

H₂ utilisation pathways and their climate impact

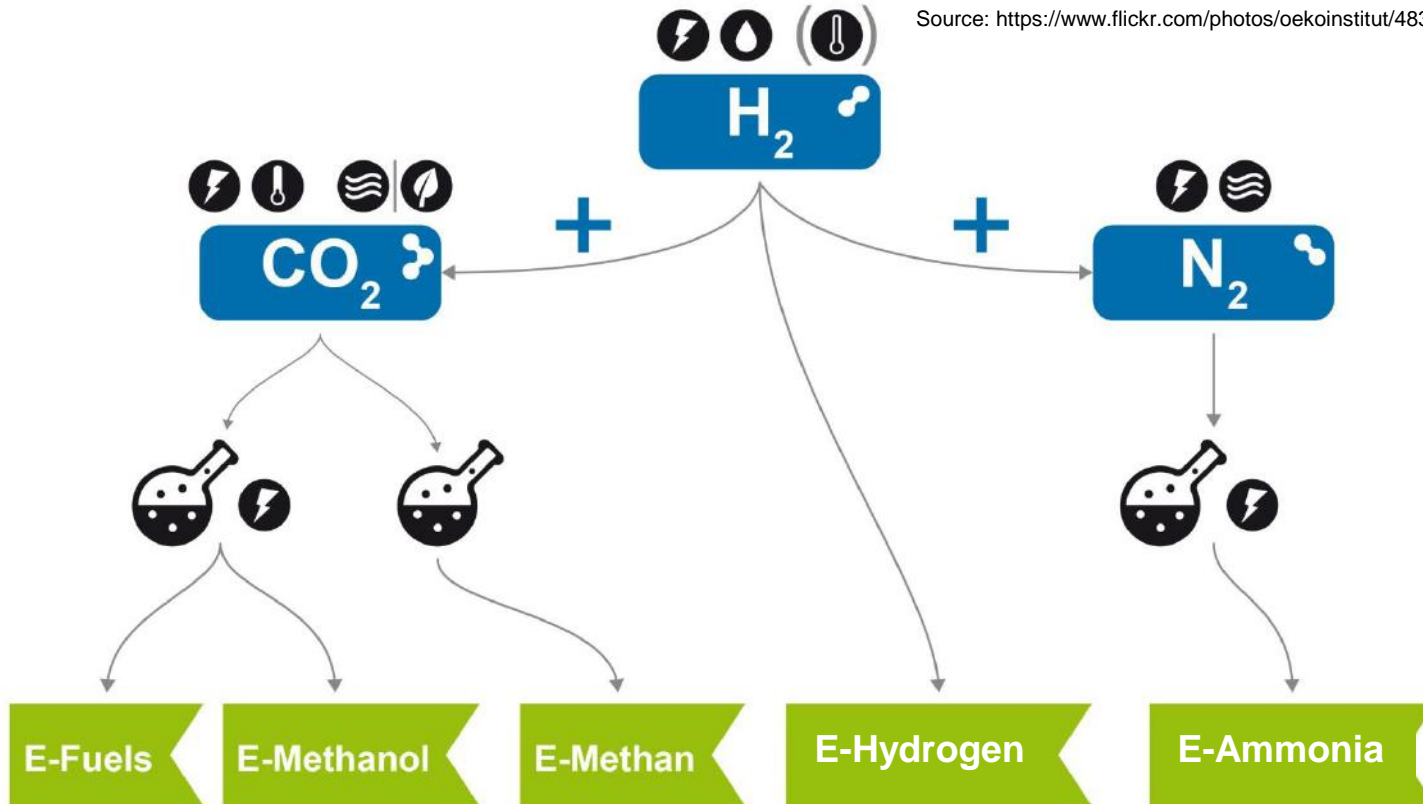
Dr. Matthias Koch and Christoph Heinemann

2nd Modellers' Exchange Workshop, Paris Agreement Compatible
Scenarios for Energy Infrastructure

Bruxelles, October 16th 2019

H₂ utilisation pathways

Source: <https://www.flickr.com/photos/oekoinstitut/48378513216/in/photostream/>



Zufuhr von:

- Strom (lightning bolt icon)
- Wasser (water drop icon)
- Luft (wind icon)
- Niedertemperaturwärme (thermometer icon)
- Hochtemperaturwärme (thermometer icon)
- nachhaltige Biomasse (leaf icon)

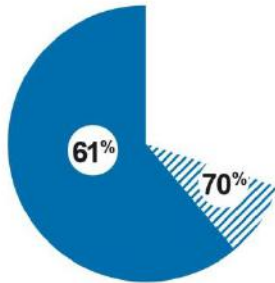
Syntheseprozess



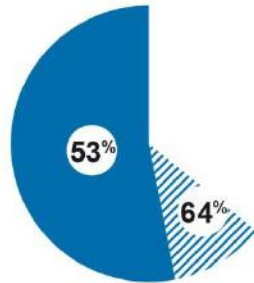
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Electrical efficiency ratio H₂ utilisation pathways

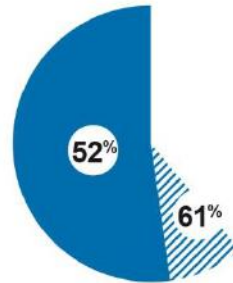
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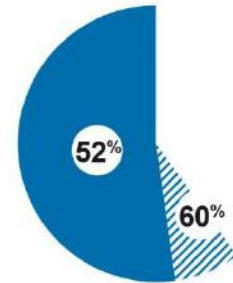
E-Hydrogen (gaseous)



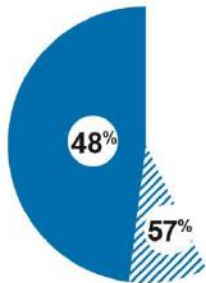
E-Hydrogen (liquid)



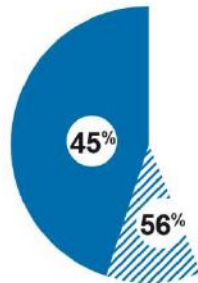
E-Methan (gaseous)



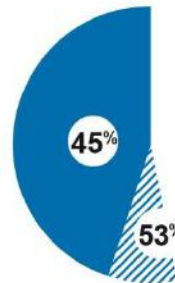
E-Ammonia



E-Methan (liquid)



E-Methanol



E-Fuel

Umwandlungseffizienz

Pro eingesetzter Kilowattstunde Strom verbleiben x Prozent im PtX-Produkt

● PtX (today)

▨ PtX (future)

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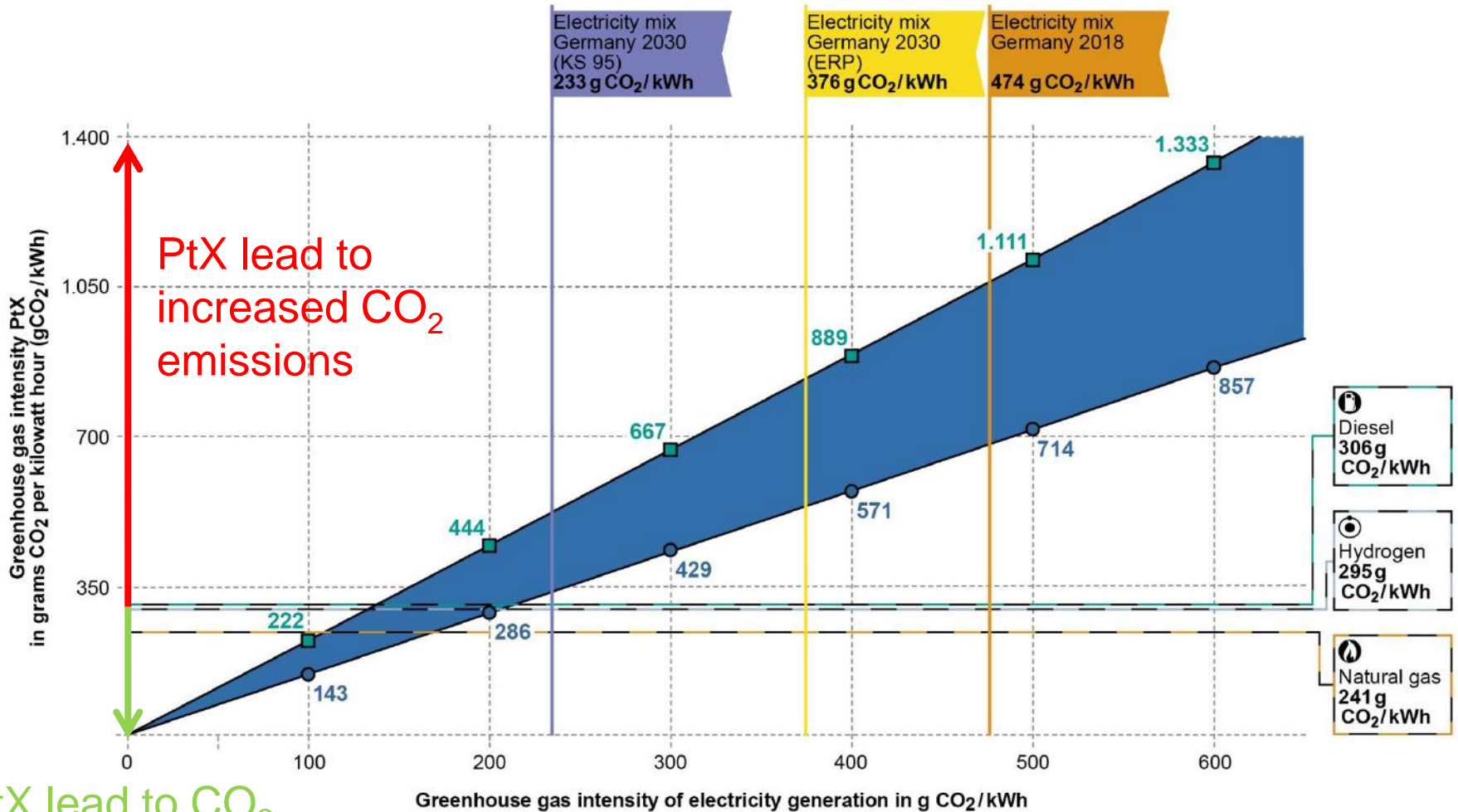
Relevant components for H₂ production pathways

- Conventional production: Reforming of **natural gas or other hydrocarbons**
 - Steam reforming (endothermic process): heat and water vapour
 - Partial oxidation (exothermic process): oxygen or air
 - CO₂-emissions of H₂ result from natural gas and other fossil hydrocarbons

- Electrolysis of water:
 - PEM (Polymer Electrolyte Membrane) Electrolysis: **electricity**
 - High Temperature Electrolysis: heat and **electricity**
 - CO₂-emissions of H₂ depend on specific CO₂-emissions of electricity generation

Power-to-X: Comparison of CO₂ emissions from PtX and fossil fuels

Climate-friendly only with very high shares of renewable electricity



PtX lead to CO₂ emission reductions

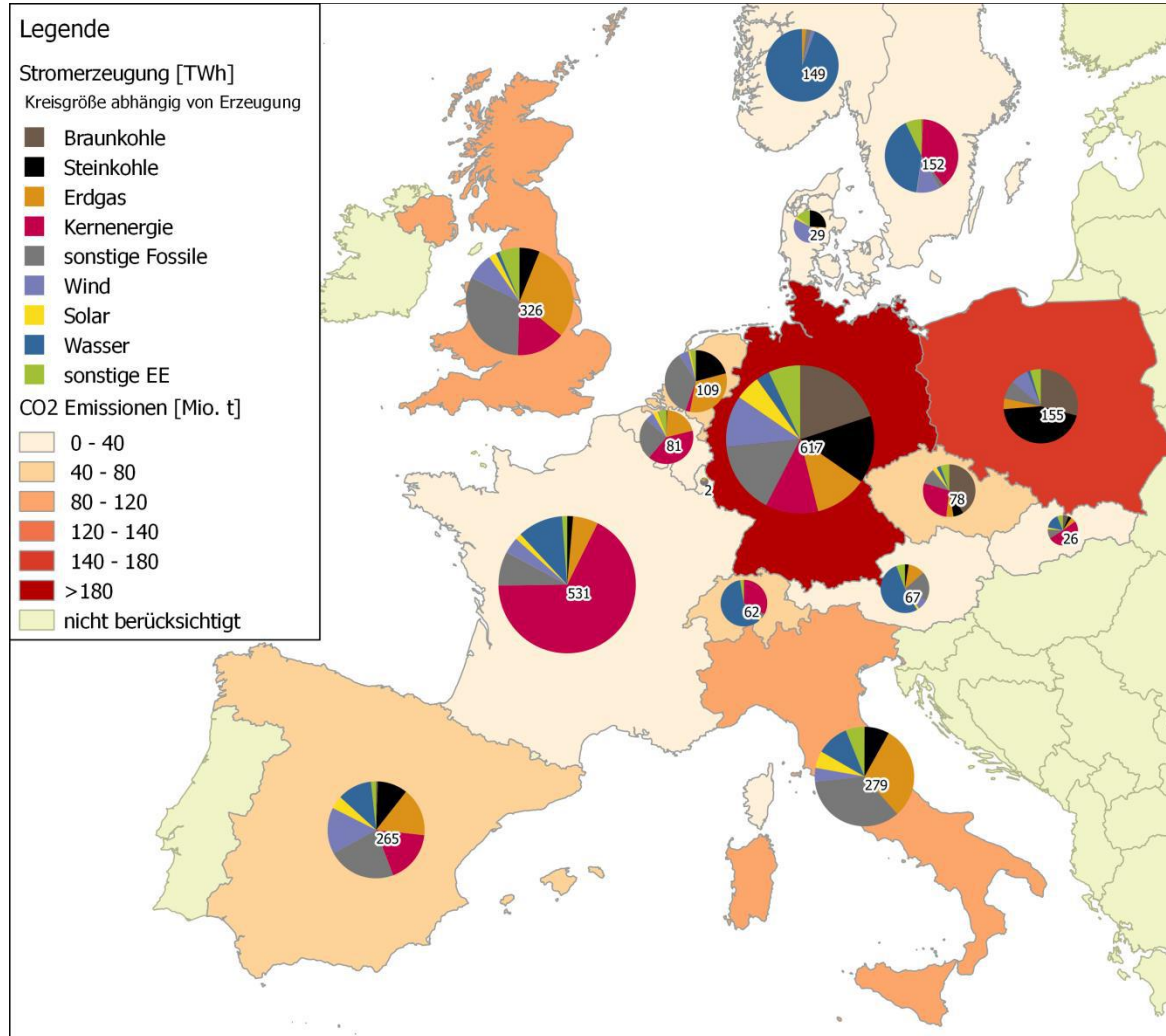
- Energy content PtX in relation to energy content electricity input: 45% (corresponds to synthetic diesel production)
- Energy content PtX in relation to energy content electricity input: 70% (corresponds to hydrogen production)
- Electricity mix according to the Oeko-Institut's Klimaschutzszenario 2050 (KS 95)
- Electricity mix according to Energierferenzprognose (ERP)
- Electricity mix in Germany 2018

Fuel mix and CO₂-emissions of electricity generation in Europe 2016

Specific CO₂-emissions of electricity generation in 2016:

- Norway: 10 g CO₂/kWh
- Sweden: 40 g CO₂/kWh
- Switzerland: 50 g CO₂/kWh
- France: 60 g CO₂/kWh
- Austria: 85 g CO₂/kWh
- Slovakia: 195 g CO₂/kWh

→ Countries with large amounts of hydro and / or nuclear power stay currently below 200 g CO₂/kWh.



Renewable targets of electricity generation in Europe

More than 100% target

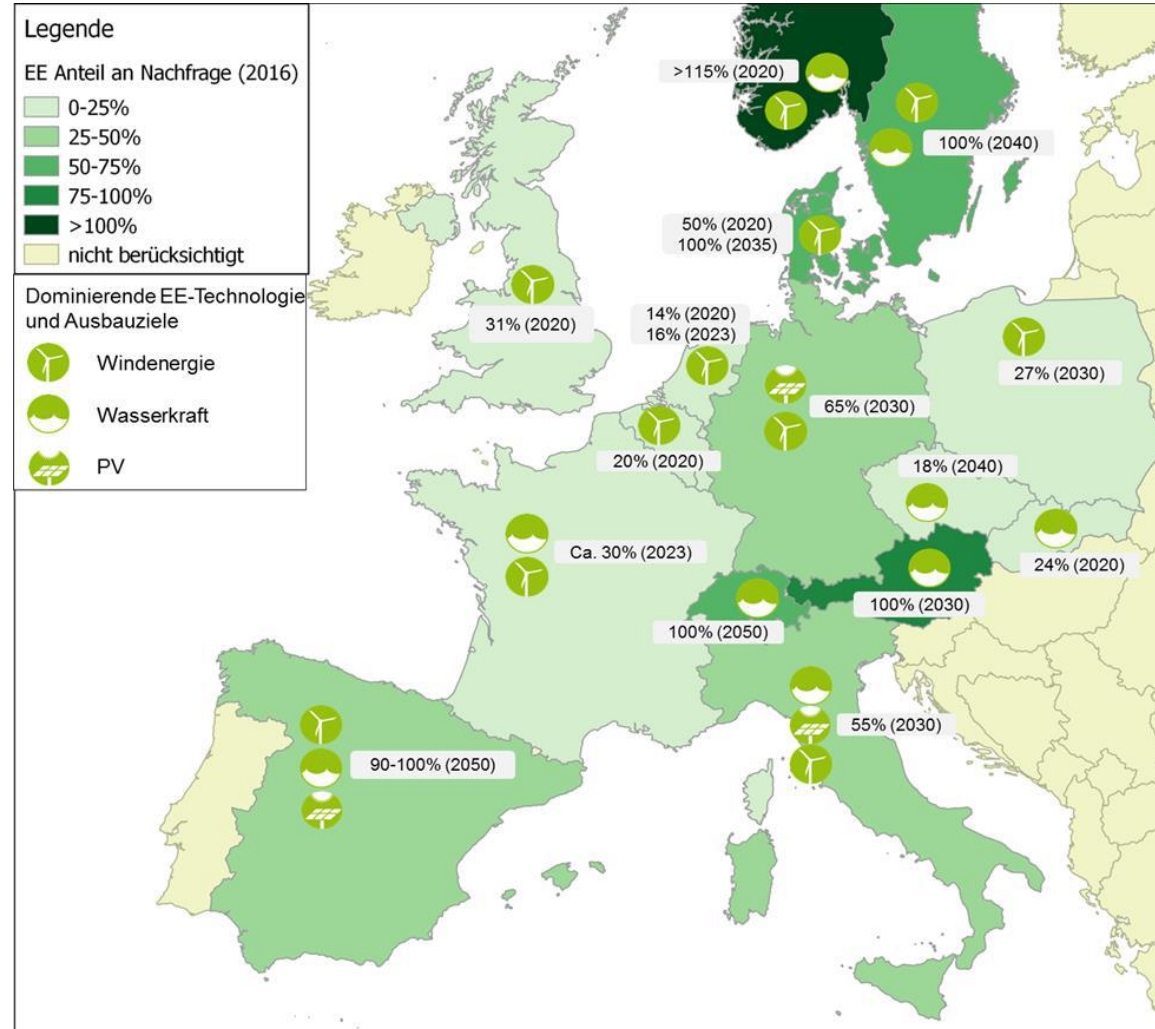
- Norway: 115 % (2020)

100% target

- Austria (2030)
- Denmark (2035)
- Sweden (2040)
- Switzerland (2050)
- Spain (2050)

At least 50% target

- Germany: 65% (2030)
- Italy: 55% (2030)



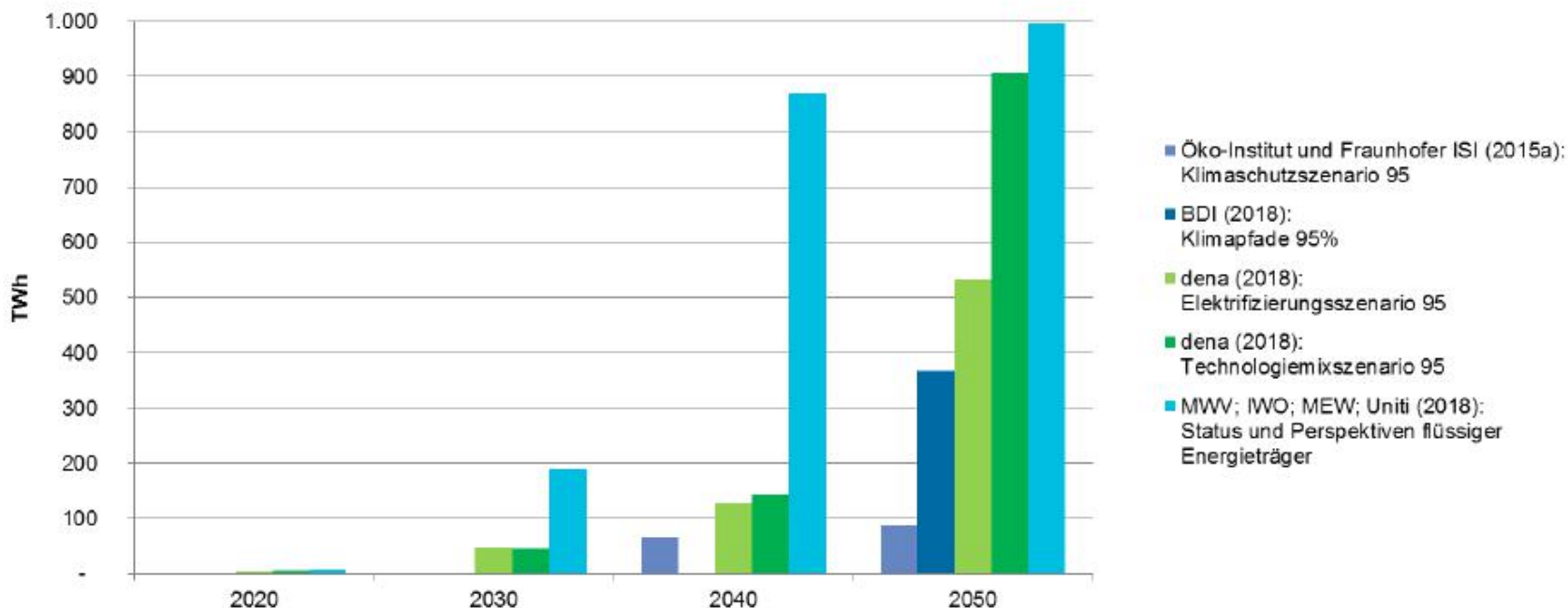
Parameters for PtX plants with positive climate impact

- CO₂ intensity of electricity generation must be
 - less than 200 g CO₂/kWh for e-hydrogen and
 - less than 140 g CO₂/kWh for e-fuels respectively.
 - PtX plants need criteria for **additional** renewable electricity.
 - PtX plants should be **flexible** enough for fluctuating renewables.

- Scale up of PtX plants should start with industrial e-hydrogen production
 - Show highest efficiency ratio
 - Comparatively low further infrastructure is needed
 - Refineries, chemical plants, steel production (e.g. voestalpine in Linz, <https://h2future-project.eu/>)

Demand of Power-to-X fuels in different climate protection scenarios for Germany

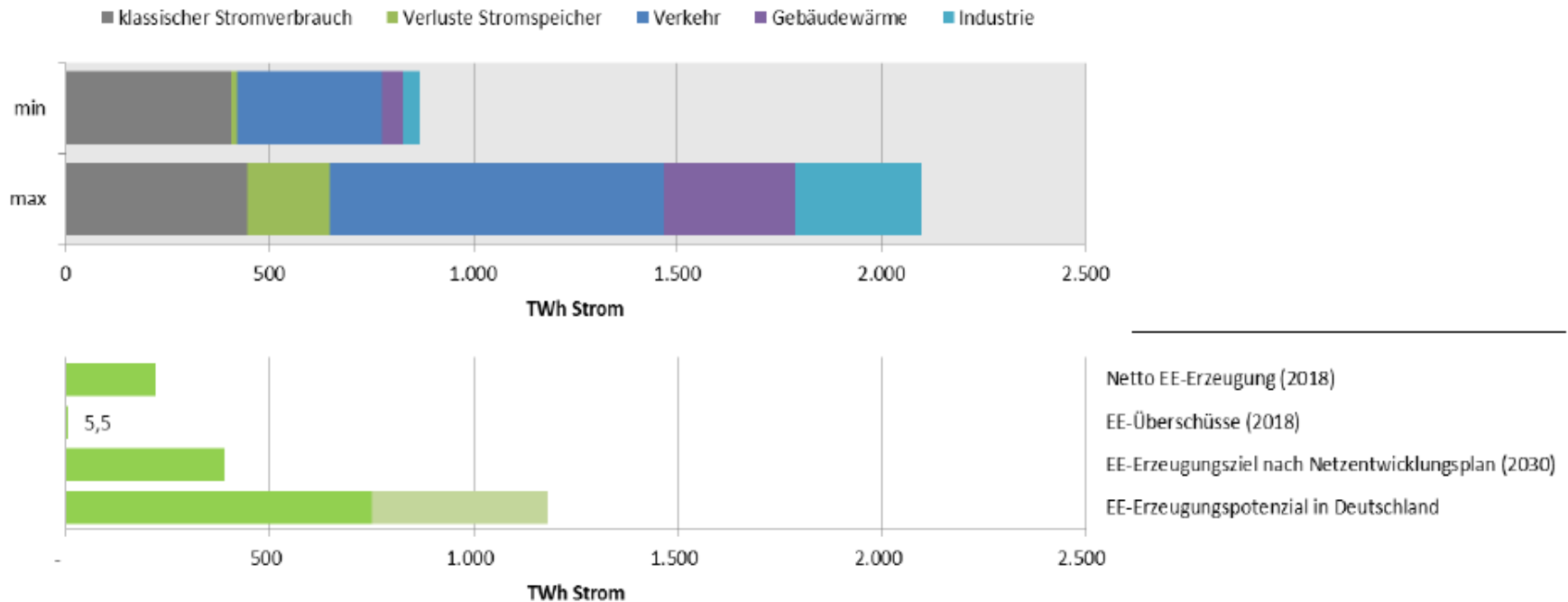
Source: Christoph Heinemann, Peter Kasten and others (2019) „Die Bedeutung strombasierter Stoffe für den Klimaschutz in Deutschland“



- PtX is not a relevant climate protection measure until 2030
- Significant increase of PtX between 2040 and 2050, depending on the assumed climate protection strategies

Electricity demand in Germany 2050: minimum and maximum approximation

Source: Christoph Heinemann, Peter Kasten and others (2019) „Die Bedeutung strombasierter Stoffe für den Klimaschutz in Deutschland“



- Electricity demand is going to increase significantly due to sector coupling
- Minimum approximation: more efficiency measures and biomass utilization
- Maximum approximation: more Power-to-X → import

Conclusions I

- Cascade of using (renewable) electricity
 - Efficiency first! – reducing demand
 - Direct utilization of electricity (e.g. e-mobility or heat pumps)
 - Power-to-X, where there is no other possibility (e.g. aviation)
- For a positive climate impact of e-hydrogen, the electricity used must show a CO₂ intensity less than 200 g CO₂/kWh.
 - Only few countries reach this target today, especially hydro and nuclear power dominated countries
 - An electricity mix of natural gas and renewable energies starts getting below of 200 g CO₂/kWh from 50% RES share
 - Coal phase out is essential for Power-to-X

Conclusions II

- For Power-to-X **additional** RES is needed (outside the national and European support schemes and frameworks)
- Flexibility of Power-to-X components is essential for using fluctuating renewable energies (trade of between flexibility and efficiency of electrolysis technologies)
- A significant part of the demand of e-fuels must be produced outside Europe, which leads to further interactions:
 - Renewable electrification of the country
 - Political stability of the country
 - Development of the country

Modeling aspects of Power-to-X

- Model based evaluation of the climate impact of Power-to-X plants via scenario comparison
 - **Baseline scenario** without Power-to-X and with conventional production of X (including the corresponding CO₂-Emissions of using X)
 - **PtX scenario** with electricity based production of X (including the corresponding CO₂-Emissions for electricity production)
 - Delta of baseline scenario and PtX scenario is the positive or negative climate impact.
- Additional demand constraint to produce X
 - Option 1: conventional process
 - Option 2: electrolysis process

Techno-economic and additional framework aspects of modeling Power-to-X

- Modeling flexibility of the plants
 - Minimum load, maximum load and available load change rate of the different components of the process chain (electrolysis, methanation, Fischer-Tropsch Synthesis, Hbaer-Bosch Synthesis,...)
 - Storage capacity for different X-products within the process chain
- Efficiency ratio and variable costs
- Indirect constraints for using only electricity with a maximum CO₂ intensity for Power-to-X to guarantee in advance that the climate impact is positive.

Further information I

- Strombasierte Kraftstoffe im Vergleich – Stand heute und die Langfristperspektive <https://www.oeko.de/oekodoc/1826/2013-496-de.pdf>
- Prüfung der klimapolitischen Konsistenz und der Kosten von Methanisierungsstrategien <https://www.oeko.de/oekodoc/2005/2014-021-de.pdf>
- Presseerklärung zur Förderung von PtX <https://www.oeko.de/presse/archiv-presse-meldungen/2019/power-to-x-transparent-und-nachhaltig-foerdern/>
- Essential elements of sound sustainability criteria for powerfuels
Impulsvortrag von Christof Timpe, Powerfuels in the European energy transition: The need for effective regulation, 17 Juni 2019, Brüssel <https://www.oeko.de/fileadmin/oekodoc/Impulse-GA-Powerfuels-Brussels.pdf>

Further information II

- Koch and other (2019): Modellbasierte Szenarienuntersuchung der Entwicklungen im deutschen Stromsystem unter Berücksichtigung des europäischen Kontexts bis 2050
<https://www.oeko.de/publikationen/p-details/modellbasierte-szenarienuntersuchung-der-entwicklungen-im-deutschen-stromsystem-unter-beruecksichtigu/>
- Christoph Heinemann, Peter Kasten and others (2019) „Die Bedeutung strombasierter Stoffe für den Klimaschutz in Deutschland“; working paper written within the Kopernikus project ENSURE <https://www.oeko.de/fileadmin/oekodoc/PtX-Hintergrundpapier.pdf>

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