# Transformation of the German Energy System as a Key for Decarbonising Transport

IHÉDATE Cycle 2023 Territories and mobility: The decarbonisation of mobility as seen from the heart of the German automotive industry

Stuttgart, June 29th 2023

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DLR

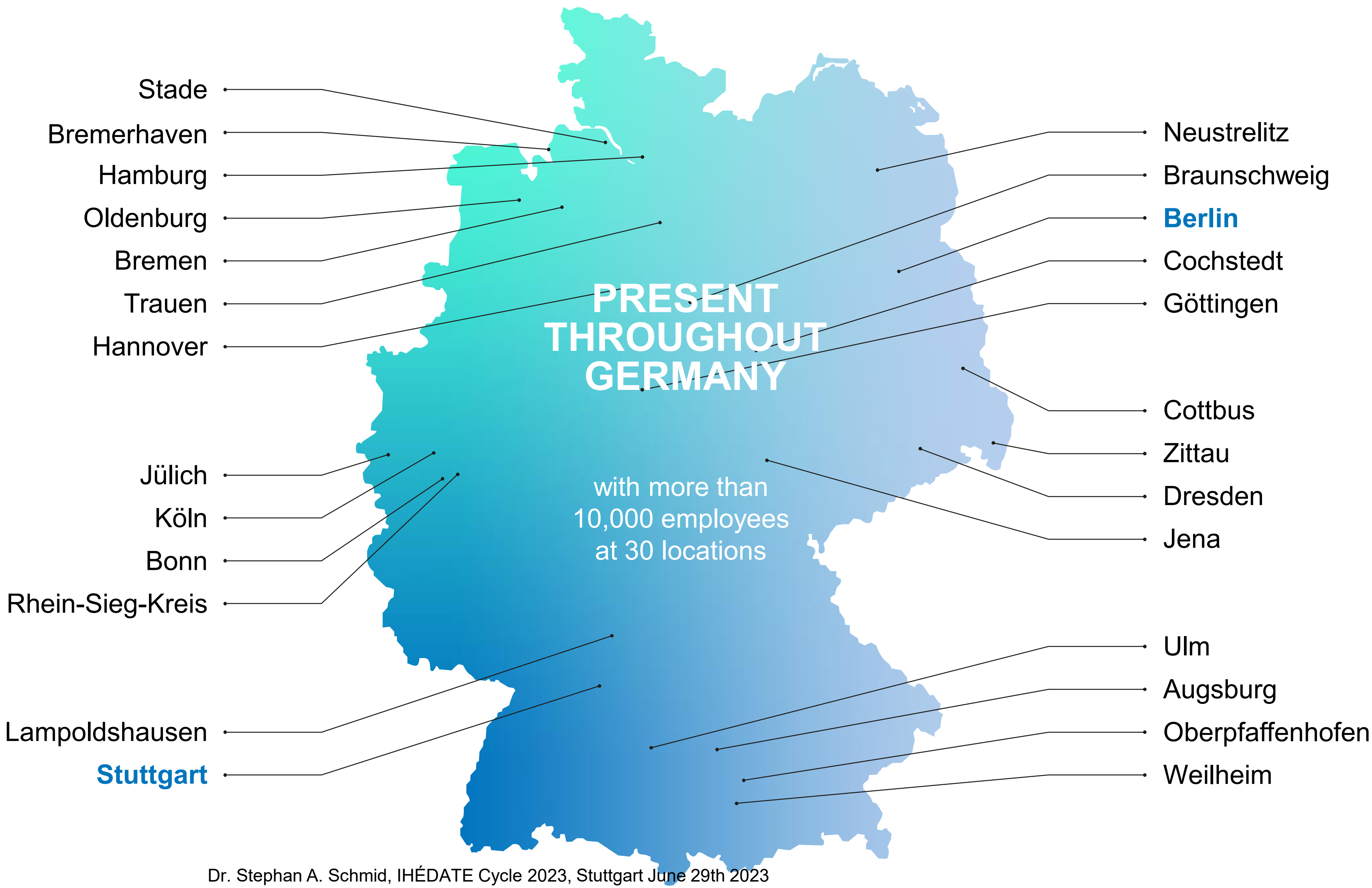
## Agenda

1. German Energy Transition:  Targets and strategies
2. German Energy Transition:  Where do we stand?
3. German Energy Transition & Transport:  Charging, eFuels, Hydrogen

# German Aerospace Center – Knowledge for Tomorrow

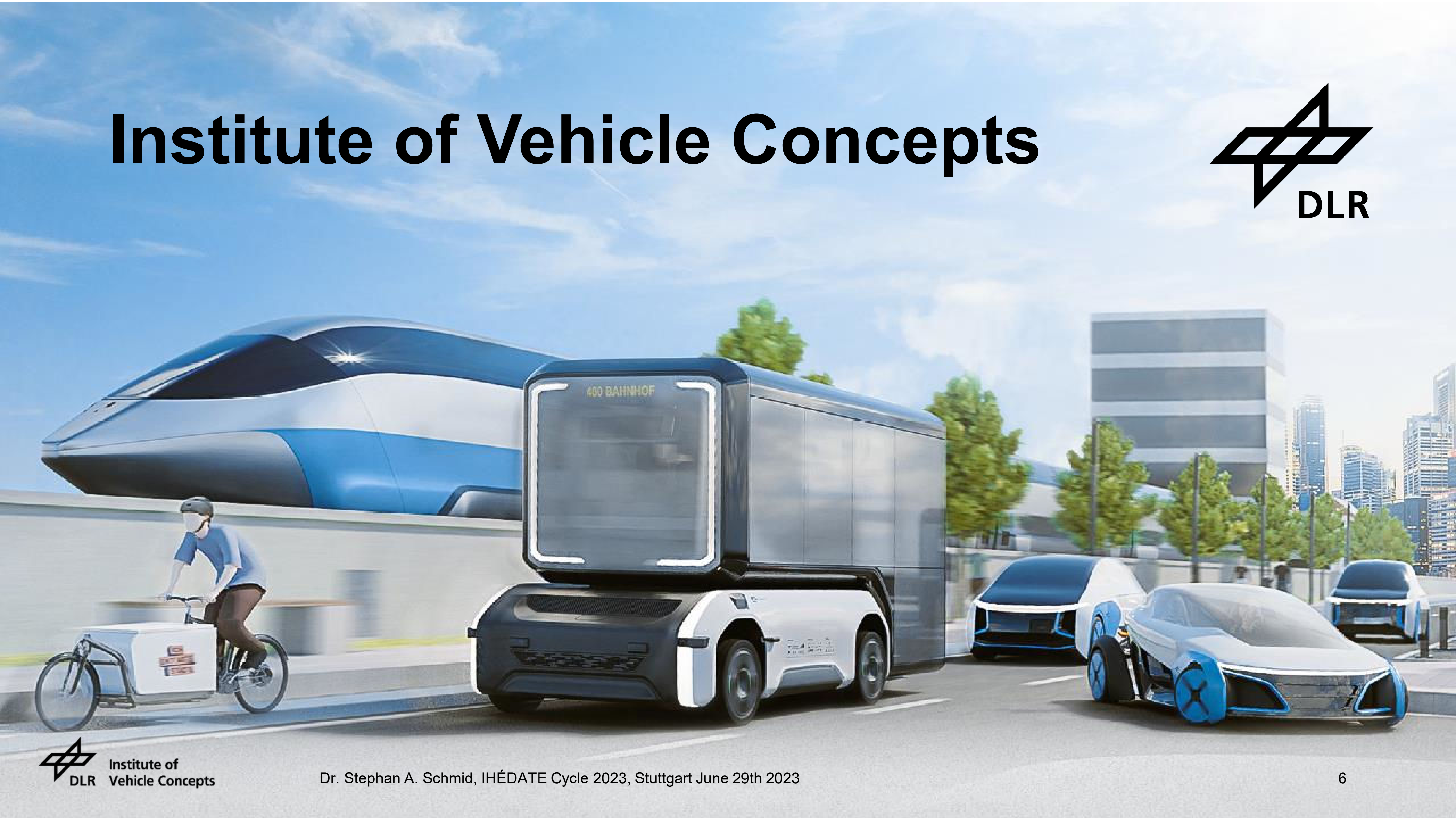
# Fields of activity

- Aeronautics and aerospace
- **Energy and transport**
- Digitisation and security
- Planning and implementation of German aerospace activities
- Project executing agency for research funding



PRESENT THROUGHOUT GERMANY
with more than 10,000 employees at 30 locations
Stade
Bremerhaven
Hamburg
Oldenburg
Bremen
Trauen
Hannover
Jülich
Köln
Bonn
Rhein-Sieg-Kreis
Lampoldshausen
**Stuttgart**
Neustrelitz
Braunschweig
**Berlin**
Cochstedt
Göttingen
Cottbus
Zittau
Dresden
Jena
Ulm
Augsburg
Oberpfaffenhofen
Weilheim

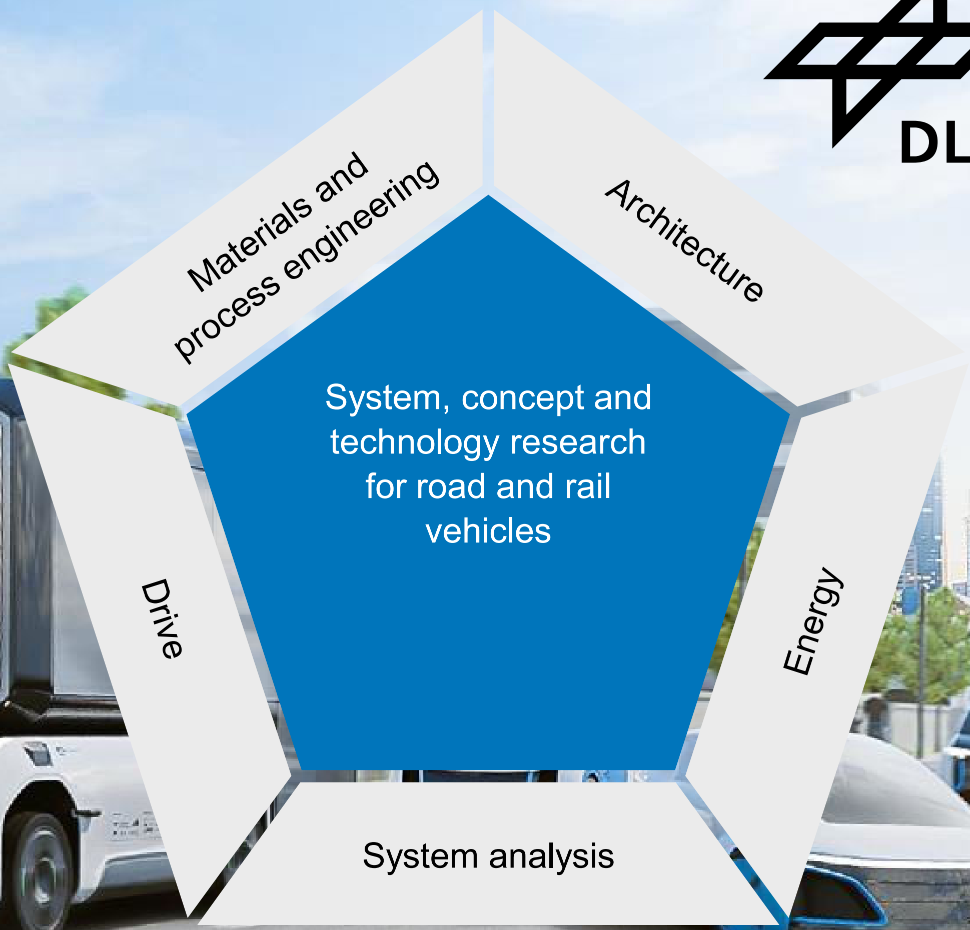
# Institute of Vehicle Concepts



## Our fields of innovation:

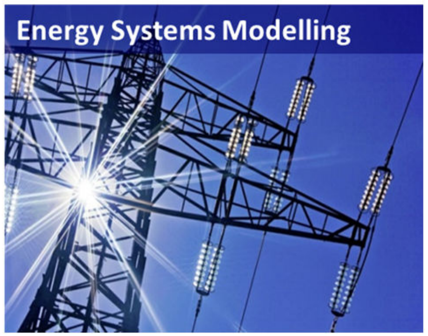
**Strategic cross-cutting topics:**

- Transformation
- Digitization
- Circular Economy
- Hydrogen applications

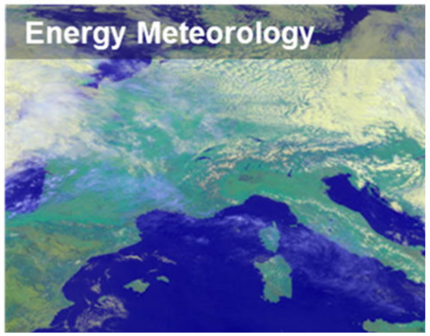


# DLR activities in energy scenario development & assessment
## at the Institute of Networked Energy Systems, Stuttgart

- Studies on the energy transition and green hydrogen supply since the 1970s, e.g. book „Hydrogen as an Energy Carrier“ from Winter/Nitsch of 1988 (Springer)
- Lead scenarios for the German Ministry for the Environment starting around 2000, e.g. German „Long term scenarios 2012“ with a first bottom-up outlook on 95% GHG reduction
- Development of global and country scenarios for NGOs since 2005, e.g. Teske et al. 2019 „Achieving the Paris Climate Agreement Goals…“
- Development of power system and infrastructure modelling in high temporal and spatial resolution since around 2005 at European level (REMix model)
- Research on methods for socio-technical scenarios, agent-based market analyses, prospective LCA-based assessment and analysis of critical resource demand, resilience …





# Energy Transition as major part of the climate protection strategy

**3 main targets of Climate protection & Energy policy in Germany:**

1. GHG reduction targets for the sectors (energy, industry, buildings, transport, agriculture, and waste management).
2. Targets for carbon sequestration in the LULUCF sector (natural sinks)
3. Targets for technical carbon sequestration to offset residual emissions (technical sinks)

Federal Ministry
for Economic Affairs
and Climate Action

Energy Efficiency
Energy consumption
Security of supply
Energy imports
The German Energy Transition
Grids & Grid Expansion
Electricity Market of the Future
Energy Research
Renewable Energy
Energy production
European and International Energy Policy
Sector coupling
Costs
Sectors
Industry
Buildings
Transport
Hydrogen
Flexibility options

## Energy Transition – main policies

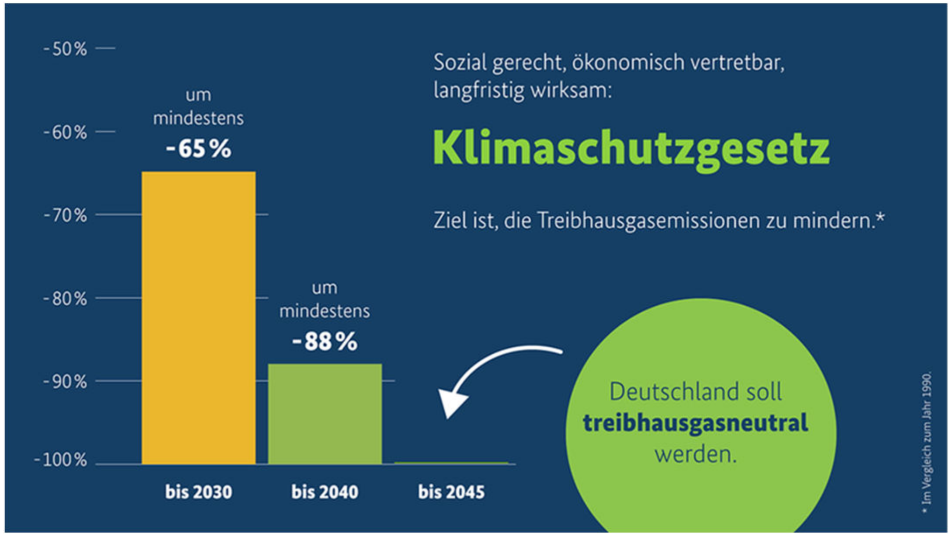
**1) Energy concept 2010**: the German government for the first time presented the guidelines for energy transformation in a comprehensive way. The focus was on achieving the minimum target of 80% GHG reduction by 2050; nuclear power was still mentioned as a bridging technology.

**2) EEG – Renewable Energy Sources Act:** is the central control instrument for the expansion of renewable energies in the power sector. (2000, 2004, 2009, 2012, 2014, 2017, 2023)

Provided investment security and high incentives: Remuneration is guaranteed by law for 20 years

Costs paid through a levy by electricity customers (2010: 2.05 ct/kWh, 2020: 6.76 ct/kWh). The levy ended in 2022; financing now via returns from CO2 pricing (Energy and climate fund)

**3) German Climate Protection Act:** aims to achieve greenhouse gas neutrality in Germany by 2045. The law is intended to help Germany make its contribution to limiting global warming to a maximum of 1.5 degrees Celsius. (2019, 2021, 2023)



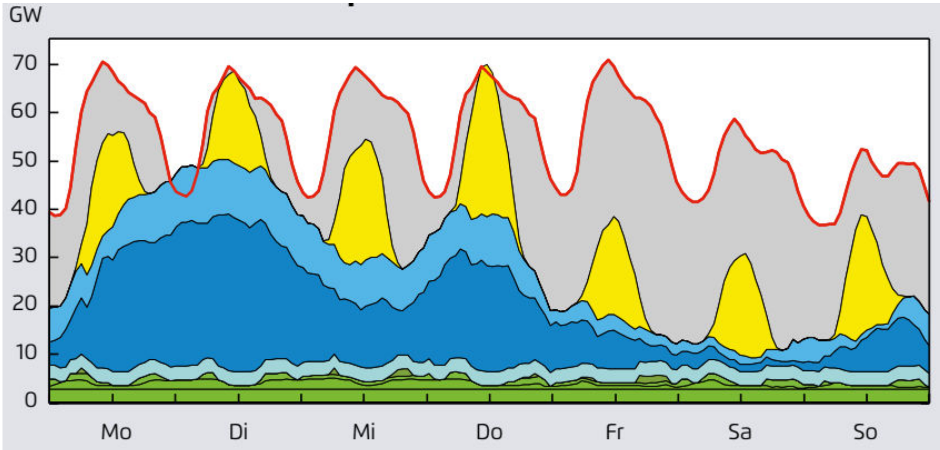
# Energy Transition – some theses I

- **The focus is on wind and solar!**
- Other potentials rather small or much more costly (hydro, geothermal, sustainable biomass…)
- These technologies are fundamentally changing the energy system and the energy market
- Wind and solar power have three **key characteristics**:
  - supply-dependent, i.e. depending on the **weather**
  - high **capital costs** and (almost) no operating costs
  - electricity production is rapidly **fluctuating**
- These characteristics are fundamentally different from and not compatible to fossil base load power plants
- Wind power and PV should be developed in parallel, because they complement each other

How do we synchronize demand and supply?

How do we minimize costs?

How do we implement the energy transition in the European context?



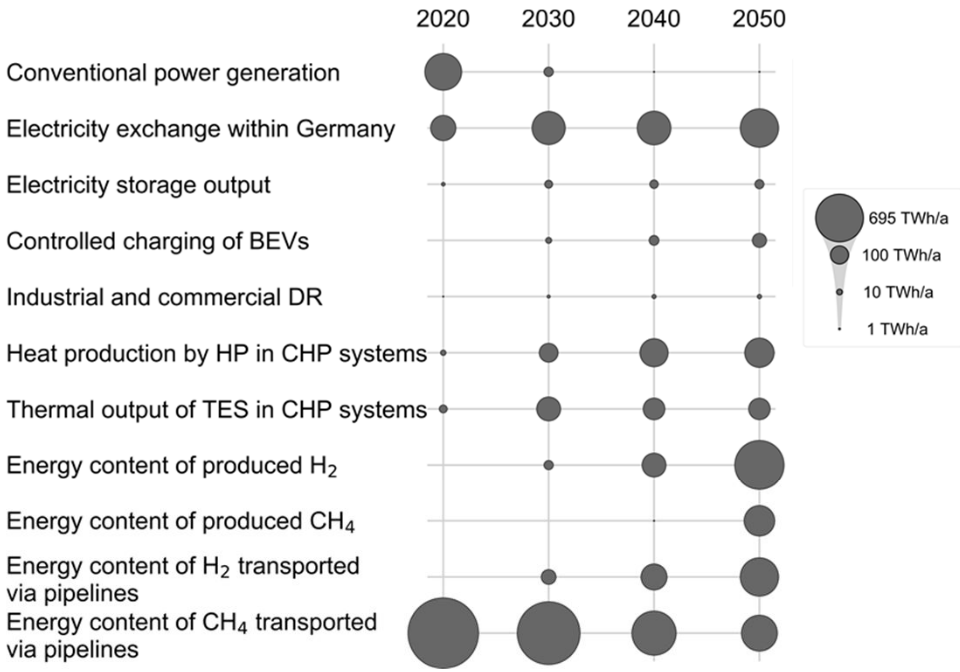

**TECHNICAL SYSTEM:** Base load power plants no longer exist. **Use flexibility potentials** by sector coupling (heat & transport). **Grid expansion** cheaper than **storage facilities** (but complementary, we need both!). **Securing the peak load** is cost-effective (gas turbines for backup). **Energy imports** needed!

**MARKET DESIGN AND REGULATION:** Today's electricity market **trades kilowatt-hours**. Wind and PV **cannot be refinanced** on the marginal cost market. A **new market design** and regulatory framework is needed, integrated in a **European context**

**EFFICIENCY:** one kWh saved is the cheapest

# Energy Transition – some theses II

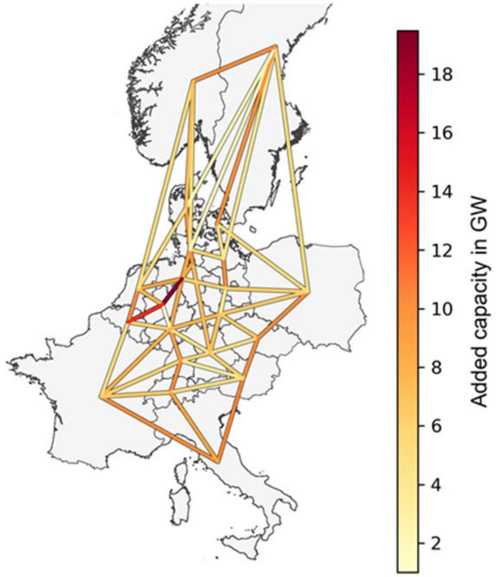
- **There is plenty of flexibility - it's just not worth it so far**
- In the future, fluctuations in generation will require a much greater flexibility of the power system
- Technical solutions are available, for example:
  - grid expansion and new storages
  - CHP and biomass plants
  - avoid generation peaks from wind/PV or use them for heat
  - load shifting in industry
  - flexible EV charging and green hydrogen generation
  - smart devices in buildings for flexible demand
- The challenge does not lie in the technology or its control, but rather in the right incentives
- Activating small-scale flexibility options at the household level via smart meters is currently too expensive.




**Decentralized power system flexibility is competitive and not displaced by large-scale grid expansion and hydrogen production**

# Energy Transition – some theses III

- **Grids, storage and sector coupling are the main options**
- Grids balance demand and supply over long distances and enable access to the most cost-effective flexibility options
- Transmission grids reduce system costs at low investment costs
- Expansion of distribution grids also cheaper than local storage
- New storage technologies are not required until the share of renewable energies exceeds 70 percent
- Local PV battery systems can be economically viable at an earlier stage due to the savings in taxes and levies
- Heat sector twice as large as the power sector; electrification (small heat pumps) and heating grids (incl. power-to-gas and large heat pumps) main options discussed (incl. heat storages)
- European interconnection will make it easier and more cost-effective to secure peak load via gas turbines




➢**Triple** capacity within Germany

➢61 GW (2020)   89 GW (2050)

➢**++** Lower-Saxony & NRW

➢12 GW HVAC + 8 GW HVDC

➢**5 times** expansion to other countries

➢29 GW (2020)  153 GW (2050)

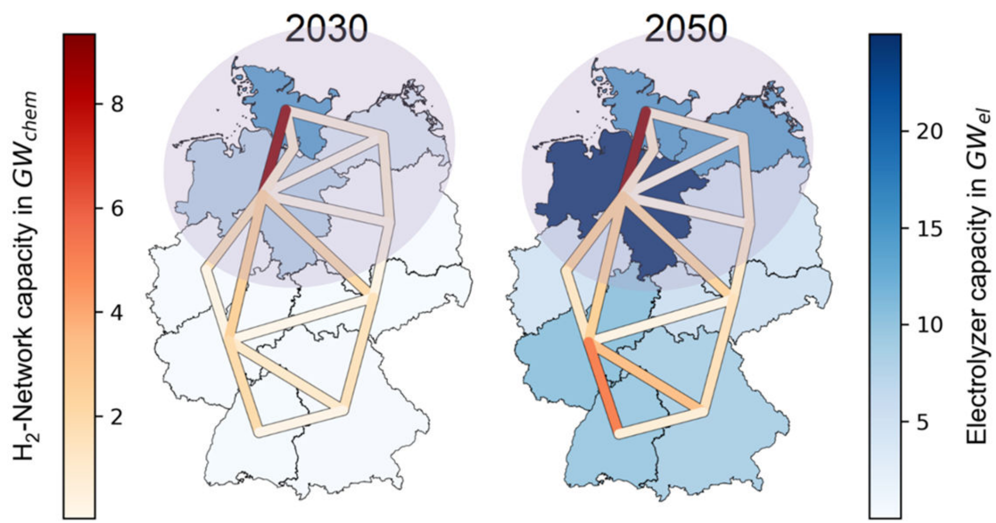
➢**++** NRW & Belgium

➢9 GW HVAC + 5 GW HVDC

➢**+**North-south expansion (~ 10 GW)

➢Expansion of electrolyzer capacity

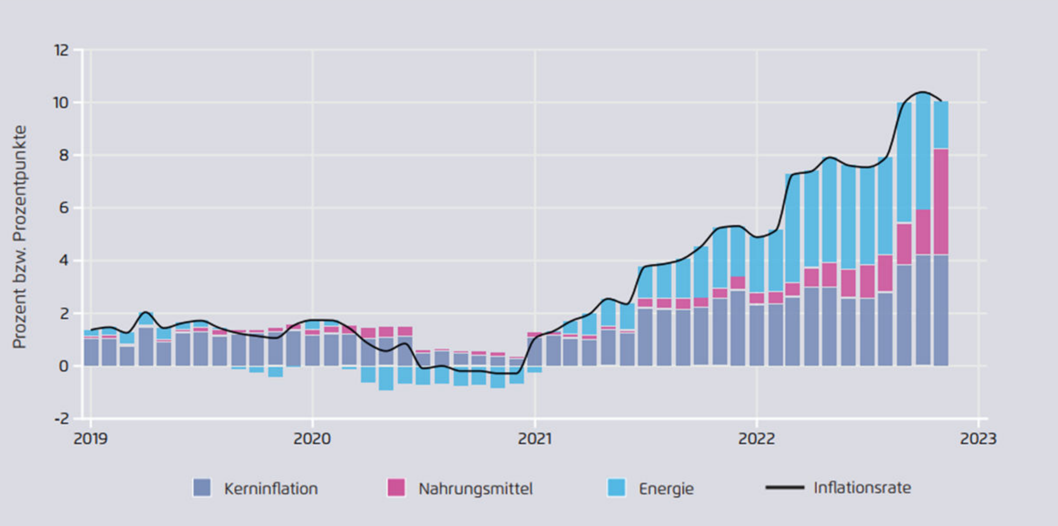
➢26 GW (2030)  96 GW (2050)



# German Energy Transition – Recent Challenges

- The **new phase in energy transition** increasingly affects the population and **public acceptance is crucial**. Example: heating law and huge resistance/discussions
- **Wind and PV is lagging behind** the expansion corridor to be achieved (limited local acceptance, long planning times).
- Required transition dynamics not yet achieved in **transport and heating**. Additional packages of measures are to be implemented to improve the situation …
- **Gas shortage situation** due to stop of gas import from Russia, compensated by use of other import options and more coal for power generation
- **High energy prices** and the resulting inflation demonstrated the need for a better accompanying social policy
- But: this brought an increase in the expansion of heat pumps and more dynamics in the district heating market. However, there is a **shortage of skilled workers** here…


Verbraucherpreisindex (Prozent) in Deutschland 2019 bis 2022 (Wachstumsbeiträge von Kerninflation, Nahrungsmittel und Energie in Prozentpunkten) Abbildung 2_1




Berechnungen von Agora Energiewende bis einschließlich November 2022 basierend auf destatis (2022c).

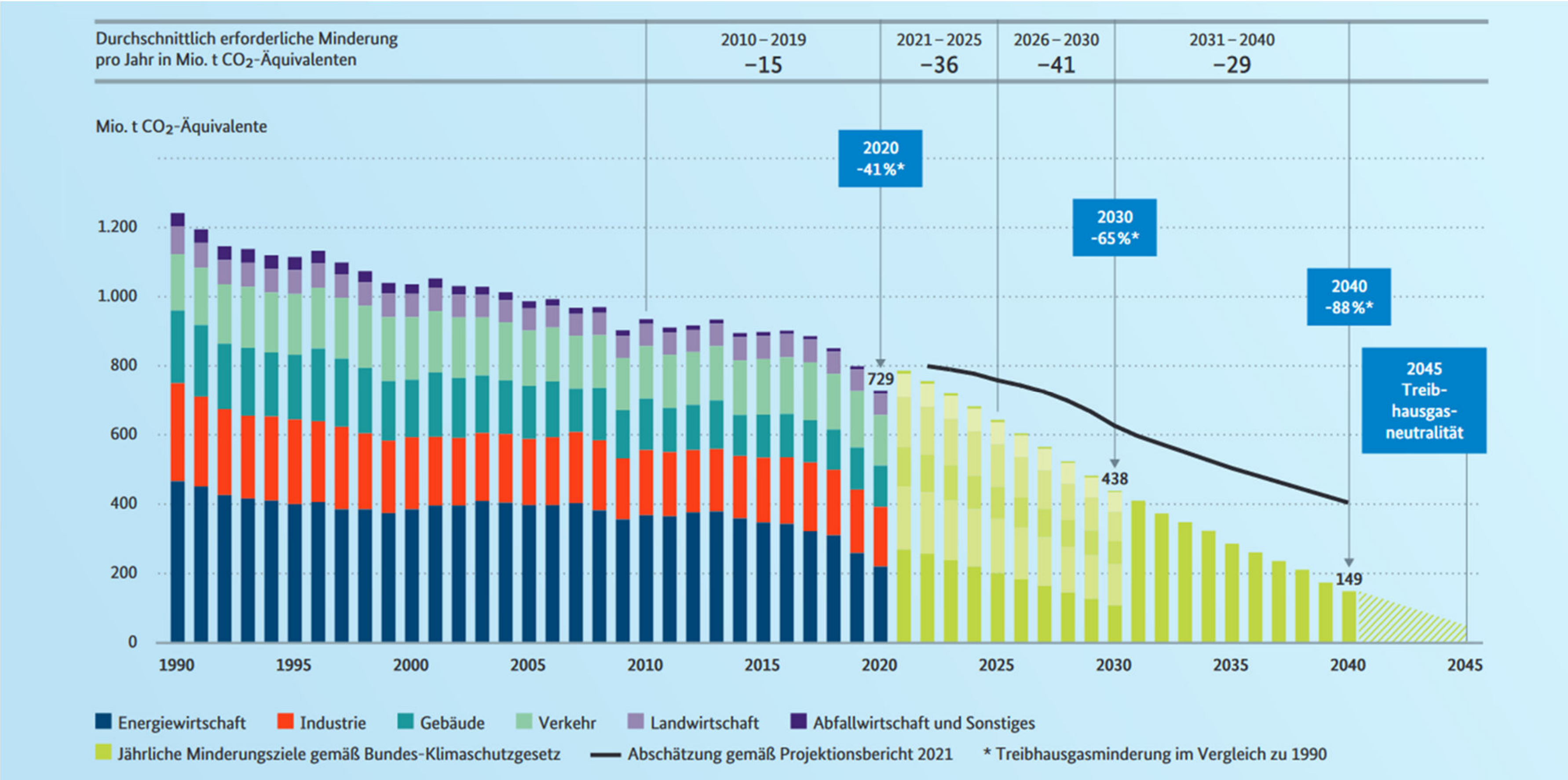
# German Energy Transition – strategic outlooks

- There is a large body of energy system analysis work to illustrate possible scenarios of the energy transition
- Some of the studies contradict each other on the role of individual reduction measures: Efficiency, hydrogen/synthetic gases and fuels, achievable degree of direct electrification, usable domestic energy potentials, ramp-up of green energy imports (electricity, hydrogen, synfuels).
- On the one hand, technology openness is required; on the other hand, important infrastructure decisions must be made. Example: what role will the gas network play in the future? (510,000 km of gas distribution network in Germany, approx. 50% of households connected)?
- In the following some exemplary outlooks!

# German Energy Transition

# Where do we stand?

# Where are we on the road to climate neutrality?
# Development of Greenhouse gas emissions in Germany

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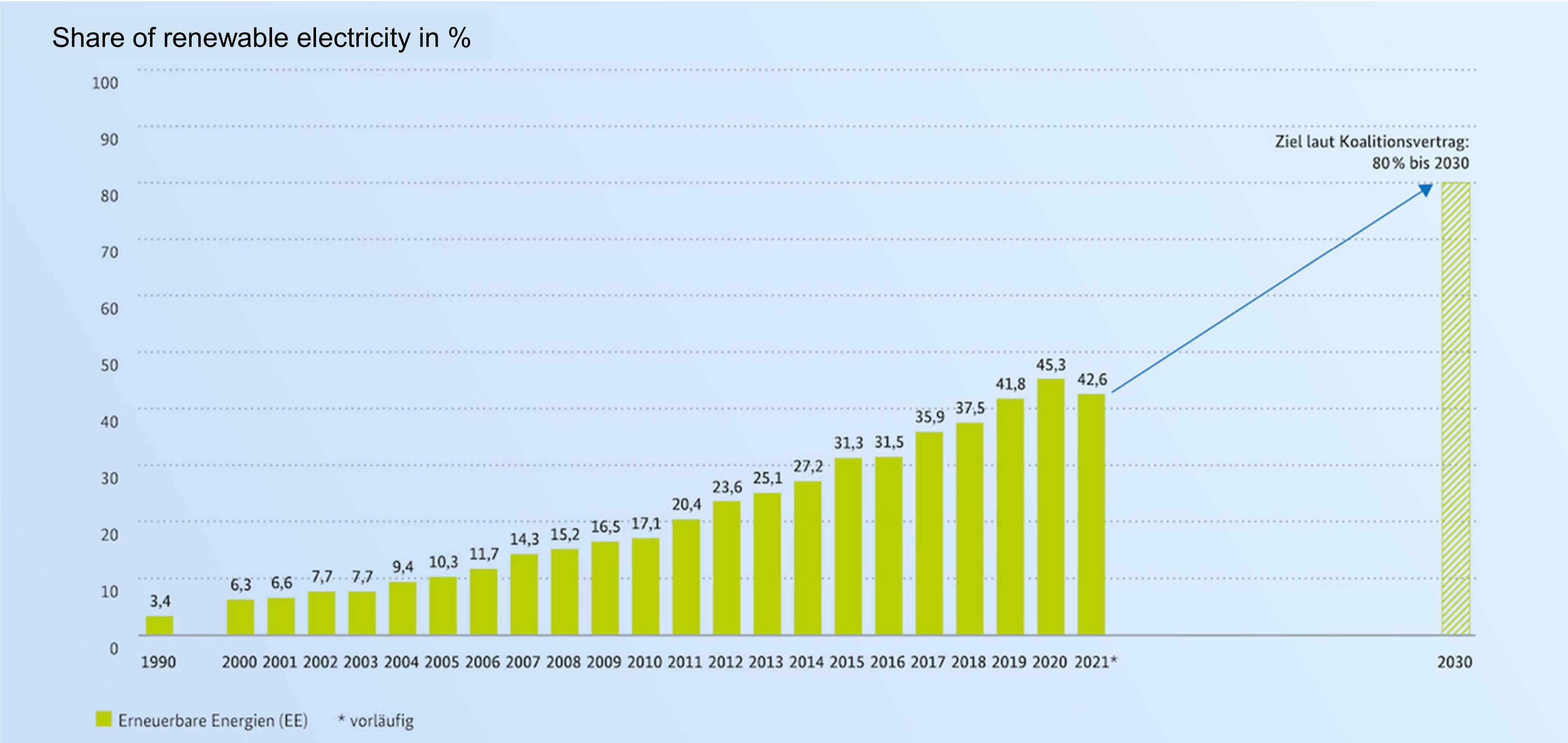
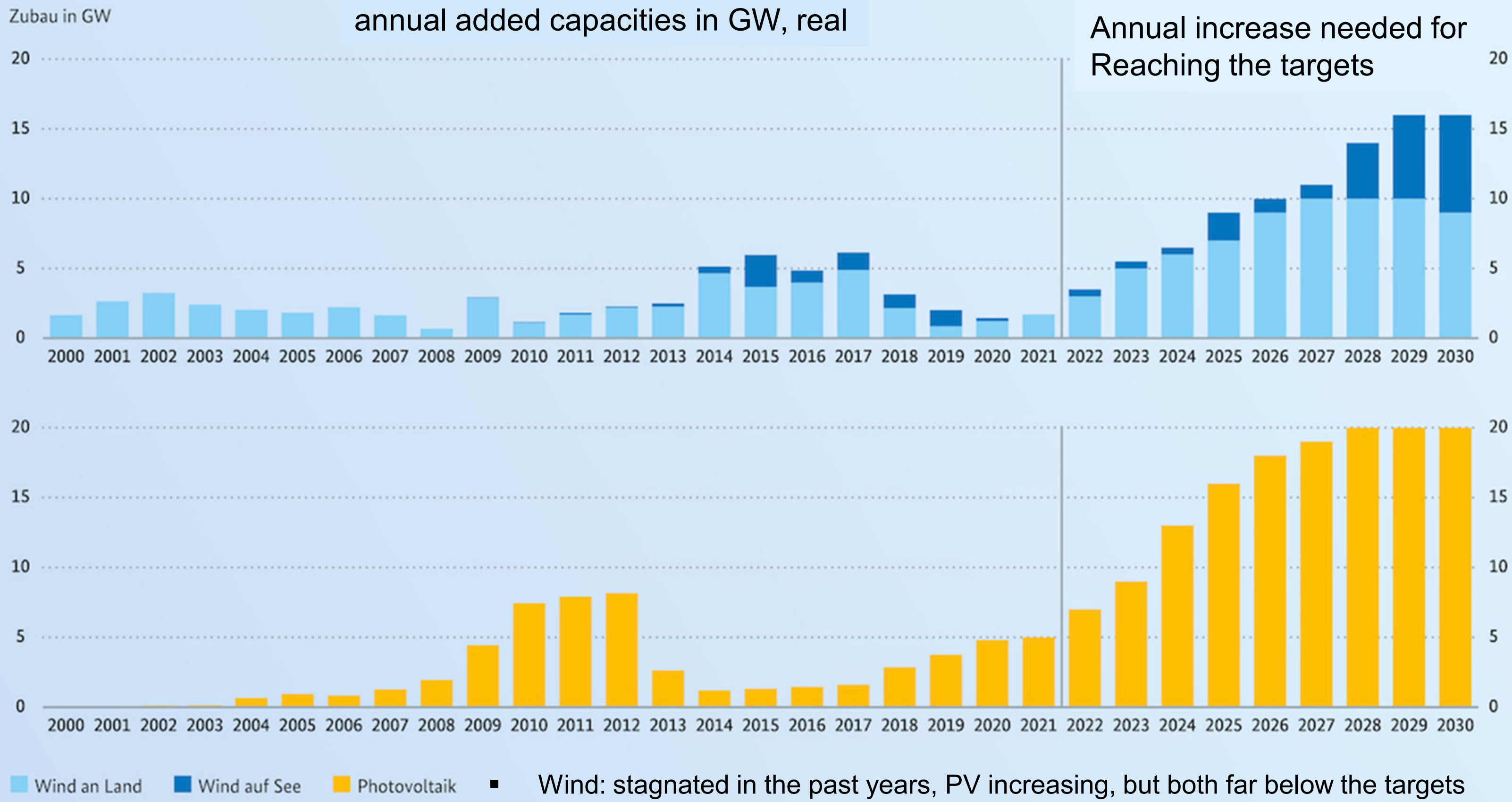
# Where are we on the road to the renewable power system? Past increase and objective to 2030

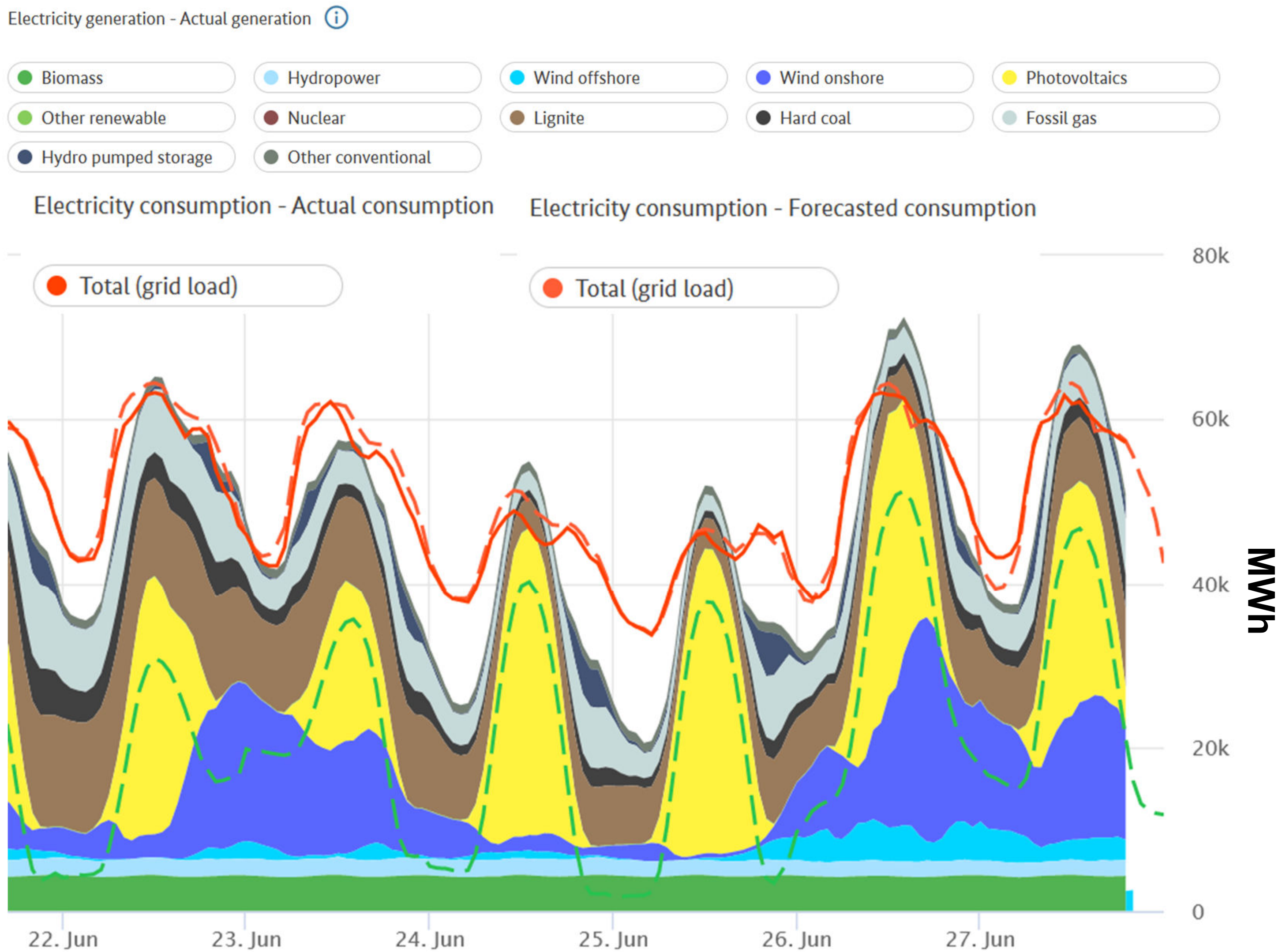


# Where are we on the road to the renewable power system?
# Past increase and objective to 2030, wind and PV added capacities




- Wind: stagnated in the past years, PV increasing, but both far below the targets

# Electricity generation and consumption in Germany




www.smard.de

SMARD Strommarktdaten

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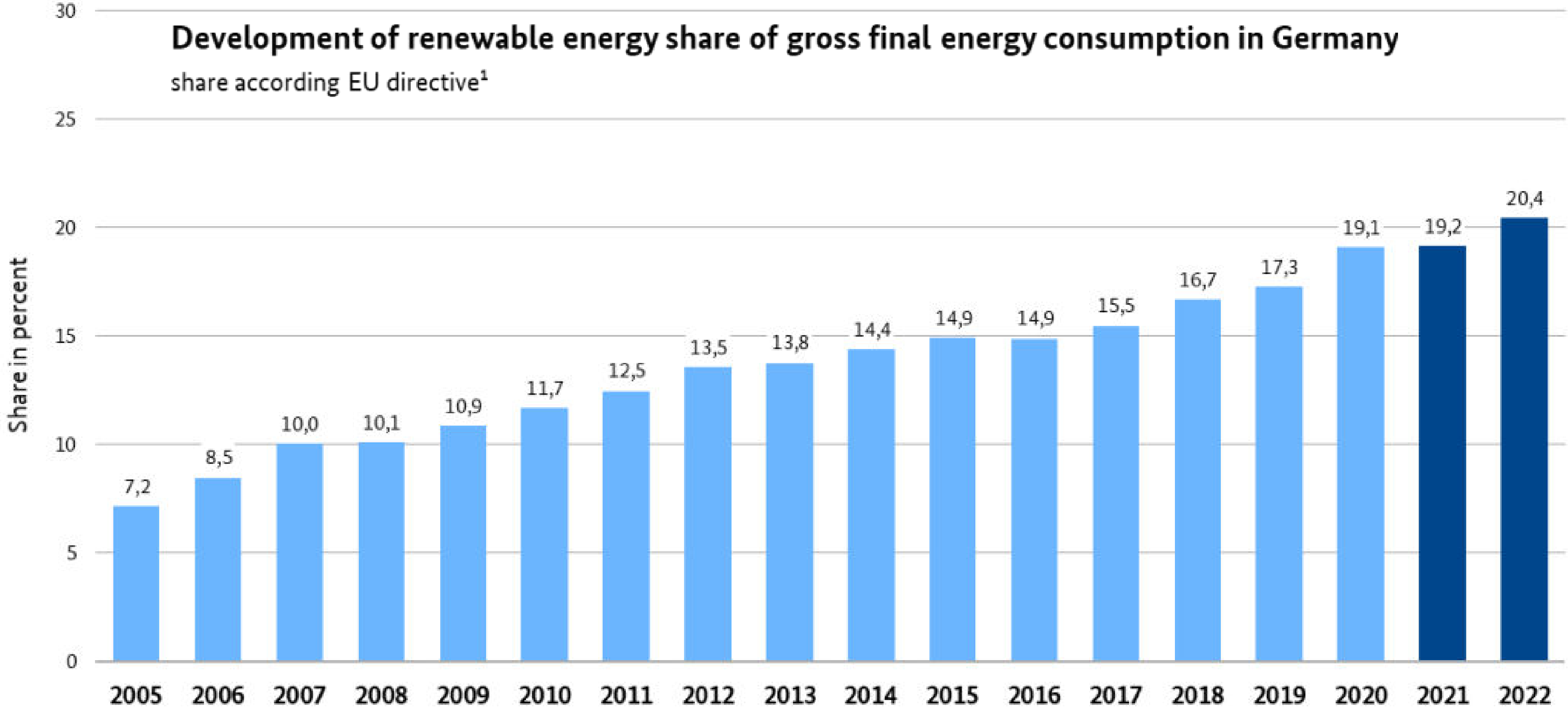
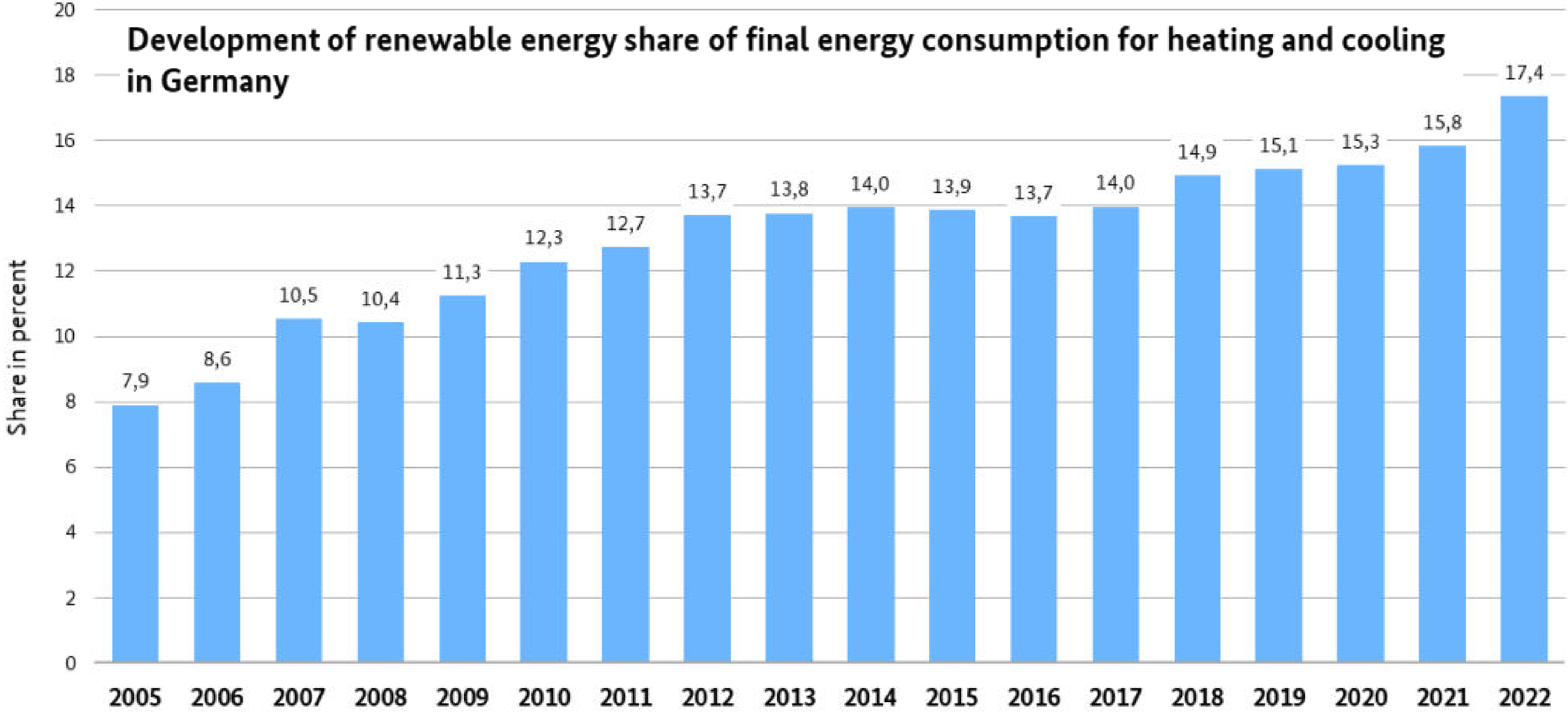
# Where are we on the road to renewable final energy?



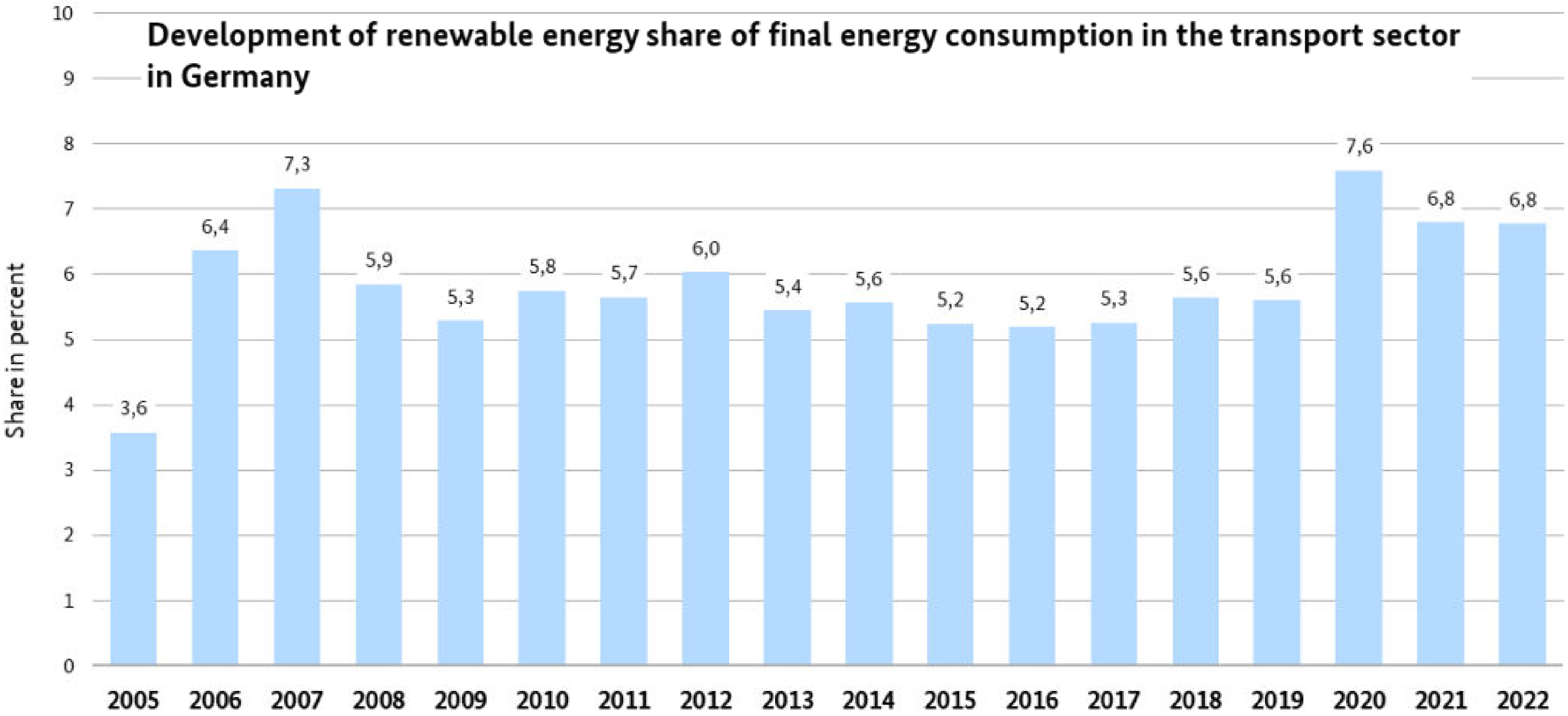

- Rather slow development due to the low transformation in transport and heating sectors

# Where are we on the road to climate neutral heating?




- Slow development of installations of heat pumps, solar collectors, biomass/biogas

# Where are we on the road to climate neutral transport?




- The strategies and measures have hardly achieved any transformation so far

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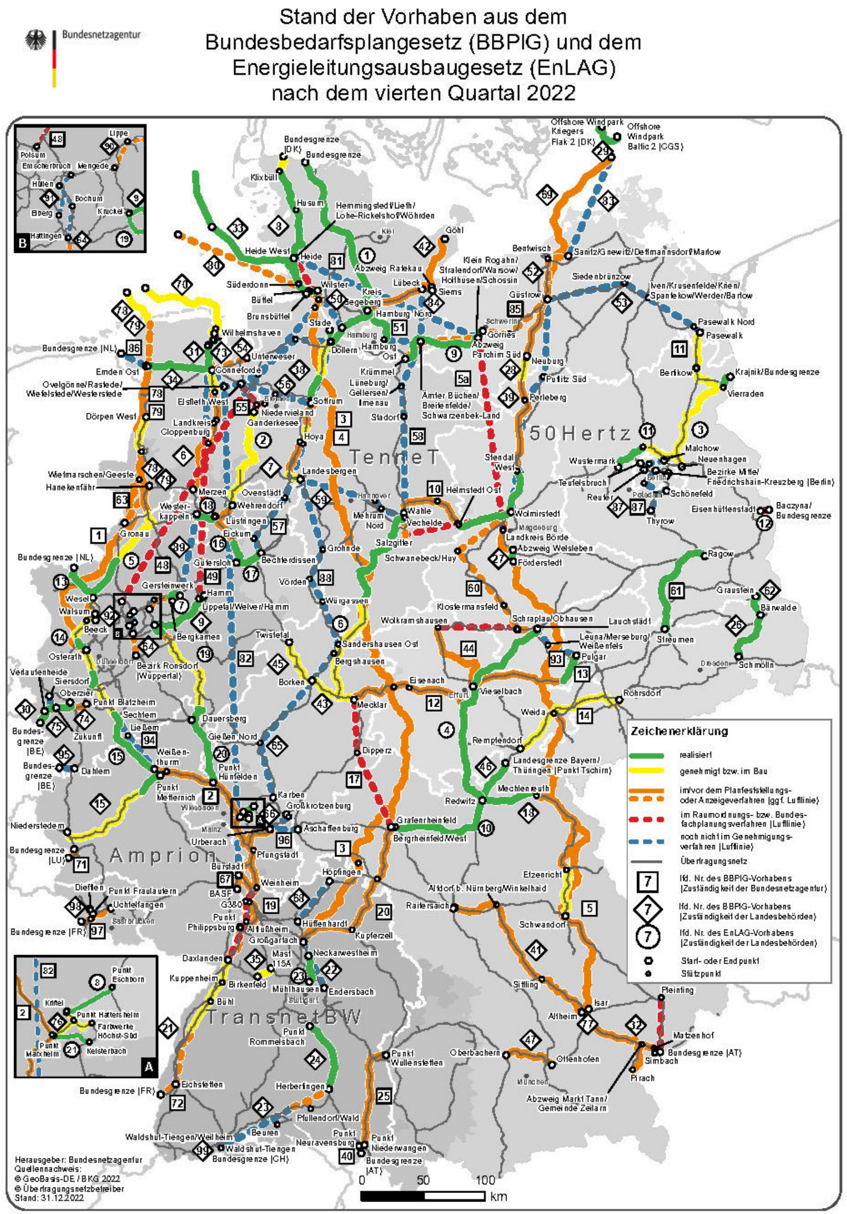
# Progress in electricity grids

**Example: High-voltage direct current transmission lines** as backbone of a modern electricity grid in Germany in the future

- E.g. high capacity North-South links: SuedLink, SuedOstLink: 2 x 2 GW, mainly underground cable
- Ultranet: 2 GW (2026)


Ref. BNetzA https://www.netzausbau.de/Vorhaben/uebersicht/report/de.html

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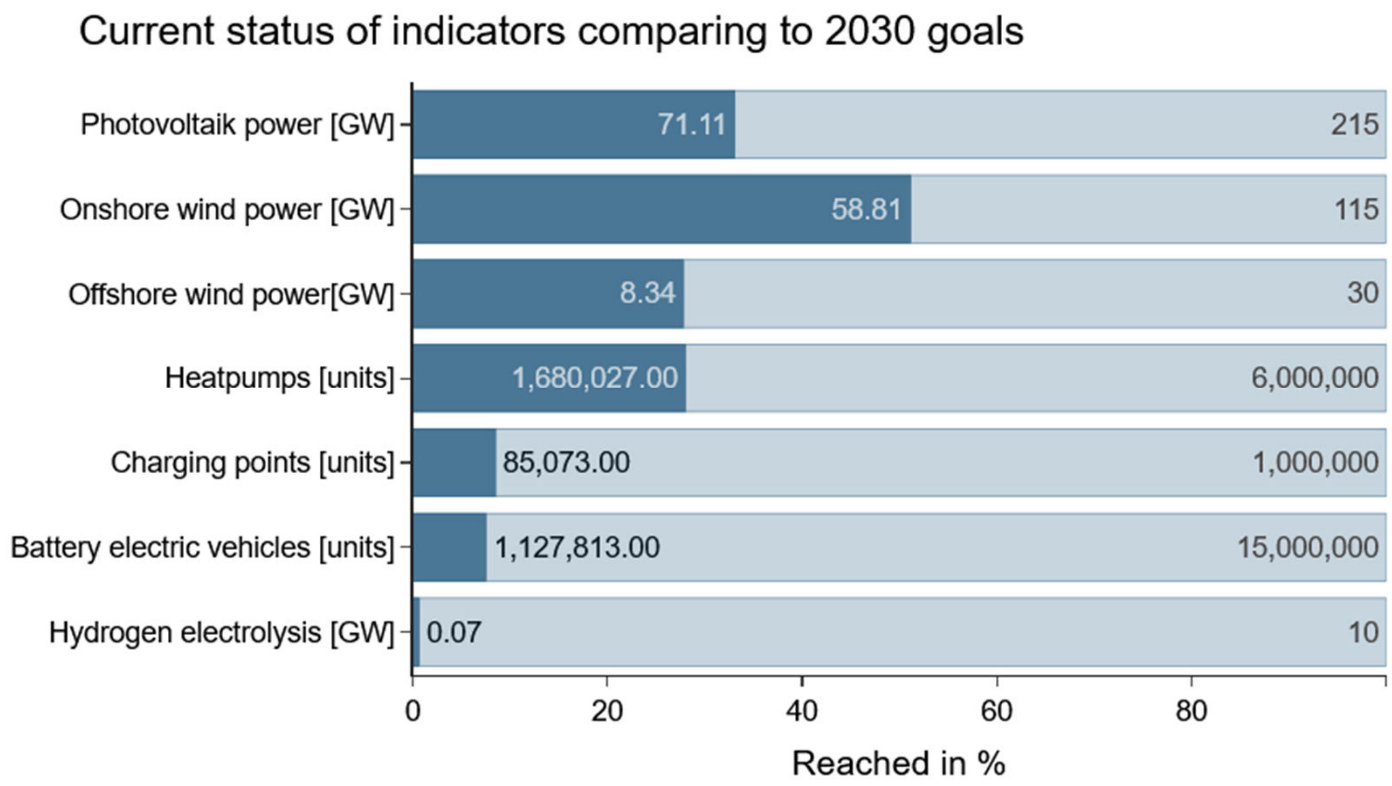
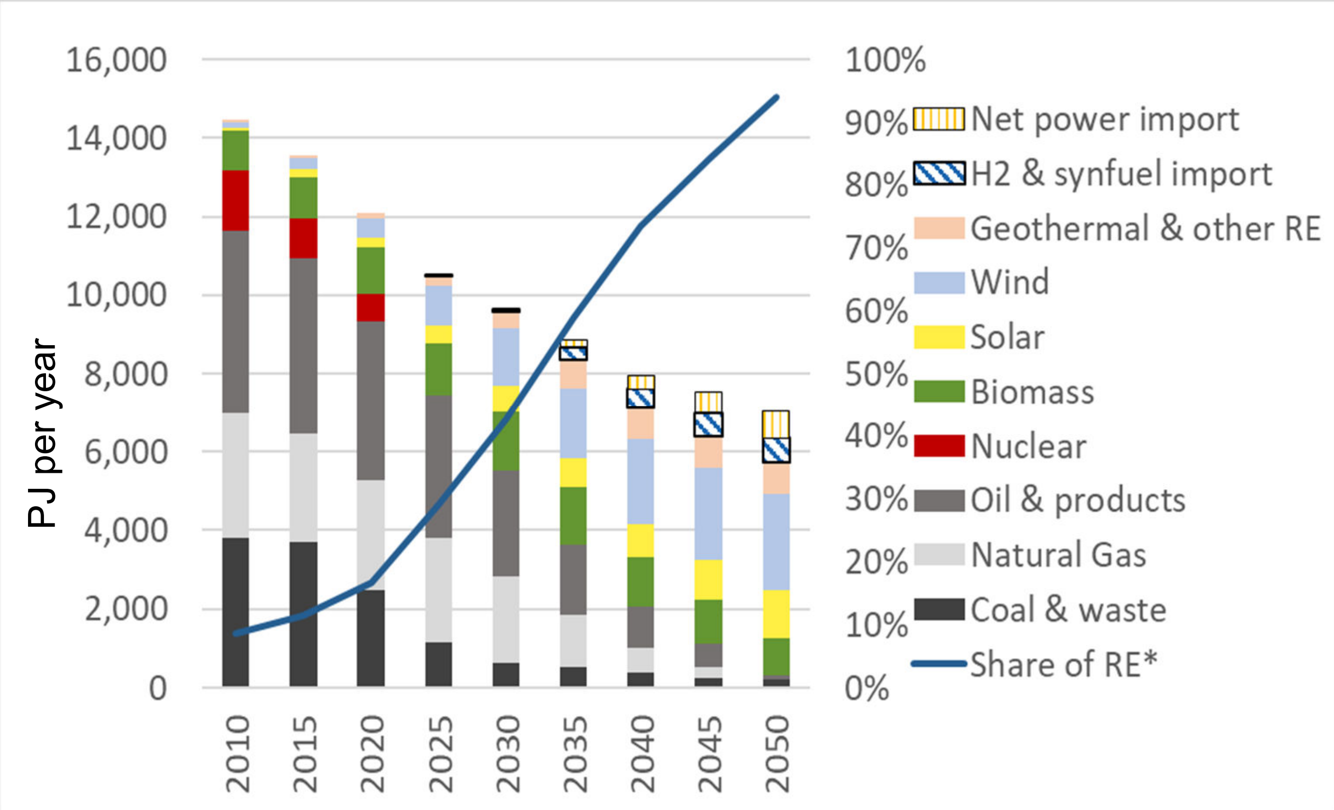
# Progress in decarbonising energy and transport

## Selected indicators




Ref.: openenergytracker.org

# Import strategies will be an important part of the solution for many countries: Example Net-zero scenario for Germany

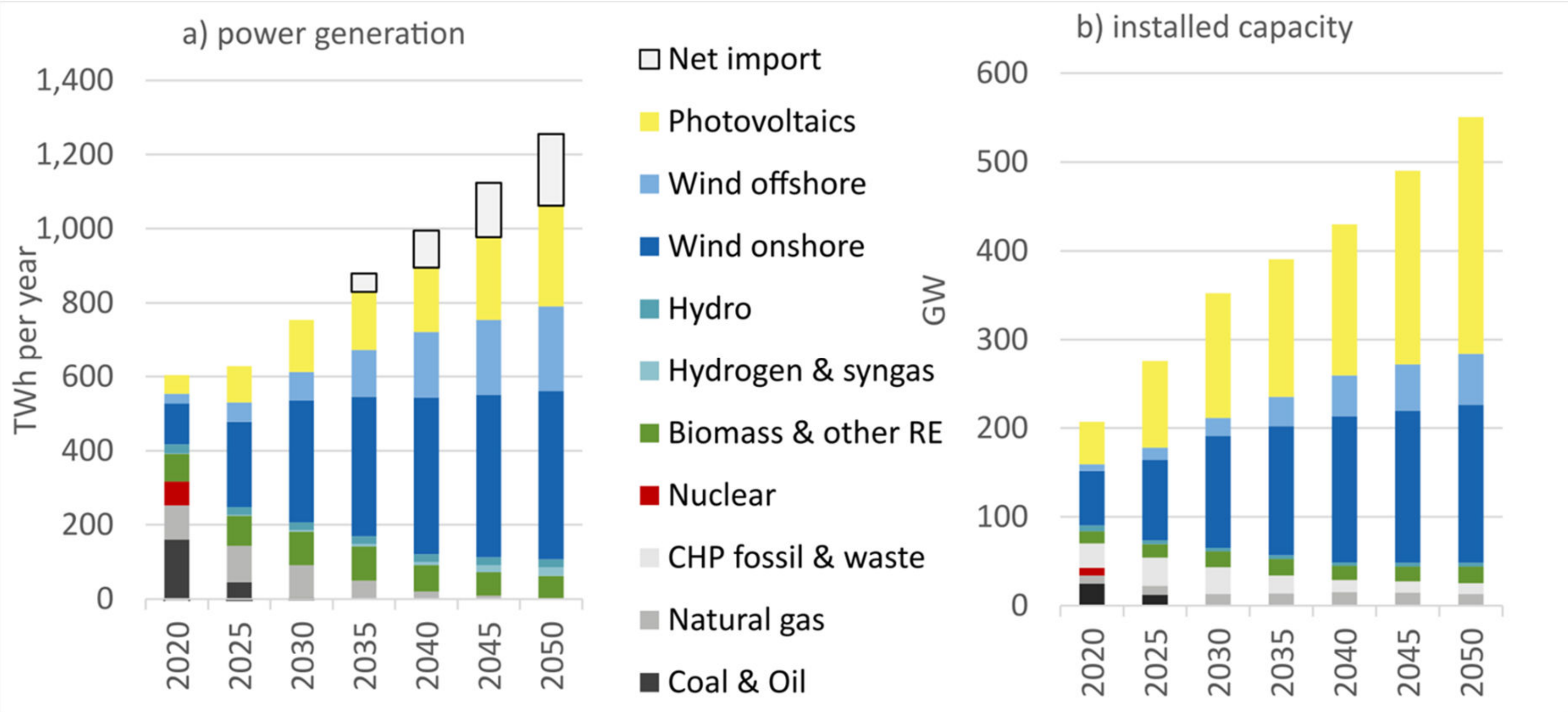



- Transformation scenarios should look at all energy needs (incl. feedstocks) and take into account all relevant supply infrastructures
- Sector coupling addresses direct and indirect electrification of heat and transport
- The demand for e-fuels for hard-to-abate activities increases the power demand considerably
- Example Germany: from today ca. 600 to theoretically approx. 1500 to 2500 TWh per year in 2050
- ►Imports of hydrogen, e-fuels, and electricity necessary, must be considered in infrastructure development in the coming years.

Primary energy supply in the Net-zero scenario for Germany according to Simon et al. (2022).
Total (theoretical) green electricity demand in this high-efficient scenario reaches 1500 TWh in 2050, of which more than 500 TWh are imported as power, $H_2$ or e-fuels. CDR measures are assumed for the last ~5% $CO_2$ reduction.

# To which extent can we deploy our own wind and PV potentials? Example Net-zero scenario for Germany

- The chart shows a massive capacity expansion, although energy imports are assumed and already deducted. The theoretical demand is up to 2500 TWh per year…




Source * Simon et al. (2022): A Pathway for the German Energy Sector Compatible with a 1.5 ° C Carbon Budget. Sustainability 2022, 14, 1025. https://doi.org/10.3390/su14021025

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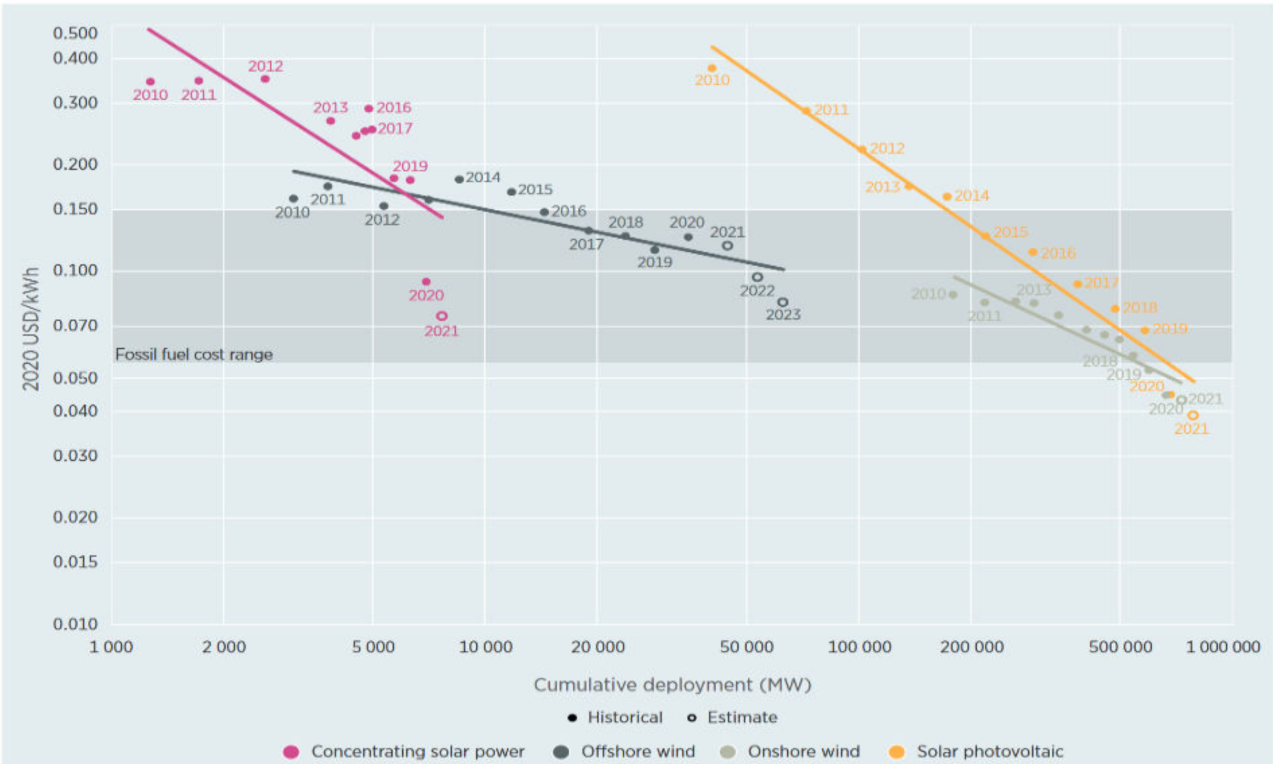
# Decreasing electricity production costs of wind and solar

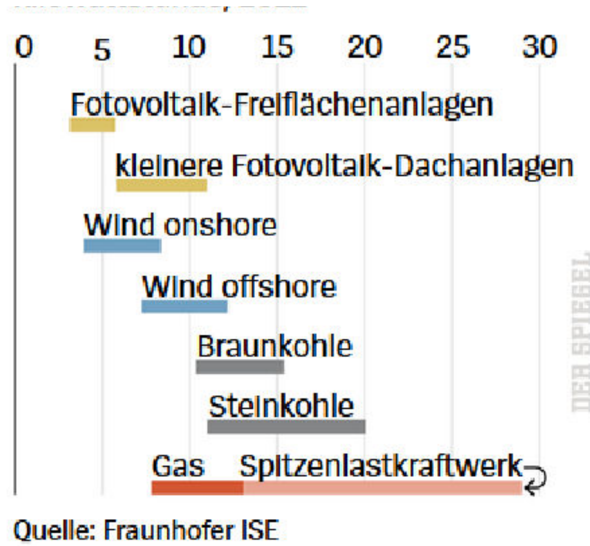
## In many world regions, renewables are the most competitive energy technologies

The global weighted-average LCOE learning curve trends for solar PV, CSP, onshore and offshore wind, 2010-2021/23




RENA - https://www.irena.org - Renewable Power Generation Costs in 2020 -

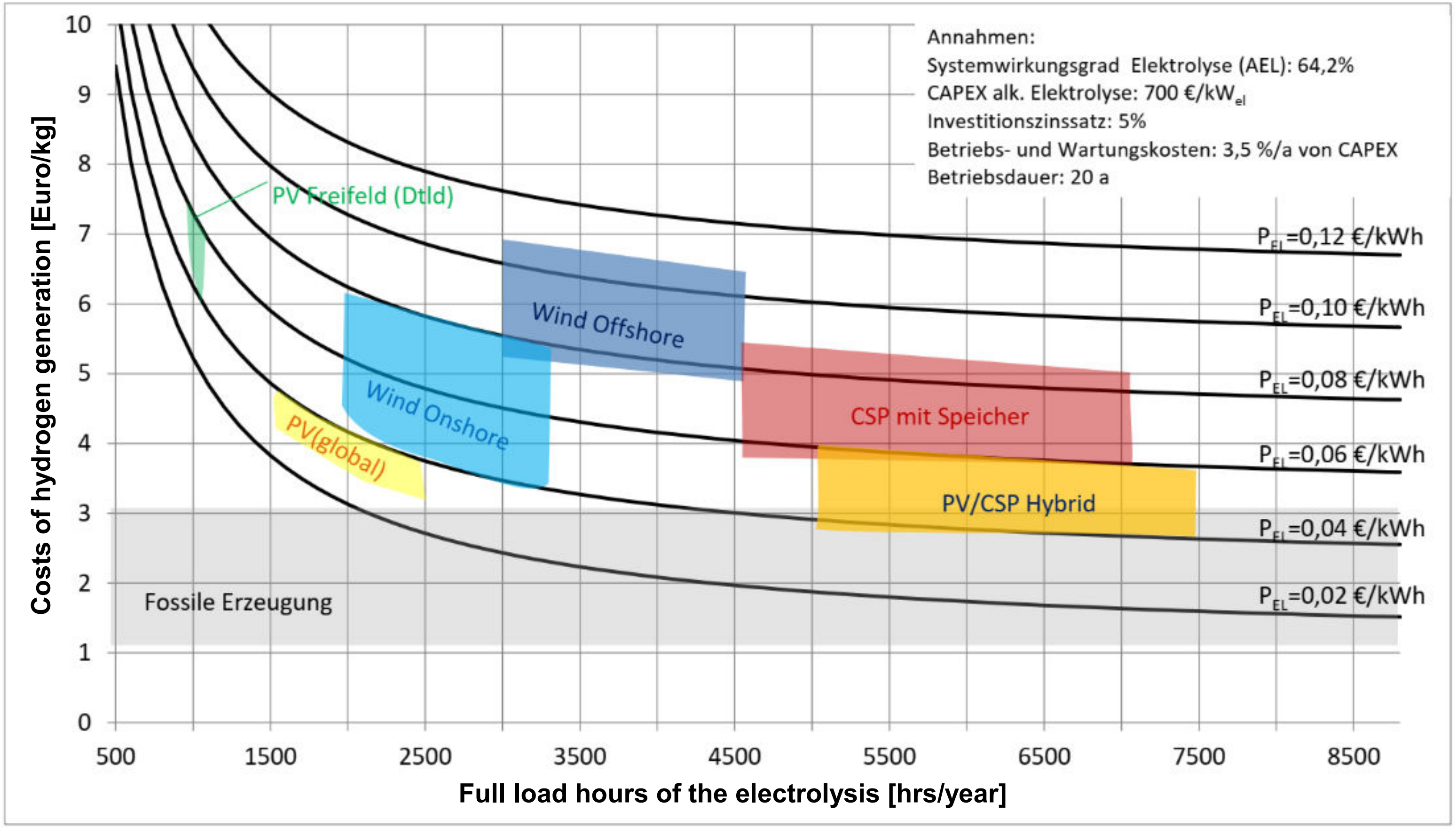
Electricity production costs in Germany, range in Euro cent per kWh, 2021






Ref.: R: Pitz-Paal, DLR, (2021), Fhg ISE (2021)

# H2 generation costs strongly depend on full load hours

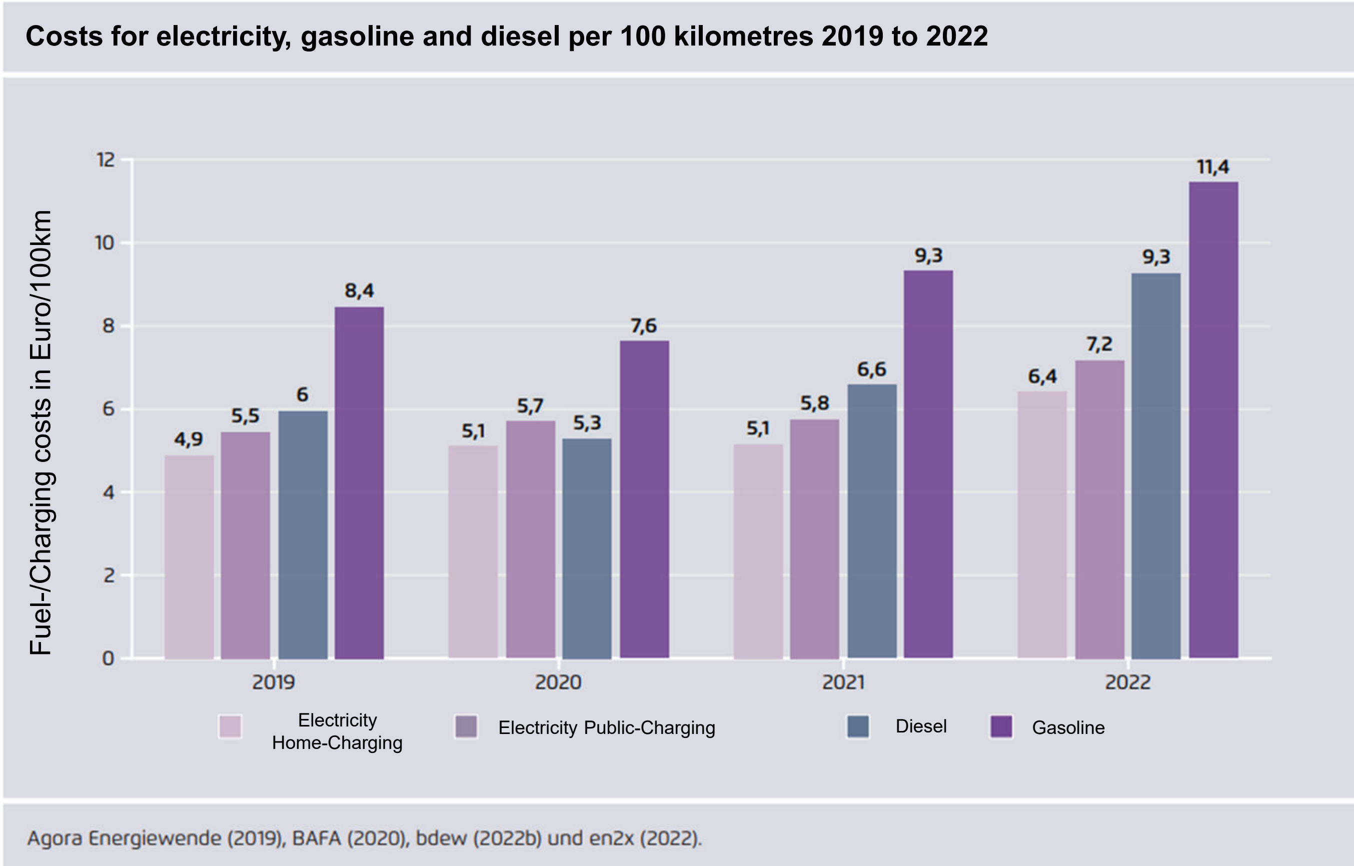




Assumptions about electrolysis:
Smolinka, T., et al., *study IndWEDe Industrialization of water electrolysis in Germany: opportunities and challenges for sustainable hydrogen for transport, electricity and heat.* 2018. https://www.now-gmbh.de/wp-content/uploads/2020/09/indwede-studie_v04.1.pdf

Electricity generation costs:
Kost, C., et al., Study *Fraunhofer ISE: Electricity generation costs for renewable energies, 2018.* https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/DE2018_ISE_Studie_Stromgestehungskosten_Erneuerbare_Energien.pdf

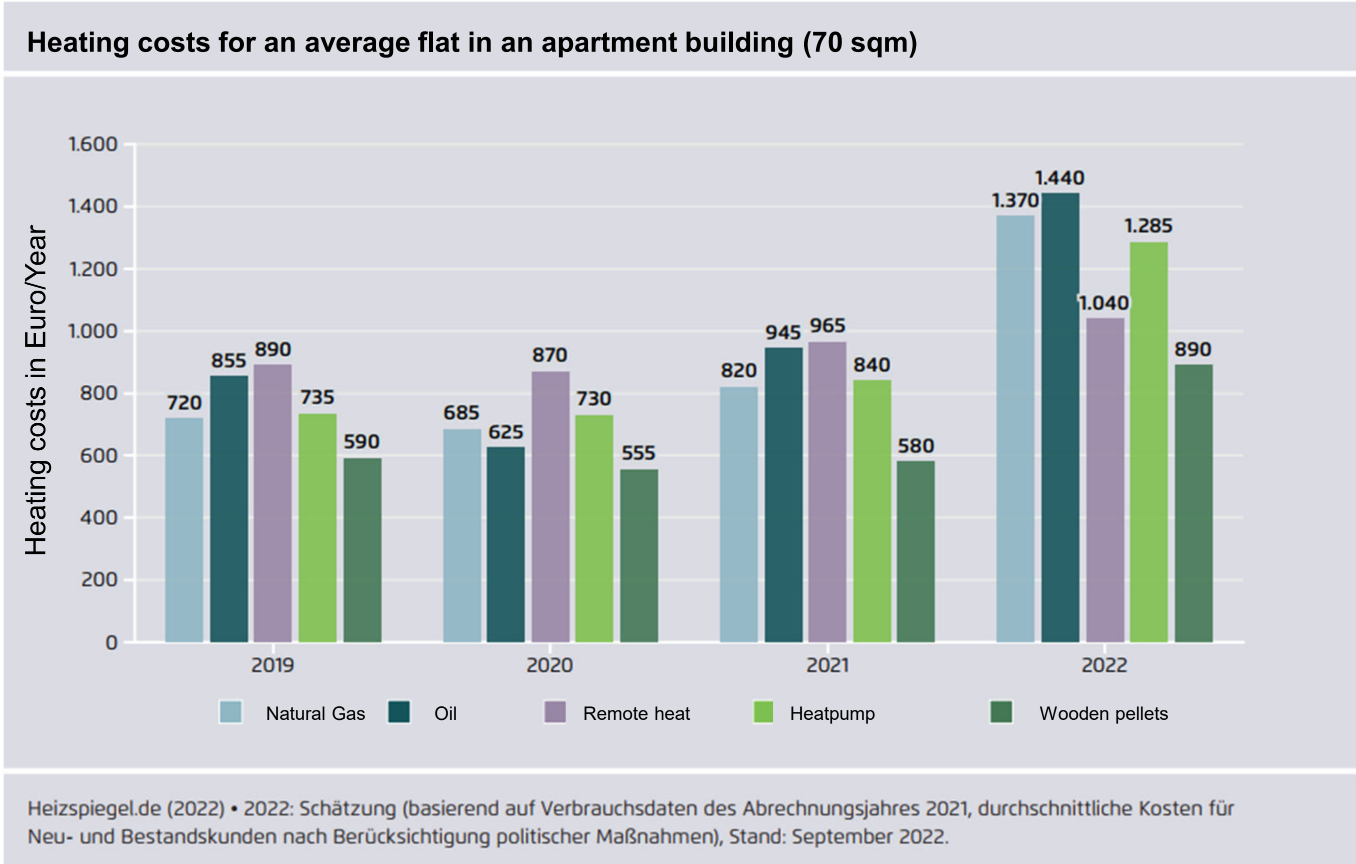
# Costs for car-driving






Ref. Agora Energiewende (2023)

# Costs for private heating






Ref. Agora Energiewende

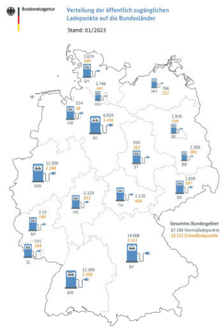
# German Energy Transition

# Transport-specific topics:

# Charging, eFuels, Hydrogen

## Charging and Infrastructure in Germany
### 2 main official information resources

Bundesnetzagentur



https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/E-Mobilitaet/start.html

Germany's main authority for infrastructure, promoting competition in the markets for energy, telecommunications, post and railways (independent higher federal authority), operationg in the scope of business of the ministries BMWK and BMDV.

Nationale LEITSTELLE Ladeinfrastruktur

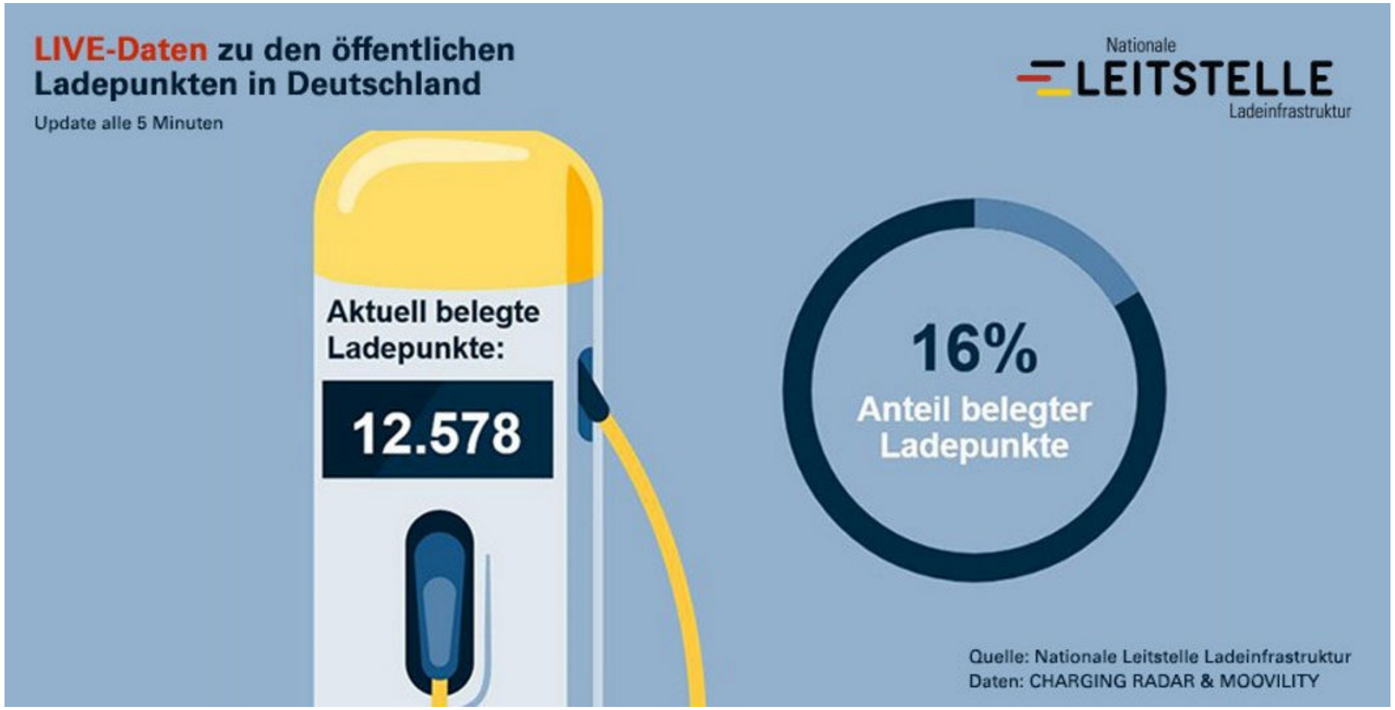
National Centre for Charging Infrastructure

https://nationale-leitstelle.de/en/

On behalf of the
German Federal Ministry of Digital and Transport
under the umbrella of the federally owned NOW GmbH

# Boosting the expansion of charging infrastructure
## headline of
## Charging Infrastructure Master Plan II


- First Charging-Infrastructure conference in June 2022 by the Federal Ministry of Digital and Transport (https://bmdv.bund.de) in Berlin
- 19. October 2022: Release of **Charging Infrastructure Master Plan II** by the Federal Government: a new overarching strategy that sets out the timetable for the next few years.



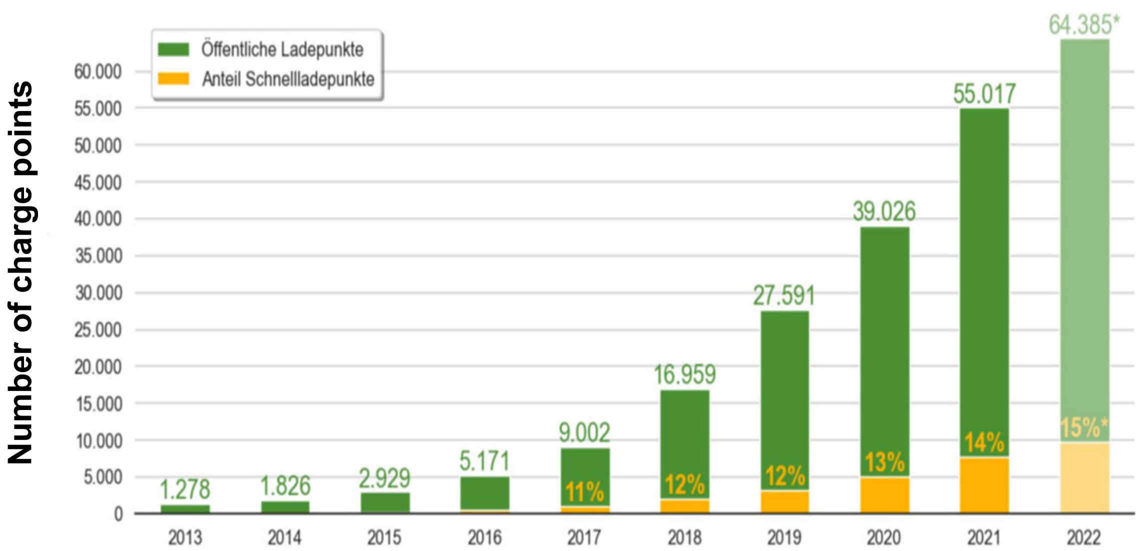

https://nationale-leitstelle.de/verstehen

# For any information on charging infrastructure in Germany, this is the point to go first:

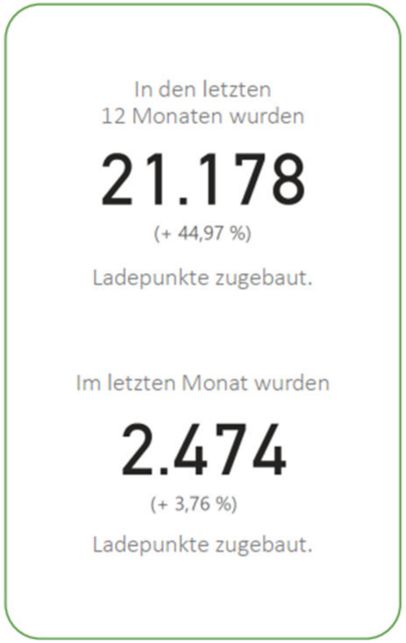
https://nationale-leitstelle.de/verstehen/

Nationale LEITSTELLE Ladeinfrastruktur

**Report:** Inventory and development of public charging infrastructure in Germany; 1st Sep. 2022




All public charge points




Fast chargers only


Ref.: Report der Nationalen Leitstelle Ladeinfrastruktur, August 2022

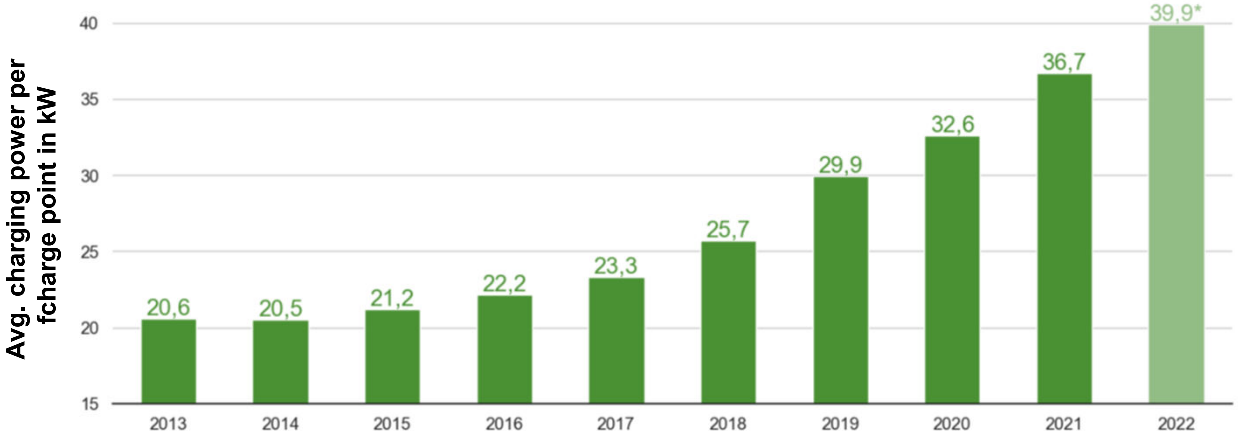
# Development of power in the stock

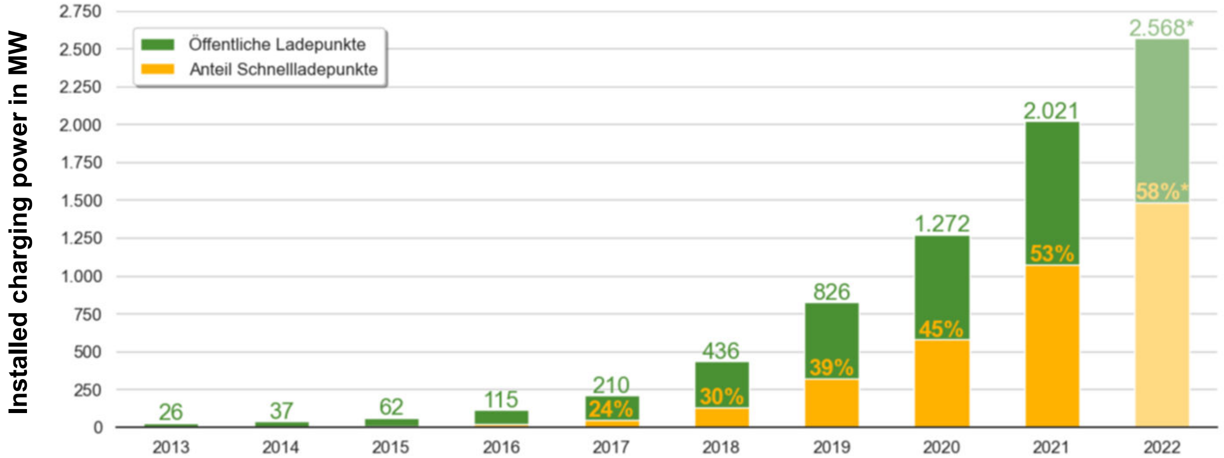
– Average charge power per chargepoint in kW:

(almost) 40% have 40 kW

– Installed public charge power is more than 2.5 GW

– 58% of the installed power is on fast charging



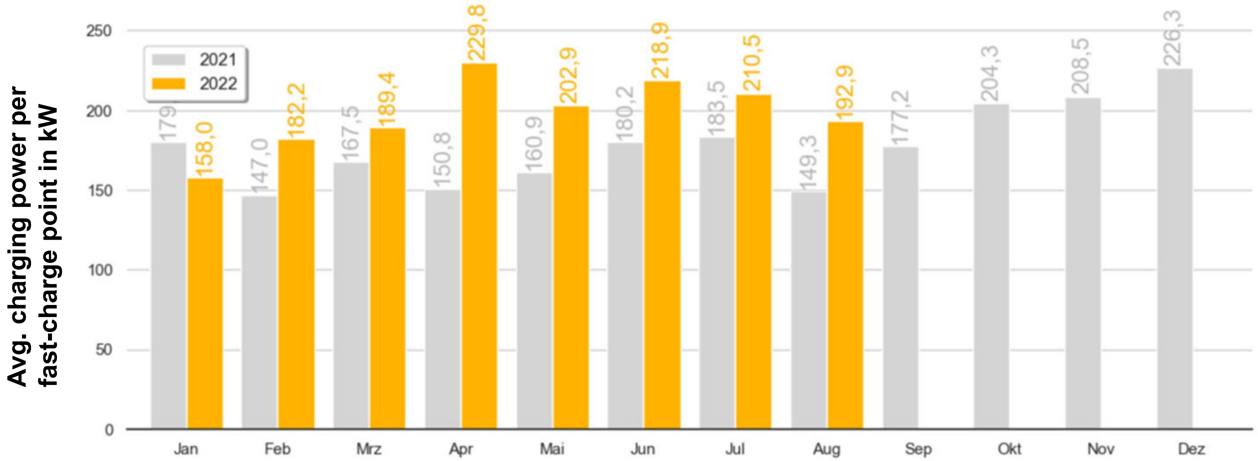



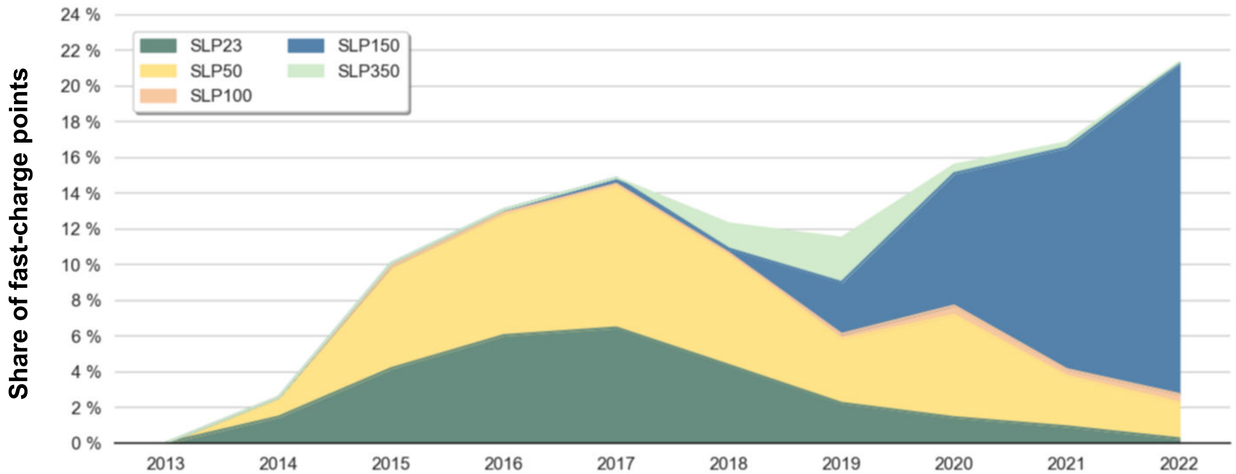

Hinweis: Die installierte Ladeleistung wird als Summe der Ladeleistungen der einzelnen Ladepunkte berechnet.
*Das laufende Jahr schließt im Gegensatz zu den Vorjahren ggf. weniger als 12 Monate ein, wodurch der Zubau geringer wirken kann.
Datengrundlage: Inbetriebnahmen laut BNetzA-Ladesäulenregister, Stand: 01.09.2022, Quelle: Bundesnetzagentur.de

Ref.: Report der Nationalen Leitstelle Ladeinfrastruktur, August 2022

# Fast charging: Characteristics of new chargers

- Average charging power of expansion is increasing
- Average charging power at close to 200 kW per average charge point




*Für die am kürzesten zurückliegenden Monate ist mit einer hohen Anzahl an Nachmeldungen zu rechnen.
Datengrundlage: Inbetriebnahmen laut BNetzA-Ladesäulenregister, Stand: 01.09.2022, Quelle: Bundesnetzagentur.de

Ref.: Report der Nationalen Leitstelle Ladeinfrastruktur, August 2022

# Boosting the expansion of charging infrastructure

## Charging Infrastructure Master Plan II

**approved October 19th 2022**

Charging infrastructure needs to be comprehensive, user-friendly and able to meet demand. In the Charging Infrastructure Master Plan II, the Federal Government has developed a new overarching strategy that sets out the timetable for the work to be undertaken over the next few years.

**Why is a Master Plan II needed?**

- … easier, quicker and more convenient to construct …
- … make operating … more attractive as a business model
- … mobilise stronger investment from private finance

- **What is included in the new Master Plan?**

- Close integration of electric mobility and the **power grid**
- Expanding the charging infrastructure for **heavy commercial vehicles**
- Making the necessary sites available as quickly as possible and with no **unnecessary bureaucracy**, particularly along motorways
- Mobilising **private investment**


Ref.: www.bundesregierung.de/breg-en/search/charging-infrastructure-master-plan-2135836

The Federal Government
G7 GERMANY

# Charging Infrastructure Master Plan II

**October 19th 2022: Cabinet approves 68 measures to speed up development of charging infrastructure**

**Integrating charging infrastructure and the electricity system:**

… demand planning … to be coordinated …Federal Network Agency and the … operators … processes for grid connection … more simply, transparently and efficiently

**Improving charging infrastructure through digitization:**

… occupancy status of charging points will be made available in real time … solid data and analyses of the distribution and use

**Empower municipalities as key players and involve them more closely:**

… local master plans, regional charging infrastructure managers, digital … tools, and guides … templates for optimizing planning and approval processes.

**Initiate charging infrastructure for e-trucks:**

… BMDV will invite tenders for an initial public truck charging network …

**Simplify and accelerate charging infrastructure deployment:**

…remove obstacles in planning and approval processes and adapt the legal basis, for example in building and immission law.

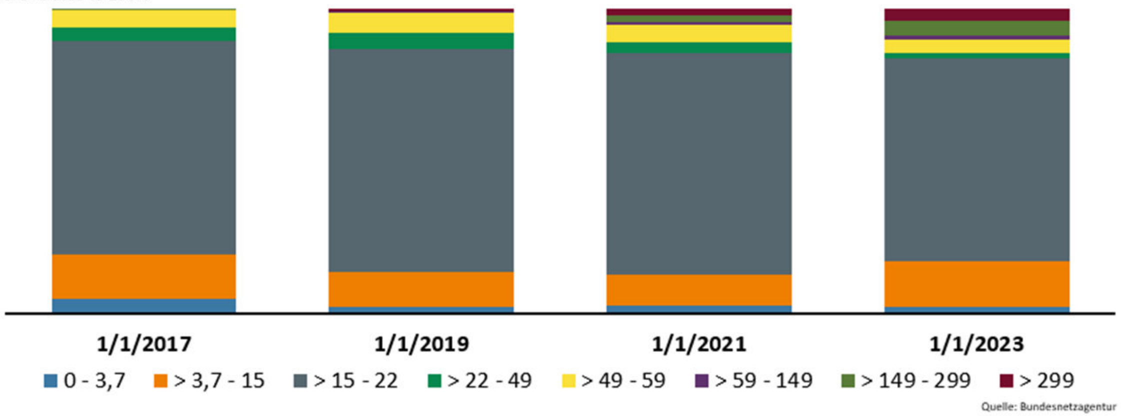
# Charging and Infrastructure in Germany

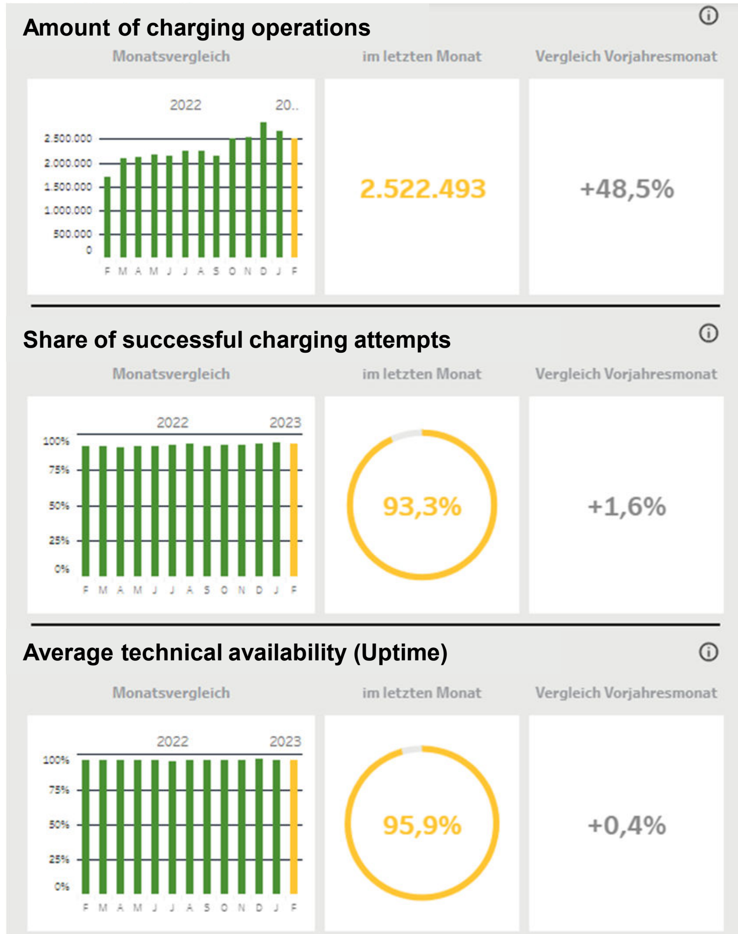
## High power chargers DC >149-299 kW are growing fastest

### Charge points by power category

| Number of charge points | 01.01.2023 | 01.01.2022 | Changes in % |
|---|---|---|---|
| 0 - 3,7 kW | 1.791 | 1.549 | 16% |
| > 3,7 - 15 kW | 11.981 | 7.933 | 51% |
| > 15 - 22 kW | 53.516 | 40.811 | 31% |
| > 22 - 49 kW | 1.725 | 1.739 | -1% |
| > 49 - 59 kW | 3.317 | 2.882 | 15% |
| > 59 - 149 kW | 1.174 | 782 | 50% |
| > 149 - 299 kW | 3.801 | 1.882 | 102% |
| > 299 kW | 3.236 | 1.969 | 64% |
| All power ranges | 80.541 | 59.547 | 35% |

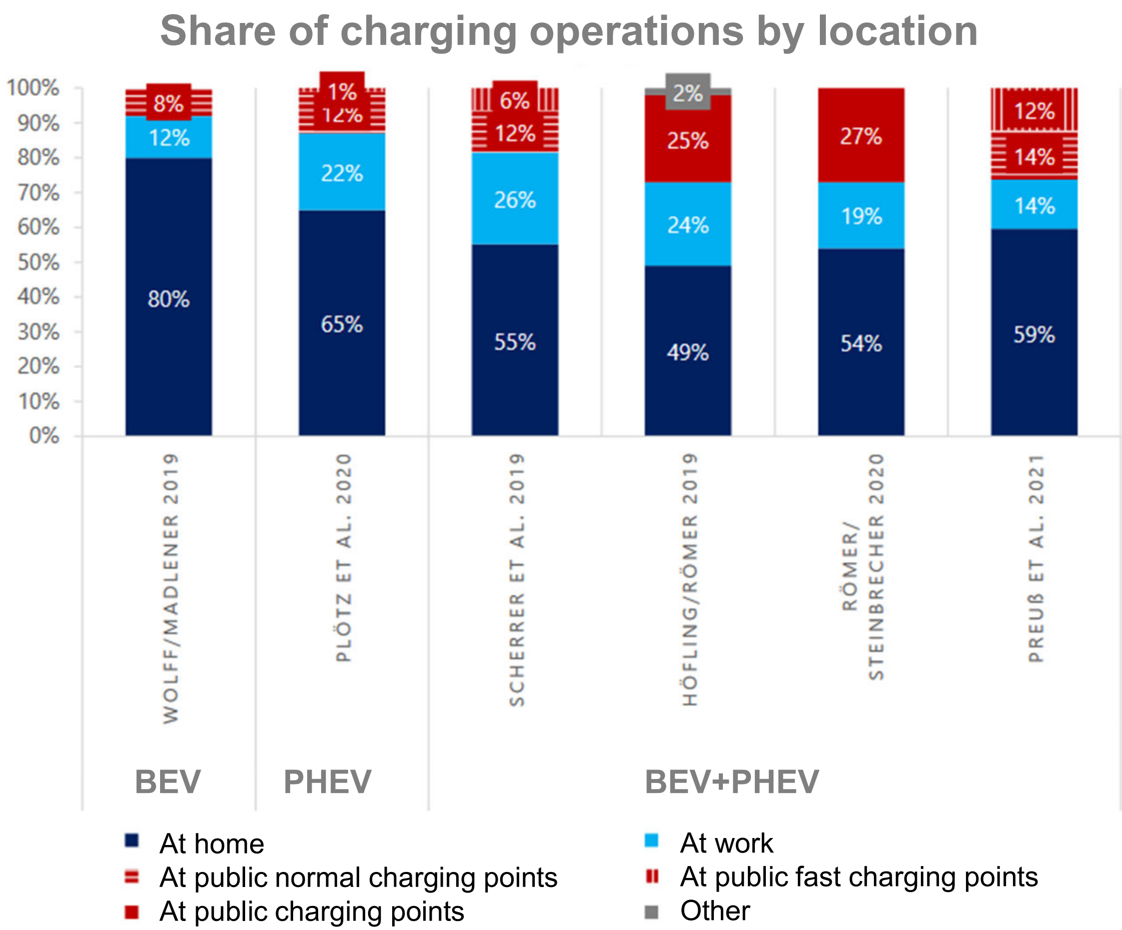
**Development of the power classes 01.01.2017 - 01.01.2023**
Share related to 100%




DLR

## Where do PEV-users in Germany charge?




- Share of **public charging is increasing** from **18%** (2019) to **26%** in 2021
- **59%** of BEV+PHEV users **charge at home**
  14% at work
  26% at public charge points
- **84% charge green** electricity at home (German average household: 30%)

Wietschel et al. (2022), n=867 Elektroauto-Nutzende in Deutschland, n=170 Flottenmanager:innen in Deutschland

Fraunhofer ISI

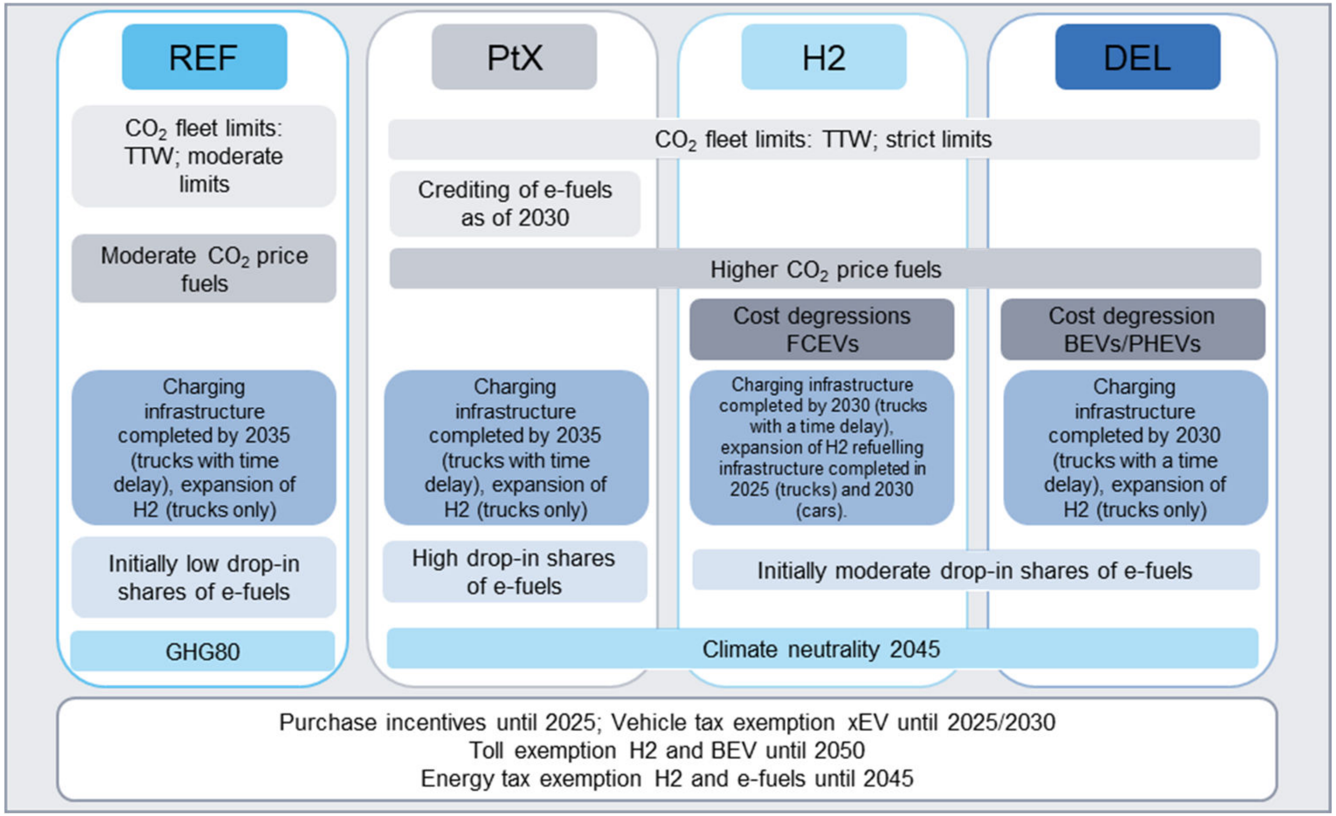
Ref.: Uta Burghard, Gesellschaftliche Akzeptanz von Elektrofahrzeugen – wo hakt es noch? EMKON23

# Energy Transition in Transport

# Analysis of future car market: EVs / eFuels / $H_2$

# Possible scenarios to reach $CO_2$ neutrality

- ✓ *Climate neutrality in the transport system by 2045*
- ✓ *Existing political framework conditions*
- ✓ *Moderate increase in transport demand*
- ✓ *Efficiency improvement of technologies*
- ✓ *From 2035, only passenger cars and light commercial vehicles with zero-emissions in DEL and H2*
- ✓ *In the PtX scenario, up to 10% proven e-fueled passenger cars possible*
- ✓ *From 2040, only heavy-duty vehicles with zero emissions*

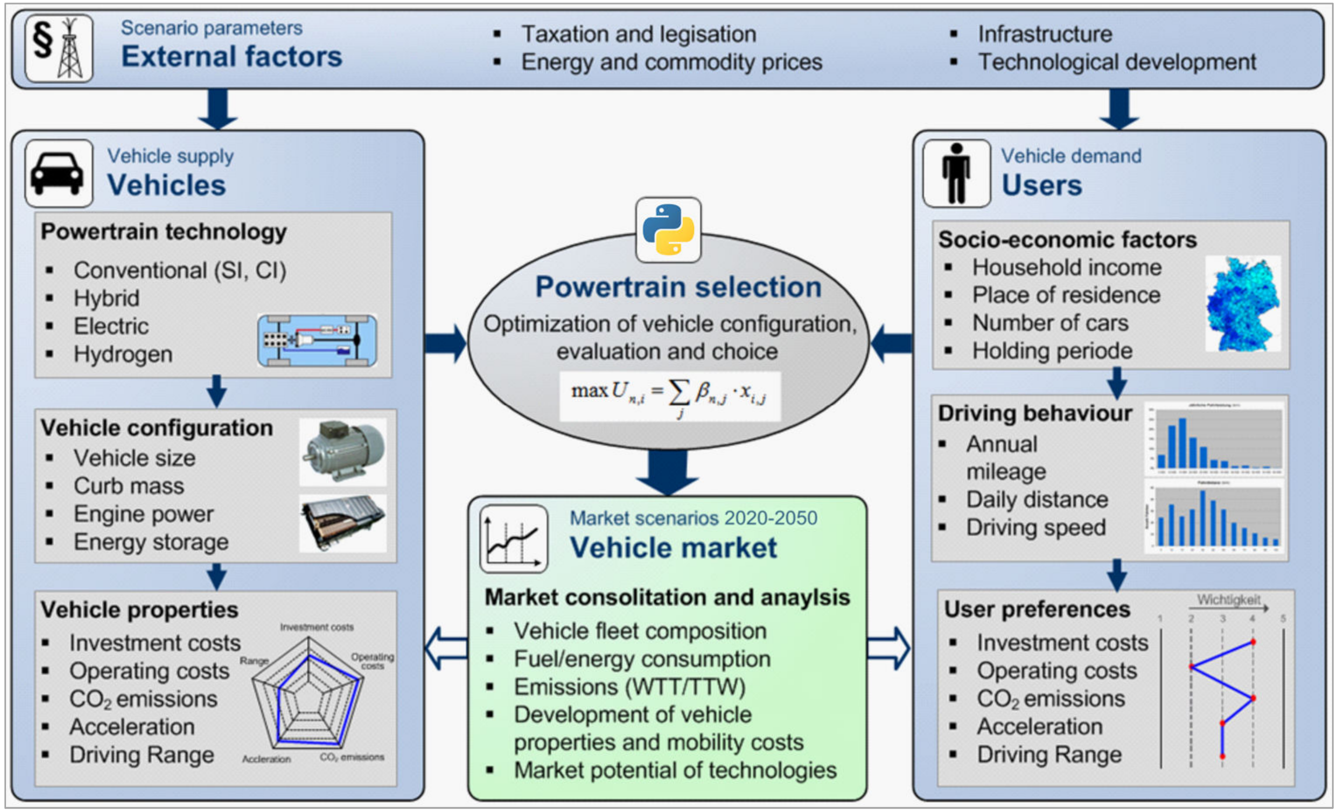



*The scenario analyses do not represent forecasts or recommendations. They describe possible paths (transformation paths) in the context of the underlying assumptions. Since the start of the project in 2018, the (global) political framework has changed very dynamically in many respects. In particular, the environmental policy changes are very welcome. However, not all legislative changes (especially the 2030 sector targets) could be fully considered in the modelling.*

VECTOR 21
Scenario analysis software

# VECTOR21: car and truck scenario and market analysis software

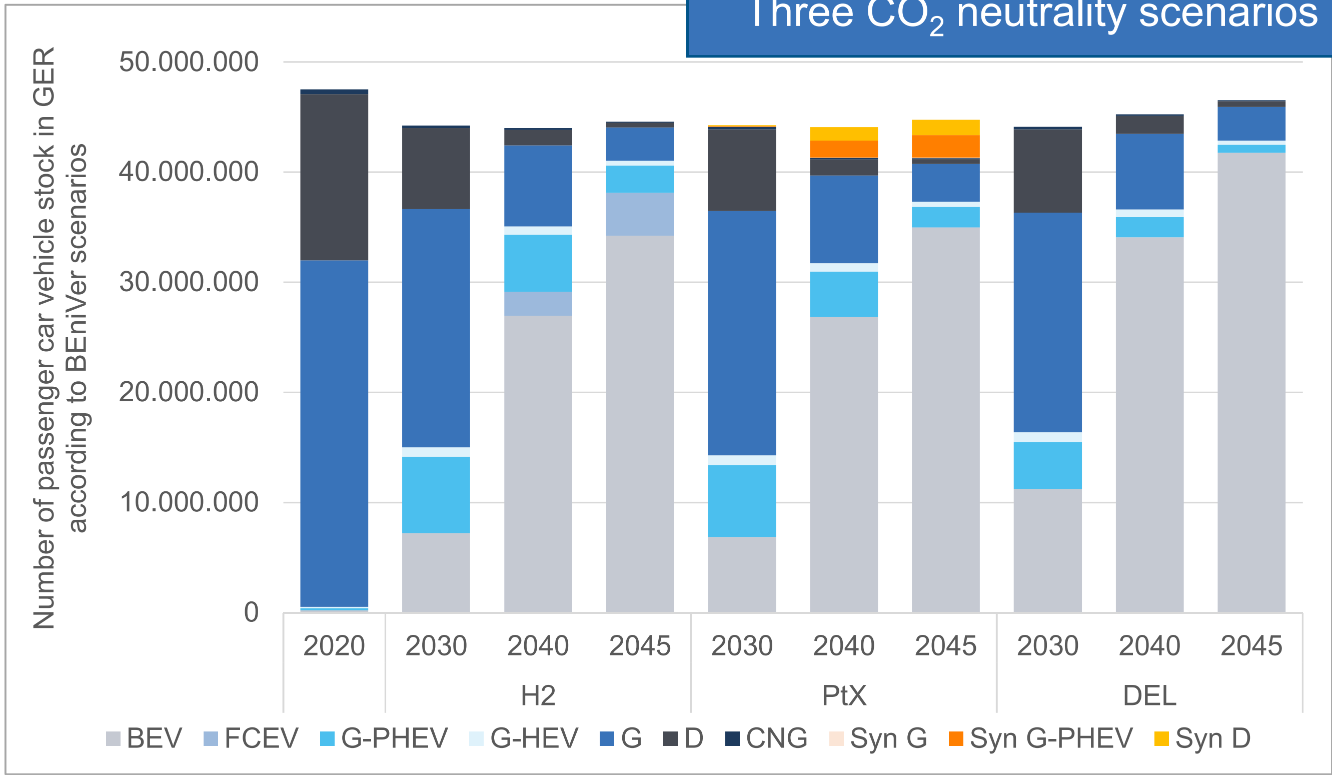
- Software developed in-house at DLR simulating future car and truck markets
- Detailed bottom-up market simulation
- Hybrid of an agent-based and discrete choice market penetration model
- Including all types of powertrain technologies
- Simulation of "synthetic fuel only" vehicles was developed within the work of this project



# Resulting passenger car vehicle stock

- Based on the modelled purchase decision, BEV vehicle stock will be at 7 to 11 million vehicles by 2030
- In the most optimistic scenario the German policy target of 15 million BEVs will be reached in 2032
- By 2045 there will still be an amount of vehicles with internal combustion engine (ICE) in the fleet
- To defossilise the ICE-stock vehicles by 2045 synthetic fuels would be needed

Three $CO_2$ neutrality scenarios



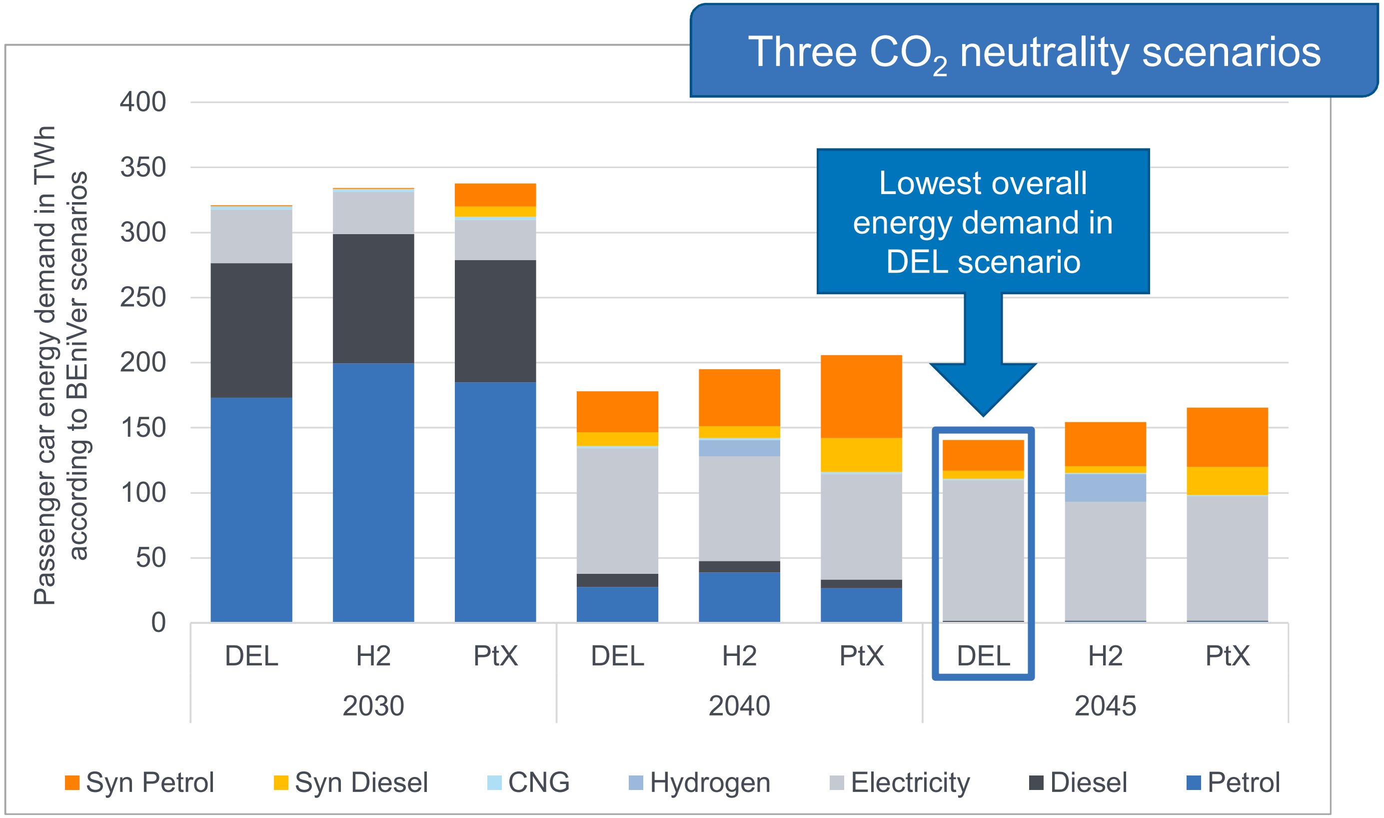
# Energy demand of passenger car stock

**Model assumptions:**

- ❖ Slightly increasing mileage by 2024 then constant extrapolation
- ❖ Drop-in of syn. fuels from 2026 on with faster ramp-up in PtX than in H2 and DEL

**Results:**

- ➢ Shift of energy demand to electricity; demand for liquid fuels continuously declining
- ➢ Higher efficiency of BEVs leads to lower final energy demand
- ➢ Demand for syn. fuels in road transport peaks around 2035-2040
- ➢ Final energy demand in 2045, as well as cumulative: PtX > H2 > DEL



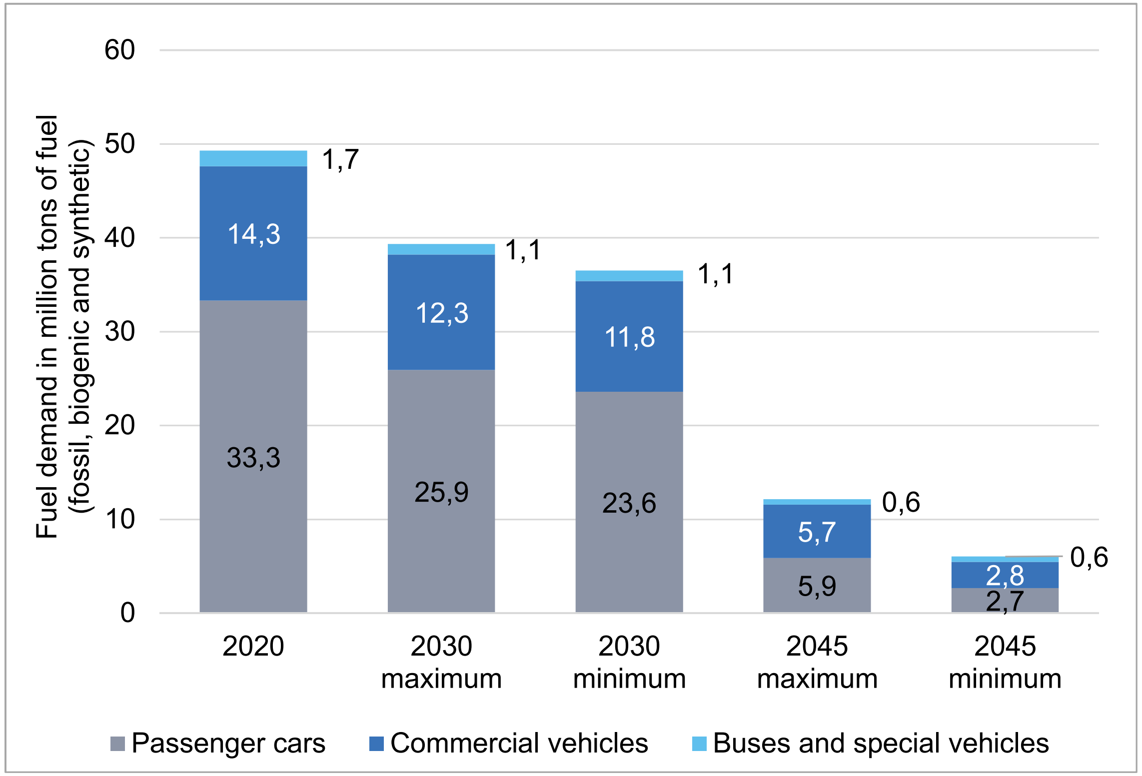
# Annual fuel demand of all road transport sectors in Germany

- Fuel demand in 2045 is driven by the **existing vehicle fleet**
- In 2045: Passenger car fuel demand still between 3 to 6 million tons
- Commercial vehicles with slower decline in fuel demand [1]
- Busses, special vehicles (emergency vehicles, military, etc.) also account for a persistent demand

➢ *In 2045: Fuel demand in aviation and maritime is up to three times higher than for road transport*

➢ *Current diesel needs of German agriculture is at 1.7 million tons (not shown as not a transport sector)*

➢ *Current biodiesel consumption is at 2.5 million tons*




[1] Özcan Deniz: Development of a scenario model for the simulation of the technology diffusion in the commercial vehicle market in Germany, 35th International Electric Vehicle Symposium and Exhibition (EVS35), Oslo, Norway, June 11-15, 2022 https://elib.dlr.de/187389/1/EVS35-340138.pdf

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ludwig bölkow
systemtechnik

# $H_2$ -Infrastructure for commercial vehicles in long-distance transport

## Current state of development and prospects


Plattform
H2BW

April 2023


Jan Zerhusen, Ludwig-Bölkow-Systemtechnik GmbH

Mathias Böhm, DLR Institute of Vehicle Concepts


e-mobil BW
Landesagentur für neue Mobilitätslösungen
und Automotive Baden-Württemberg

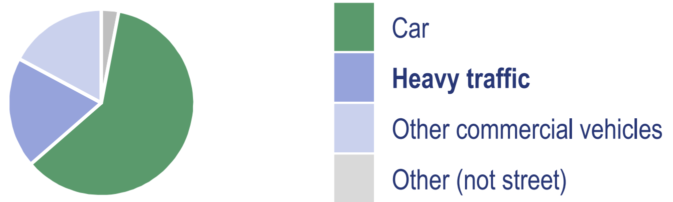
# Hydrogen - Important for GHG reduction in transport

- Germany's ambitions: Climate neutral 2045
  (Climate Protection Act, 2021)
  - Total GHG emissions: - 65% (1990 vs. 2030).
  - **Transportation sector**: 164 MtCO2eq. ↘ 85 MtCO2eq. (2019 vs. 2030)
    - **Heavy-duty vehicles: ~ 1/5 of sector emissions**

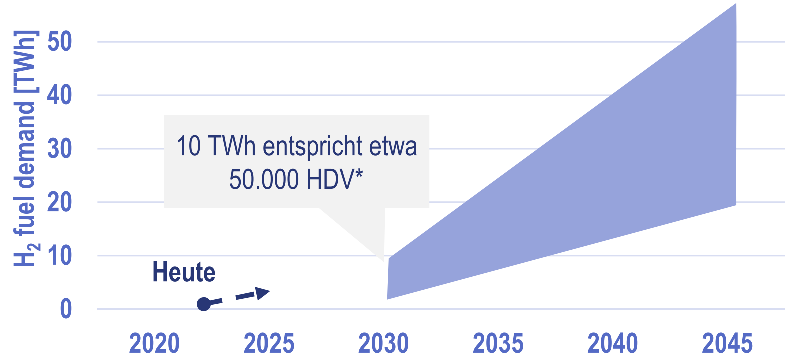
- Current studies on climate neutrality by 2045:
  - **$H_2$ -demand in the transport sector** primarily for **heavy commercial vehicles for long-distance transport**
  - Strong increase from 2025

**Aim of the study:** overview of $H_2$ fuel supply and refueling for long-distance trucking from the perspective of regulation, standardization, technology, and cost.

**GHG emissions Transport sector**



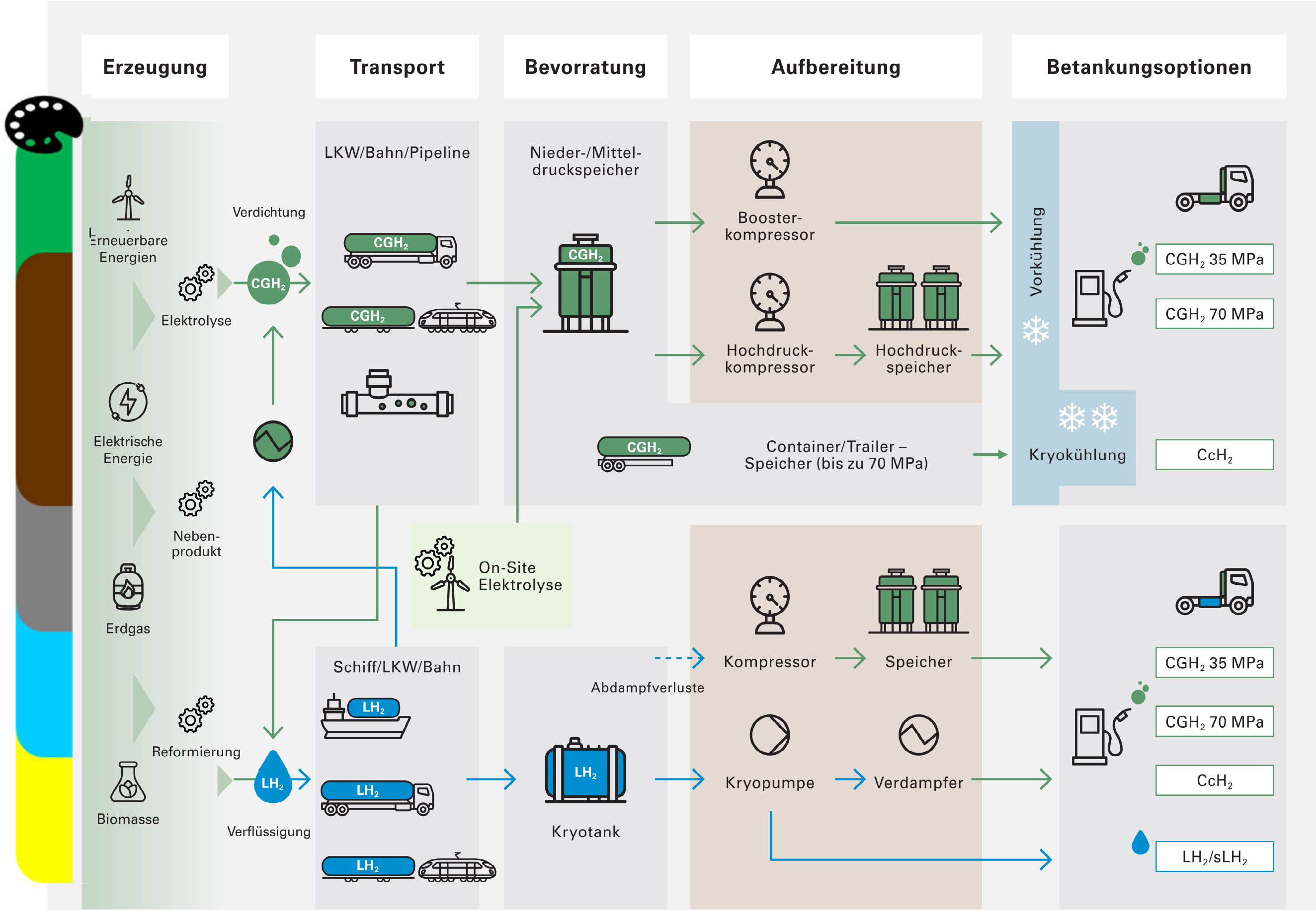

**Projection: $H_2$ -demand in road traffic**




* 80,000 km/a, 260 $kWh_{H2}$ /100km (7.8 kg/100 km)

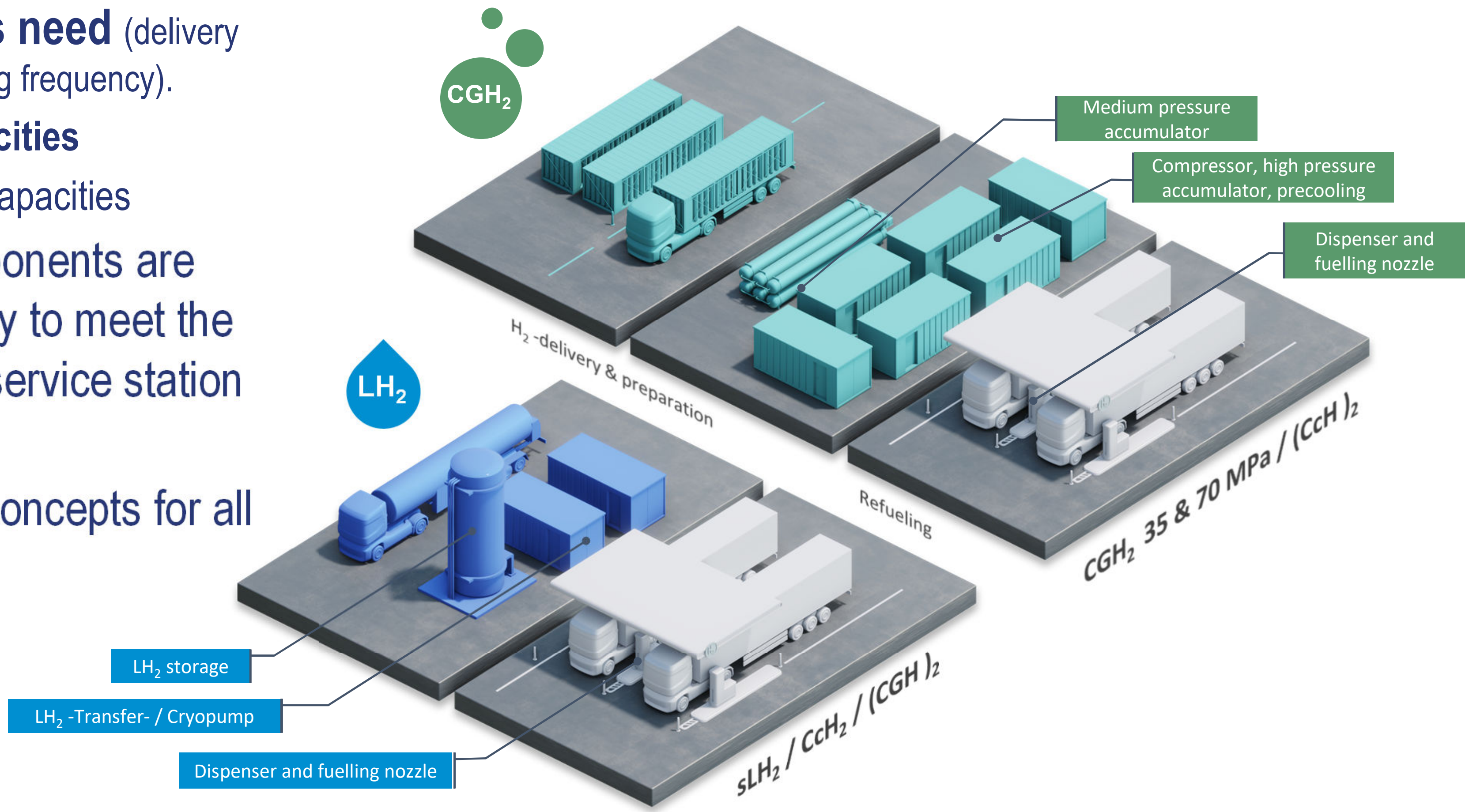
# Various different options to provide $H_2$ to the end consumer

- The **delivery of** $CGH_2$ and $LH_2$ **by means of truck semi-trailers predominates in** the supply of today's $H_2$ filling stations.
- **On-site generation** via electrolysis and the use of **pipelines** are **other $CGH_2$ supply options.**
- Alternative $H_2$ carriers are possible, but not subject of investigation (e.g. $NH_3$ , $CH_4$ O, LOHC )



# $H_2$ -filling station ≠ $H_2$ -filling station

- **High refueling rates need** (delivery quantity/fueling and refueling frequency).
  - High **$H_2$** storage **capacities**
  - High **$H_2$** compressor capacities
- Service station components are developed specifically to meet the requirements of the service station application
- $LH_2$ -fueling station concepts for all $H_2$ -fuel options



# Optimal solutions depend on capacity and location

- The capacities of **future HRS for trucks** lie in the range of **several tons per day**
- High $H_2$ demands require appropriate **H supply paths$_2$**
  - Must be **site specific evaluated, designed, projected** and implemented
- **Pipeline connection** especially for very **economical, especially for very high volumes**
  - if necessary, further $H_2$ customers to be taken into account
- The delivery of pressurized hydrogen via truck comes up against its limits

| Gas station size: | | XS | S | M* | L | XL |
|---|---|---|---|---|---|---|
| Market share diesel filling stations | [%] | < 4 | 18 | 22 | 31 | 26 |
| Annual diesel levy | [million l/a] | 0,7 | 1,5 | 2,5 | 7,5 | 11 |
| Translated into $H_2$ -filling stations | | | | | | |
| Annual H levy $_2$ | [t$H_2$ /a] | 150 | 300 | 500 | 1.600 | 2.300 |
| Daily H -discharge $_2$ | [t$H_2$ /d] | 0,5 | 1 | 2 | 6 | 8 |
| Refueling per day (@ 30kg) | [#/d] | 17 | 33 | 66 | 200 | 267 |
| Refueling per day (@ 60kg) | [#/d] | 8 | 17 | 33 | 100 | 133 |
| Number of refueling stations | [#] | 2 | 2-3 | 3-4 | 4-6 | 6-9 |
| Space requirement | m² | 200-350 | 250-800 | Depending on concept and technology | | |
| Indicative investment costs (70 MPa refueling, $LH_2$ - / $CGH_2$ -plant) | [€ million] | | 1,5 / 2,5 | | | 11 / 17 |
| H -supply parameters$_2$ | | | | | | |
| Delivery frequency CGH -Trailer $_2$ | [Trailer/d] | 0,5 | 1,0 | 2,0 | (6,0) | (8,0) |
| Delivery frequency LH -Trailer$_2$ | [Trailer/d] | 0,15 | 0,3 | 0,7 | 2,0 | 2,7 |
| Electrolysis power | [MWe] | 2 | 4 | 8 | 25 | 33 |
| Capacity connection pipeline | [Nm³/h] | 500 | 1.000 | 2.000 | 6.000 | 8.000 |

Assumptions: Indicative investment costs based on Ludwig-Bölkow-Systemtechnik GmbH (LBST)-HRS model; net capacity $CGH_2$ -trailer 1,000 kg, $LH_2$ -trailler 3,500 kg; electrolysis with 50% utilization u. 50 kWh/kg; 50% utilization of connecting pipeline.
* Minimum capacity of 2 t/day according to Commission proposal for Alternative Fuels Infrastructure Regulation (AFIR), Article 6, paragraph 1 [41] (as of October 2022).

Source: (based on NOW and H2Mobility, supplemented with own data)

**Capacities of conventional service stations, translated into $H_2$ capacities**

# $LH_2$ as a vector for all $H_2$ fuel options.

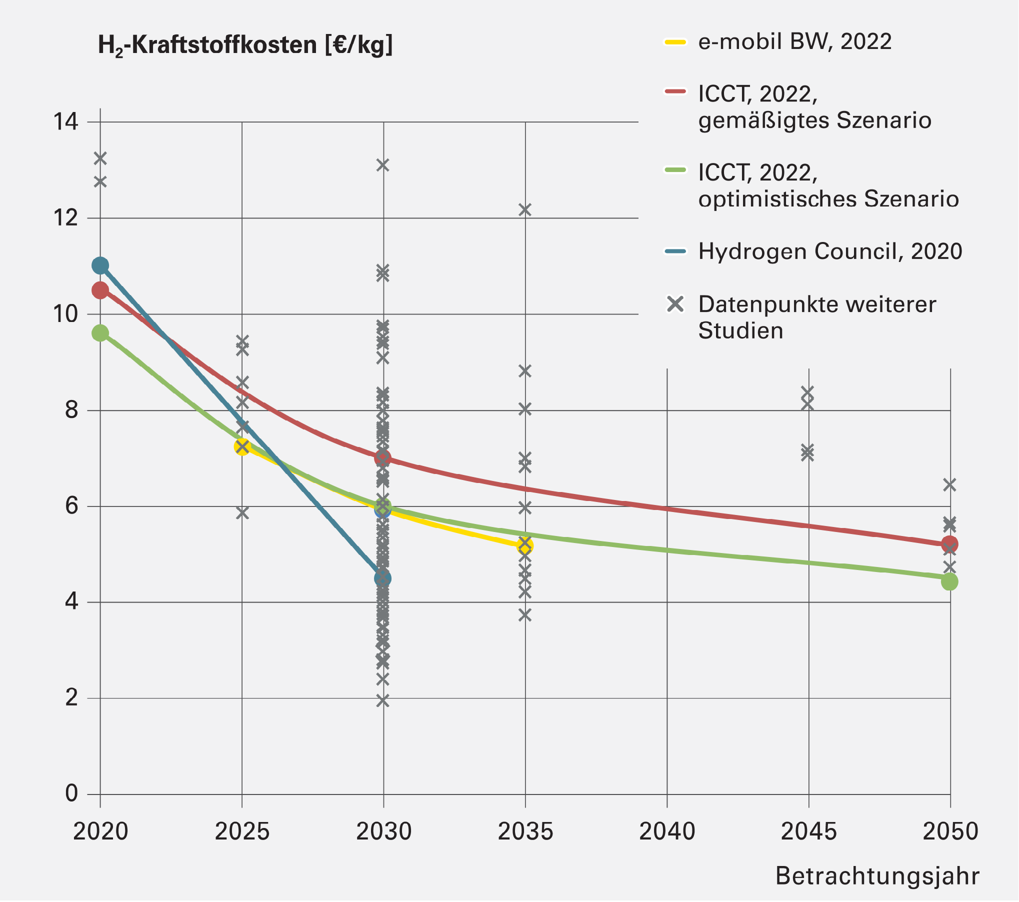
- **$LH_2$** -Liquefaction capacities in Europe **only available to a limited extent:**
  - Significant capacity expansion required (possibly supplemented by $LH_2$ imports) to establish $sLH_2$ and/or $CcH_2$ as a fuel.
- **Technology development required:**
  - Increase plant capacity
  - Reduction power demand
  - Cost reduction
- **$LH_2$ -Know-how** and technology are **limited to a few suppliers** worldwide
- Fueling stations with on-site generation and liquefaction are not anticipated

| Anlieferoptionen an HRS ≥2 t $H_2$/d | $H_2$-Kraftstoffoptionen für Lkw im Fernverkehr | | |
|---|---|---|---|
| | 70 MPa | $sLH_2$ | $CcH_2$ |
| $CGH_2$-Trailer (ND) | Sehr hohe Anlieferfrequenz | Kein Flüssigwasserstoff | Kein Flüssigwasserstoff |
| $CGH_2$-Trailer (HD) | Mehrere Anlieferungen pro Tag | Kein Flüssigwasserstoff | Kein Flüssigwasserstoff (eingeschränkt mit Kryokühlung) |
| $LH_2$-Trailer | | | |
| $CGH_2$-Pipeline | | Nur als regionaler $LH_2$-Hub mit Verflüssiger | Nur als regionaler $LH_2$-Hub mit Verflüssiger oder mit Kryokühlung |
| Vor-Ort-Elektrolyse | | | |

**Kompatibilität:** Ja Eingeschränkt Eher nicht
($H_2$ -delivery and $H_2$ -fuel option)

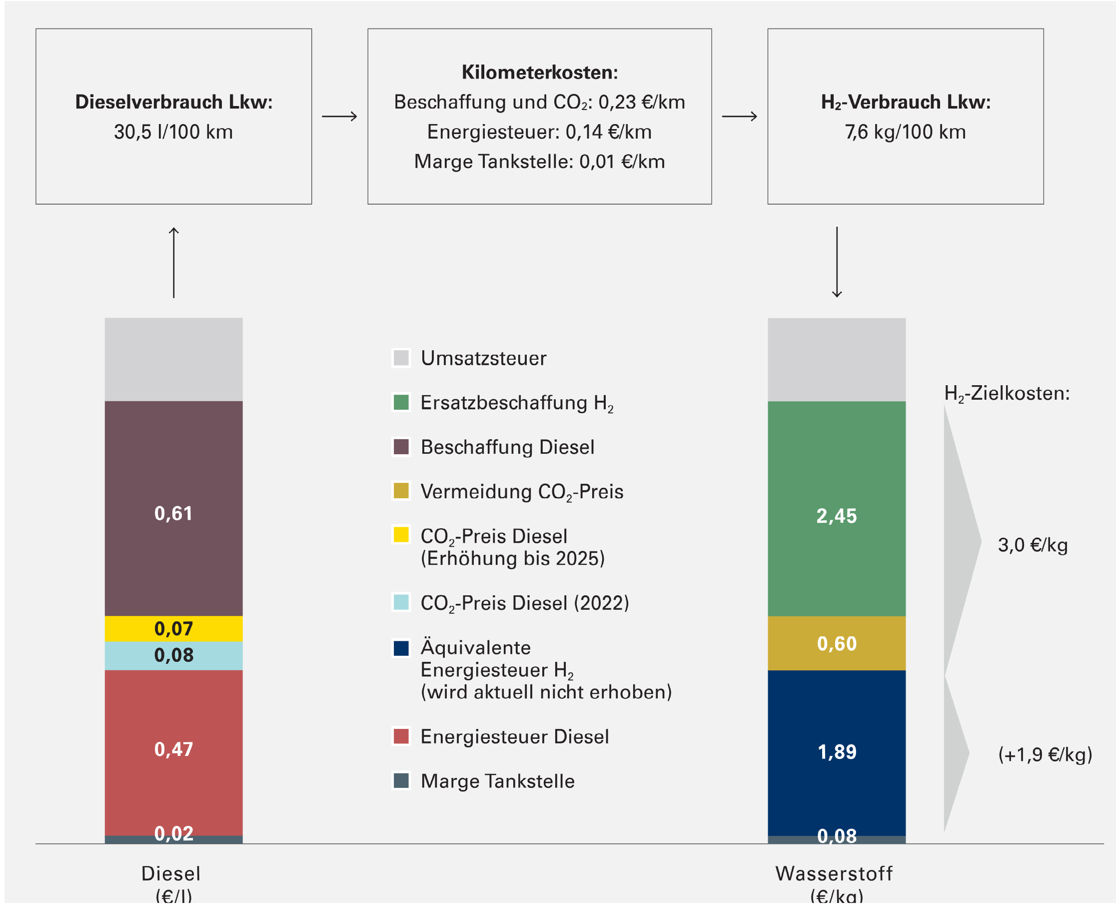
# $H_2$ fuels - cost reduction to ~ €5/kg expected

- Results of a **meta-analysis**:
  - Cost today: 10 to 15 €/kg
  - **Costs in the medium term: 4 to 6** €/kg
  - Limited study and data available for $sLH_2$ and $CcH_2$
- Differences in terms of timing: until 2030 vs. after 2030
- **Crucial to the cost decline**:
  - Mass production and economies of scale
  - Good utilization of the supply and refueling infrastructure
  - Optimized supply and logistics concepts



# Parity Fuel costs: 1.4 €/liter$_D$ → 3 to 5 €/kg$_{H2}$

- **Transport costs** (€/tkm) relevant for logistics:
  - Cost of vehicle, fuel, driver, toll, ...
  - **Fuel only one parameter**
- Fuel Cost Consideration:
  - **Parity: Diesel = Cost H ?$_2$**
  - Parity: 1.4 €/L$_D$ = 3 to 5 €/kg$_{H2}$
- **Parity $H_2$ -fuel costs possible** at:
  - High diesel procurement costs
  - Differentiated energy tax rates
  - Further increase in $CO_2$ price




Assumption diesel costs: 1.4 €/L; fluctuation range (2020 to 2022) approx. 1.0 to 2.3 €/L

# $H_2$ -fueling network for heavy-duty vehicles is in its infancy

- **$H_2$ filling stations are currently subsidized in Germany by up to 80%.**
  - **Requirements**
    - Possibility of 70 MPa refueling, 2 t $H_2$ /d, TEN-T network (10 km) or within urban nodes, light and heavy commercial vehicles
  - **Evaluation criteria:**
    - Subsidy input (€/kg)
    - Technology openness for 35 MPa, $LH_2$ , $CcH_2$
    - Business model
    - $H_2$-reference concept
    - Operating experience Applicant

Gefördert durch: Bundesministerium für Digitales und Verkehr | Koordiniert durch: NOW-GMBH.DE | Projektträger: PtJ Projektträger Jülich Forschungszentrum Jülich | Finanziert von der Europäischen Union NextGenerationEU

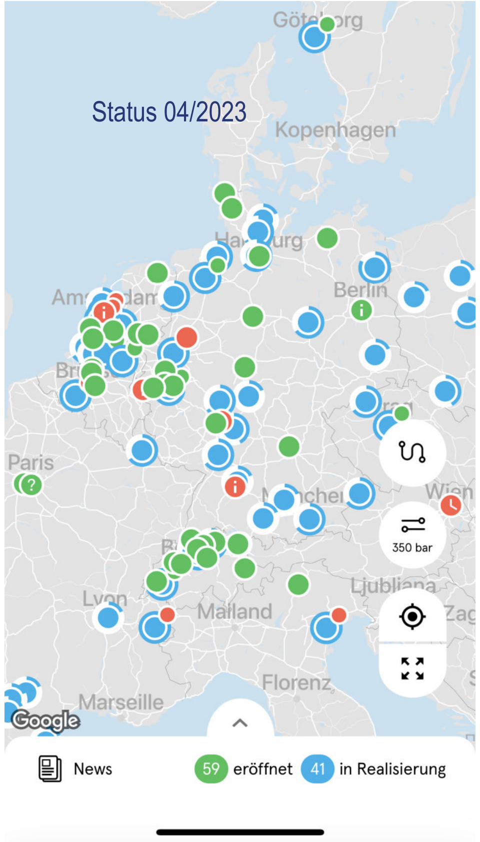
**Förderrichtlinie für Maßnahmen der Marktaktivierung im Rahmen des Nationalen Innovationsprogramms Wasserstoff- und Brennstoffzellentechnologie**

AUFRUF ZUR ANTRAGSEINREICHUNG

FÖRDERUNG VON ÖFFENTLICH ZUGÄNGLICHEN WASSERSTOFFTANKSTELLEN IM STRAßENVERKEHR MIT SCHWERPUNKT SCHWERLASTFAHRZEUGE

(03/2023)

bmdv_nip_call_for_public_fuel_stations_nfz_2023-1.pdf (ptj.de)




H2.LIVE: Hydrogen refueling stations in Germany & Europe

# $H_2$ –fueling stations: building-plans of stakeholder-initiatives

- **Vehicle and/or infrastructure providers form** cooperations
  Goal: coordinated roll-out of vehicles and infrastructure
- Increasingly **pay-per-use models are being** developed
  – fixed km flat rate (€/km) + maintenance including $H_2$ -fuel supply

traffic review

Home > Nachrichten > Nfz + Fuhrpark > TotalEnergies und Air Liquide bauen 100 Wasserstoff-Tankstellen für Lkw

**TotalEnergies und Air Liquide bauen 100 Wasserstoff-Tankstellen für Lkw**

02.03.2023 - 09:42

**Jet H2 Energy baut bis 2024 zehn H2-Tankstellen**

electrive.net

Brennstoffzelle | Dänemark | Deutschland | E-Busse | E-Lkw | FCEV | H2 Energy | H2-Tankstellen | JET | Jet H2 Energy | Joint Venture

Energie & Infrastruktur >

19.09.2022 - 14:47

**E.ON und Nikola planen Infrastruktur für H2-Lkw in Europa**

h2-mobility

08.11.2022

**hylane und H2 MOBILITY Deutschland kooperieren bei Tankinfrastruktur für Wasserstoff-Lkw**

Daimler Truck, IVECO, OMV, Volvo, TotalEnergies, Linde

Hyundai Hydrogen Mobility – Partnership with H2Energy

GP JOULE – Trust your energy. clean logistics

Phillips 66, H2 energy Europe, Hyundai, H2 energy

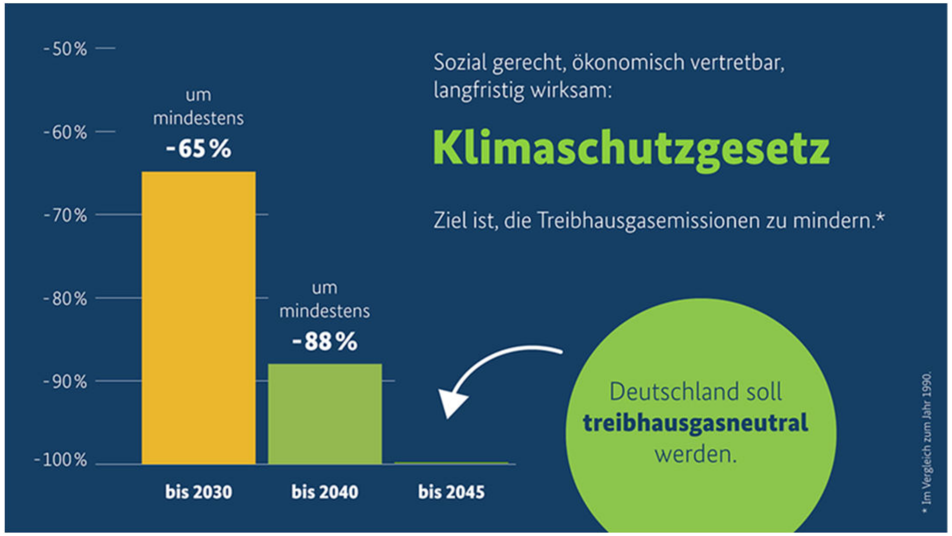
e.on, Nikola, H2 MOBILITY, hylane

# Transformation of the German Energy System as a Key for Decarbonising Transport

# Summary

## Summary

- The German Energy Transition „project“ is a tremendous effort and a challenge to all stakeholders as well as to society
- There are no blue-prints, so a continous adjustment of measures and policies are necessary
- The German Energy Transition made good progress, however further actions are ahead: increase of capacities, adjustment of market mechanisms, outreach for continuous support by society
- Energy industry is committed, they ask for continuation of stable boundary conditions



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