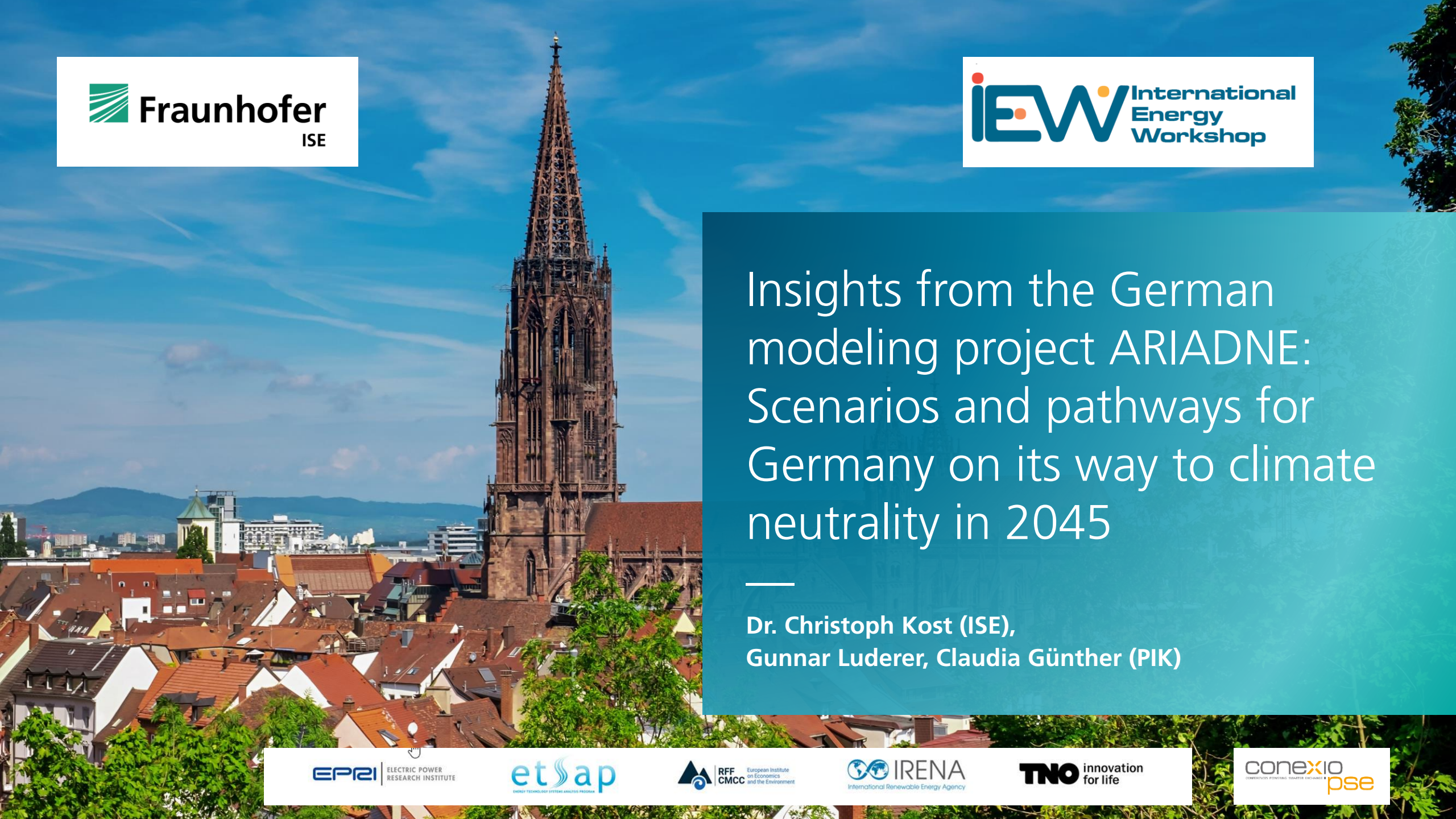

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International Energy Workshop

Insights from the German modeling project ARIADNE: Scenarios and pathways for Germany on its way to climate neutrality in 2045

Dr. Christoph Kost (ISE),
Gunnar Luderer, Claudia Günther (PIK)

EPRI ELECTRIC POWER RESEARCH INSTITUTE · etsap ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM · RFF CMCC European Institute on Economics and the Environment · IRENA International Renewable Energy Agency · TNO innovation for life · conexio pse

Insights from the German modeling project ARIADNE: Scenarios and pathways for Germany on its way to climate neutrality in 2045

- 3 total systems models
- 3 sector models
- Impact analysis environment & distribution

Model of the Fraunhofer ISE: REMod

Total system perspective
REMIND, REMod, TIMES PanEU

Cross-sectional analysis
- **sector linkage:** REMod E2M2s
- **synthetic energy sources and hydrogen:** REMod REMIND
- **negative emissions:** REMIND

Sector analysis
- **traffic:** VECTOR21 (DLR-FK), DEMO (DLR-VF) REMIND/EDGE-T
- **buildings:** REMod TIMES PanEU, REMIND
- **industry:** FORECAST TIMES PanEU, REMIND, REMod, NEWAGE
- **potential analysis wind and solar energy:** energyANTS

Impact analysis
- **environment:** Brightway2, PREMISE, carculator, CMAQ/SMOKE, TM%_FASST, MFA-model
- **distribution:** CO2 consumption model
- **macroeconomics (future):** ISI-Macro NEWAGE

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https://ariadneprojekt.de/publikation/deutschland-auf-dem-weg-zur-klimaneutralitat-2045-szenarienreport/

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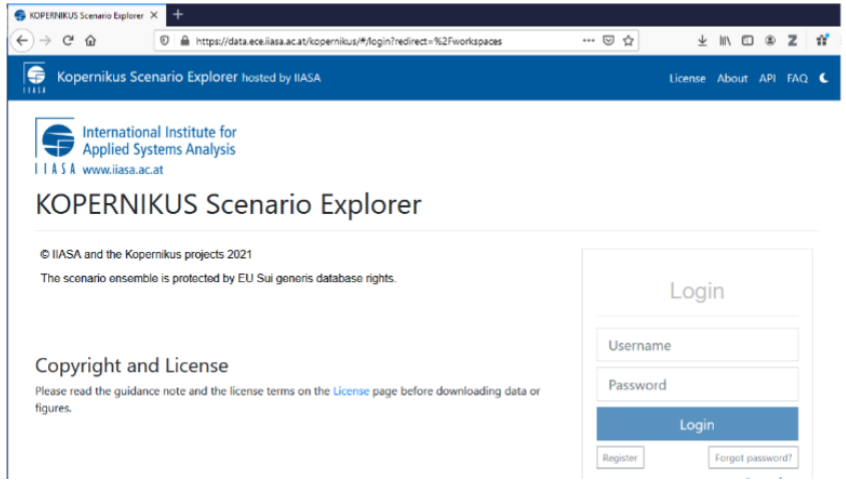
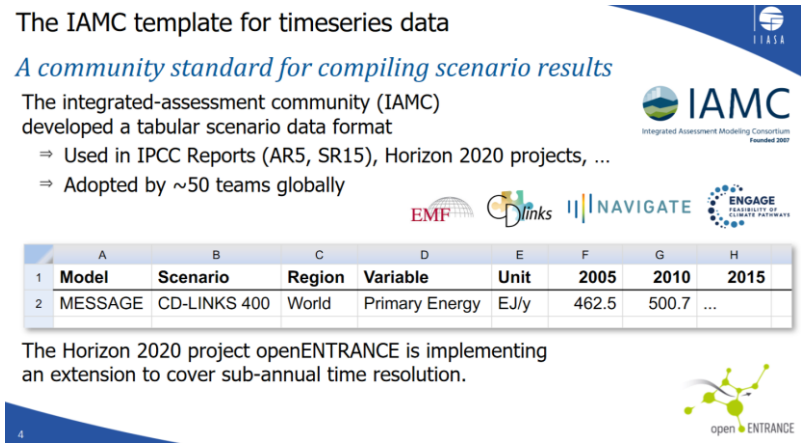
Advantages of common database and analysis packages

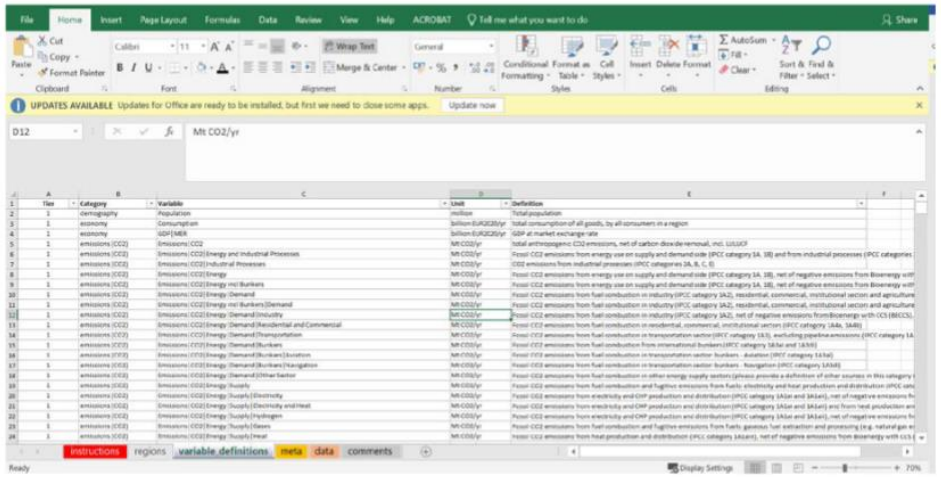
Scenario Database



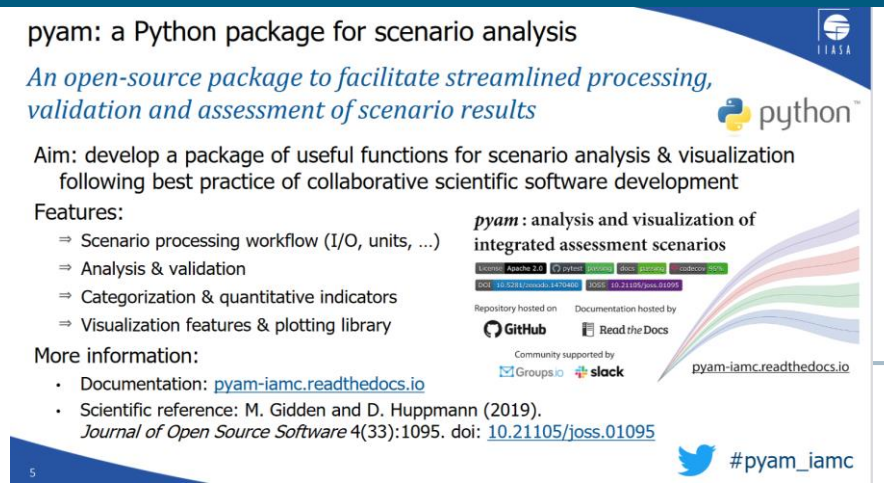
IAMC template



Data exchange



PYAM



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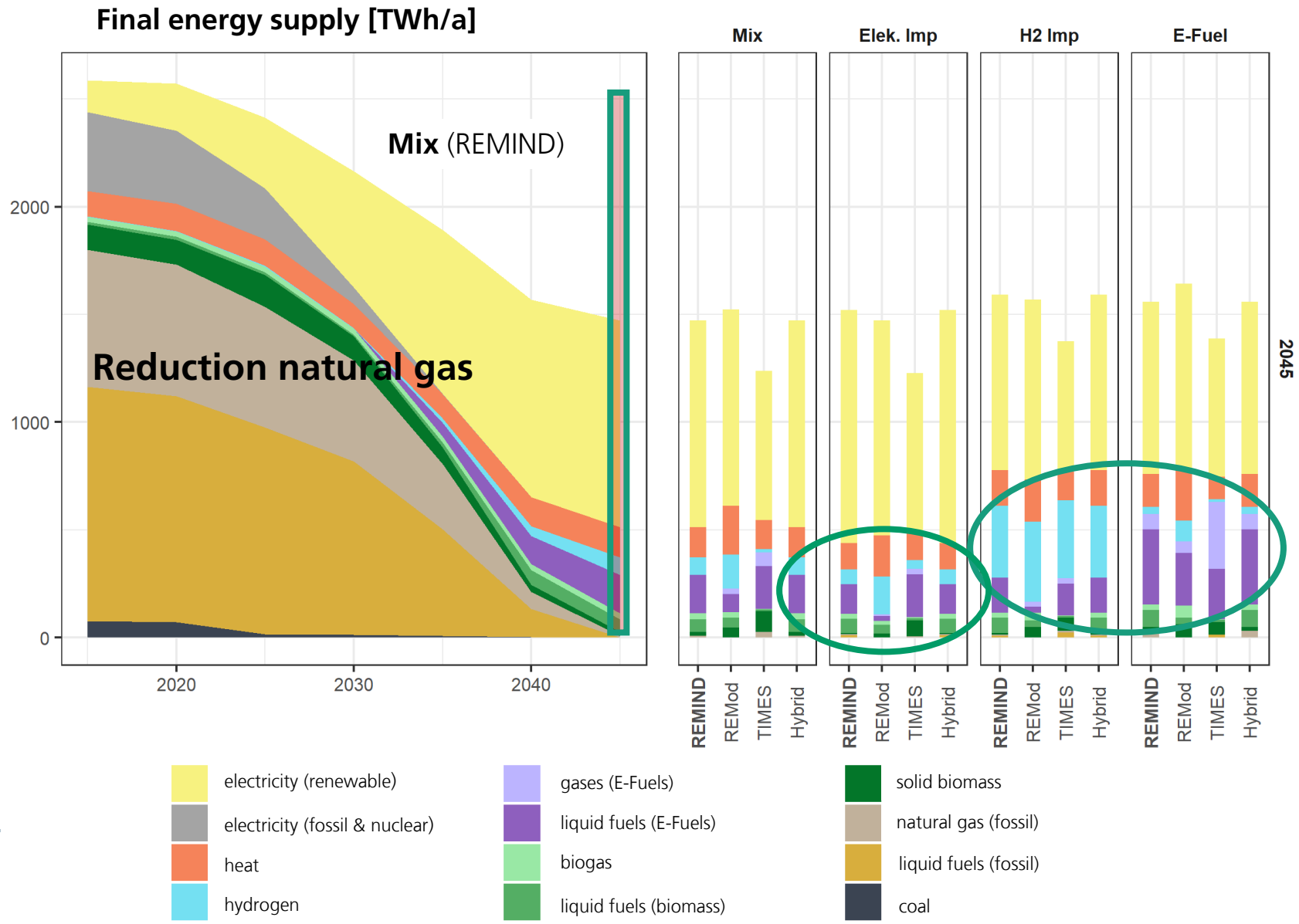
Scenarios

Scenario Name	Scenario Description	EE-Importe (2045)
Technology mix	**Mix** Technology mix between electrification, hydrogen and synfuels in final energy use	Total import potential for RE based energy carrier of **250-350 TWh/a** in 2045.
Direct Electrification	Priority of direct electrification, Variants **Elek. Imp** (higher RE-Importe) **Elek. DE** (lower RE-Importe)	**Elek. Imp** Total import potential for RE based energy carrier in 2045 of ca. **230-360 TWh/a**, with 50-100 TWh electricity
		Elek. DE: Less import potential of ca. **130-200 TWh** in 2045 leads to higher local use of RE
Hydrogon	Priority of direct use of hydrogen, Variants **H2 DE** (lower RE-Importe) **H2 Imp** (higher RE-Importe)	**H2 Imp:** Total import potential for RE based energy carrier in 2045 of ca. **350-580 TWh**, with 250-400 TWh hydrogen
		H2 DE: Less import potential of ca. **150-190 TWh,** with 100 TWh hydrogen) leads to higher local use of RE and Power-to-X
Synthetic E-Fuels	**E-Fuel** Priority for use of synthetisc E-fuels	**:** Total import potential for RE based energy carrier in 2045 of **470-600 TWh**, with ca. 400 TWh E-Fuels

Model comparison: final energy



- Proportional share of fossil fuels on final energy: (incl. material use): <3%
- Final energy demand:
  – 34-59% compared to 2019
- Percentage of electricity of final energy: 40-69%
- Proportion hydrogen and E-Fuels: 8-37%

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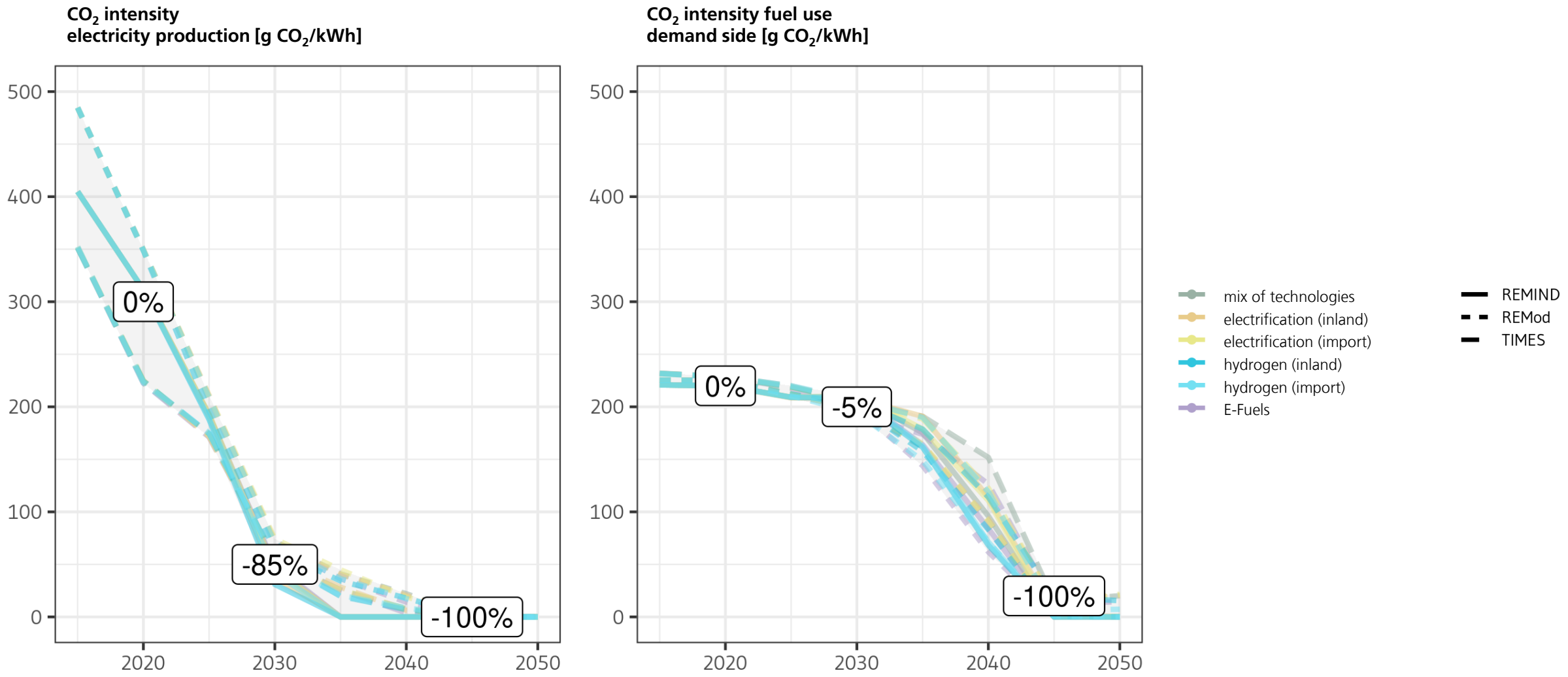
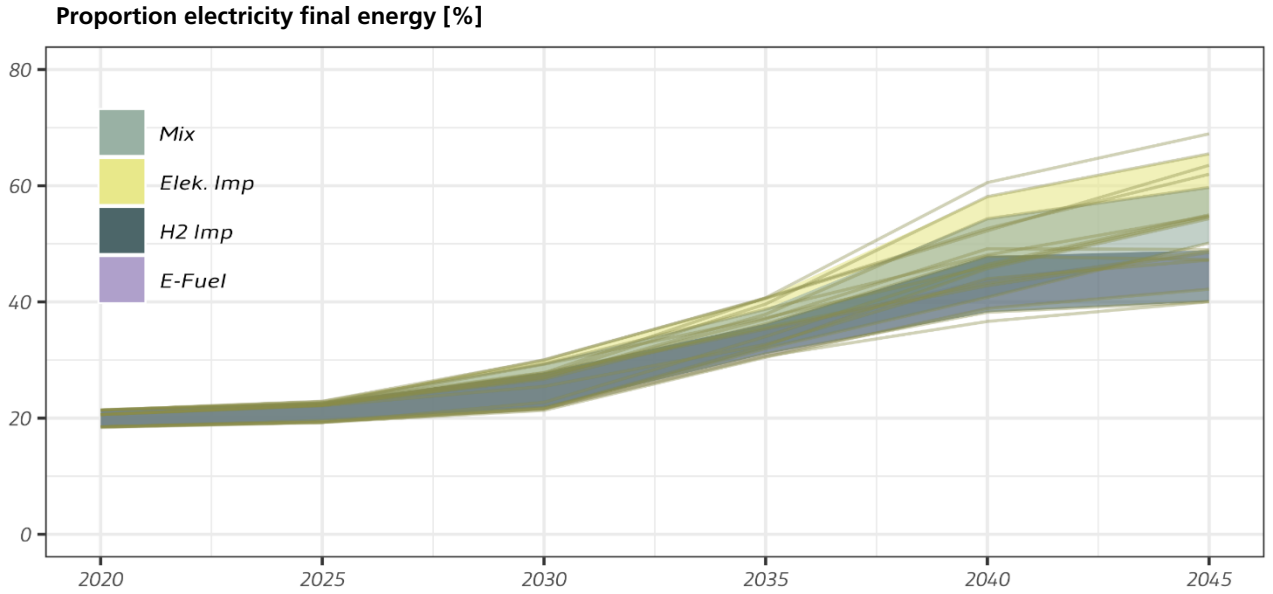
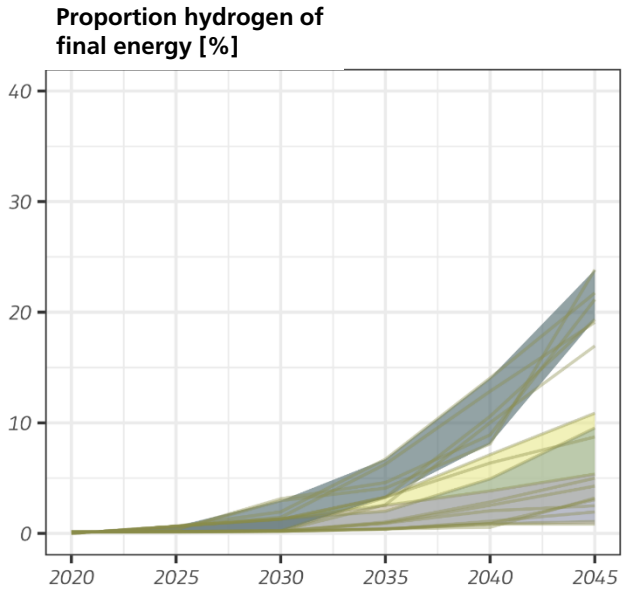
CO_2 intensity electrical vs. non-electrical energy supply

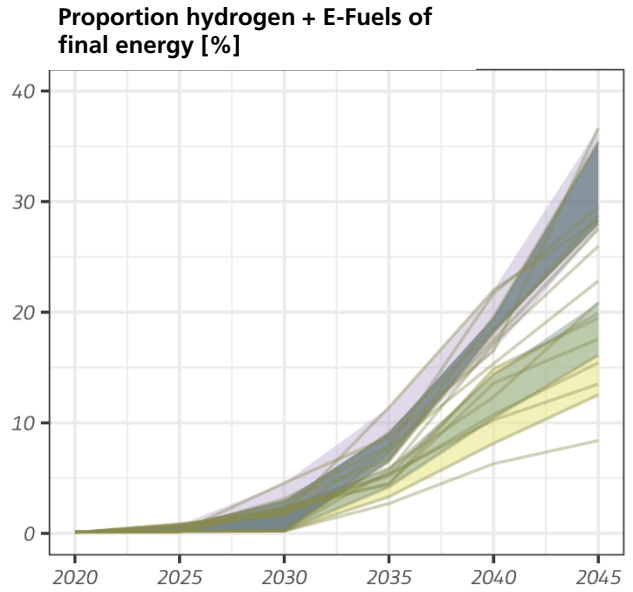


Direct and indirect electrification

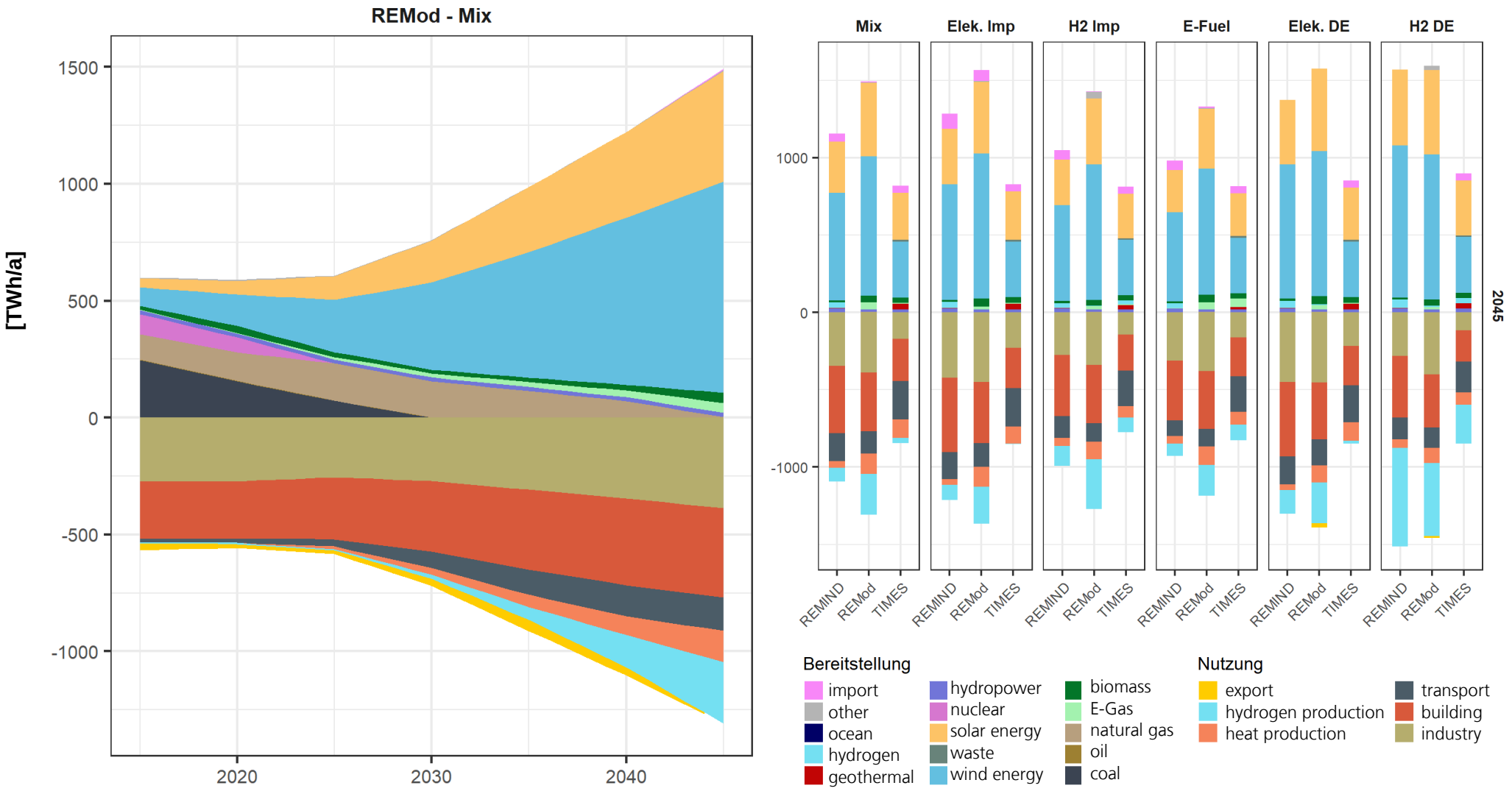
- Proportion electricity:
  40-69% of final energy
- Proportion hydrogen/E-Fuels:
  8-37% of final energy
- 300-400 TWh H2/E-Fuels also in electrification scenarios





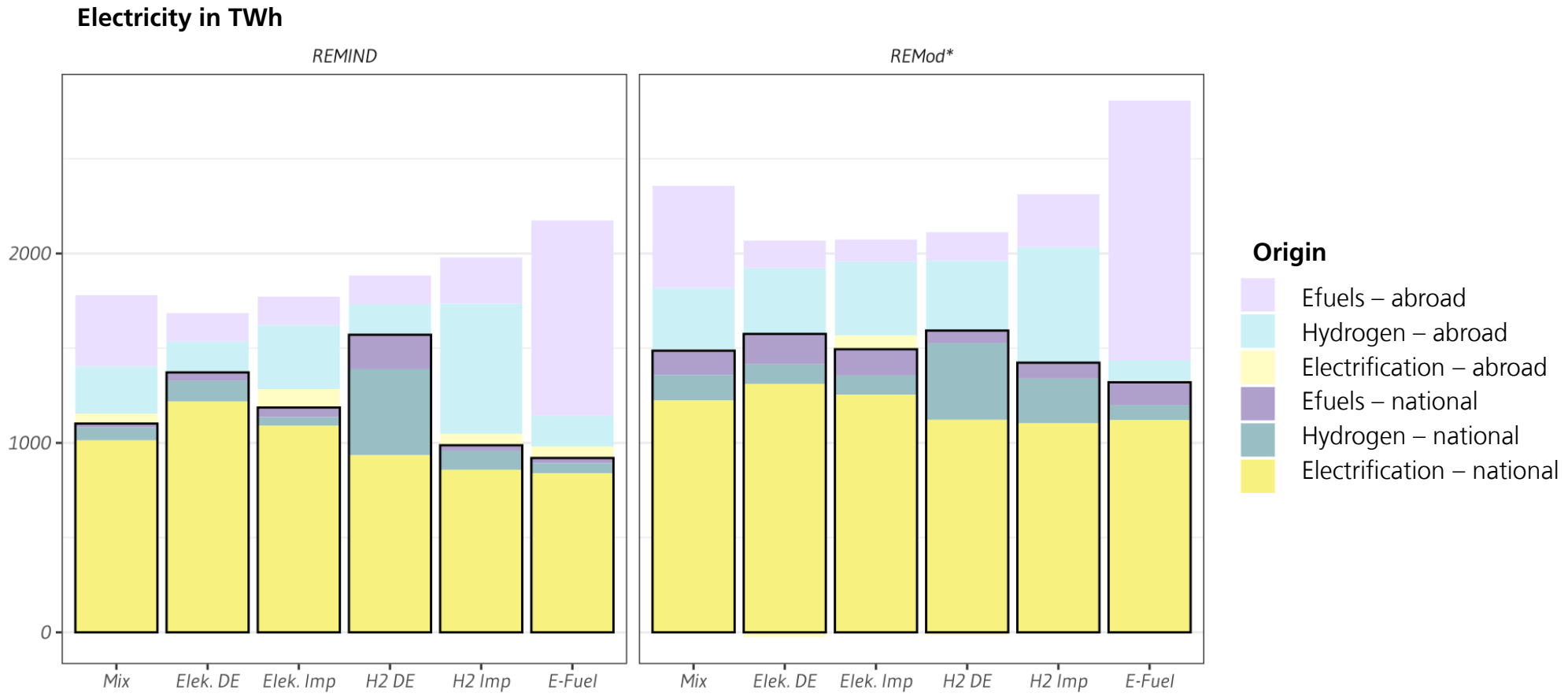


Electricity supply and usage



Electricity demand from renewables

National and international



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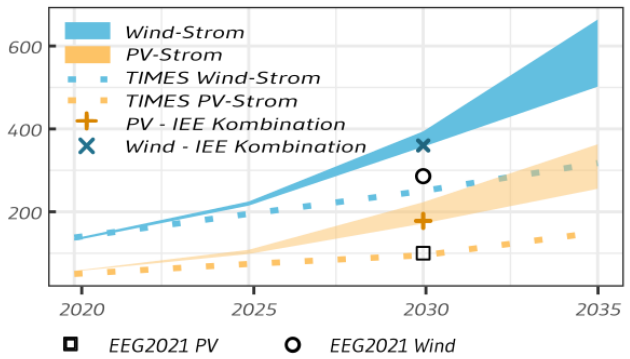
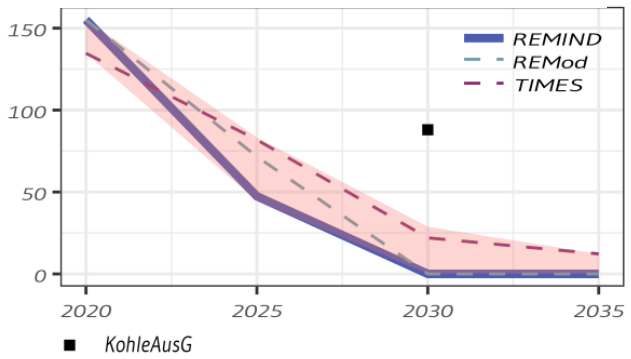
Transformational mile stones until 2030

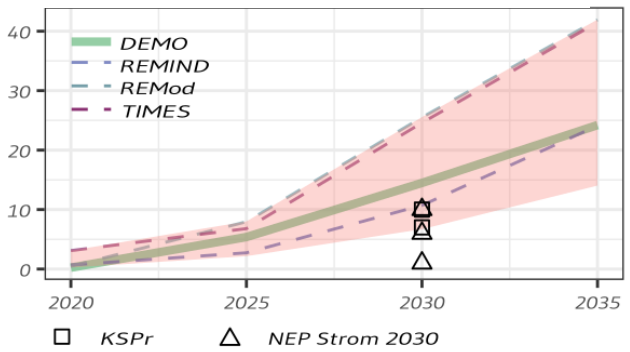
Electricity generation wind + PV [TWh/a]



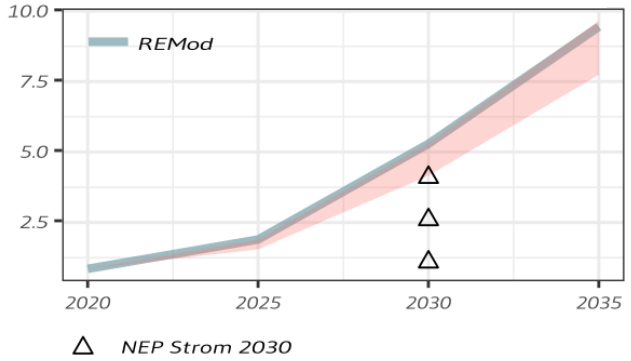
Electricity generation coal [TWh/a]



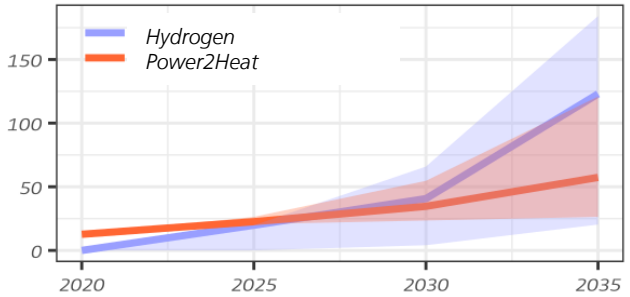
Stock of electrical vehicles [million]



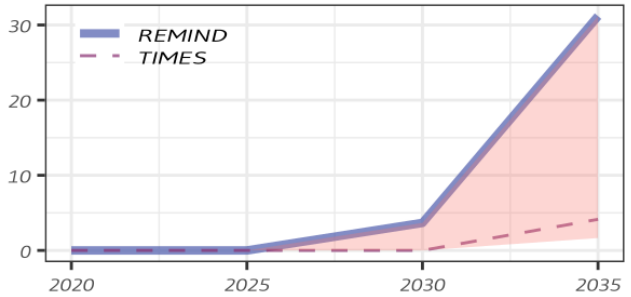
Stock of heat pumps [million]



Hydrogen and P2Heat demand [TWh/a]



CO2 capture and mitigation [MtCO2/a]



- Electricity demand rises in most scenarios for 23-34% until 2030
- Threefold increase of electricity production from wind and PV
- (Nearly) complete phase-out of coal-fired electricity generation
- Orient new procurements and investments in the demand sectors transport, industry, buildings towards compatibility with climate neutrality
- Expansion of infrastructures: electricity grids, hydrogen grids, charging infrastructure e-mobility, CO2 storage

Take aways

Insights from the German modeling project ARIADNE: Scenarios and pathways for Germany on its way to climate neutrality in 2045

- Large German project for energy system analysis to consolidate energy pathways
- Data and evaluation platform created -> huge benefits on result evaluation
- System and sector models are interlinked, simulation and optimization models are used
- High efforts to reach climate neutrality in each sector
- Size of project and wide use of different model leads to large impact on energy policy in Germany

https://ariadneprojekt.de/publikation/deutschland-auf-dem-weg-zur-klimaneutralitat-2045-szenarienreport/

Thank you!

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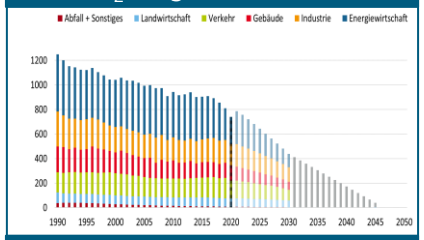
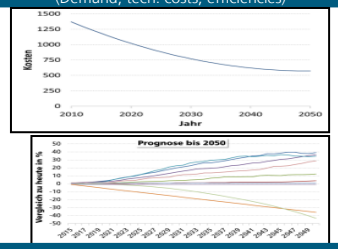
REMod – Cross-sectoral energy system model

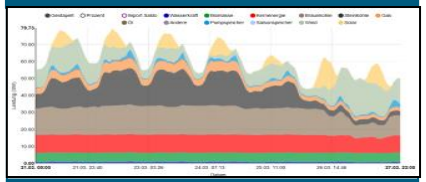
CO_2-target(-80 -95%)



Data input
(Demand, tech. costs, efficiencies)



Hourly profiles (weather, demand)

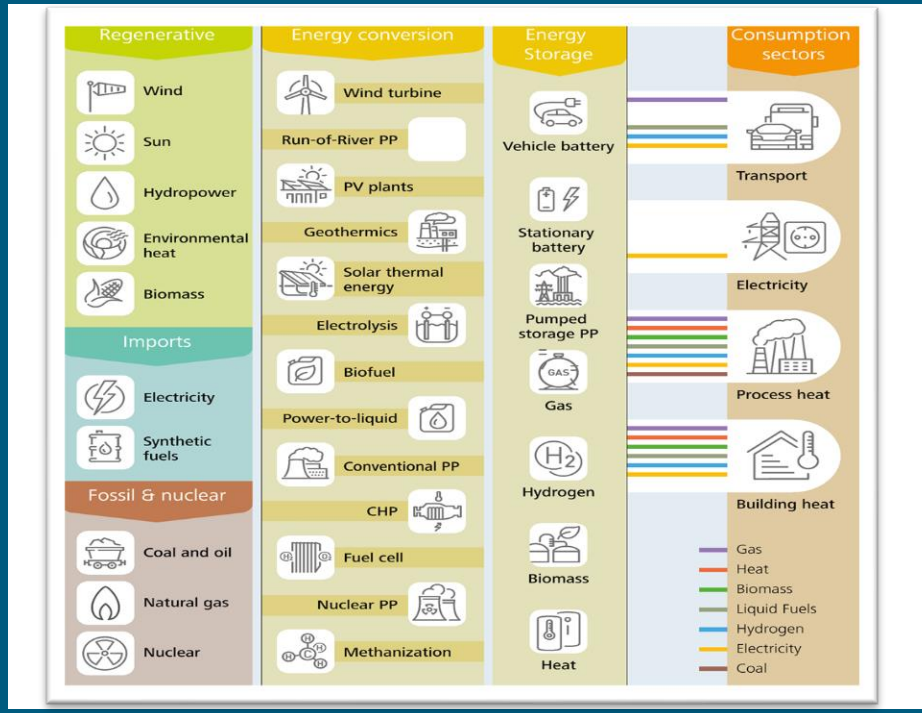


Energy converters today (all sectors)

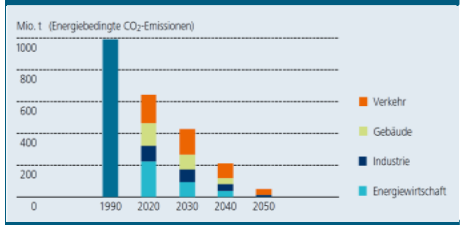
Core of the model

Hourly optimization. Non-linear.
All energy sources, converters, storages and consumption sectors.
Target function: Minimization of total system costs
Boundary conditions: Security of supply and CO_2 emissions

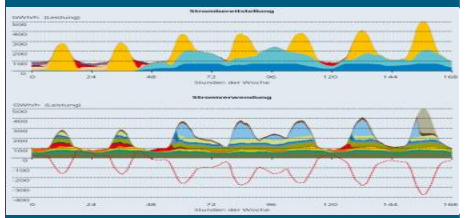
Energy Sources | Energy Conversion and Storage | Consumption Sectors



Decarbonisation per sector

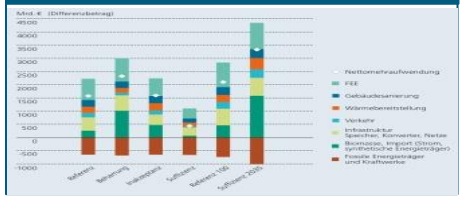


Sector-coupled operating results



Energy converters until 2050 (all sectors)

System costs of transformation



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Methodology
Energy System Model REMod

Inventory

1990	1991	1992	…	2017	2018	2019
Conventional and renewable power plants (PV, Wind, …)						
Buildings and heating systems						
Traffic (vehicle fleets etc.)						
Industrial processes and trade						

New installations, replacement, renovation

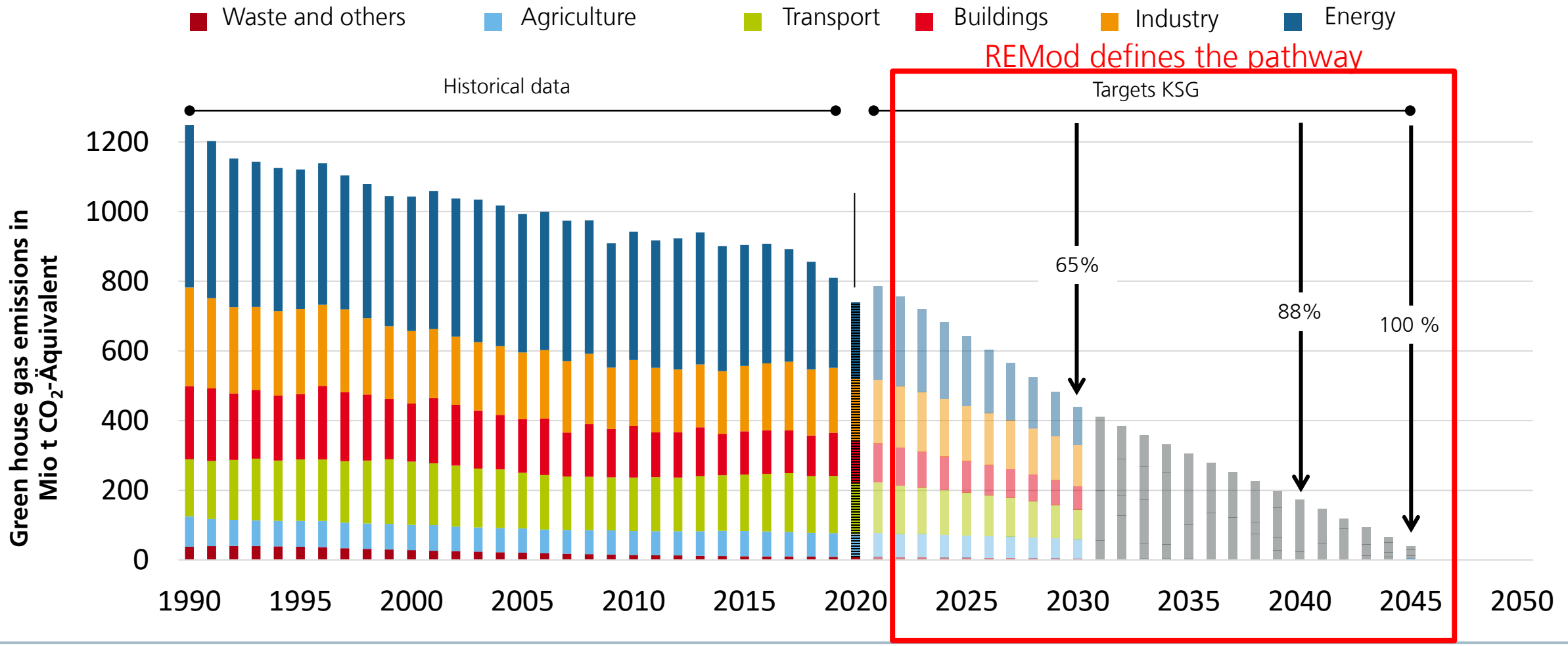
2020	2021	2022	…	2048	2049	2050
Conventional and renewable power plants (PV, Wind, …)						
Buildings and heating systems						
Traffic (vehicle fleets etc.)						
Industrial processes and trade						
Storage (electricity, heat, gases)						
Power-to-X-Technologies						

Simulation (1 h time steps) of the entire system from today until 2050

CO_2 limit (for each year)?

Optimization of new installations, replacement, renovation
Target function: Minimum cumulative system costs from 2020-2050

Greenhouse gas emissions



Historische Daten und VJS: Vorjahreschätzung (VJS) der deutschen Treibhausgas-Emissionen für das Jahr 2020. Umweltbundesamt, 15.3.2021

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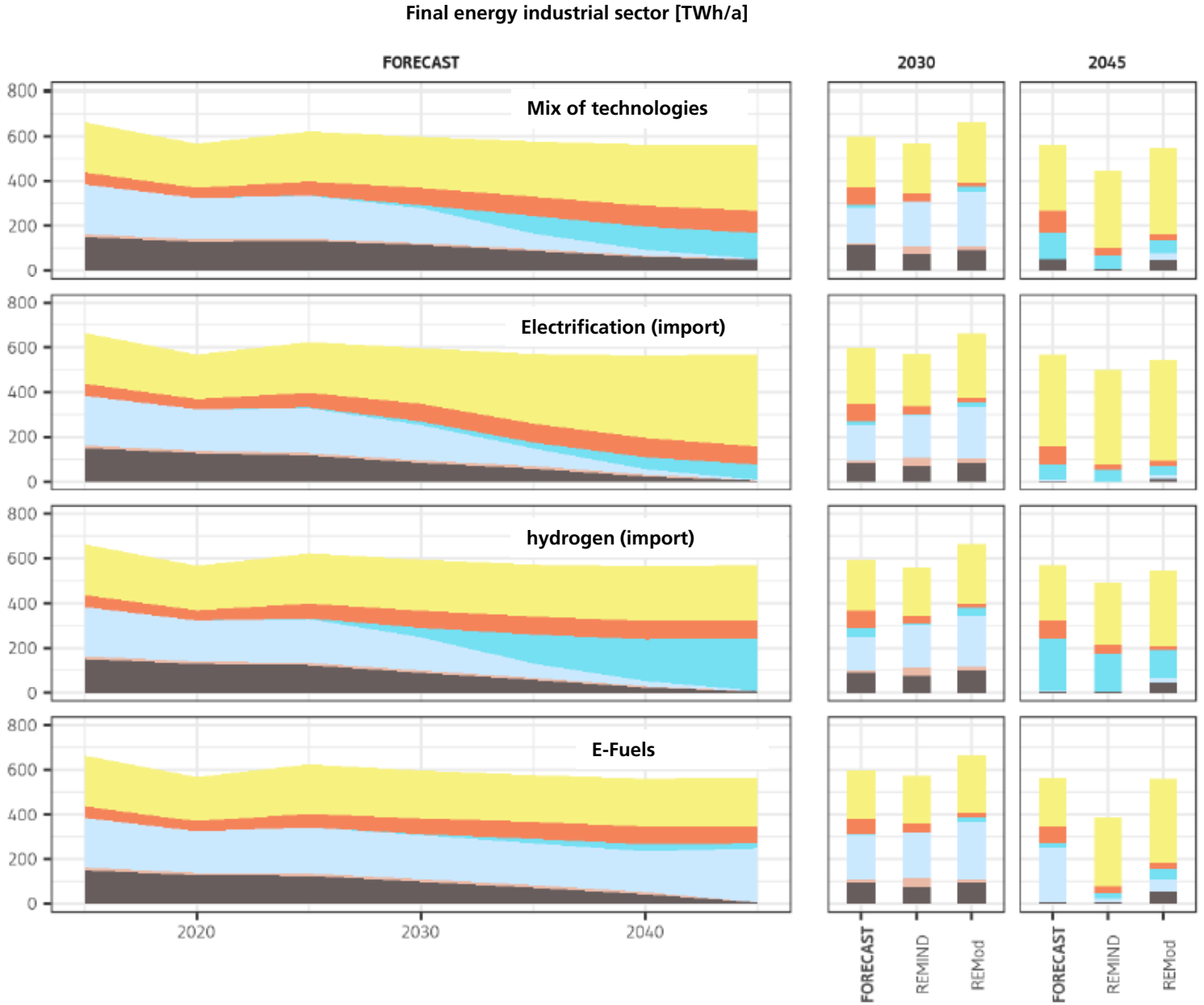
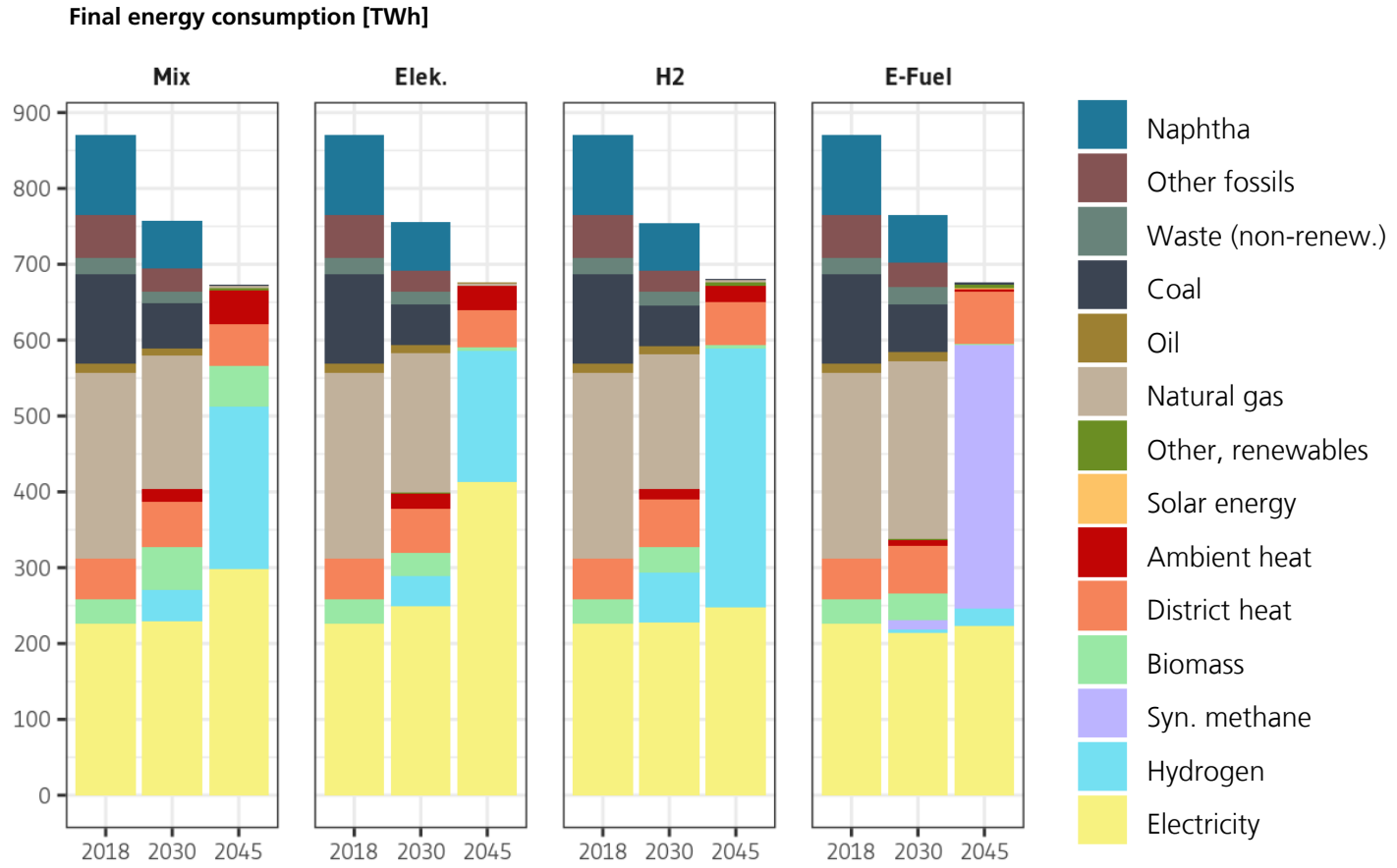
Development of final energy within the industrial sector



The INDUSTRIAL TRANSITION requires high amounts of CO_2-neutral energy sources, but also other measures

- **In addition to energy and material efficiency, circular economy and CCU/S**
- **New CO2-neutral processes:**
  - steel, ammonia, methanol/olefins
  - ~170 TWh H2-demand in 2045 distributed over few sites
- **Extensive use of CO2-neutral energy sources in remaining process (electricity, hydrogen, synthetic methane)**
- **Generation of CO2-neutral H2 and PtG outside of the industrial sector changes the picture**



Industrial energy demand (energetical and material) (2018-2045, TWh). Source: Fraunhofer ISI-FORECAST Model.

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