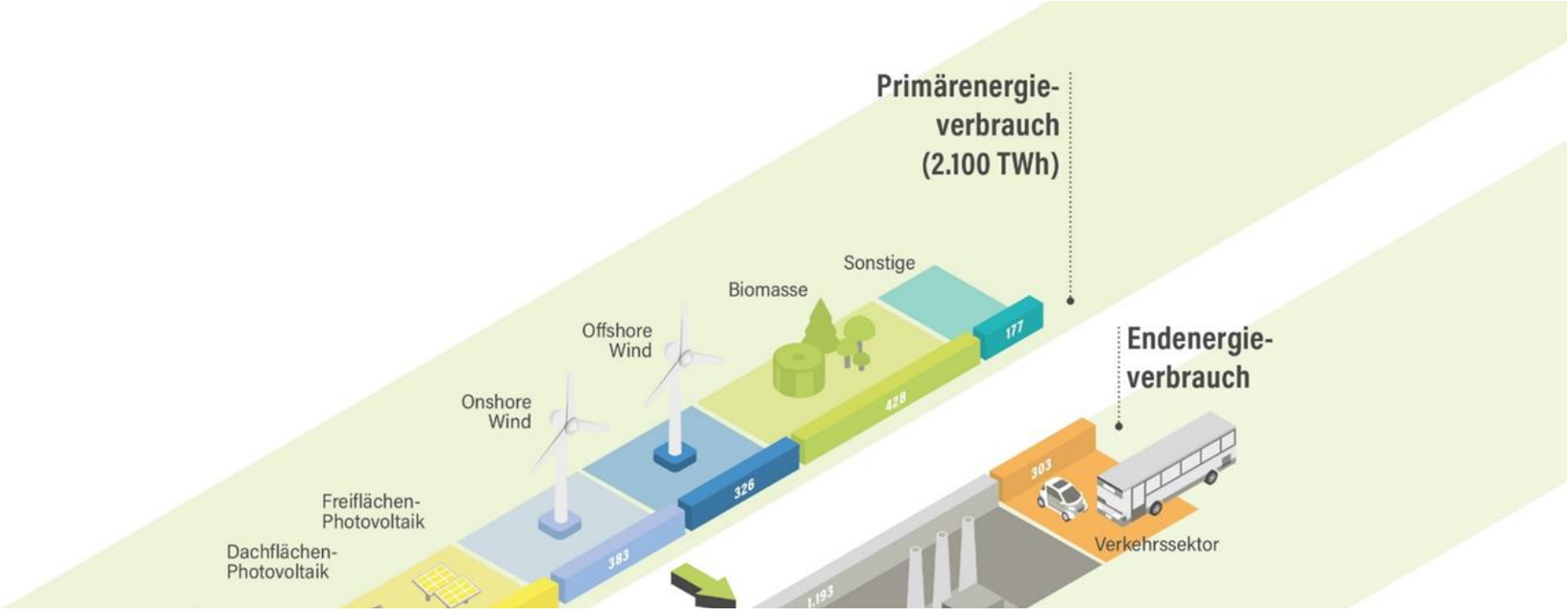


Strategies for a Greenhouse Gas-neutral Energy Supply by the Year 2045

09.06.2022 | F. KULLMANN, T. SCHÖB, P. MARKEWITZ, L. KOTZUR, D. STOLTEN

Agenda

- ... what have we done?
  - ... how did we do it?
    - ... what does a greenhouse gas neutral strategy look like?
      - ... what conclusions can be drawn?

Scenario definition and assumptions

Greenhouse gas-neutral scenario by 2045 ("net zero")

- Digressions on various topics, e.g..
  - LULUCF emissions sink
    - Expansion of renewable energies
      - Hydrogen import price
        - Defossilization of the chemical industry

Basic assumptions and framework conditions

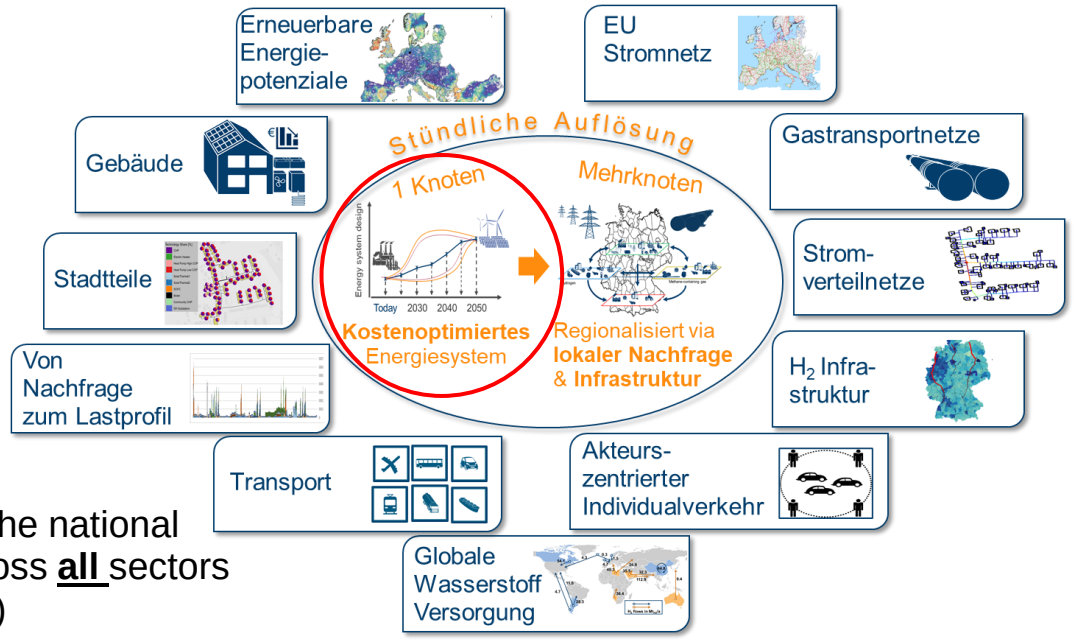
- Greenhouse gas reduction targets from 2030 in accordance with the Climate Protection Act (KSG).
- GHG emissions from agriculture cannot be completely avoided
- Phase-out of nuclear energy and coal-fired power generation in accordance with the AtG and KVBG
- Annual GDP growth of 1.2%, moderately rising energy prices, etc.

LULUCF: Land use, Land-use change and Forestry GHG: Greenhouse gases AtG: Atomic Energy Act KVBG: Coal-fired Power Generation Termination Act
KSG: Climate Protection Act

Approach, models, methods

Core model

Integrated energy system model ETHOS/NESTOR



Method

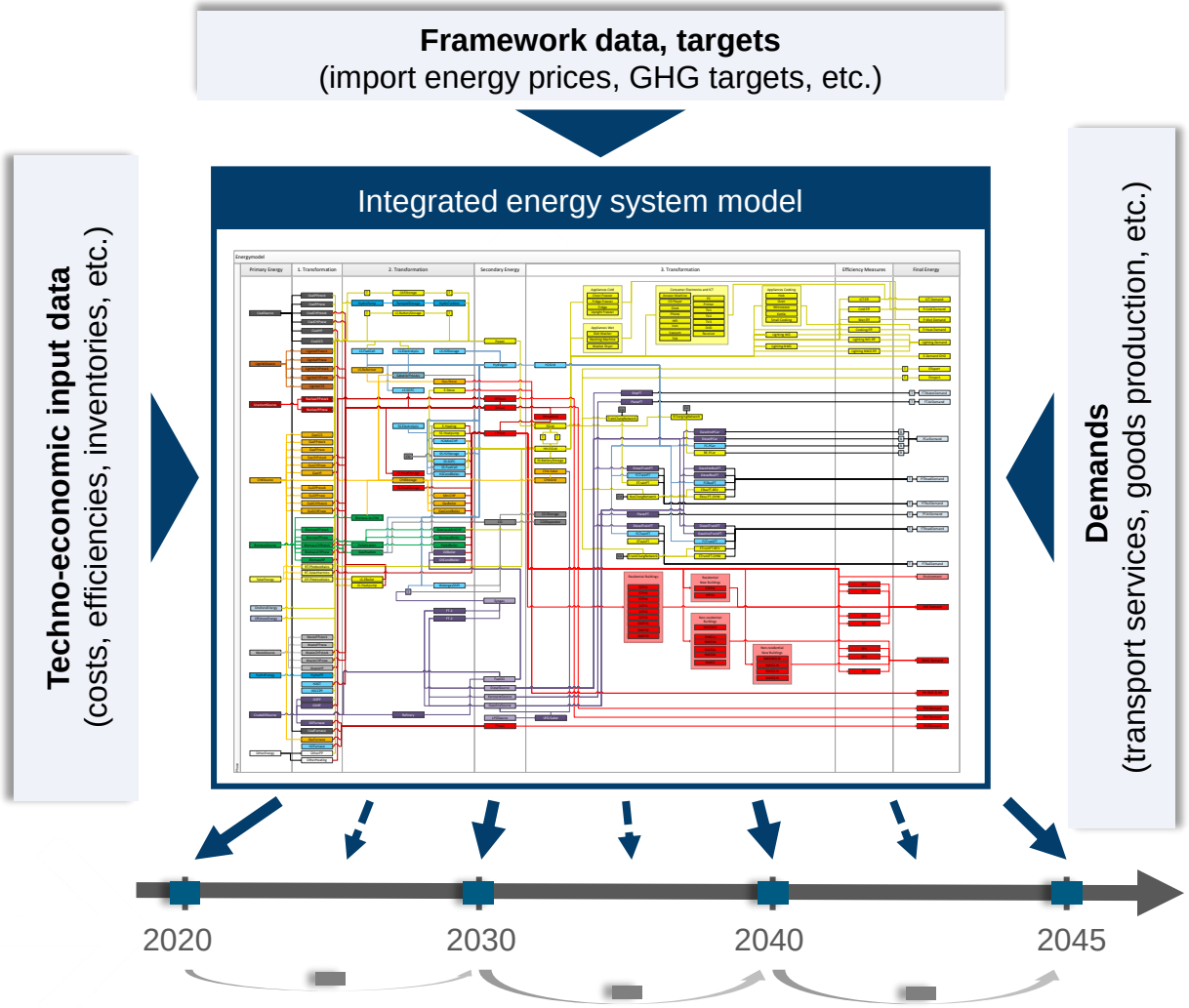
1. **Optimization of** the national energy supply across **all** sectors (cost minimization)
2. **Optimized** H_2-infrastructure analysis

Result

Cost-optimal scenario under the set boundary conditions "Omniscient planner"

NESTOR: National Energy System with SecTOR Coupling

The ETHOS / NESTOR model



Special features & characteristics

- National energy supply
- Detailed implementation of:
  - Energy supply, industry, buildings and transport
  - PtX Technologies
  - Energy storage
  - CO_2 capture & storage
  - …
- About 1300 techniques
- Hourly resolution

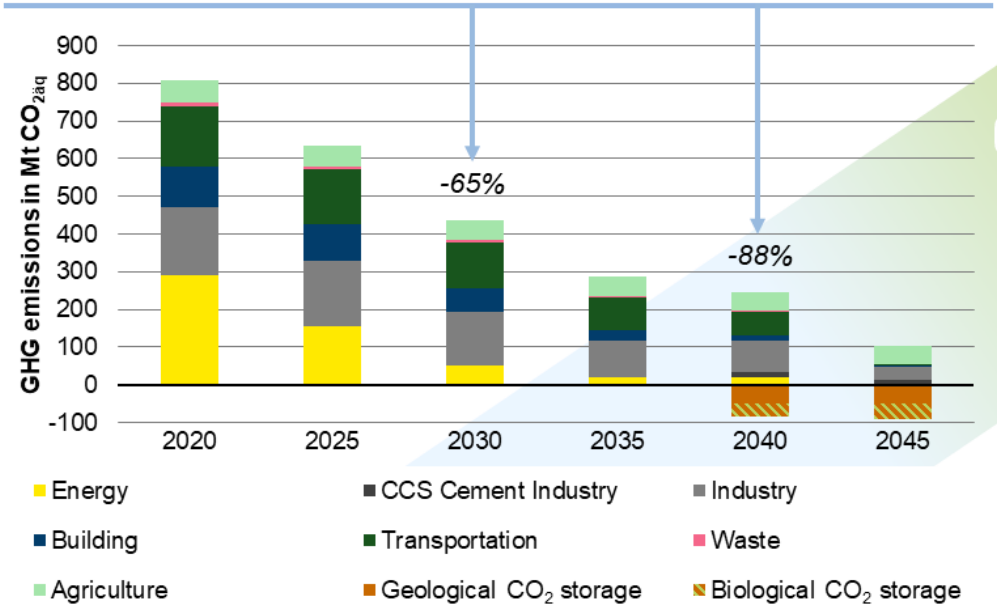
Method

Cost optimization

"All mitigation measures are in competition with each other"

NESTOR: National Energy System with SecTOR Coupling

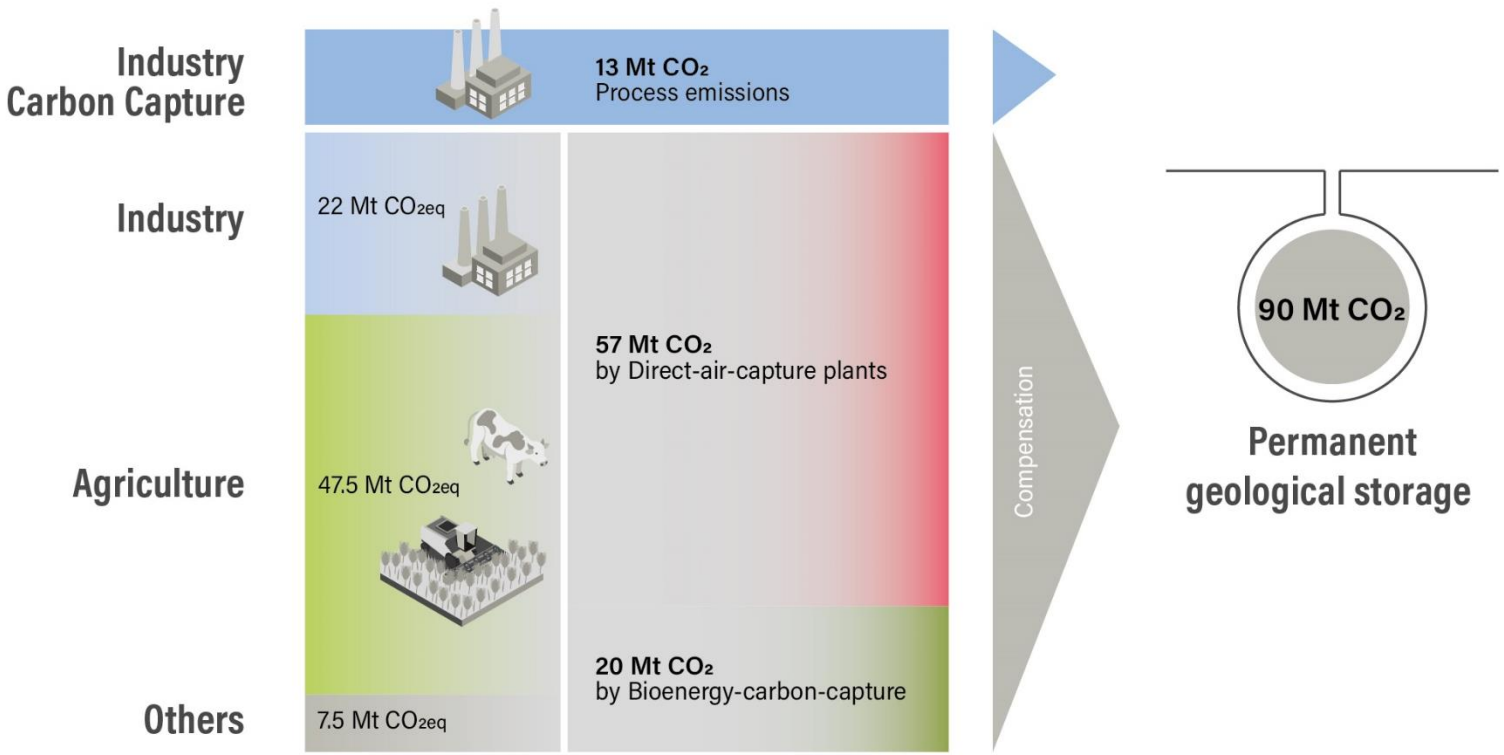
01 Greenhouse gas neutrality can only be achieved with permanent geological CO_2 Storage



100 KSG2045

► Adapt Carbon Dioxide Storage Act (KSpG)

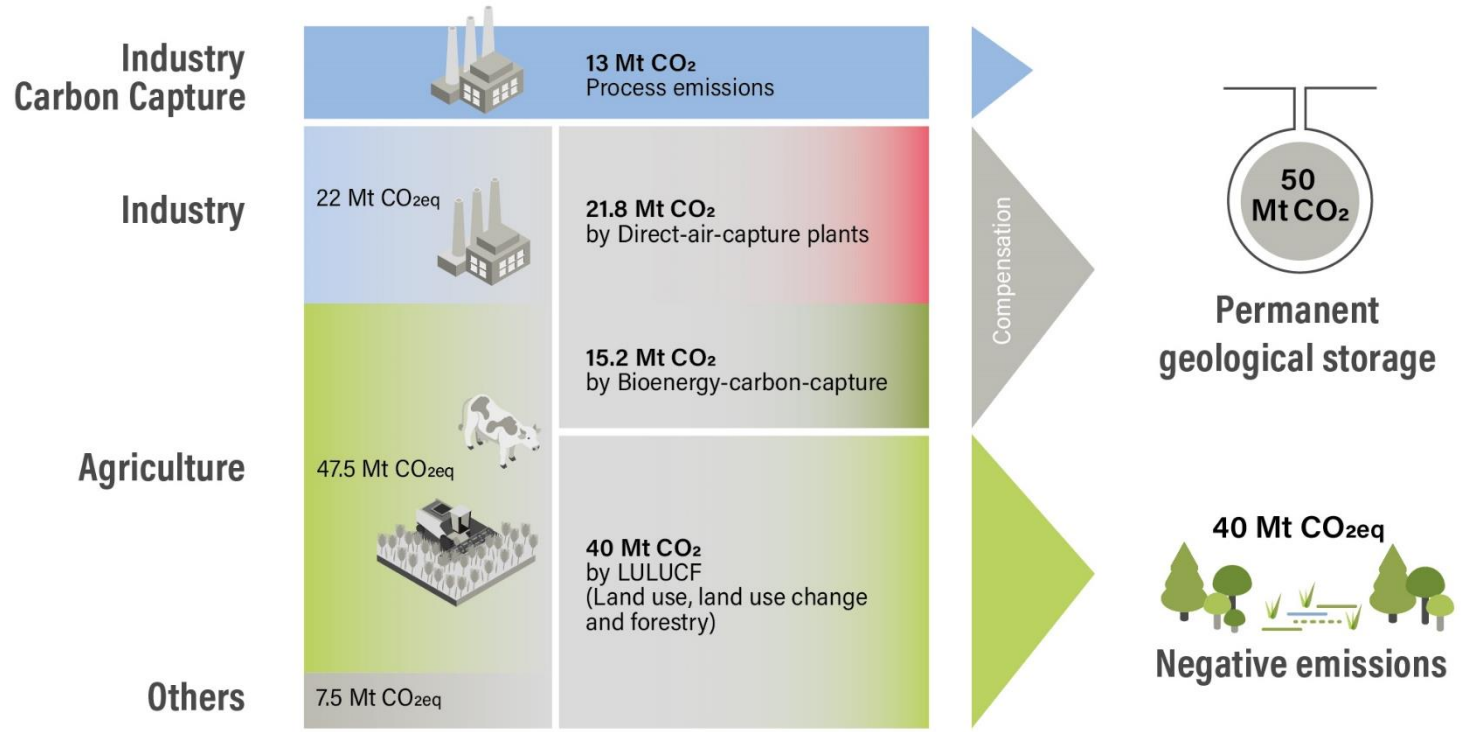
01 Annual geological CO_2 storage demand **without** LULUCF measures in 2045



- Annual geological CO_2 storage of approx. 90 million t in 2045

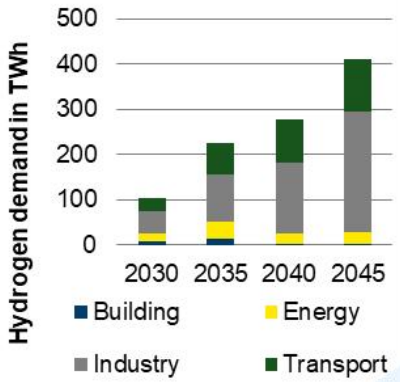
LULUCF: Land use, Land-use change and Forestry.

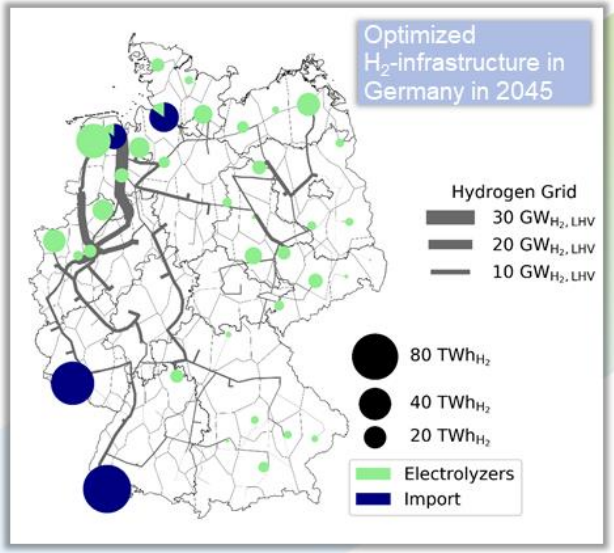
01 Annual geologic CO_2 storage requirements **with** LULUCF measures in 2045.



- Even with LULUCF measures, geological CO_2 storage is necessary: 50 million t/a.
- Adapt Carbon Dioxide Storage Act (KSpG)

02 Hydrogen is an important building block for the success of the energy transition





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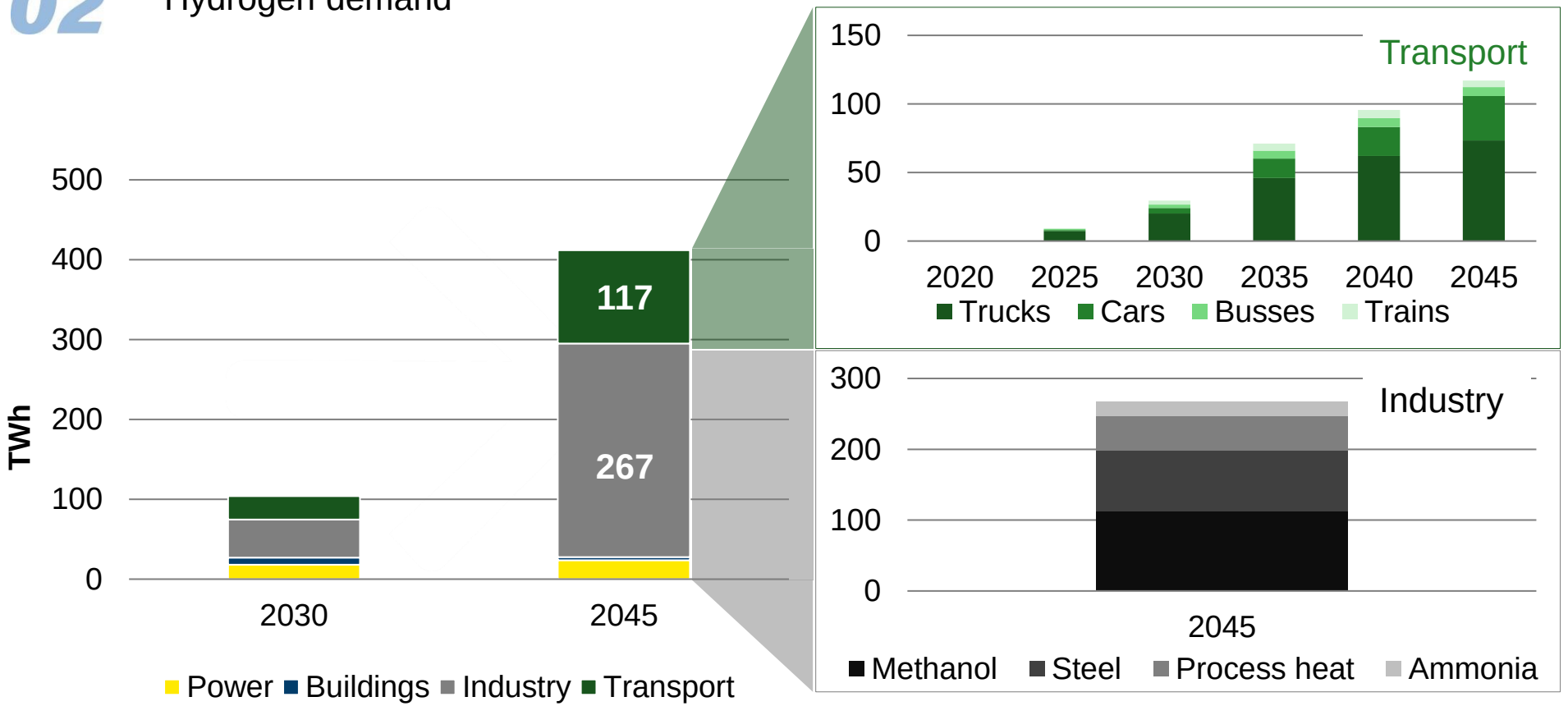
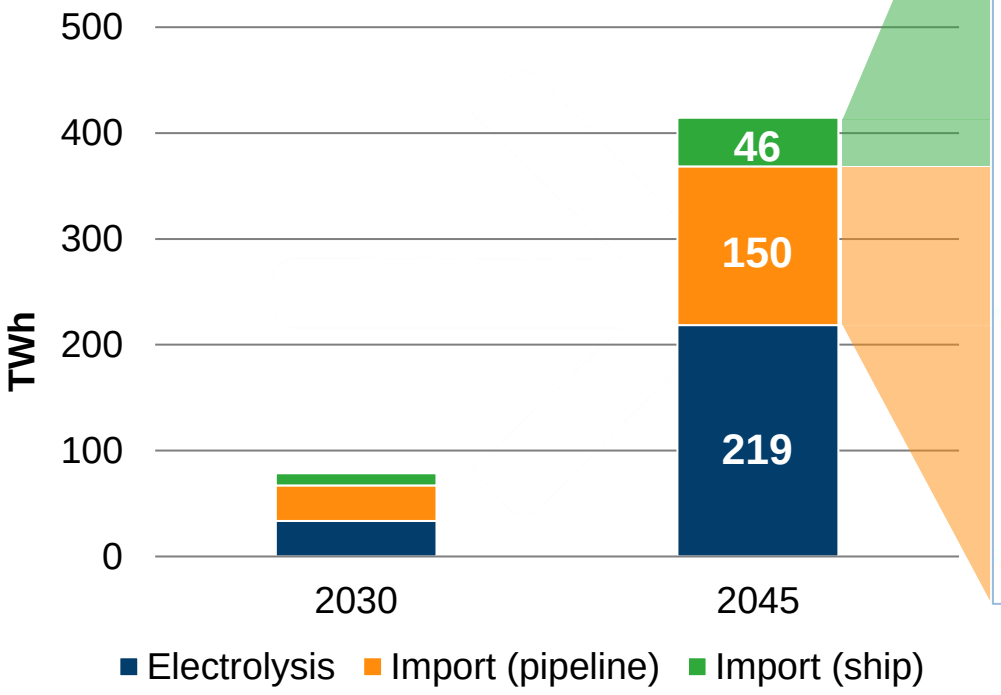
► Invest in salt caverns and pipelines promptly

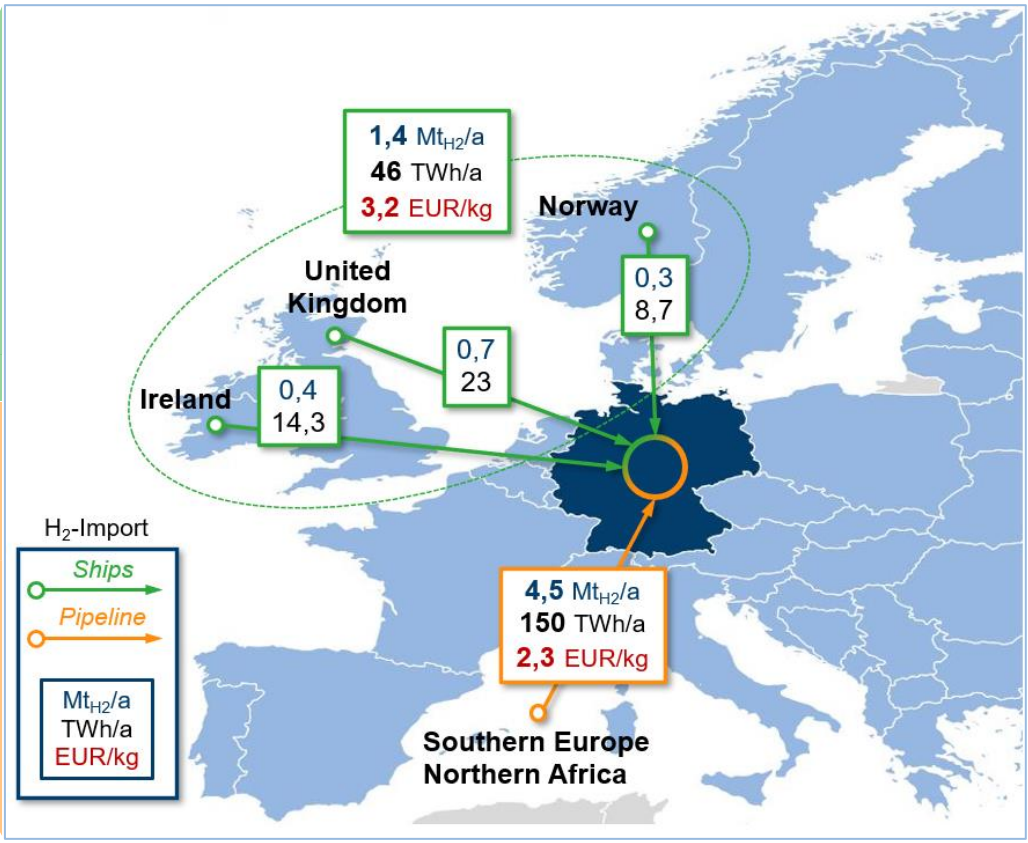
02 Hydrogen demand



- About 70% of future hydrogen demand is accounted for by industry
- Hydrogen use in buildings plays only a minor role

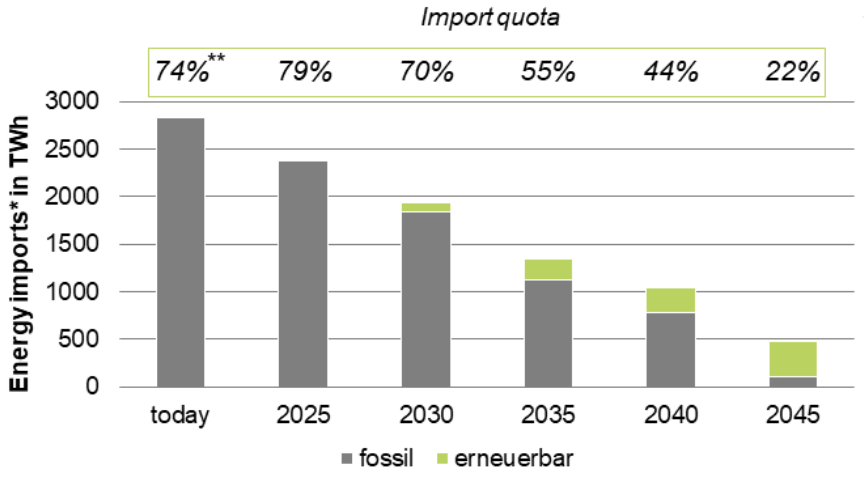
02 Hydrogen production in 2045





- Hydrogen imports are necessary
- Domestic hydrogen production is also economically feasible

03 Greenhouse gas neutrality causes a decrease in the energy import dependency



* incl. non-energetic demand
** AGEB: energy balance 2019, https://ag-energiebilanzen.de/7-0-Bilanzen-1990-2016.htmlx

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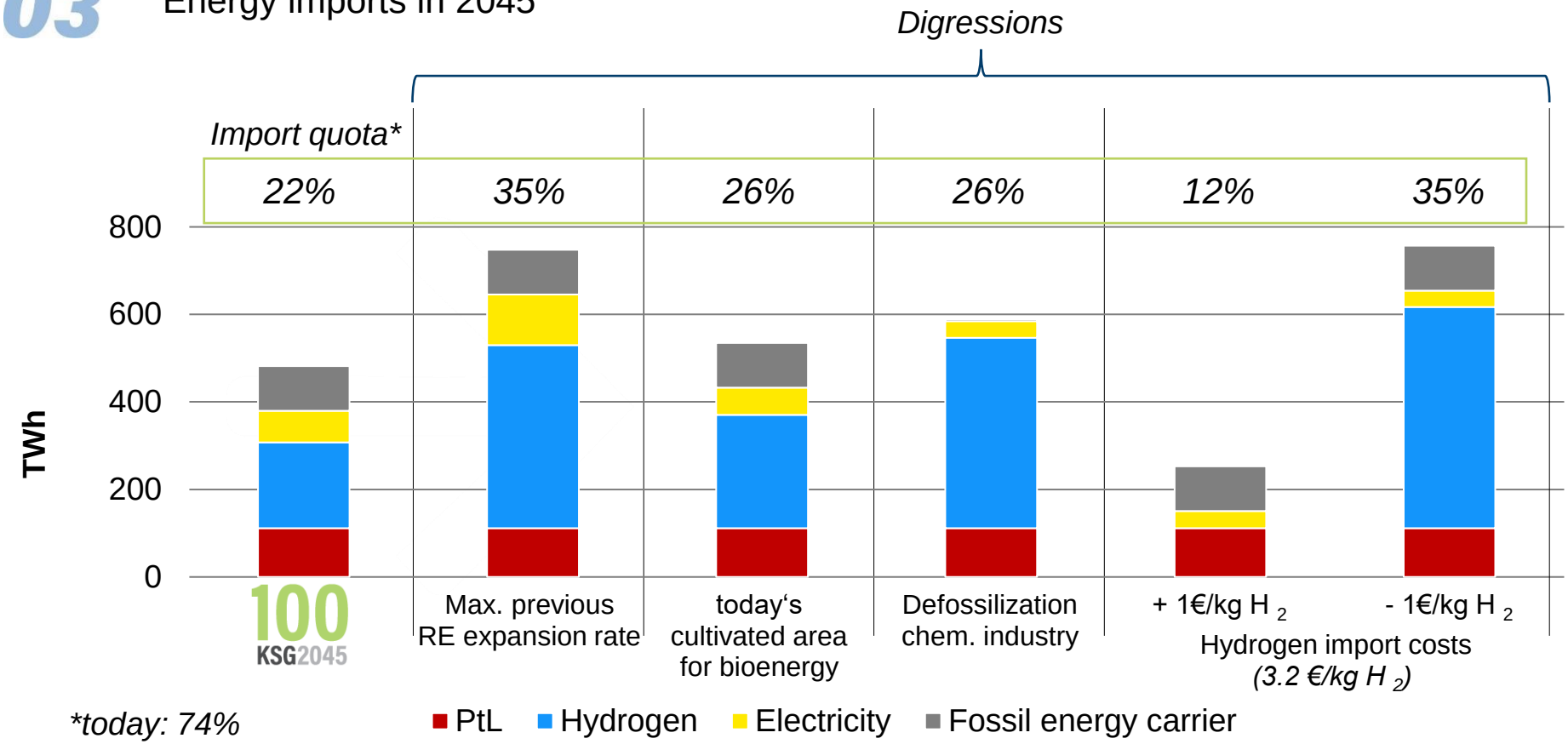
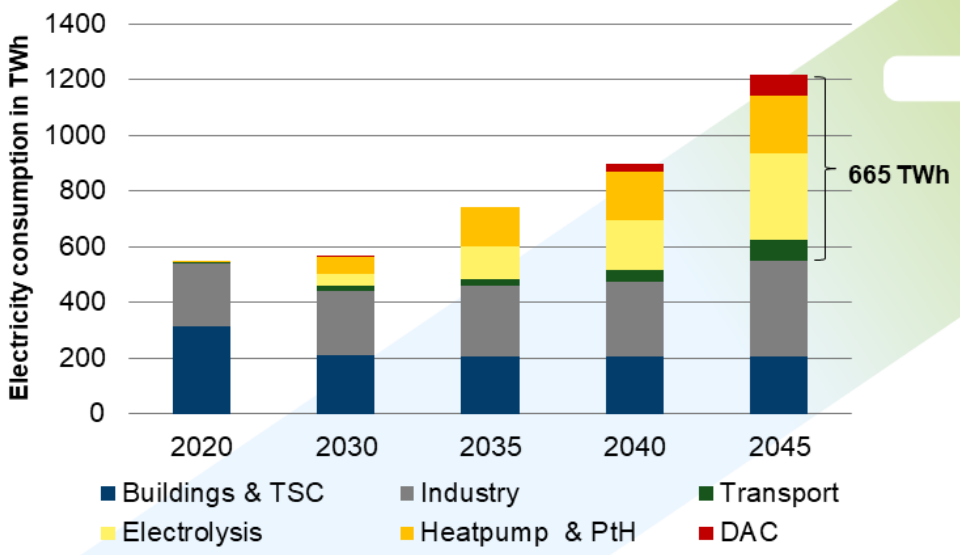
► Greater independence from energy price risks

03 Energy imports in 2045



- A maximum of around one-third of the energy supply will have to be imported in 2045

04 Sector coupling doubles electricity consumption in Germany



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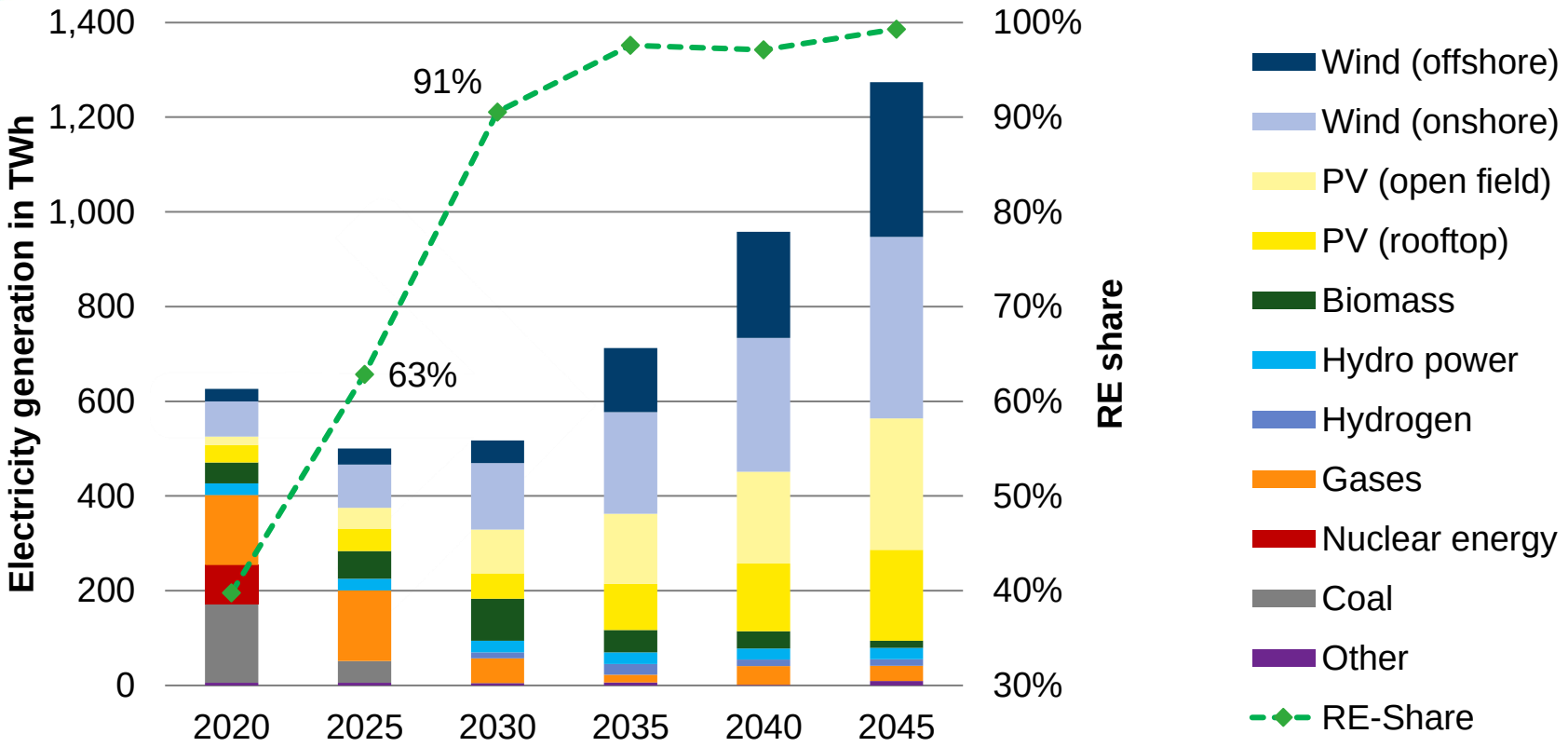
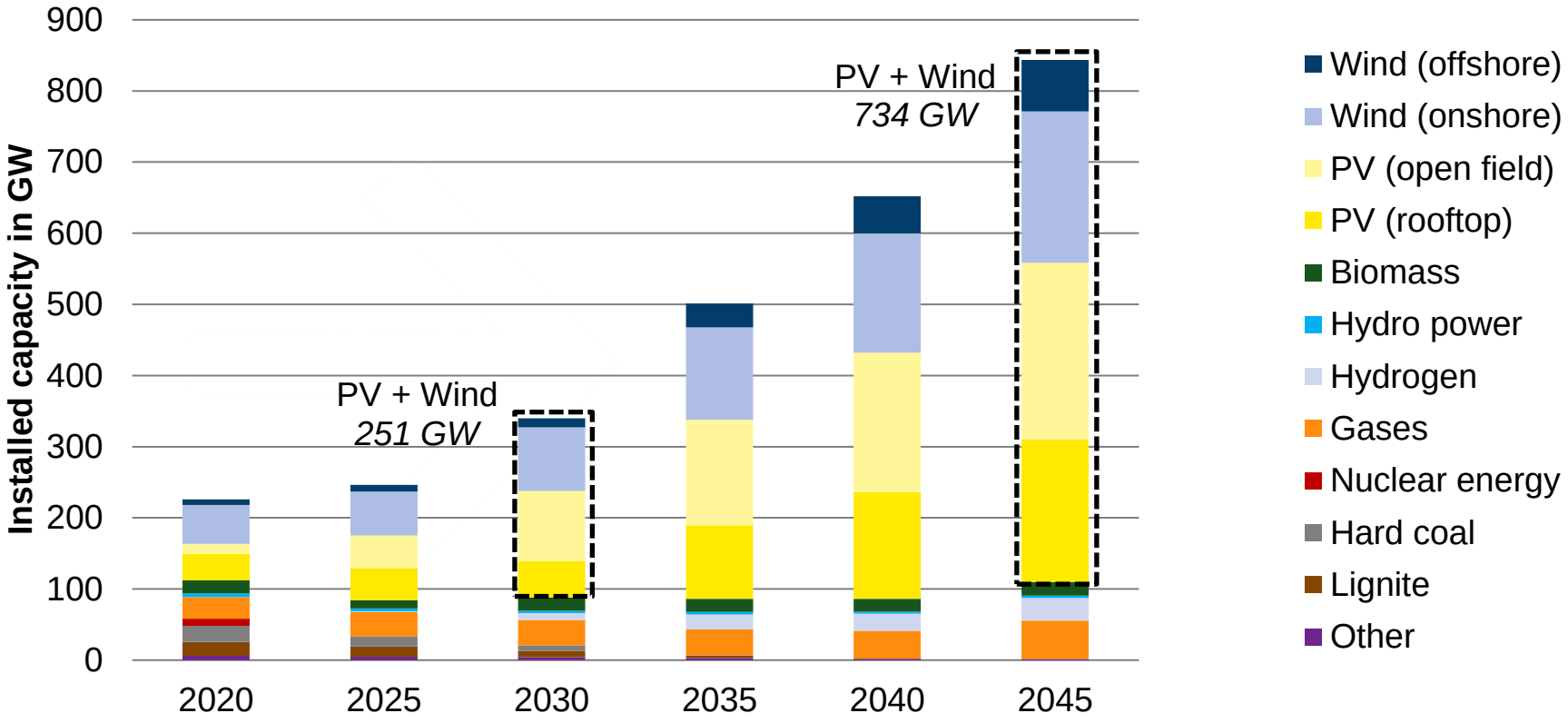
► Efficiency measures: cost-efficient & prevent greater power consumption

04 Power generation



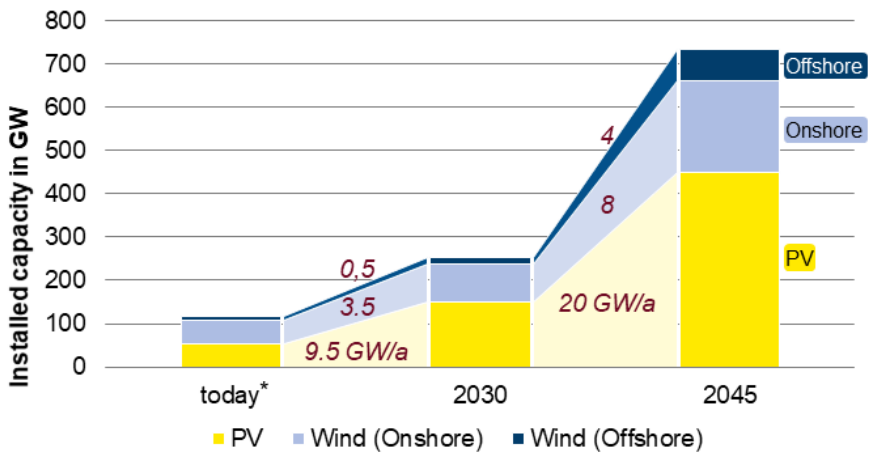
- Exploiting electricity efficiency potential means lower generation
- Increase the share of renewables at a fast pace (2025: 63%).

04 Installed generation capacity



- Doubling of today's wind power and PV capacity by 2030
- Share of PV (open-field and rooftop) in 2045: 53%.

05 The pace of renewables expansion must be accelerated



* https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/start.html

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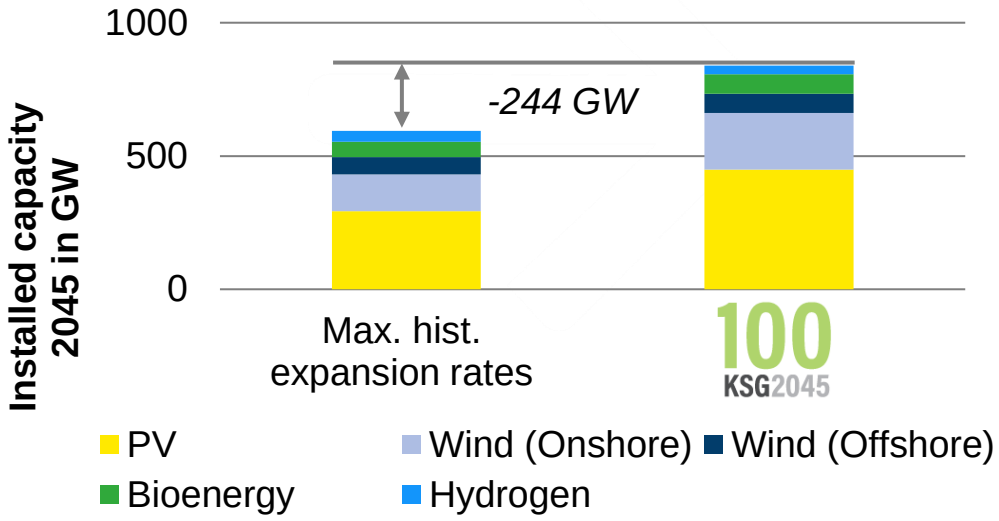
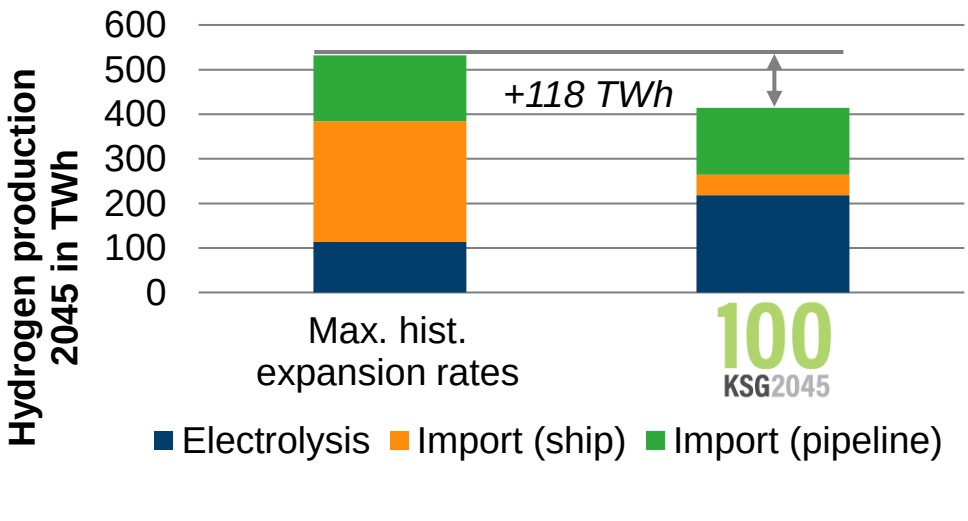
► Shorten and simplify approval and planning procedures...

05 Excursus on wind and PV expansion rates

in GW/a	**Maximum expansion rates in the last 10 years[1]**	**Expansion rates required over the next 25 years**
Wind-Onshore	4,9	6,3
Wind Offshore	2,3	2,6
PV	9,0	15,8

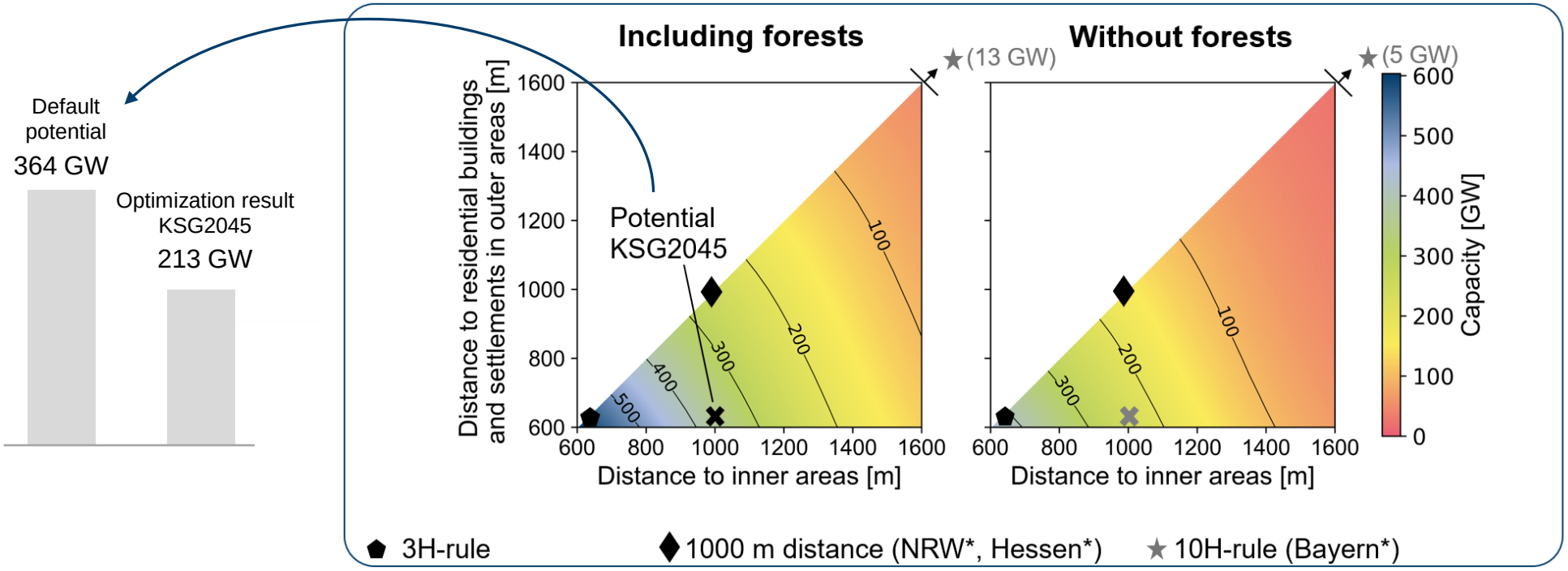




- If the expansion rates are not achieved, this will lead to higher energy imports

[1] BMWi Information Portal Renewable Energies. Renewable Energies Working Group - Statistics https://www.erneuerbare-energien.de/EE/Navigation/DE/Home/home.html

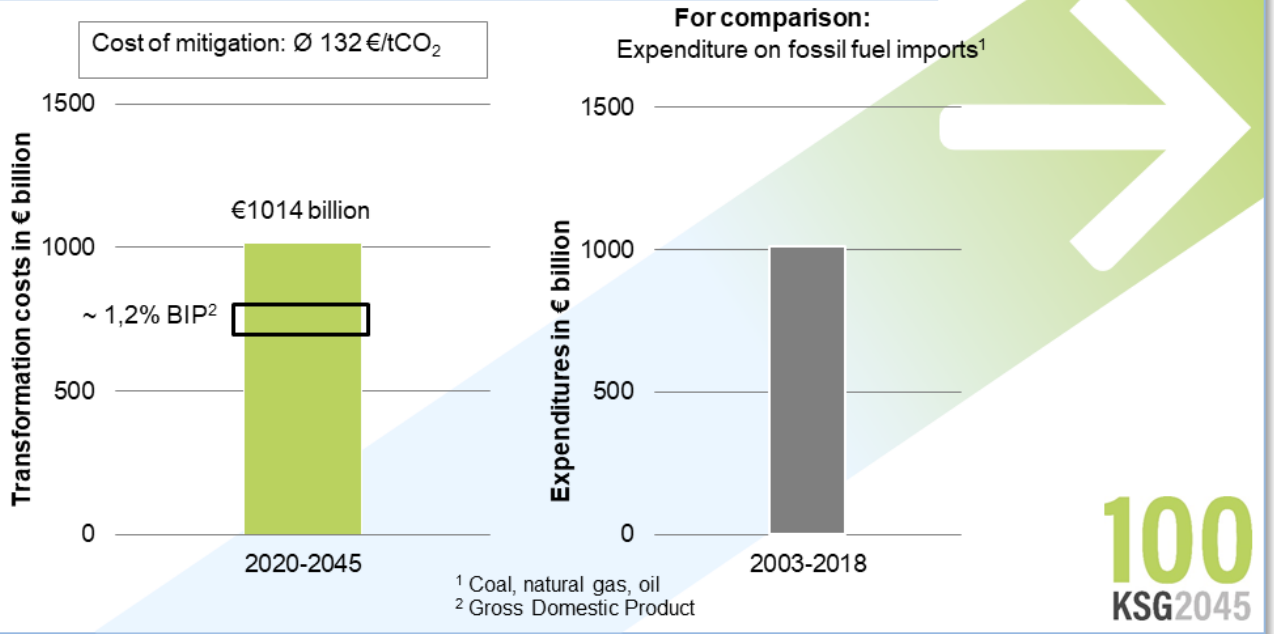
05 Potential analysis wind power onshore



* Extreme case in which all residential buildings in outer areas are protected by outer area statute („Außenbereichssatzung“)

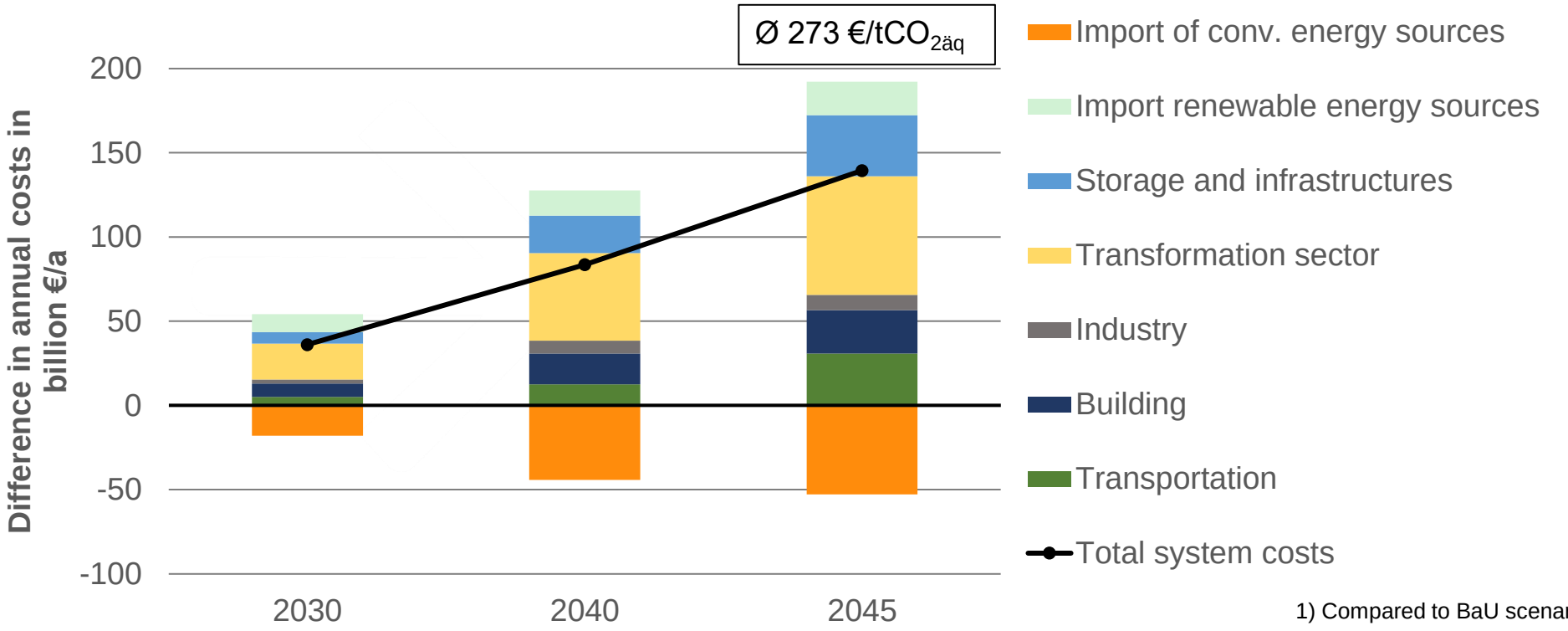
- Only 59% of the analyzed potential for onshore wind (364 GW) is utilized
- Even excluding the forest areas, there would be enough wind energy potential

Greenhouse gas neutrality by 2045 is technically and economically feasible



► Prerequisite: Transformation is tackled promtly in all sectors

Annual additional costs for greenhouse gas neutrality[1)]



1) Compared to BaU scenario

- Sharp increase in additional costs at the end of the period
- Largest share of costs: energy sector (RE expansion, electrolysis, DAC, etc.)

Scenario KSG2045 - at a glance

Annual CO_2 storage	**50 - 90 million t**
More than a doubling of today's electricity consumption	**1200 TWh**
Savings in the final energy sectors compared to today	**30%**
Average expansion rate of onshore wind power	**6.3 GW/a**
Average photovoltaic expansion rate	**15.8 GW/a**
Hydrogen demand	**12 million t**
Additional costs of the transformation strategy over next 25 years	**1 trillion €**

- Transformation is technically and economically feasible
- Action period: only 25 years - immediate action at all levels

Thank you for your attention!

On this page you will find our study to dowload and further information:

Institute for Energy and Climate Research
Techno-Economic Systems Analysis (IEK-3)
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