



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

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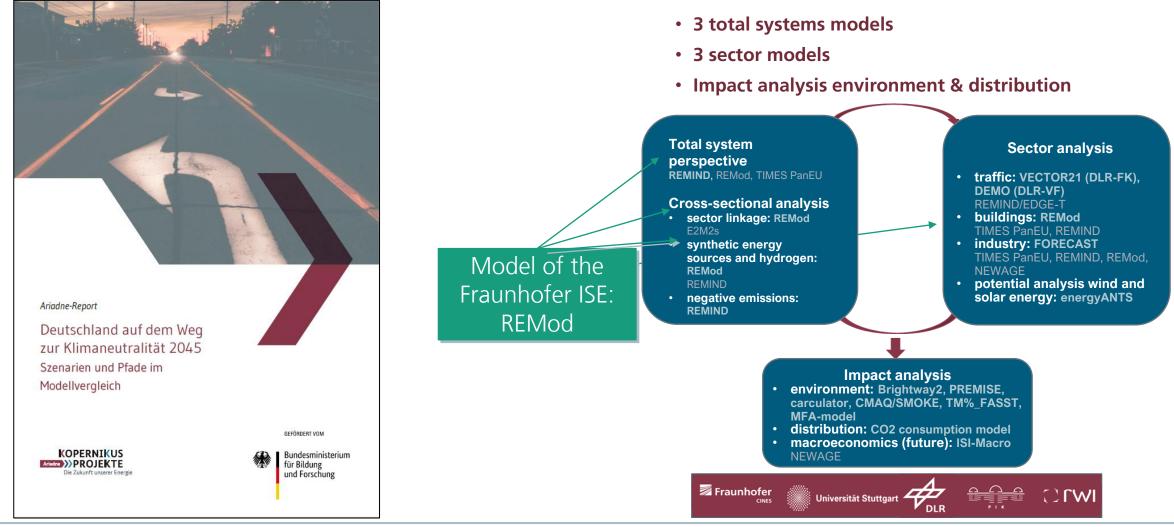




TNO innovation for life



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



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



Advantages of common database and analysis packages

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Data exchange

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IAMC template

The IAMC template for timeseries data

A community standard for compiling scenario results

The integrated-assessment community (IAMC) developed a tabular scenario data format

 $\Rightarrow\,$ Used in IPCC Reports (AR5, SR15), Horizon 2020 projects, ...

 \Rightarrow Adopted by ~50 teams globally



1		А	В	С	D	E	F	G	н	
	1	Model	Scenario	Region	Variable	Unit	2005	2010	2015	
	2	MESSAGE	CD-LINKS 400	World	Primary Energy	EJ/y	462.5	500.7		

The Horizon 2020 project openENTRANCE is implementing an extension to cover sub-annual time resolution.



-

n python

#pyam_iamc

PYAM

pyam: a Python package for scenario analysis

An open-source package to facilitate streamlined processing, validation and assessment of scenario results

Aim: develop a package of useful functions for scenario analysis & visualization following best practice of collaborative scientific software development

Features:

- ⇒ Scenario processing workflow (I/O, units, ...)
 ⇒ Analysis & validation
- ⇒ Categorization & quantitative indicators
- ⇒ Visualization features & plotting library

Documentation: pyam-iamc.readthedocs.io

More information:

Community supported by S Groups:0 # slack pyam-iamc.readthedocs.io

GitHub

pyam: analysis and visualization of

Documentation hosted by

Read the Docs

integrated assessment scenarios

Apache 2.0 O pytest passage docs passage o

 Scientific reference: M. Gidden and D. Huppmann (2019). Journal of Open Source Software 4(33):1095. doi: 10.21105/joss.01095

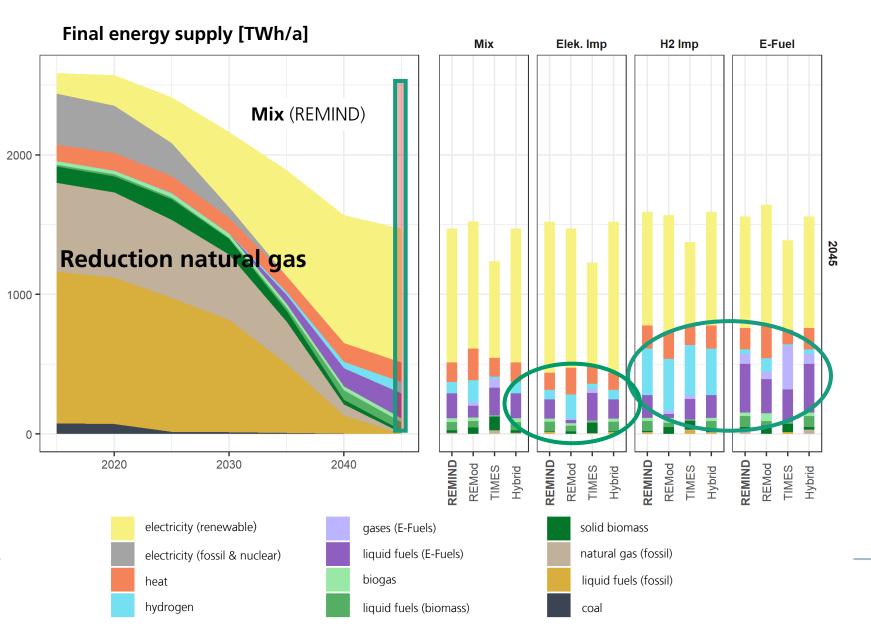


Scenarios

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. Imp Total import potential for RE based energy carrier in 2045 of ca. 230-360 TWh/a , with 50-100 TWh electricity		
	Elek. DE (lower RE-Importe)	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		



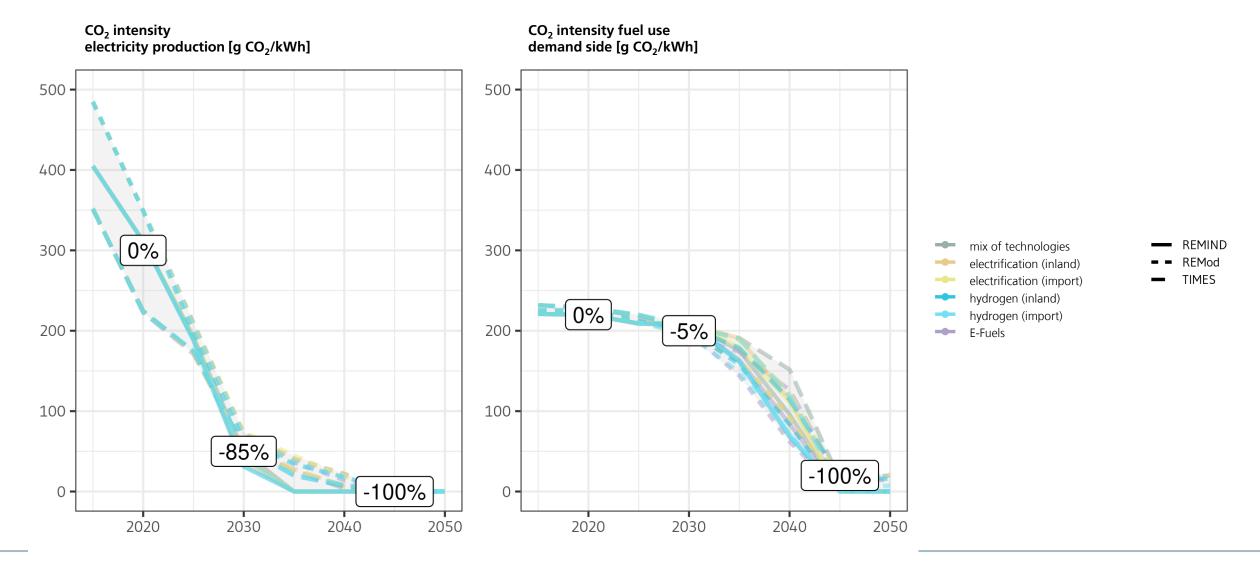
Model comparison: final energy



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



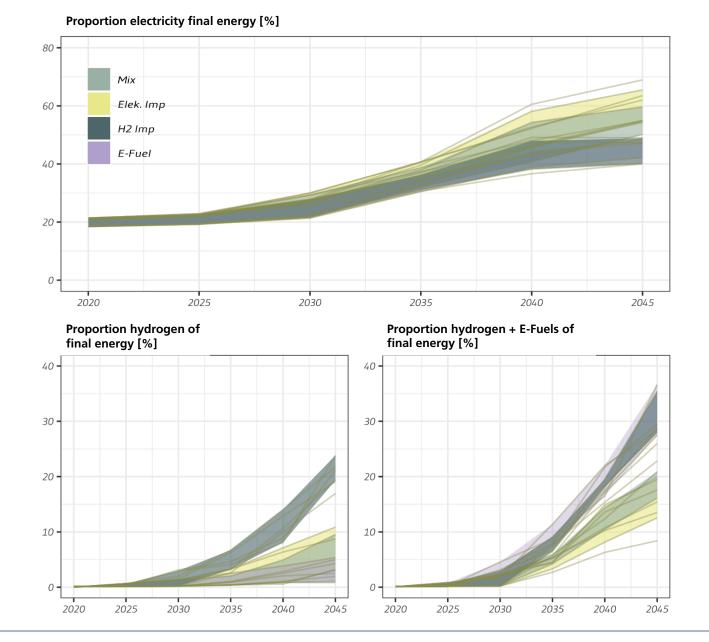
CO₂ intensity electrical vs. non-electrical energy supply





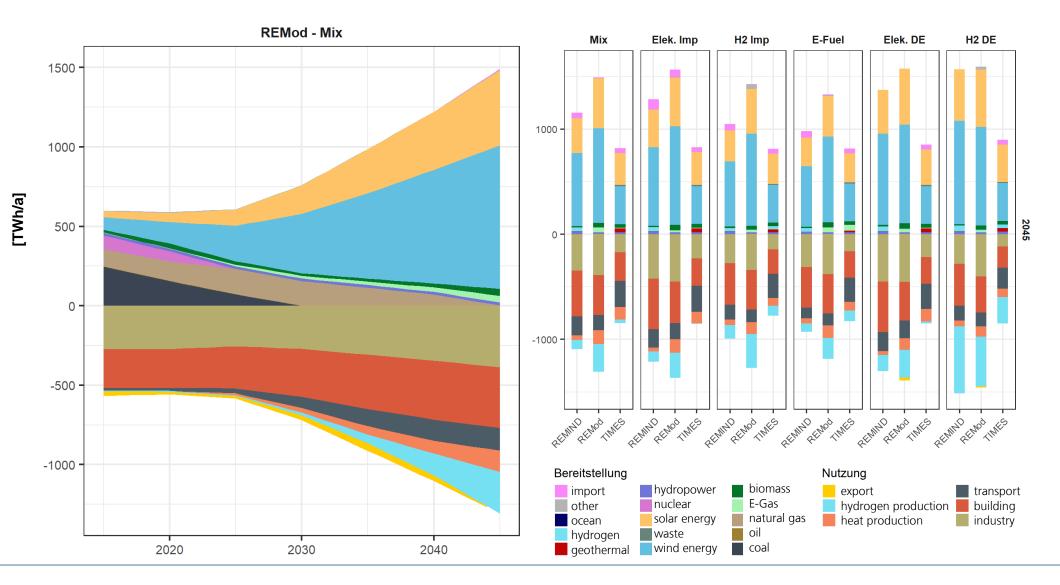
Direct and indirect electrification

- 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

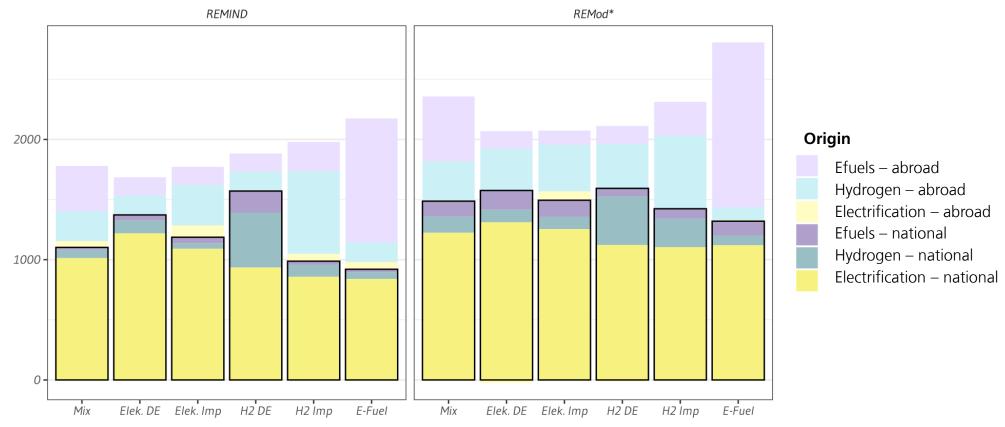




Electricity demand from renewables

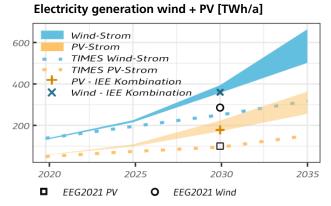
National and international

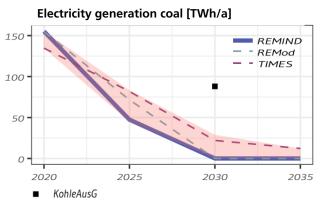
Electricity in TWh



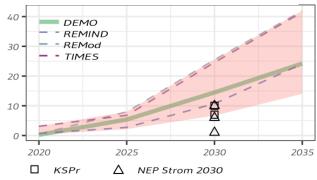


Transformational mile stones until 2030

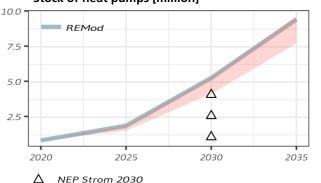




Stock of electrical vehicles [million]

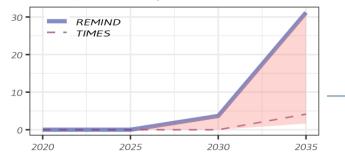






Hydrogen and P2Heat demand [TWh/a]

CO2 capture and mitigation [MtCO2/a]



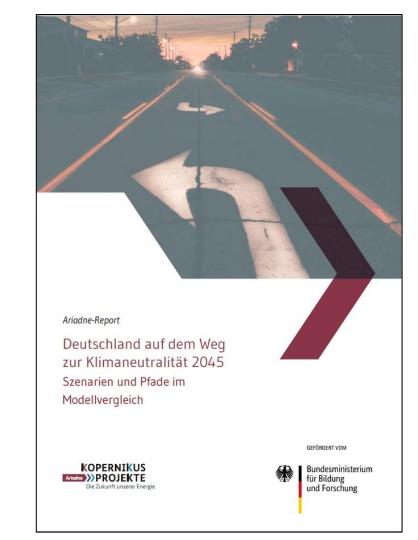
- Electricity demand rises in most scenarios for 23-34% until 2030
- Threefold increase of electricity production from wind and PV
- (Nearly) complete phase-out of coal-fired electricity generation
- Orient new procurements and investments in the demand sectors transport, industry, buildings towards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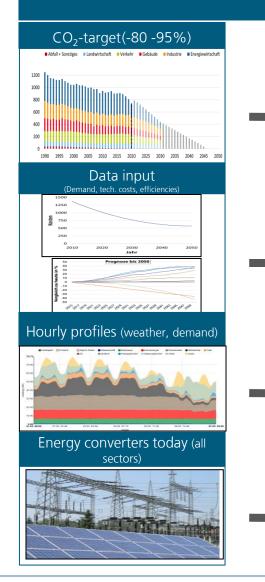






REMod – Cross-sectoral energy system model

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 CO₂ emissions # Wind Wind turbine B -议 **Run-of-River PP** Vehicle batter PV plants Transport 0 38 Hydropower Geothermics Stationary battery F Environmental heat Solar thermal energy £ No Electricity Biomass Electrolysis Pumped storage PF **M** GAS Biofuel (3) Process heat Electricity Gas Power-to-liquid 103 Synthetic (H₂) Conventional PP = cHydrogen СНР К **Building heat** 38 Coal and oil Fuel cell Gas Heat Biomass 6 Nuclear PP Natural gas Liquid Fuels ßi

Heat

B

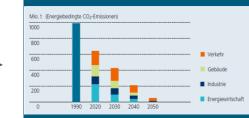
Nuclear

Hydrogen

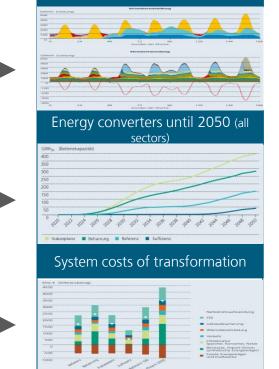
Electricity

Coal

Decarbonisation per sector

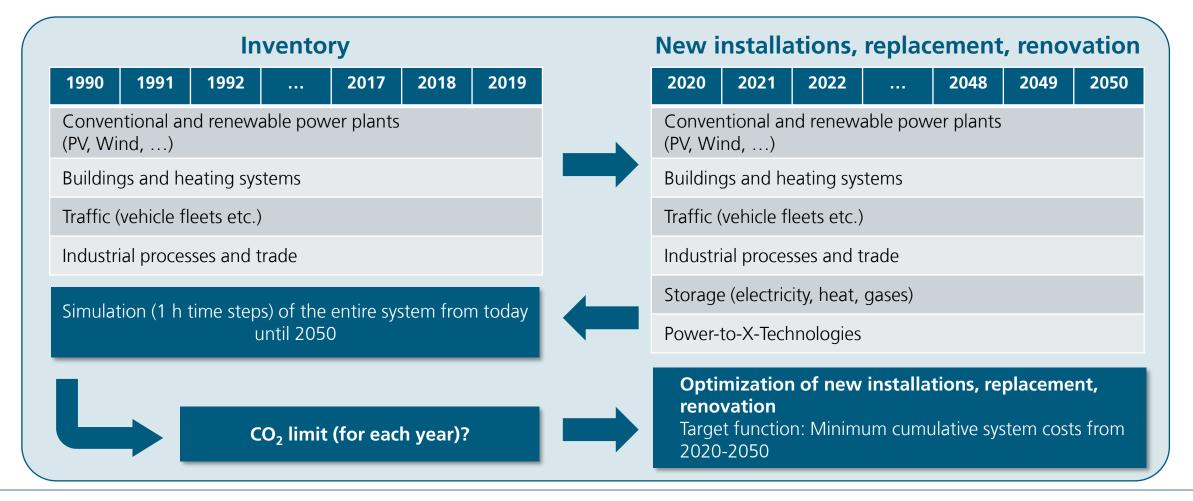


Sector-coupled operating results



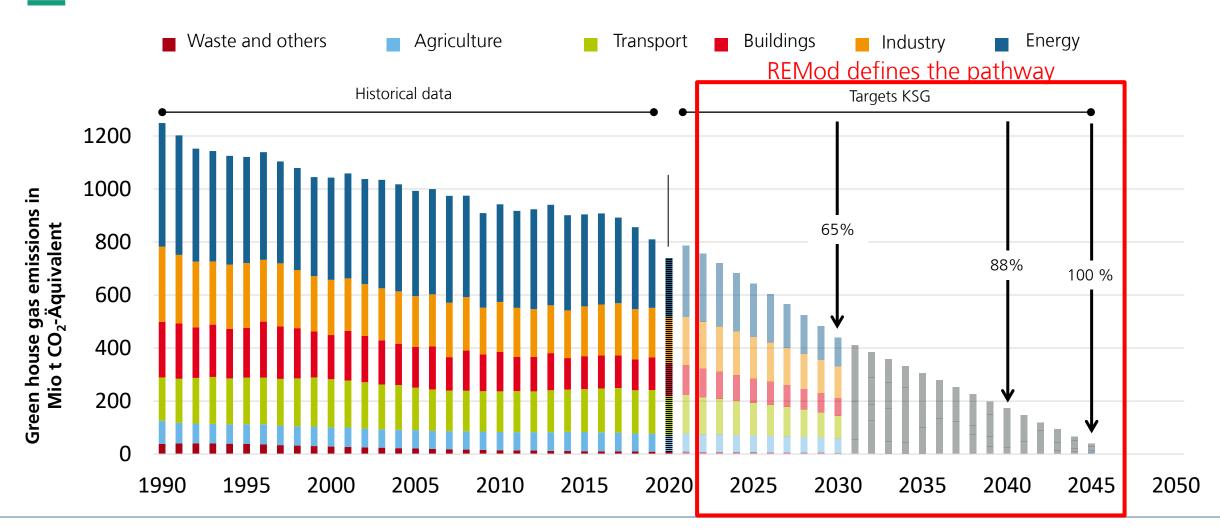


Methodology Energy System Model REMod





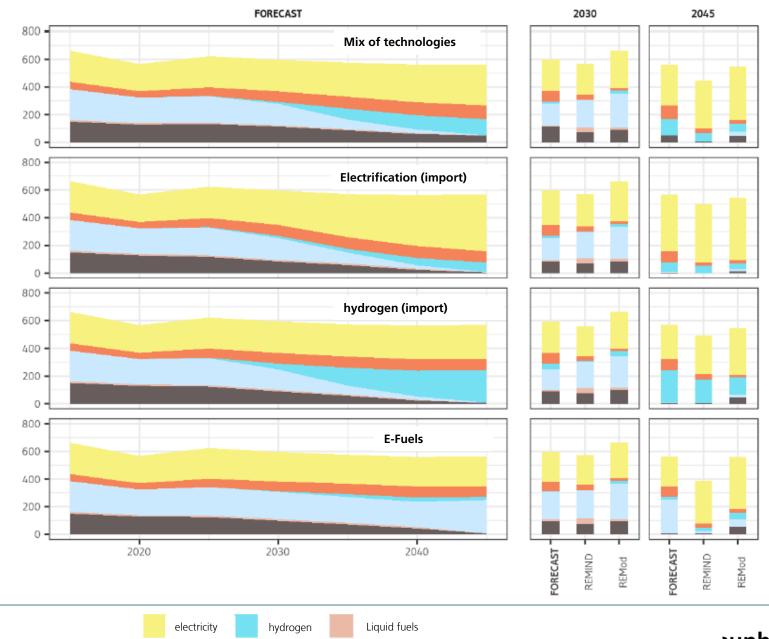
Greenhouse gas emissions



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



Development of final energy within the industrial sector



Solid fuels

heat

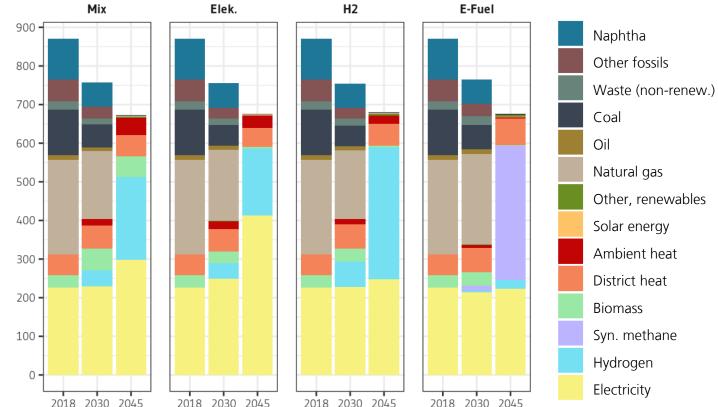
gases

Final energy industrial sector [TWh/a]

aunhofer

The INDUSTRIAL TRANSITION requires high amounts of CO₂-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.



Final energy consumption [TWh]