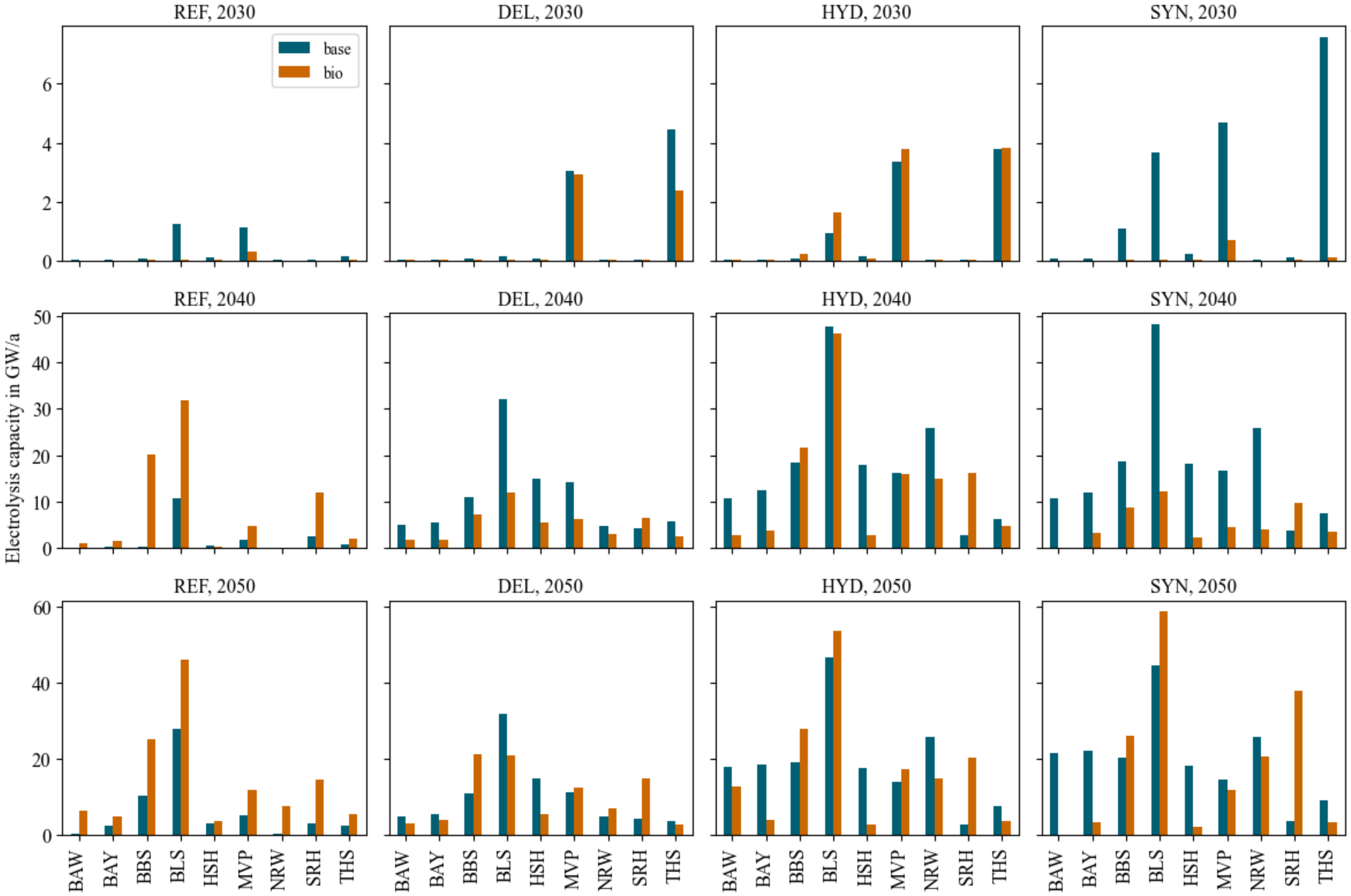


Imports



Fuel origin for fuel demand TWh/a
Diesel_FAD
Gasoline_FAD
Kerosin_FAD
0
50
100
import
domestic
import
domestic
2030
2040
2045
2030
2040
2045
SYN
SYN_bio

Electrolysis capacity per node (x), year (facet y), scenario (facet x) and biofuel (parameter group)



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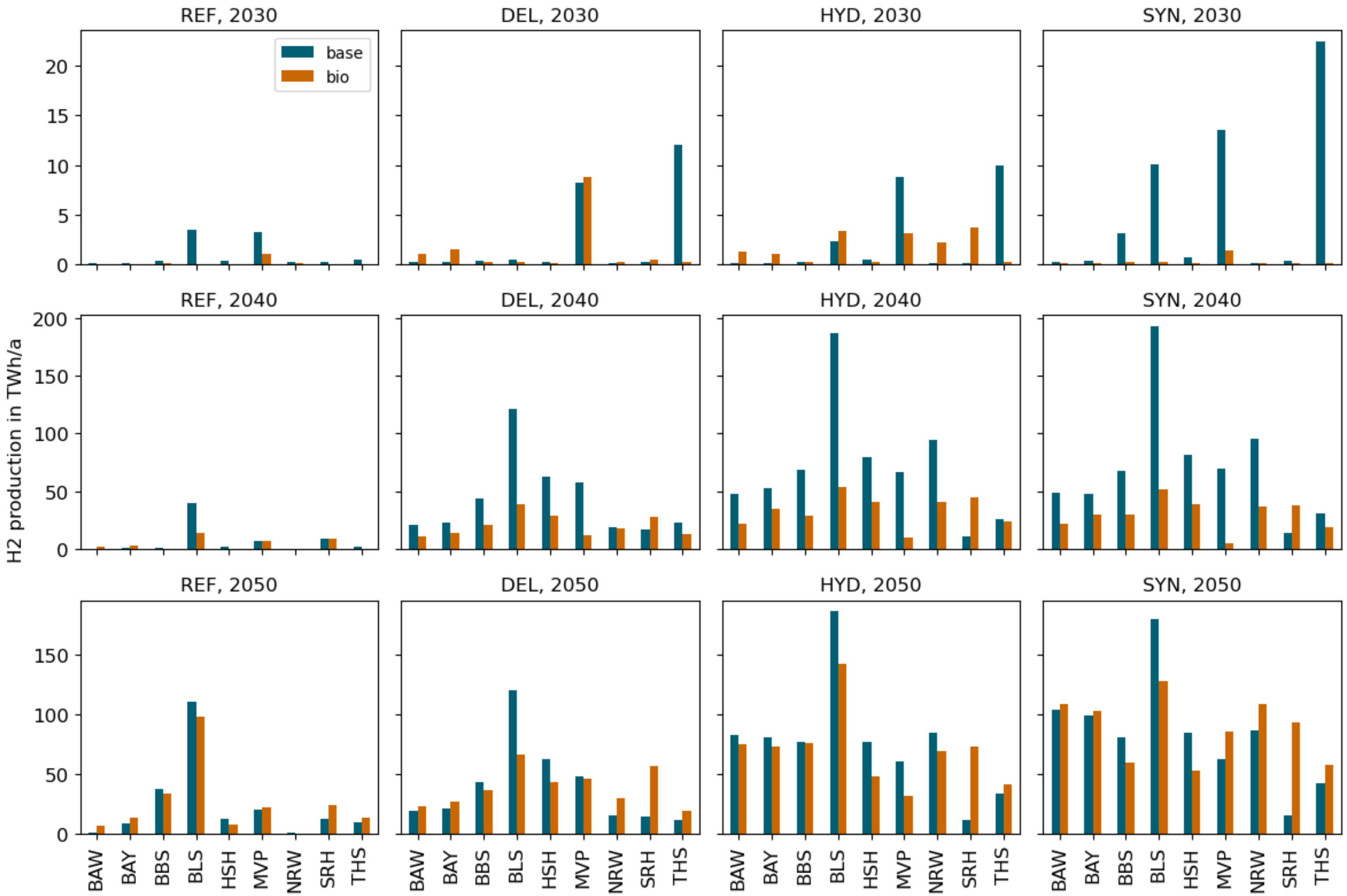
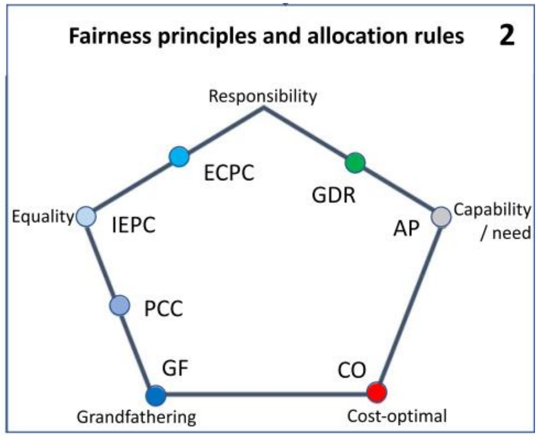
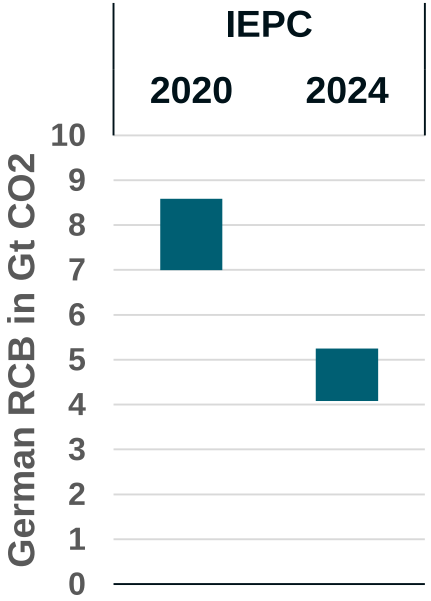


Approach





Global RCB from 2020 onwards: 400-1200 Gt. Assumption: 890 Gt

German Remaining Carbon Budget (RCB) calculation

German RCB from 2020 onwards: 7-8.6 Gt

Energy system transformation scenarios

[4] Wulff et al. (submitted)

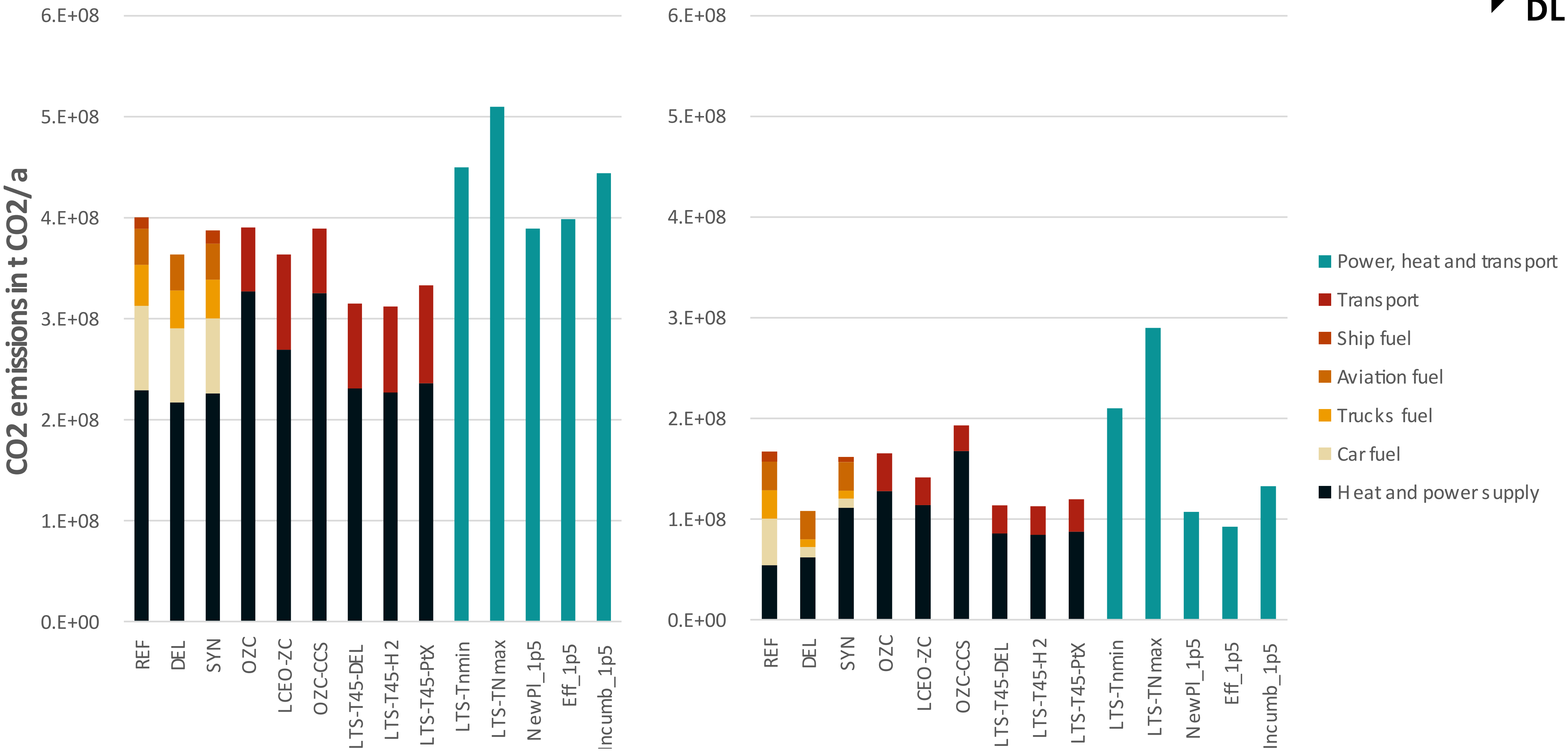
Literature scenarios

[6-10]

Sensitivity analyses

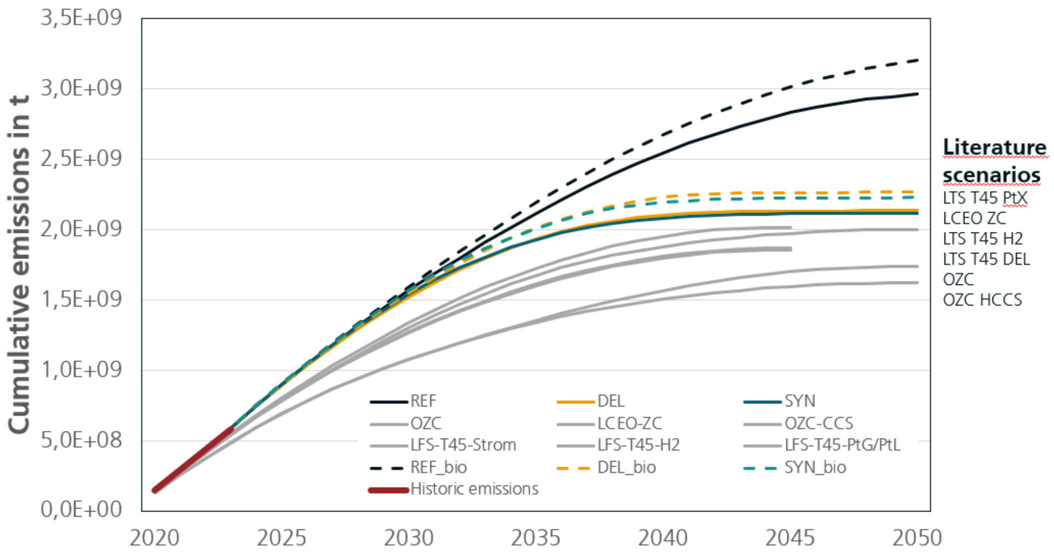
Own calculations for vehicle supply chain and international aviation emissions

[2] IPCC (2023)
[3] Van den Berg et al. (2020)

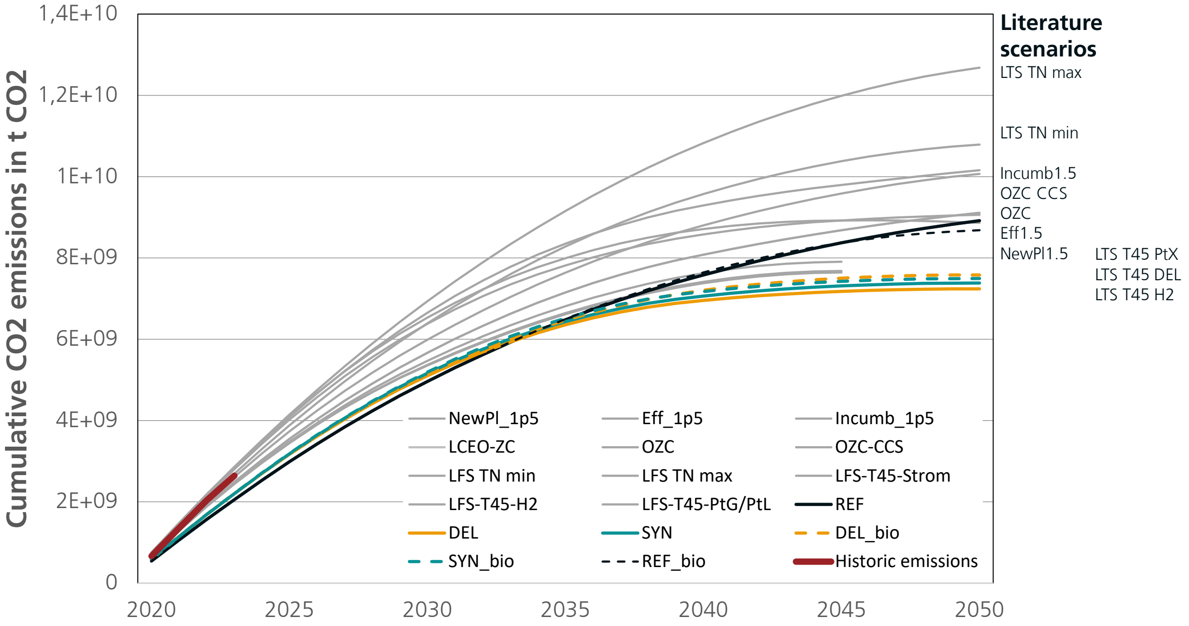

CO2 emissions in t CO2/a
6.E+08
5.E+08
4.E+08
3.E+08
2.E+08
1.E+08
0.E+00
REF
DEL
SYN
OZC
LCEO-ZC
OZC-CCS
LTS-T45-DEL
LTS-T45-H2
LTS-T45-PtX
LTS-Tnmin
LTS-TNmax
NewPl_1p5
Eff_1p5
Incumb_1p5
Power, heat and transport
Transport
Ship fuel
Aviation fuel
Trucks fuel
Car fuel
Heat and power supply

Cumulative transport sector emissions amount to 3.1-3.3 Gt CO2 emissions

Transport sector



Energy system



Cumulative transport sector emissions amount to 3.1-3.3 Gt CO2 emissions

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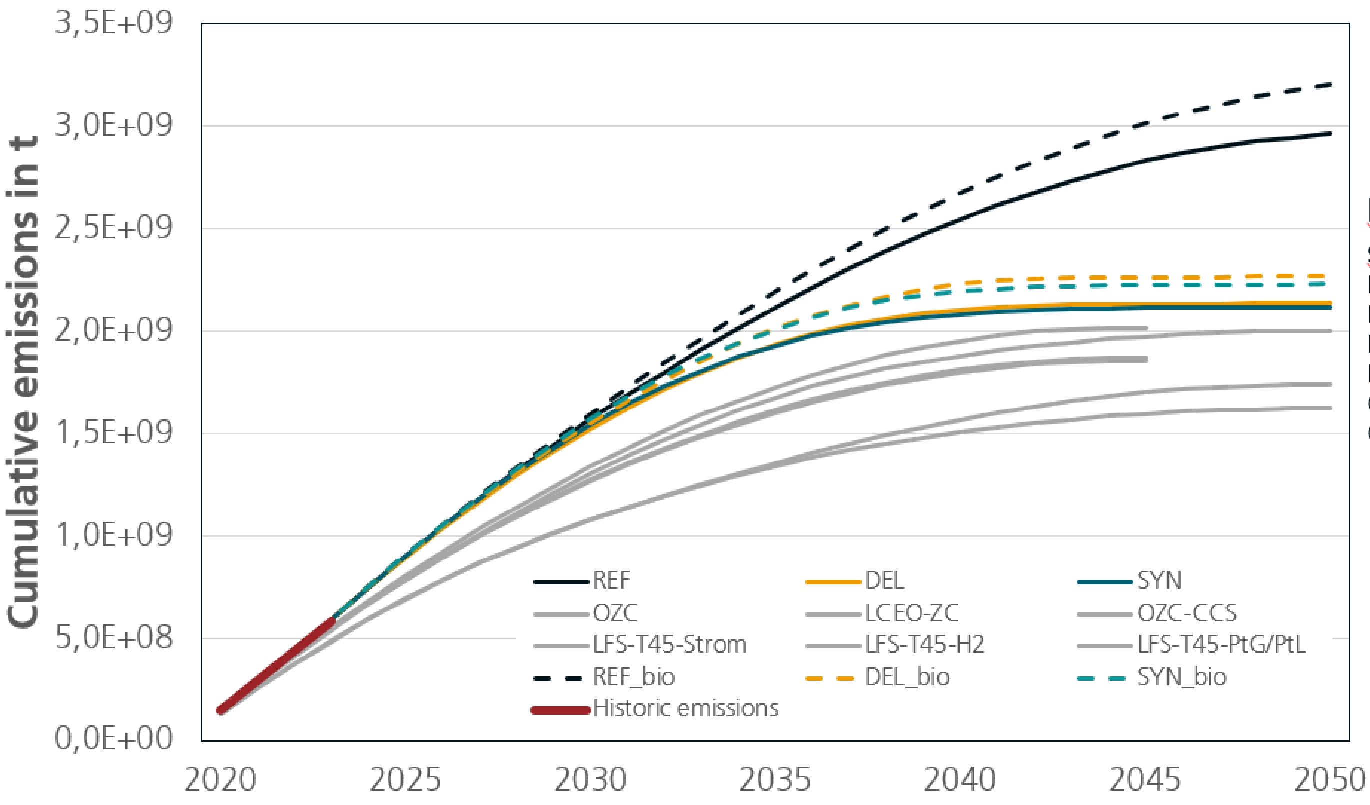
- Demand-side variations are less influential than structural assumptions e.g. top-down vs. Bottom-up modeling
- Transformation of transport sector is mostly carried out in the decade 2030-2040

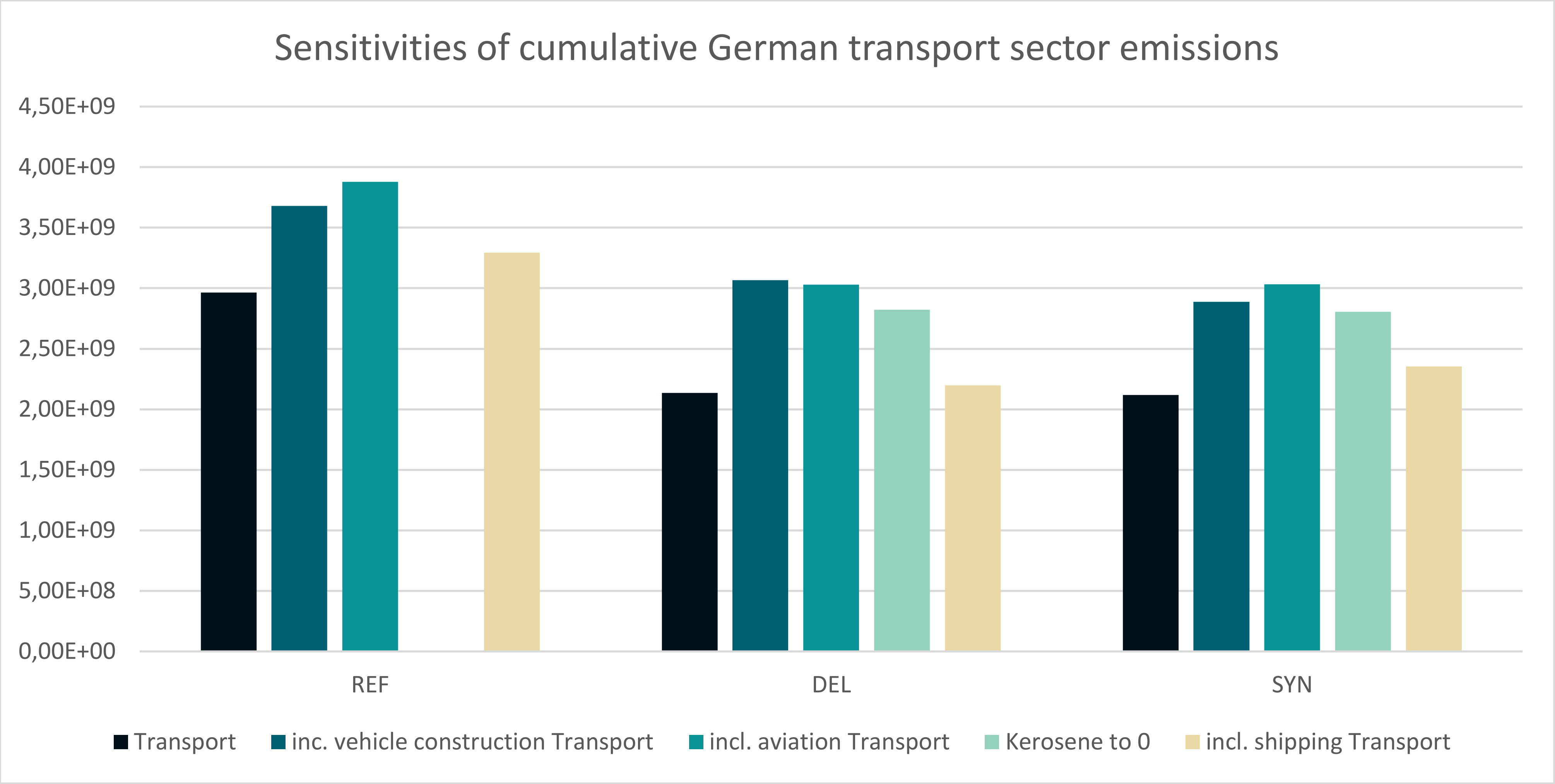
Discussion

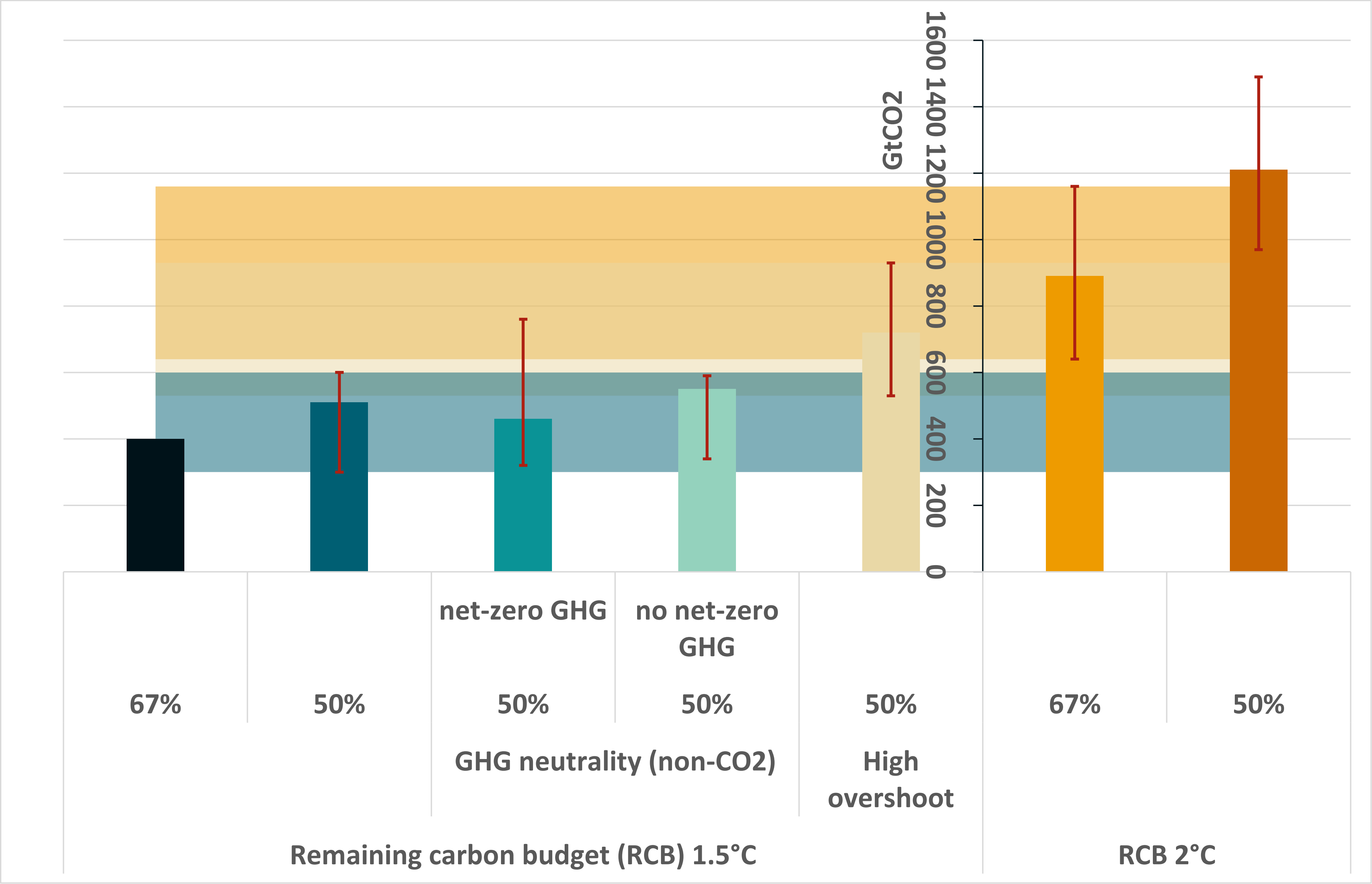
Very ambitious, reaching sales of 3 Mio. battery electric vehicles / a and 150,000-200,000 battery electric trucks in the fastest growing years



Literature scenarios
LTS T45 PtX
LCEO ZC
LTS T45 H2
LTS T45 DEL
OZC
OZC HCCS

Sensitivities




GtCO2
1600
1400
1200
1000
800
600
400
200
0
net-zero GHG
no net-zero GHG
67%
50%
50%
50%
50%
67%
50%
GHG neutrality (non-CO2)
High overshoot
Remaining carbon budget (RCB) 1.5°C
RCB 2°C