Hydrogen Technology: Conversion to the Carbon Neutral Society

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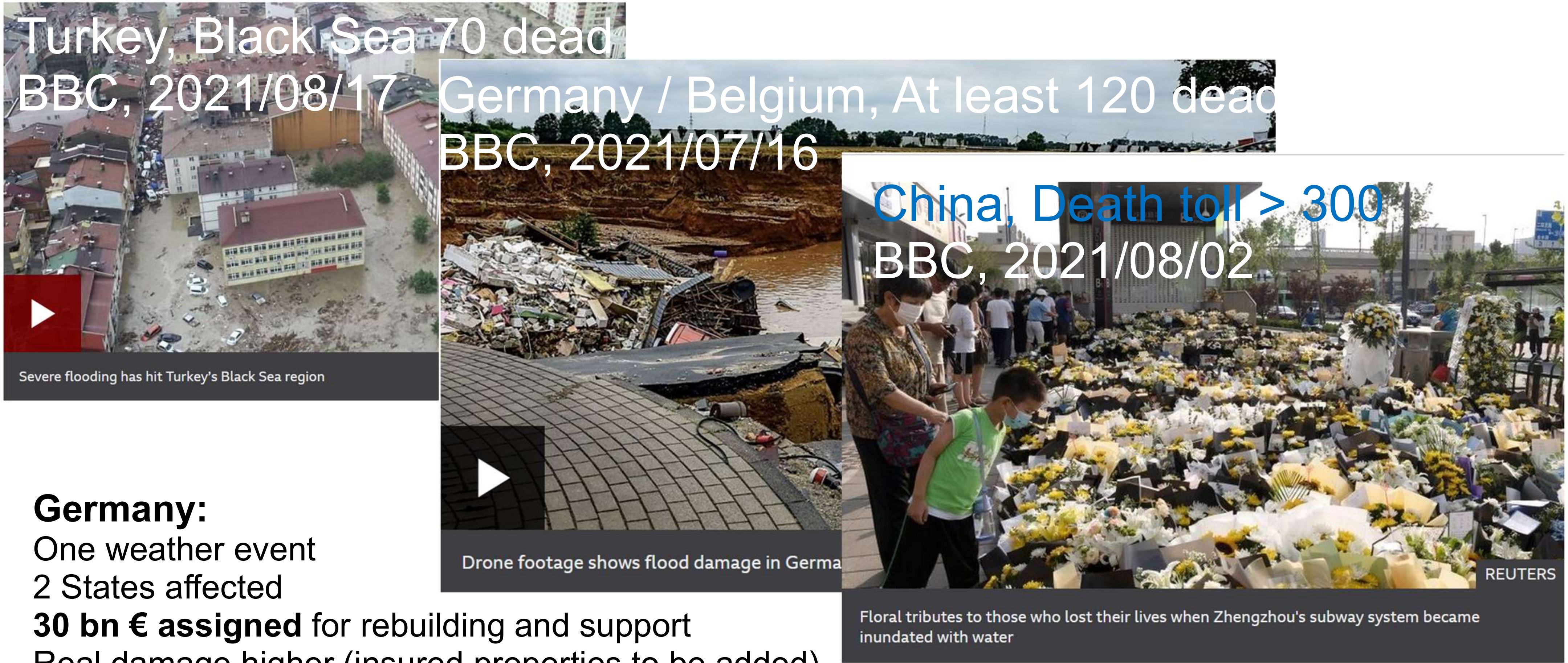
Climate Change is to be Addressed

Extreme Weather Events Get Stronger to Unprecedented Levels

Torrential Rain Causes Severe Losses and Damage all over the World

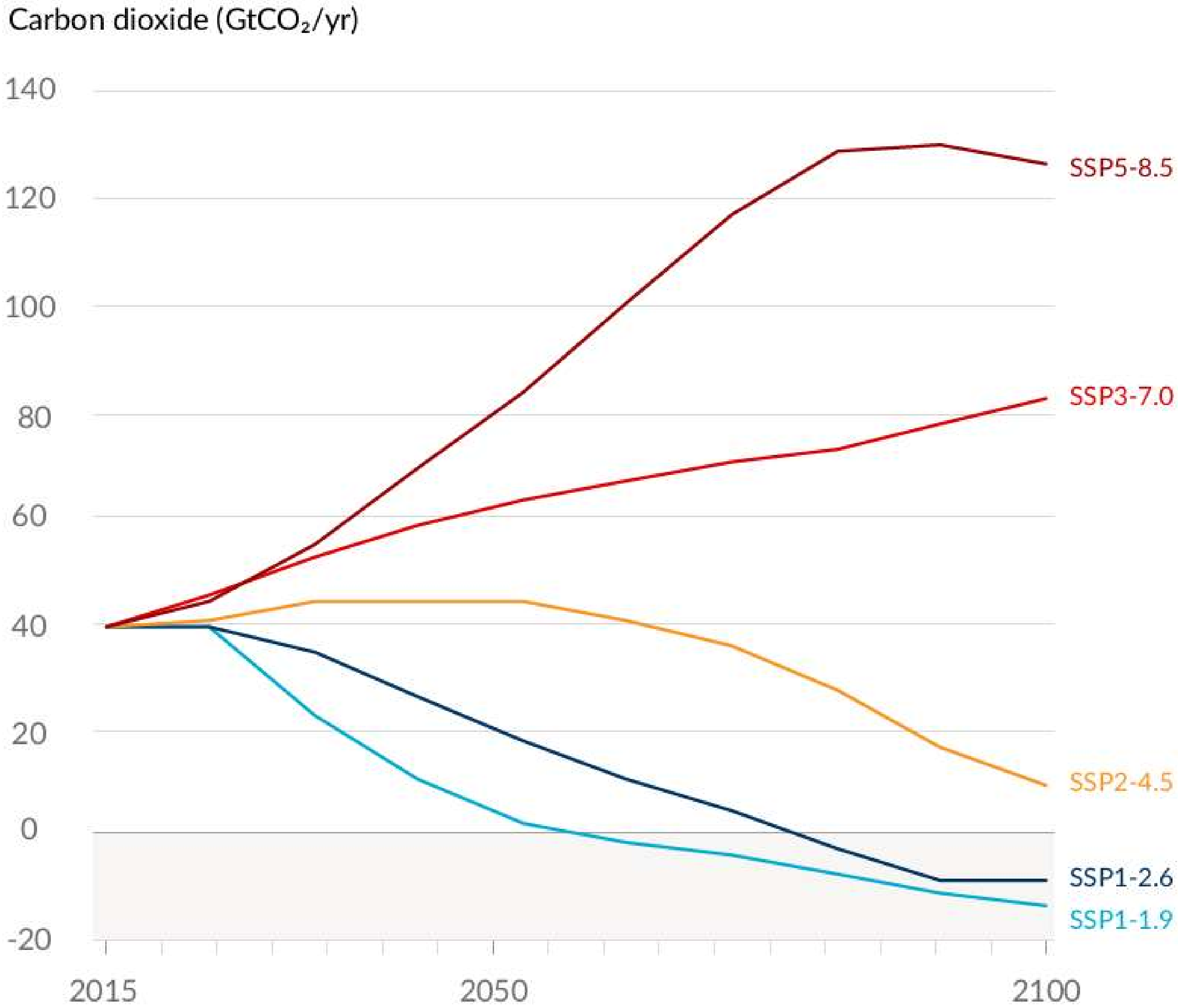


Germany:
One weather event
2 States affected
30 bn € assigned for rebuilding and support
Real damage higher (insured properties to be added)
German federal budget 2019 : 343 bn € (www.bmwi.de)
Overall public budget DE2019: 1103 bn € (cp. www.destatis.de, Press relase #005, 21/06/01)

… so do Wildfires all over the World.

The increase is proven and undisputed,
Is it anthropogenic or natural, is there any science on it?

Five Scenarios of the IPCC and the Resulting Global Warming

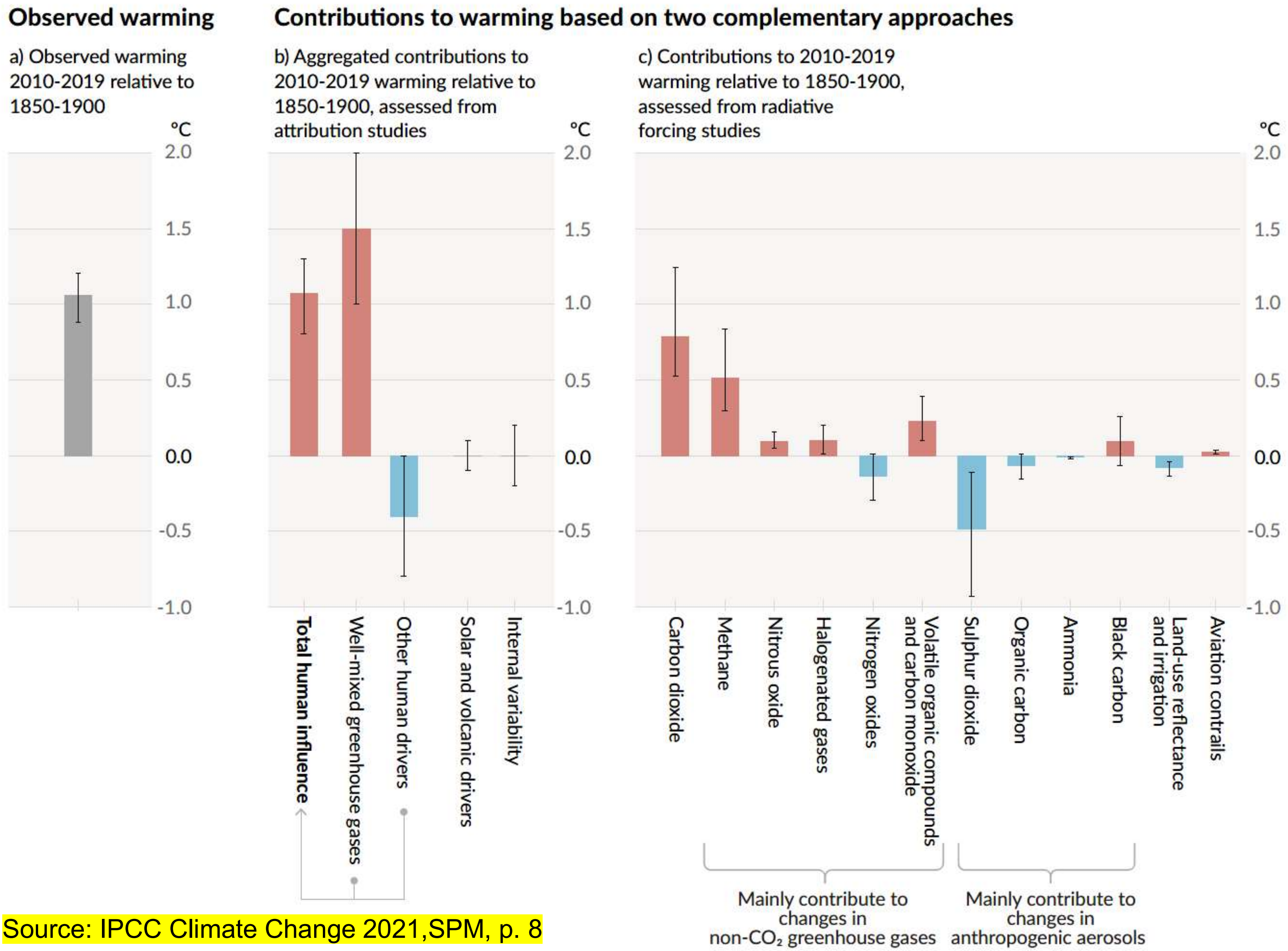


2021-2040	2041-2060	2081-2100
1.6	2.4	4.4
1.5	2.1	3.6
1.5	2.0	2.7
1.5	1.7	1.8
1.5	1.6	1.4

Global warming / best estimates taken from table SPM.1 for the scenarios on the left side
(cf. much more differentiated presentation in the IPCC 2021, SPM)

IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

“Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling”



Source: IPCC Climate Change 2021,SPM, p. 8

"D. Limiting Future Climate Change" Major statements of the IPCC 2021 Climate Change

D.1 From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.

D.2 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations, and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (high confidence).

Source: IPCC Climate Change 2021,SPM, pp. 36-41

Consequences for Energy Systems

To stay within the COP21 goal of **1.5 degrees negative emissions are needed** from 2050 on.
Even the **2.0 degree goal requires negative emissions** in the long run.
Assuming that some countries are not in a position to follow that pathway that quickly, others need to get there even faster than the average.

⇒ Carbon-air-capture CAC will gain impetus

Methane contributes notably to global warming
Sources are fossil fuel extraction, pipeline leakage, agriculture and landfills

⇒ Natural gas use and potential SNG use are to evaluated for their methane slip

Keeping the 1.5°C goal requires a swift and strong change in the energy system of the world

Hypotheses for this presentation:

- **Hydrogen** in its molecular form **is suitable to substituting NG** and **fossil fuels** in many areas
- **Hydrogen is a precursor** for NH_3, methanol, syn-naphta for the chemical industry & for syn-fuels
- Unavoidable **process related CO_2** point emitters can be tapped **as CO_2 sources**
- **Bridging technologies are to be questioned** for their CO_2 efficacy and cost efficiency
- If the switch of the energy carrier is done appropriately, **limited emissions** will be strongly **reduced by default**

Methodology of Designing the Energy Mix

at IEK-3

Cost Optimization of an Energy System under Constraints

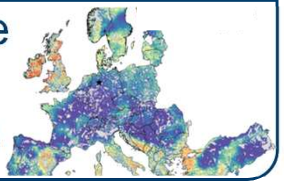
E T H O S

The Energy Transformation Optimization Simulation Suite

Entirely based on public data + proprietary data possible

Applicable for any country / region / continent

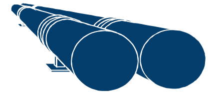
Renewable Energy Resources



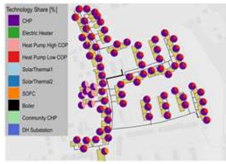
European Power Grid

Buildings

Gas Transportation Grid

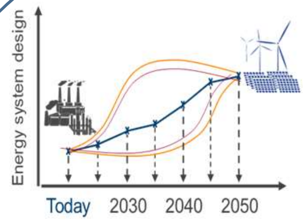


Districts



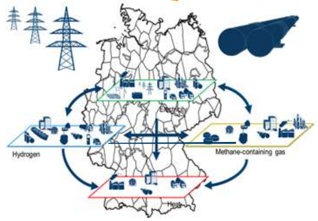
Hourly Resolution

1 Node



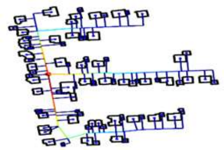
Cost optimized energy system

~80 Nodes
NUTS2

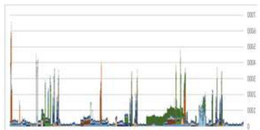


Regionalized via **local demand** and **infrastructure**

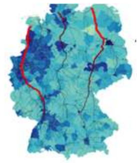
Electricity Distribution Grid



From Demand to Load Profile

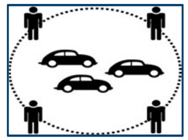


H_2 Infra-structure



Transpor-tation

Actor Centered Individual Transportation



H_2 Inter-national Provision

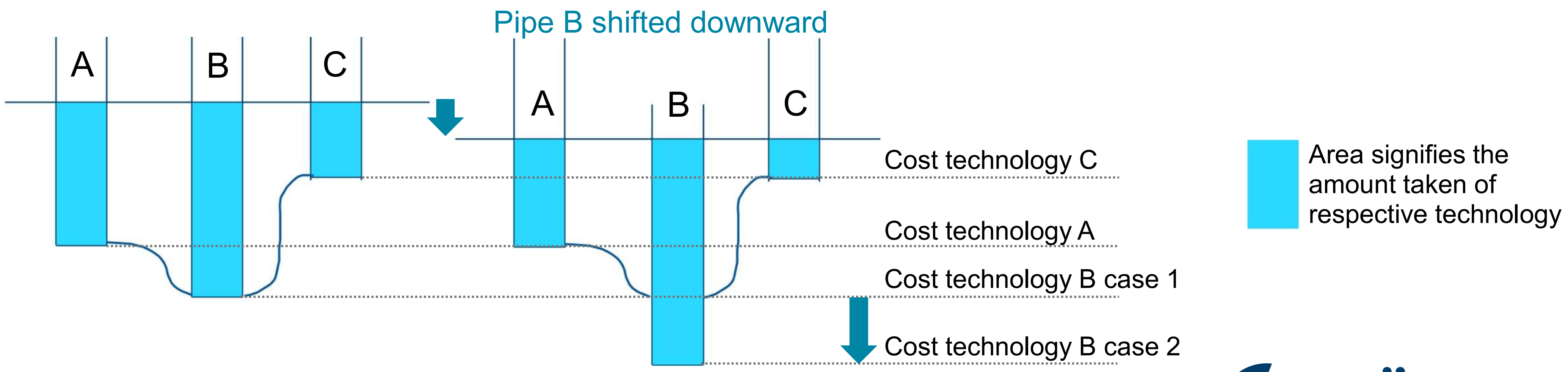
NUTS2: EU-wide statistical classification for regions: 800k to 3 mn inhabitants

We approach the Energy Technologies as Communicating Pipes Minimizing the Systems Cost under Constraints

- Which energy technology is to be chosen is determined by technical properties and cost
- The cheapest way to cut out CO_2 is chosen.
- Since cost can be dependent on penetration of a technology (e.g. good wind-sites get successively taken) this needs an iterative process
- All 1300 technologies considered compete during simulation on > 2000 pathways
- Hourly resolution

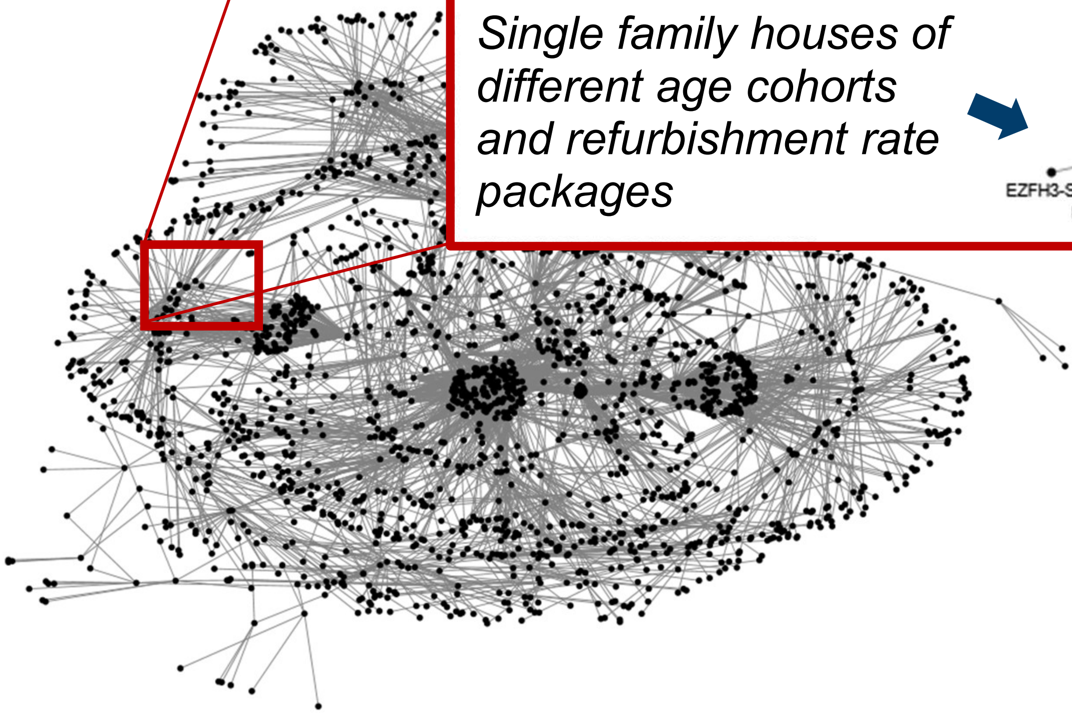
- We do not arbitrarily set quantities of certain technologies, unless it is requested
- Constraints guarantee a realistic view: e.g. only < 5% of the existing capacity of a technology added p.a.
- Demand drives the "market", technologies furnish the demand
- Regionalization via GIS* data of demand and infrastructure

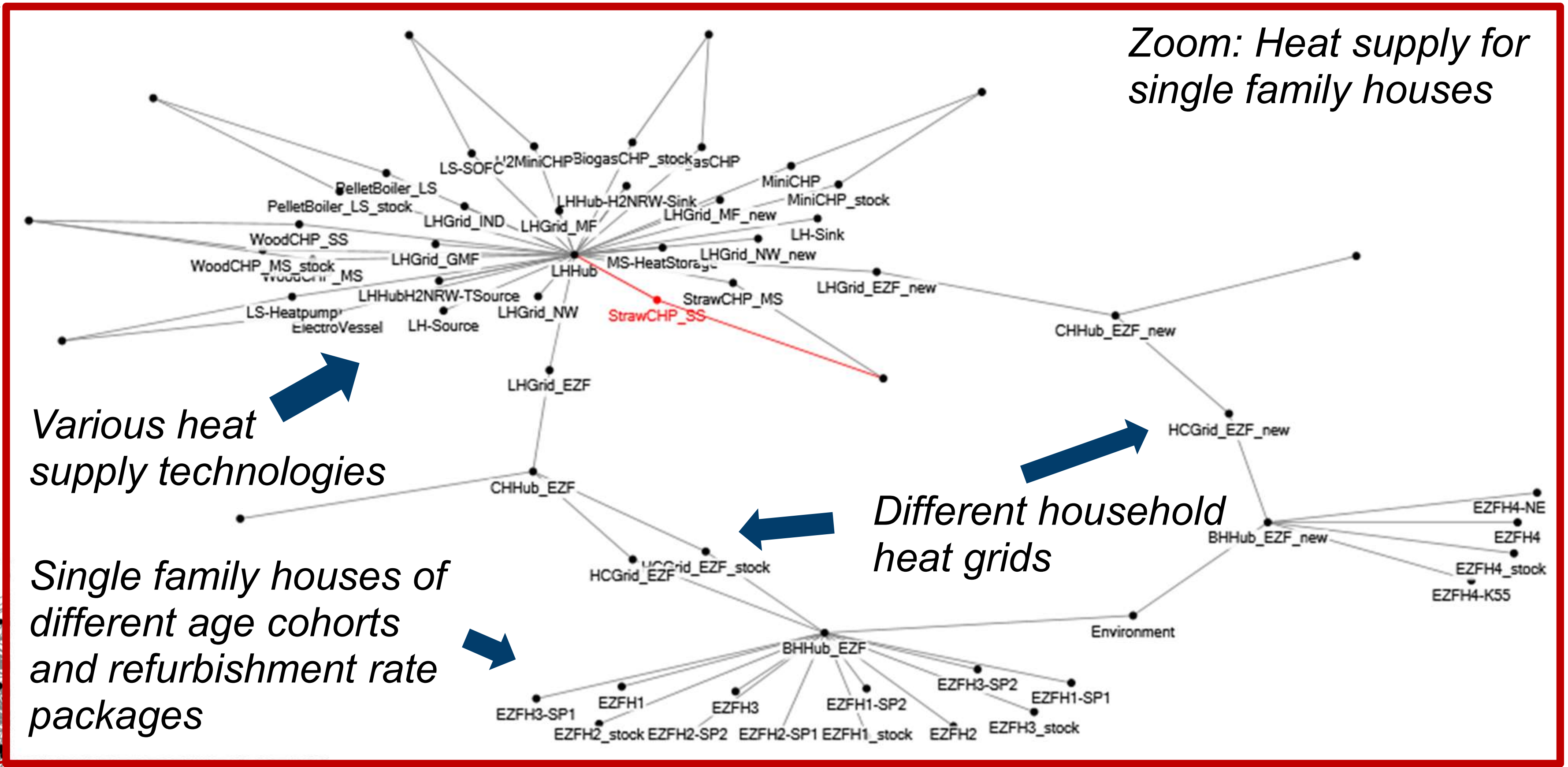
Technologies compete as communicating pipes do



*GIS: Geographic Information System

A Glimpse into the Optimization within ETHOS





Information on each node:

- ► Investment cost
- ► Cost range
- ► Efficiency
- ► CO_2-emissions
- ► Potential
- ► Commodities
- ► Operational costs
- ► Interest rate
- ► Lifetime

JÜLICH Forschungszentrum

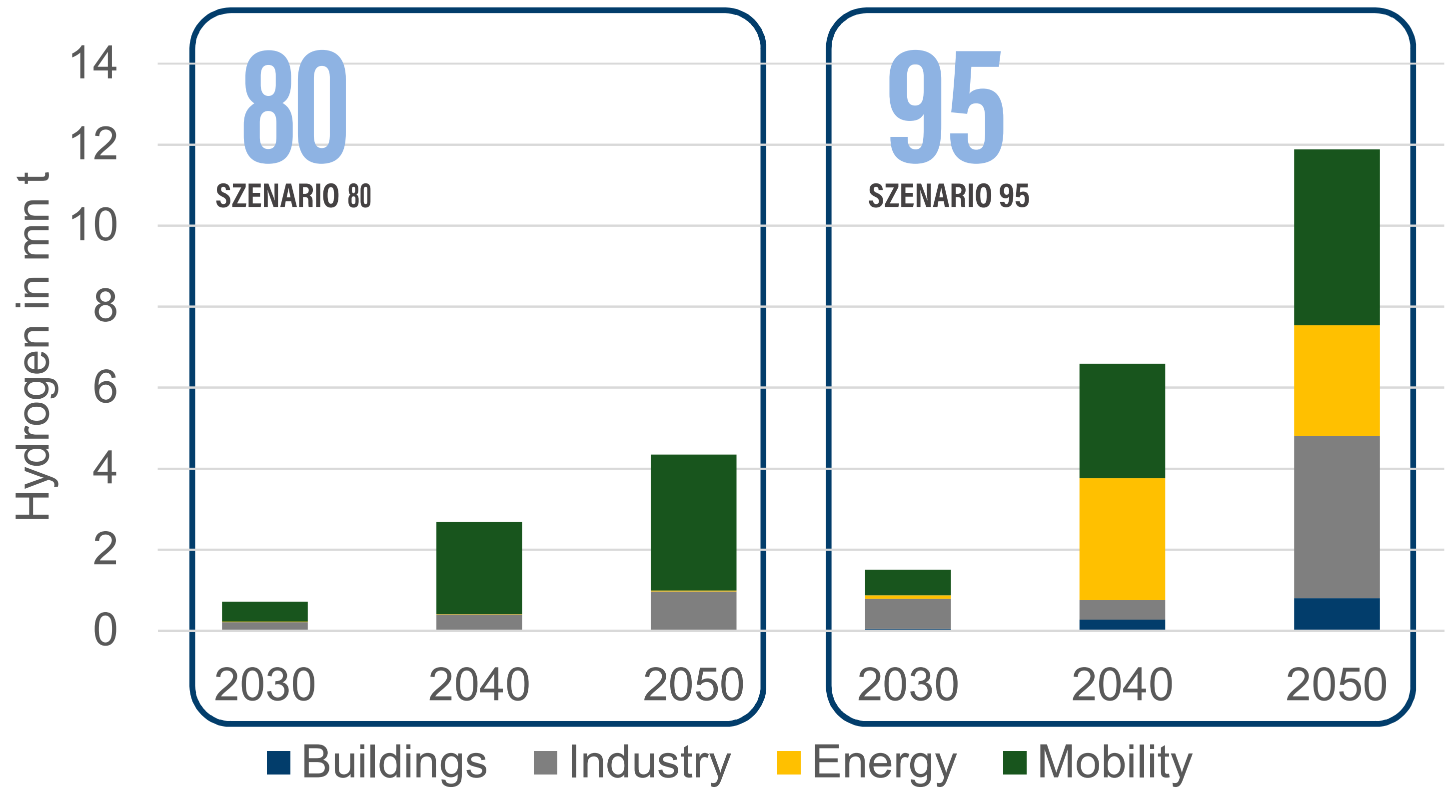
Transition Requirements

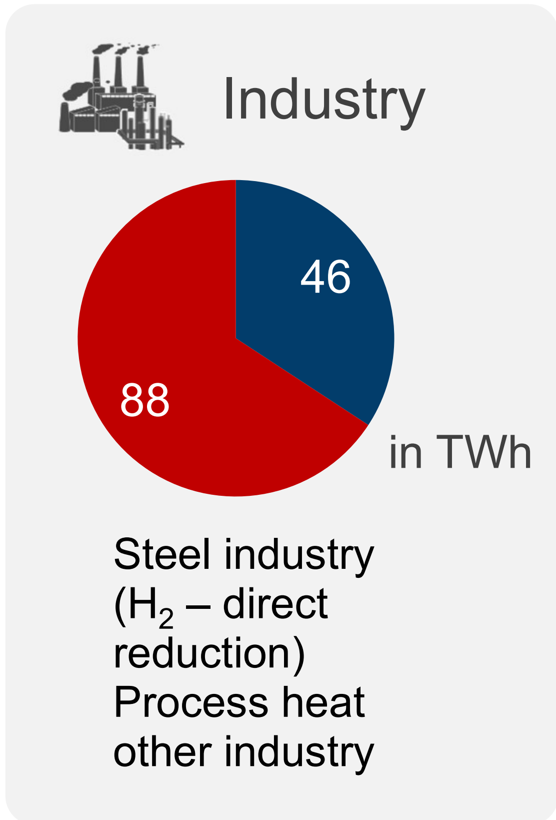
Basic Requirements for a Future Energy System

- In 2050 **CO_2 emissions** based on 1990 to **be reduced** to about zero (climate targets 1.5-2.0°C)
- **Germany: climate neutrality 2045 (cast in law 21/06/24)**
- After the transition period energy should be **no more expensive** than today
- **Limited emissions** shall be reduced
- Electricity, fuels and heat must be available with **high reliability w/ renewables**
- **All energy sectors** need **to be addressed**
- Teratogenic, carcinogenic and poisonous substances to be avoided in public handling
- Nucear hazards to be considered
- Radiative forcing to be considered (e.g. methane 30) for new energy pathways

Transition Pathway
ES 2050 – a study as of 2019

Hydrogen Demand Triples for the 95% Scenario

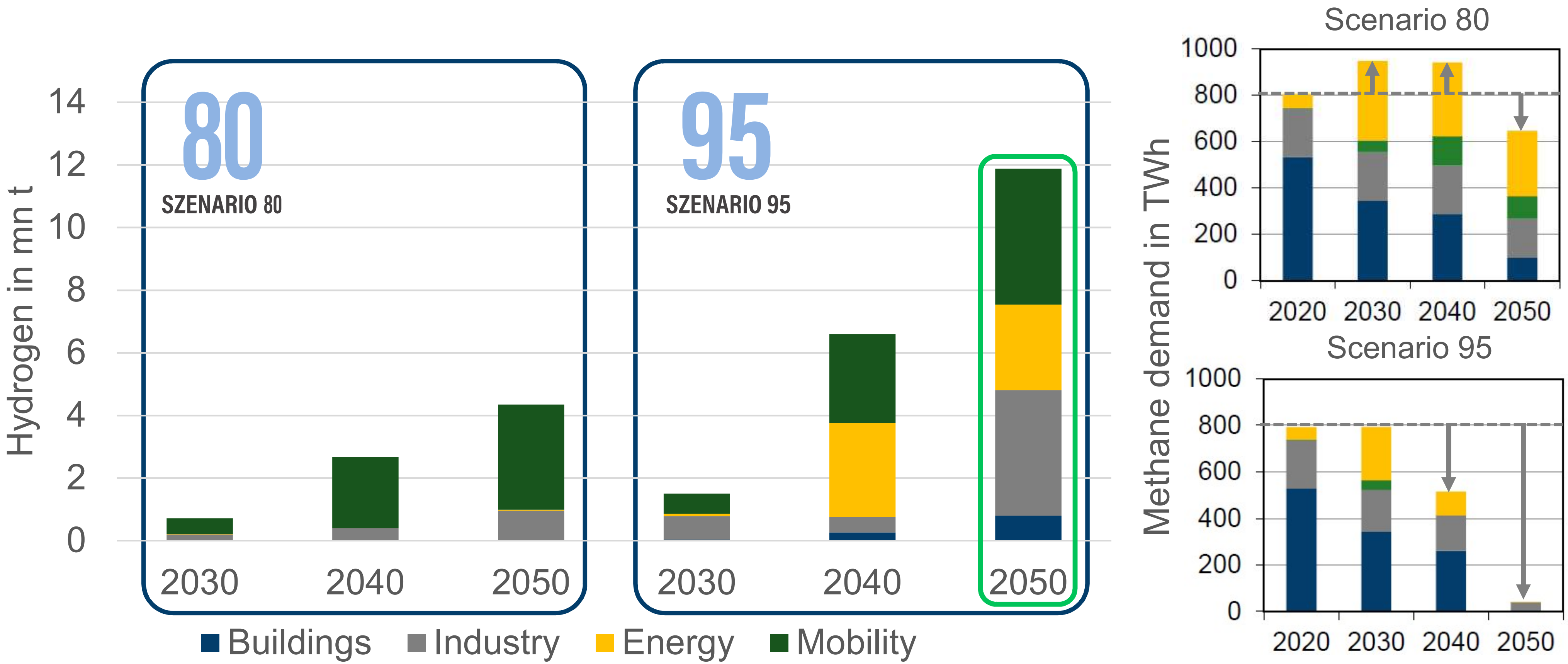




- Scenario 80: Hydrogen demand of 4 mn t p.a. (mostly transport and industry)
- Scenario 95: Hydrogen demand of 12 mn t across all sectors (incl. process heat)
- Preliminary result: a climate neutral scenario adds no further H2 demand owing to cheaper renewable energy w/ direct use of power

Wege für die Energiewende – Kosteneffiziente und klimagerechte Transformationsstrategien für das deutsche Energiesystem bis zum Jahr 2050. Schriften des Forschungszentrums Jülich, Reihe Energie & Umwelt/Energy & Environment, Band/Volume 499; Robinius M., Markewitz P., Lopion P., Kullmann F., Heuser P.-M., Syranidis K., Cerniauskas S., Schöb T., Reuß M., Ryberg S., Kotzur L., Caglayan D., Welder L., Linßen J., Grube T., Heinrichs H., Stenzel P., Stolten D.: https://juser.fz-juelich.de/record/877960/files/Energie_Umwelt_499.pdf

Hydrogen and Methane Demand



- Scenario 80: Hydrogen occurs in mobility and industry only,
  NG demand rises in between before dropping in 2050
- Scenario 95: H_2 in all sectors ➔ infrastructure development & supply chain analysis needed

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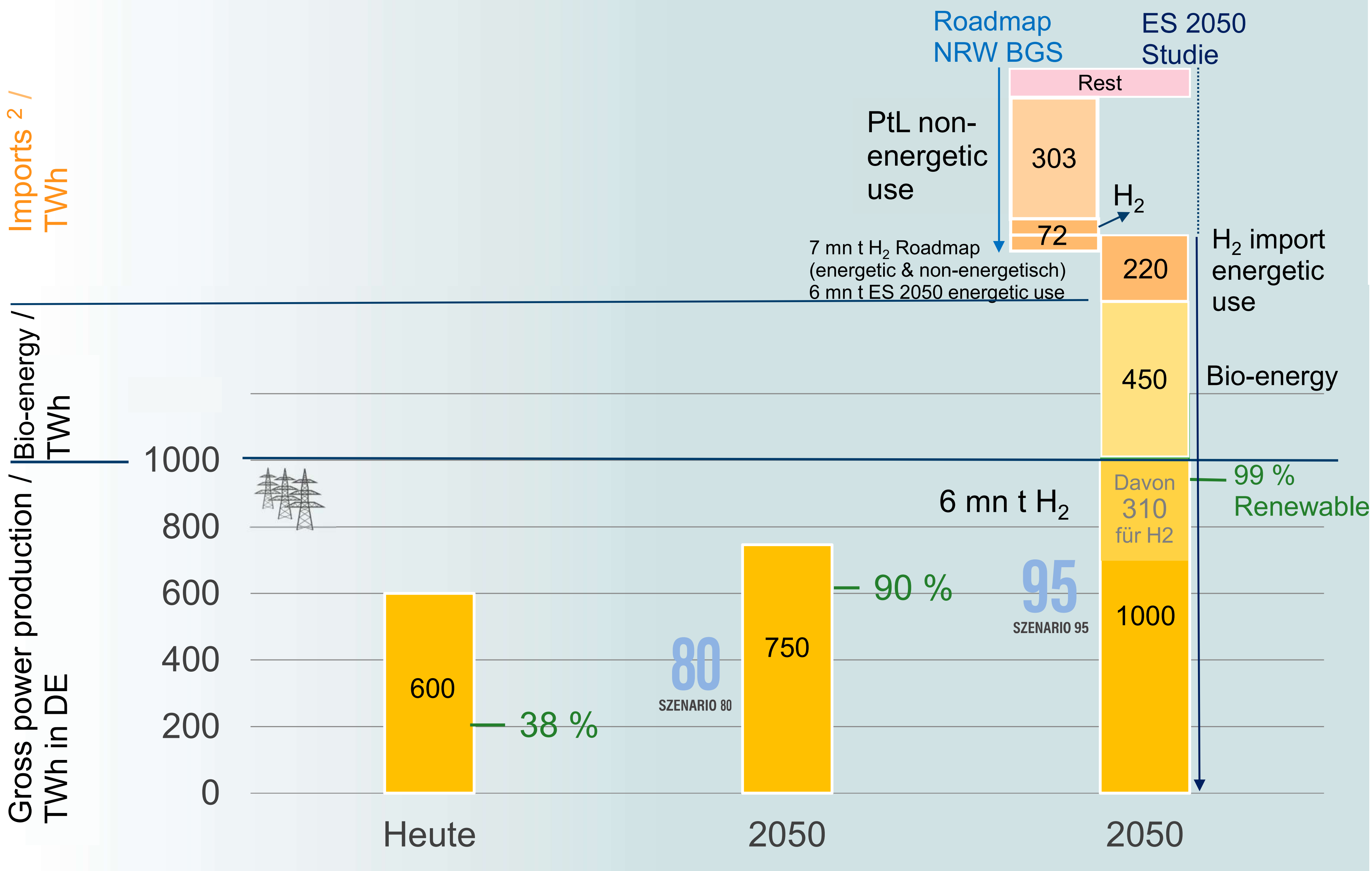
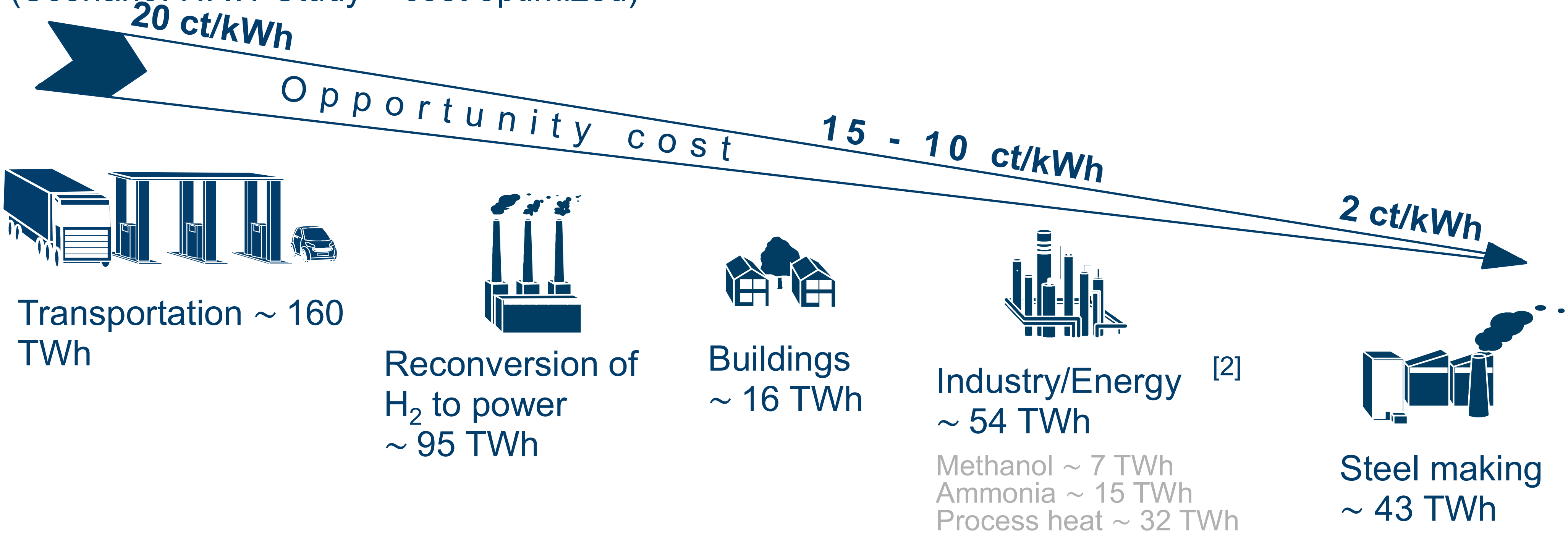
Substitution of Fossils Leading to 95% Reduction in CO_2 Emissions

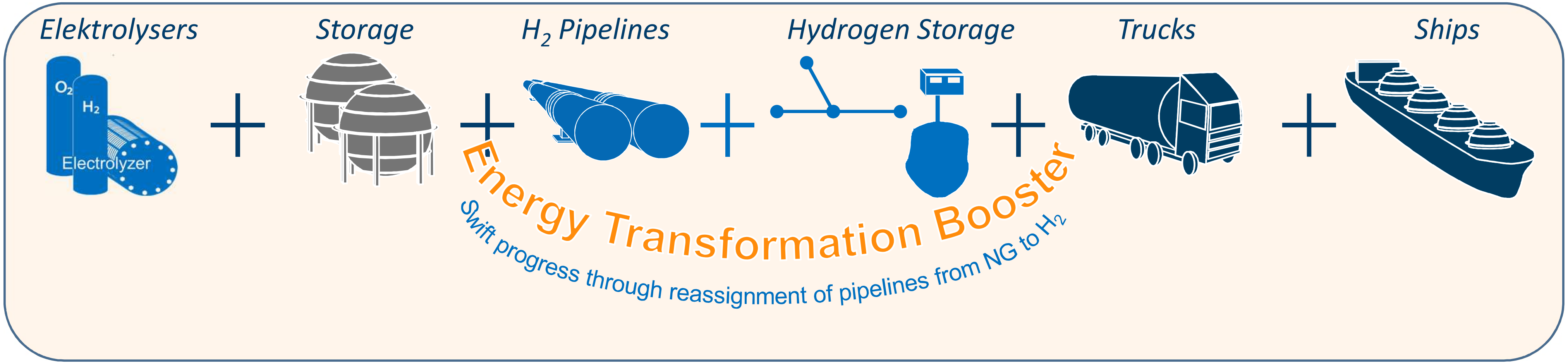


[1] ohne Strom Im- und Export, da vernachlässigbar; [2] Importe als Primärenergie an dt. Grenze

Hydrogen as a Backbone of the Energy Transition

(Scenario: NRW Study – cost optimized)



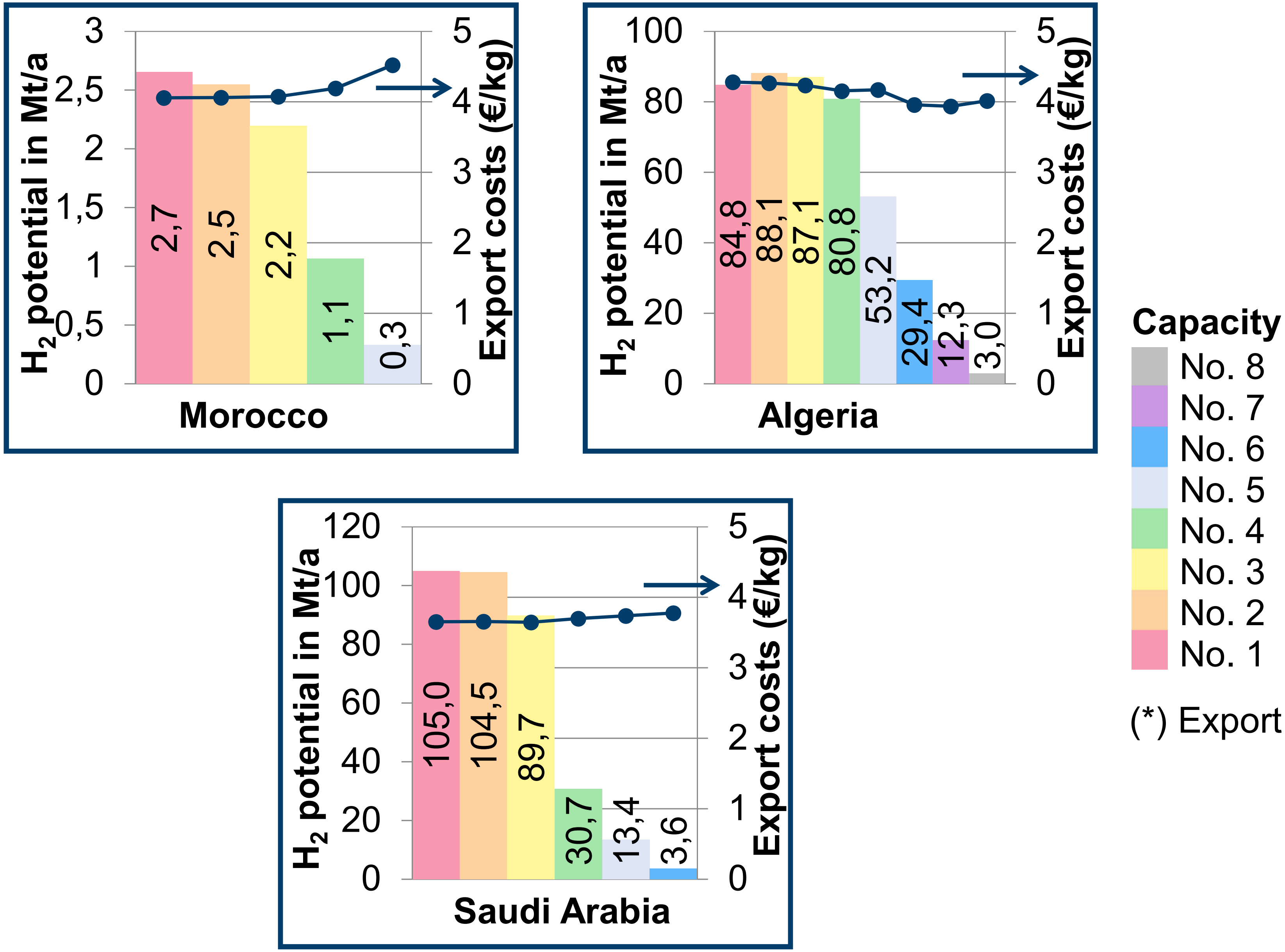


[1] S. Cerniauskas et al. (2021) Wissenschaftliche Begleitstudie für die Wasserstoff-Roadmap NRW (erscheint demnächst).
[2] Ohne Rohstoffbedarf der chemischen Industrie
[3] Equity Research / Goldman Sachs; Green Hydrogen, September 22, 2020

Hydrogen as a Commodity

Can these Quantites be Delivered?

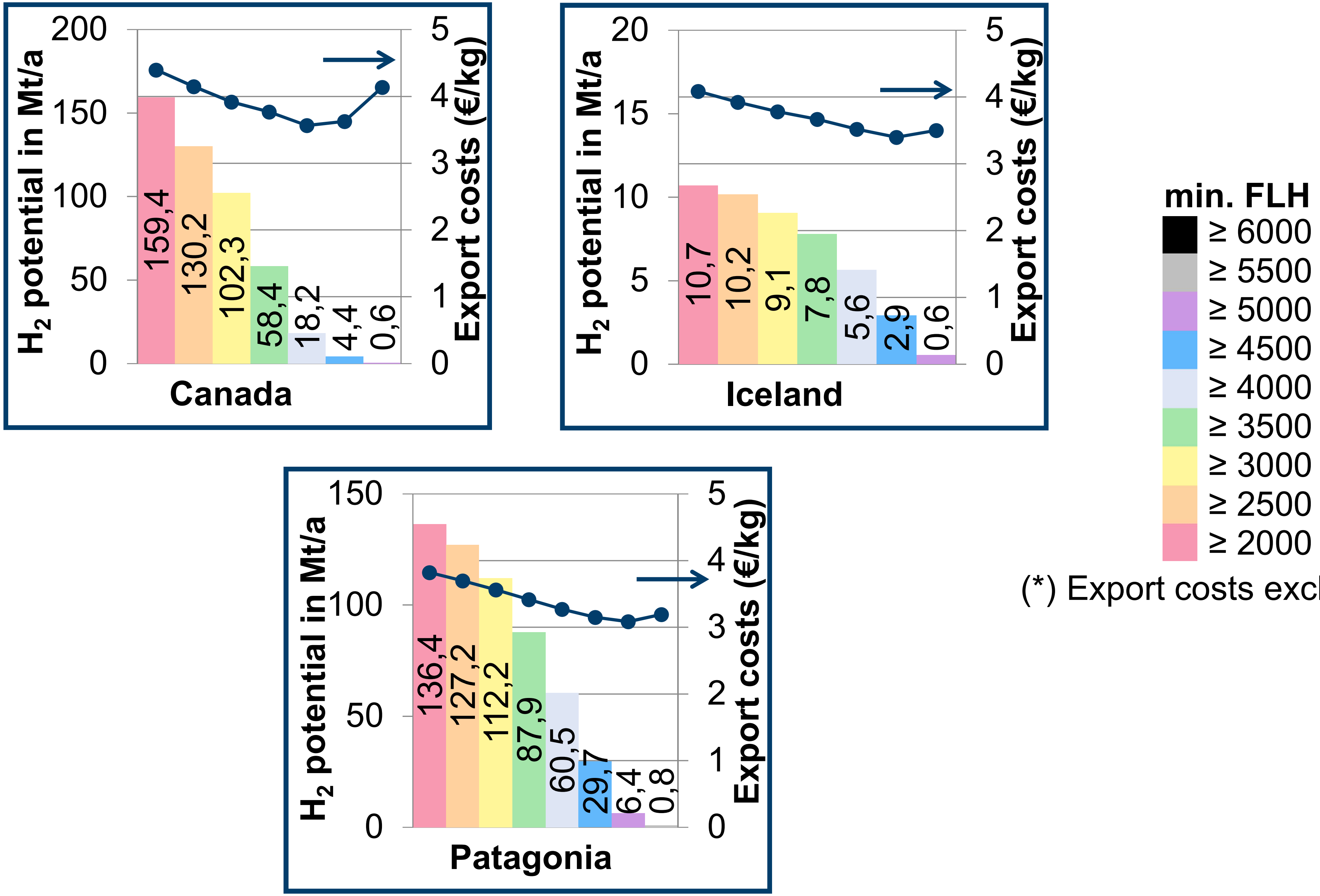
Worldwide H_2 Export Potential in Exemplary High Insolation Countries (*)



Capacity expansion = Degree of potential utilization

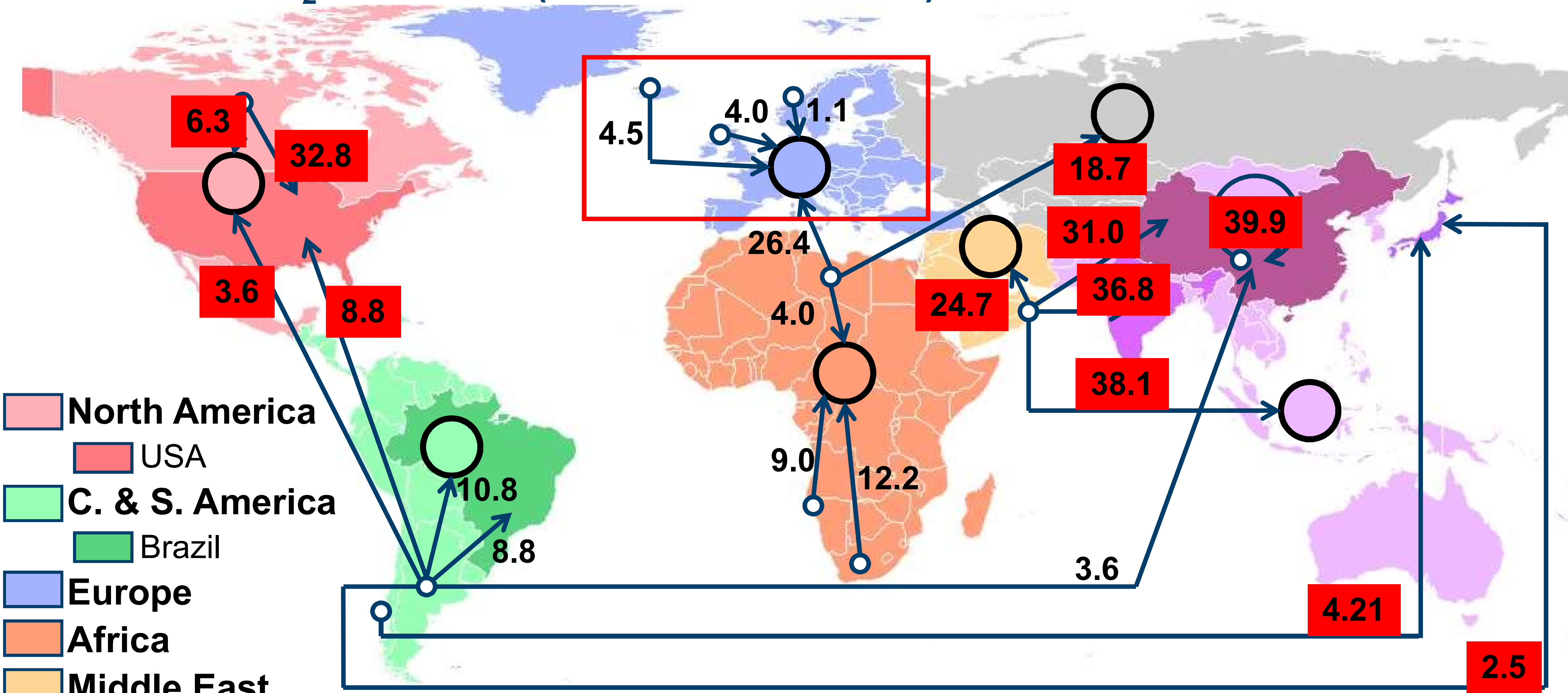
(*) Export costs excl. shipping

Worldwide H_2 Export Potential in Exemplary Strong Wind Countries (*)



(*) Export costs excl. shipping costs

Worldwide H_2 Allocation (Reference Scenario) - Flows in million tons

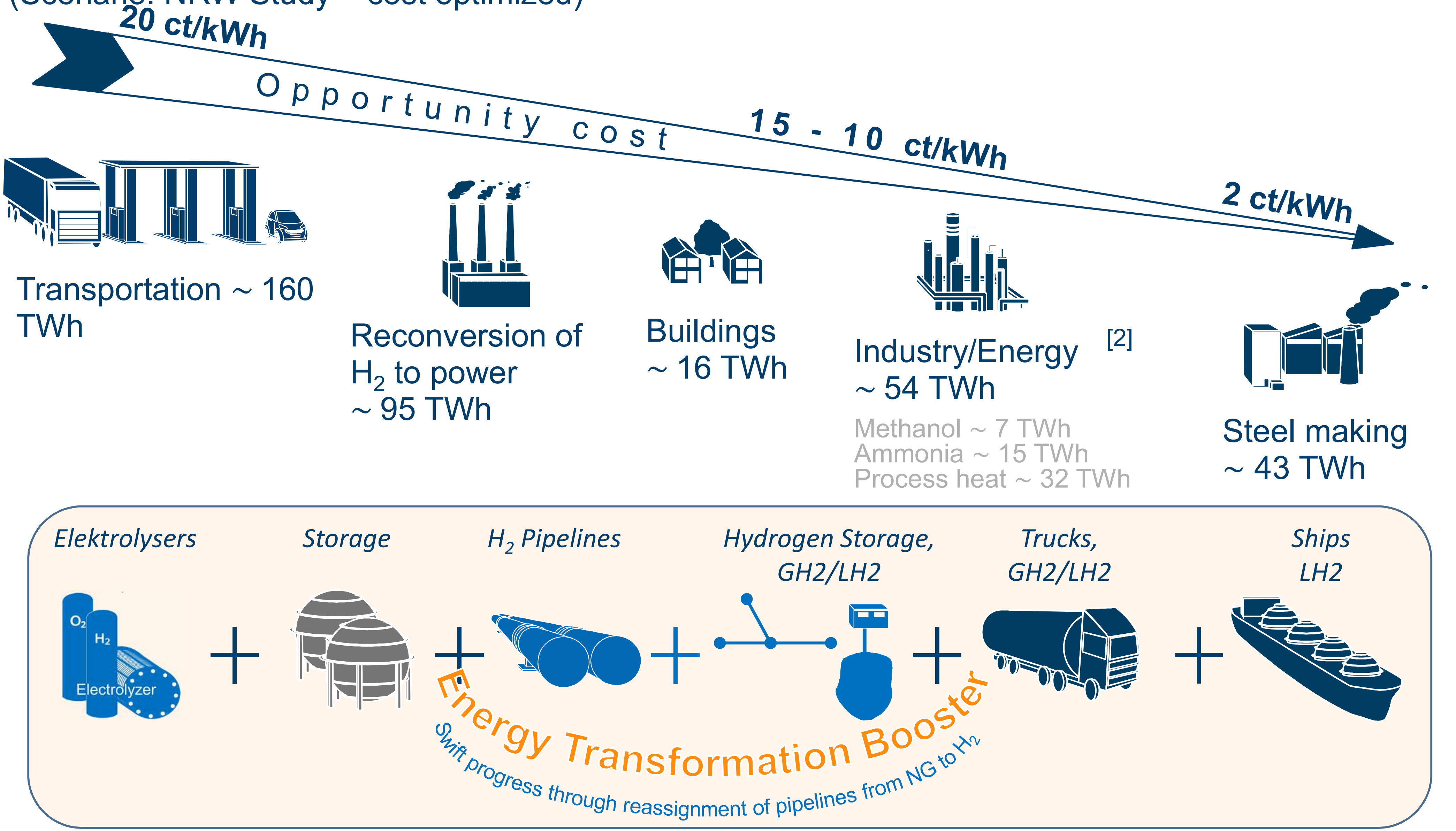


	Germany	Japan	Europe	USA	China	India	Southeast Asia
Demand in Mt/a	4.57	6.7	31.4	41.7	70.9	36.8	38.1
Import cost in €/kg	3.61	3.83	3.86	3.68	4.05	3.84	3.99

Market Introduction Through Markets with High Cost Allowance

Hydrogen as a Backbone of the Energy Transition

(Scenario: NRW Study – cost optimized)



[1] S. Cerniauskas et al. (2021) Wissenschaftliche Begleitstudie für die Wasserstoff-Roadmap NRW (erscheint demnächst).
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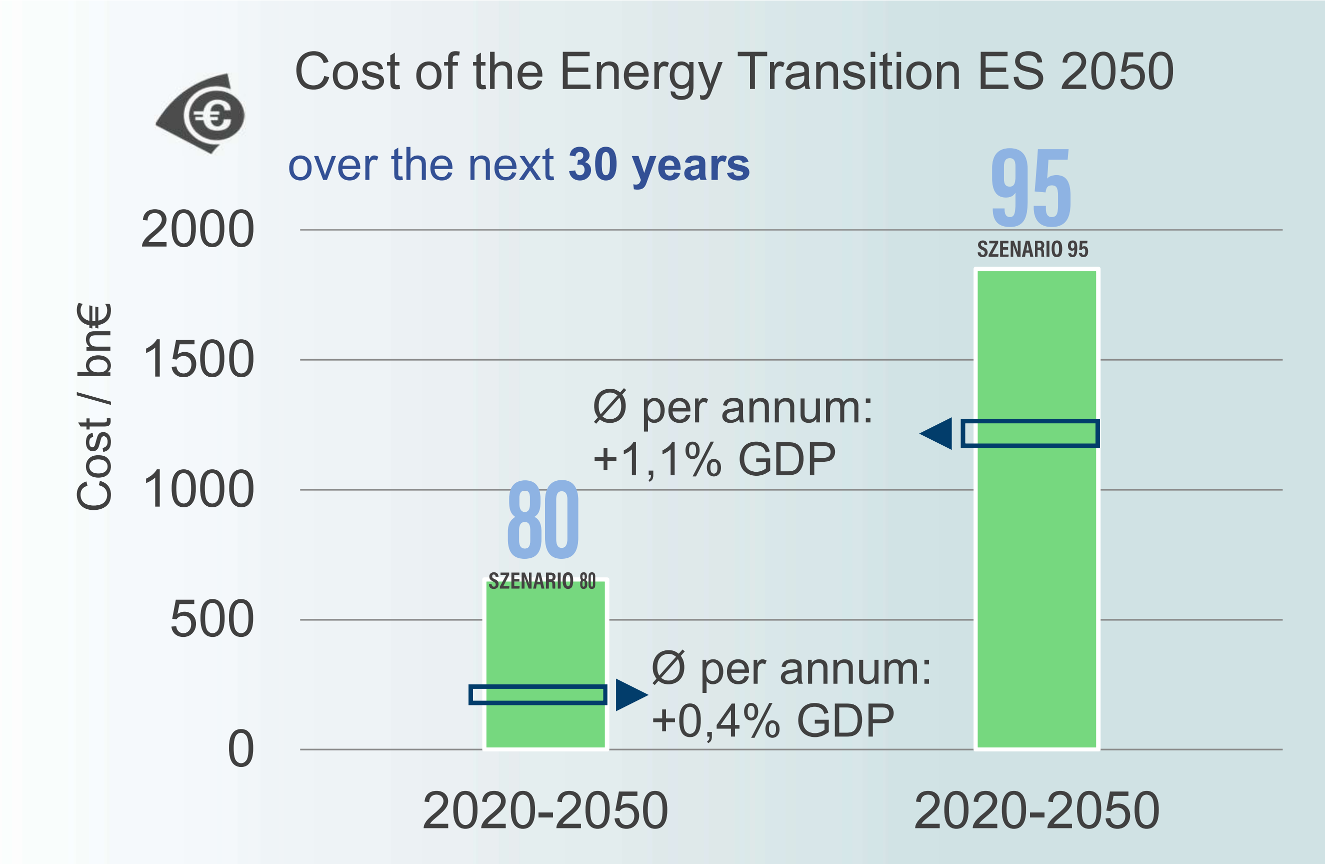
Cost of Transition

Cost of Setting up a Renewable Energy Infrastructure for Germany



❶About 1800 bn € over 30 years
⇒ 60 bn p.a
(ES2050 scenario)
@ cost 2019, 95% CO_2 reduction;

❷@ cost 2021; 95% CO_2 reduction
(BAU95 scenario)
- 20% cost compared to ❶

❸Climate neutral scenario 2045
+ 32% cost compared to ❶
+ 52% cost compared to ❷

First rough estimate:
A climate neutral scenario costs about 90 bn € for DE p.a.
(~ 1.7% GDP p.a) => affordable)
(detailed verification process ongoing, final results to be published 11/2021)

Cost comparison of CO_2 Reduction Scenarios:
- 80% CO_2 2050: defined as 100% base line
- 95% CO_2 2050: adds 180% to the cost of 80%
- Climate neutral at 2019 cost level: adds 52% to the cost of 95% 2050
- Climate neutral at 2021 cost level: adds 32% -”-
- Full decarbonization of industry comes on top (substitution of raw materials)

Lessons Learnt

On hydrogen amount:

- With cheaper renewables less hydrogen is needed for higher direct use of electricity
- With more ambitious climate goals more hydrogen is needed
- Reassignment of NG-pipelines to H2 is very cost effective
- Both effects level off in our scenarios at about 400 TWh, corresponding to 12 mn tons of H_2

On hydrogen market:

- Substantial amounts go to industry
- The opportunity cost od the industry are lower than market introduction prices
- Transportation provides high opportunity cost for hydrogen
- Hence, hydrogen in transportation is important for establishing a hydrogen market
- Addressing all markets distributes the infrastructure cost to a larger extent
- Whether households need hydrogen depends very much on the local situation
  - Can renewables, e.g. PV, geothermal, be installed?
  - Can houses be refurbished - insulated, etc?
  - Are refurbishments of houses restricted under monument protection?

Thank You Very Much for the Attention!