PATHWAYS INTO THE ENERGY FUTURE

Sustainability as a Societal Goal

Prof. Dr. Christopher Hebling

Fraunhofer Institute for Solar Energy Systems ISE

Symposium for the Inauguration of the

Global Zero Emission Research Center

January 29th 2020, New Otani, Tokyo
www.ise.fraunhofer.de

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People

Poul La Cour: Hydrogen Production by Electrochemical Water Splitting

Hydrogen Production with a Wind Power Plant in Denmark in the 1880s

- Danish Physicist, inventor and director of the cummunity college in Askov, Denmark
- First wind power plant for rural electrification in 1891
- Hydrogen system
  - Alcaline electrolysis cell
  - H_2 / O_2 storage vessels
  - Gas light for hydrogen gas for the college building

Poul la Cour (1846 - 1908)

Source and picture credits: en.wikipedia.org/wiki/Poul_la_Cour
http://www.poullacour.dk/engelsk/menu.htm

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Alkaline Electrolyzers in the 100-MW-Class since the 1930s

Green Hydrogen from Hydro Power for the Fertilizer Production

But: Market displacement of the electrolyzers due to the steam methane reforming technology since the 1970s

 Picture credits: Fell – StatoilHydro, 2008

Renewables

Renewable Capacities are Growing

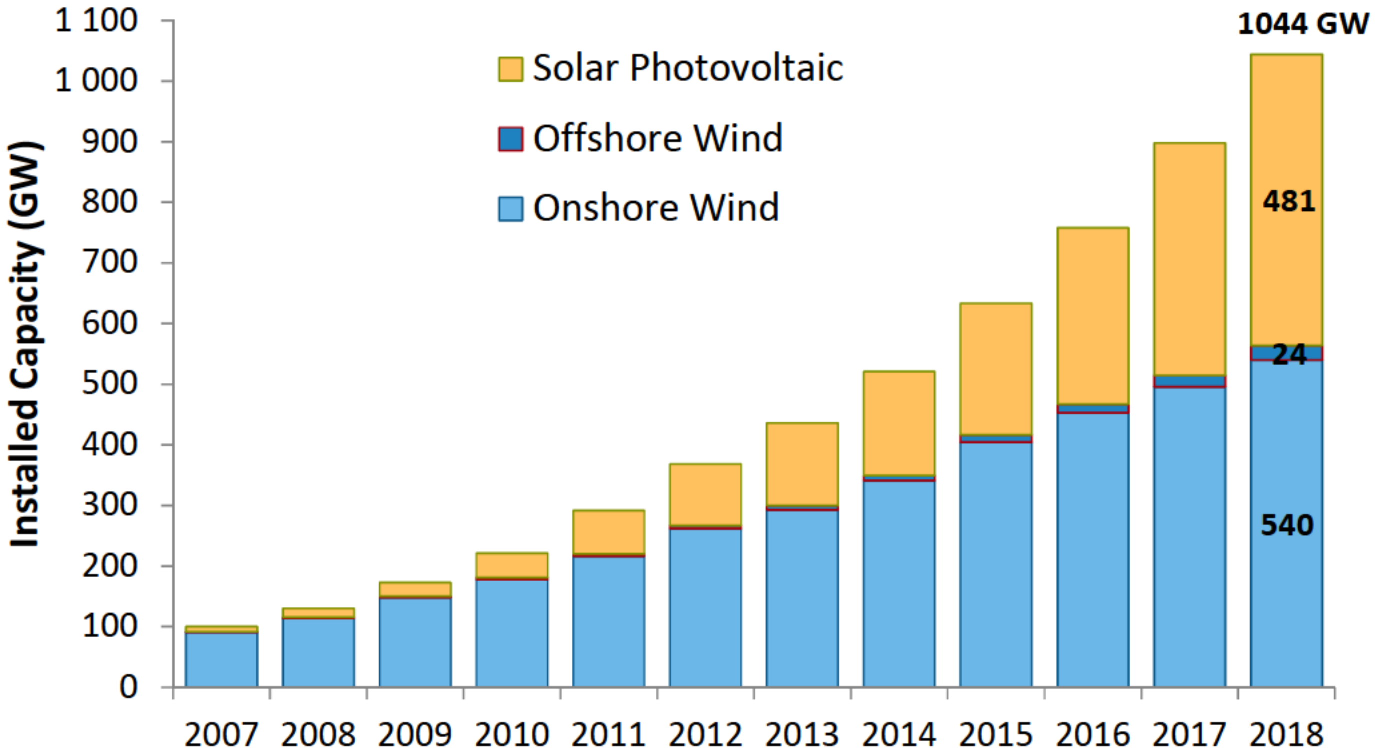
Global Wind and Photovoltaic Installations beyond 1TW Total Capacity

Renewables in 2018:

2356 GW Global Renewable Generation Capacity:

- 564 GW Wind
- 481 GW Photovoltaics
- 1295 GW Hydro
- 118 GW Bioenergy

=> 175 GW increase in global new renewable generation capacity in 2018 (86% Solar and Wind)



 Source: IRENA, 2019, http://resourceirena.irena.org/gateway/dashboard/

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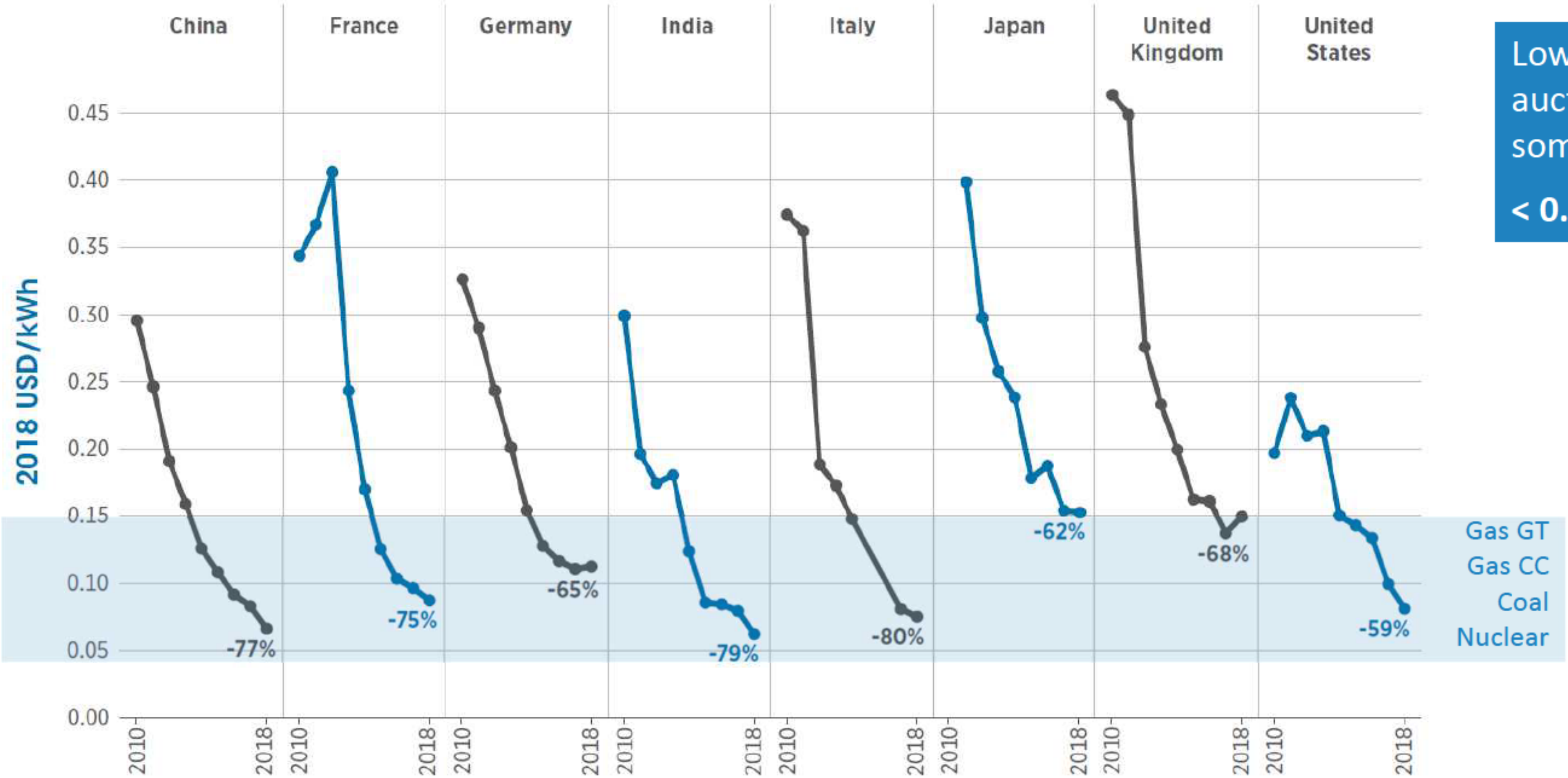
Levelized Cost of Electricity (LCOE) of Photovoltaik Projects

2010 – 2018 (country-average; utility-scale)

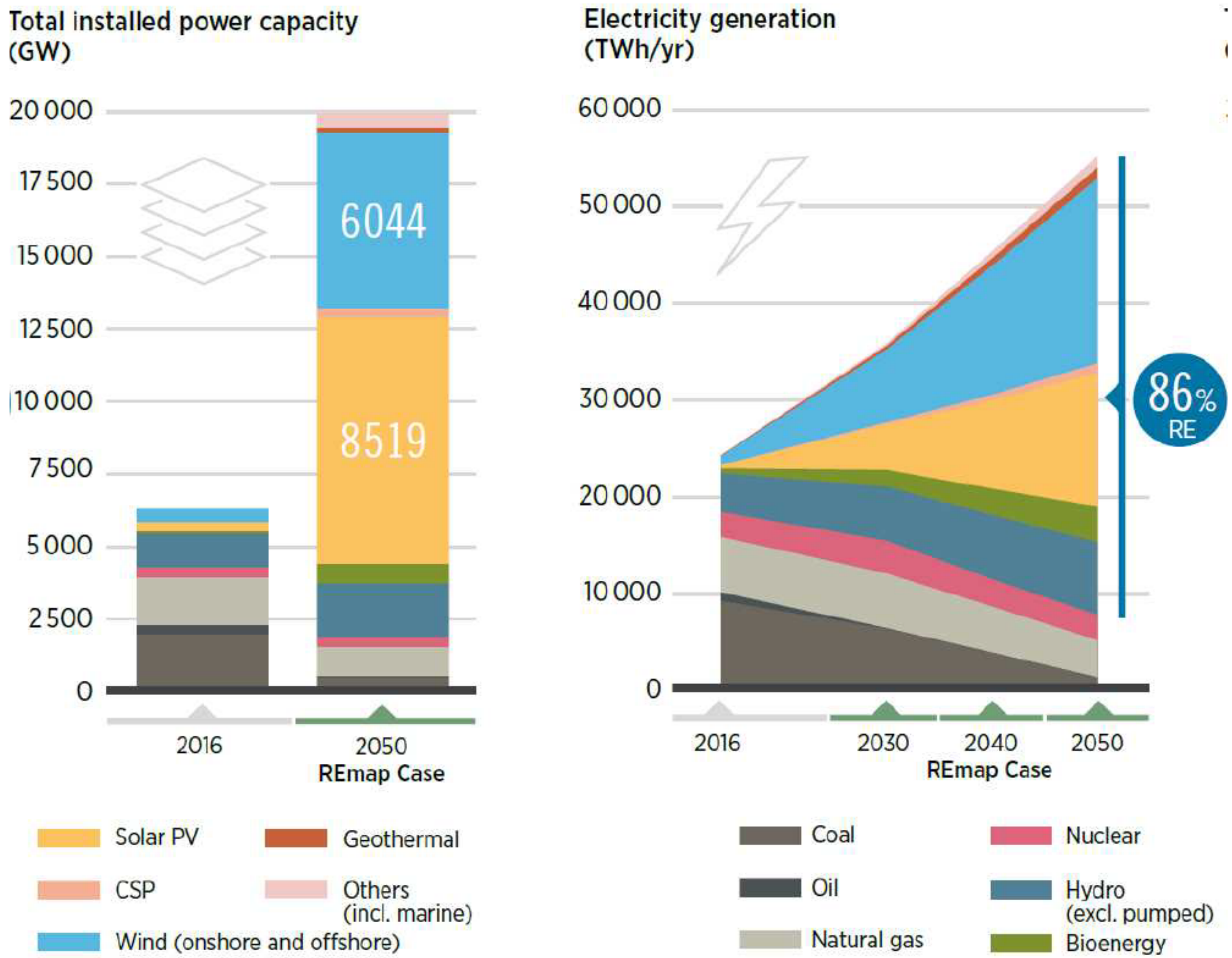


Lowest PPA and auction price data in some regions:

< 0.02 USD/kWh

 Source: Renewable Power Generation Costs in 2018, IRENA

Scenarios fo 2050



→ Doubling global electricity demand

→ Dominant role of wind energy and photovoltaics for power generation

Report: IRENA, Global Energy Transformation – A Roadmap to 2050 (2019 edition), ISBN: 978-92-9260-121-8
https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

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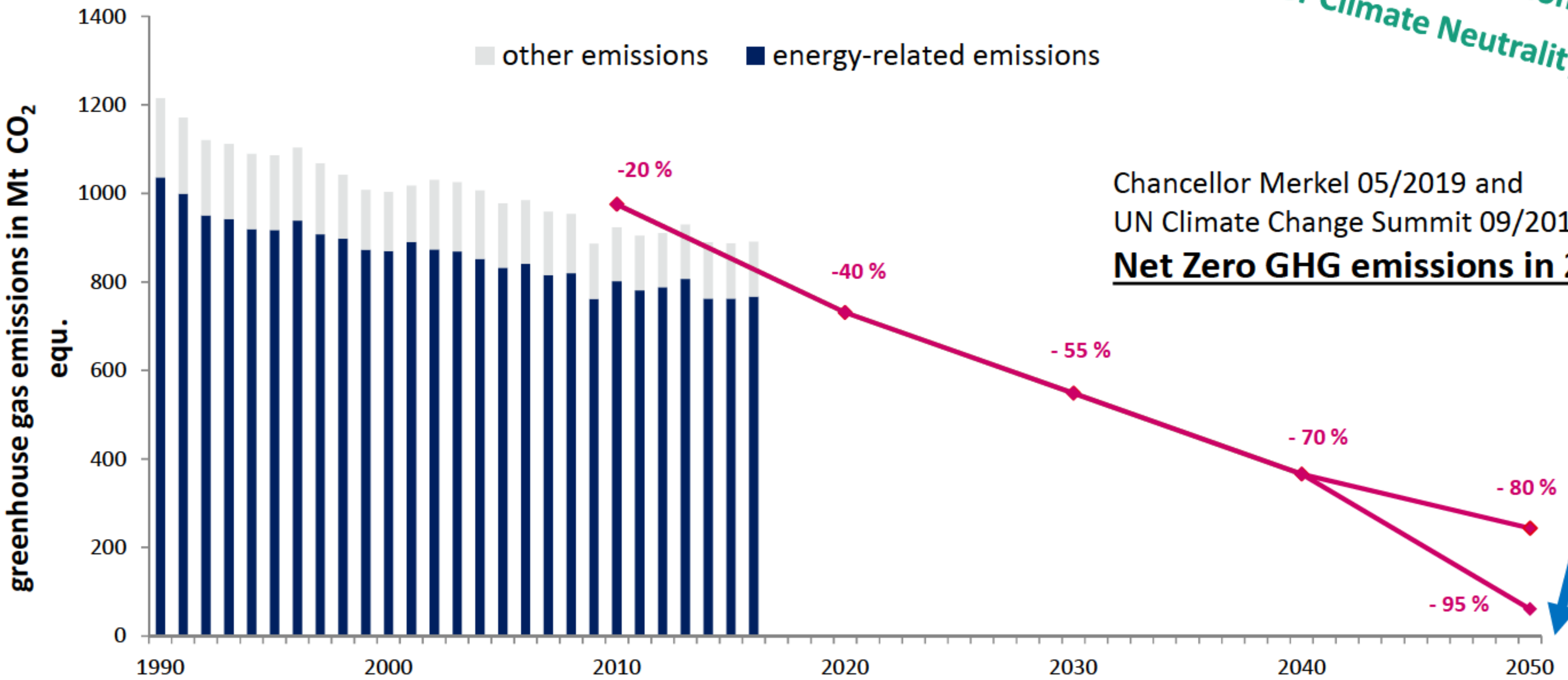
Paths

Main Goal of the Energy Transformation in Germany

Reduction of Fossile Greenhouse Gas Emissions

European Commission:
Green Deal (€1 trillion until 2030)
For Climate Neutrality in 2050



Chancellor Merkel 05/2019 and
UN Climate Change Summit 09/2019:
Net Zero GHG emissions in 2050

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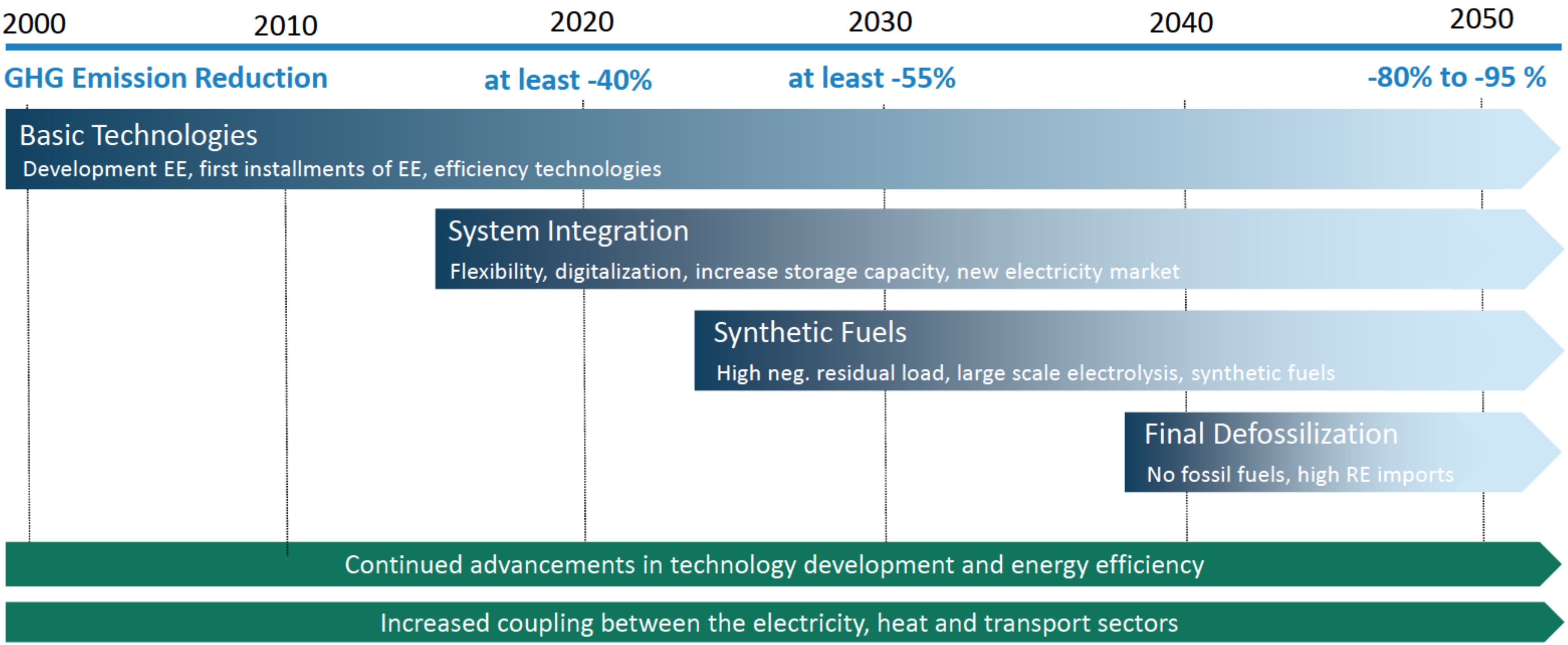
Targets and Phases of the Energy Transformation in Germany

A Cost and Climate Compatible Transformation of the Energy System



According to acatech (November 2017):
»Sektorenkopplung - Optionen für die nächste Phase der Energiewende«.

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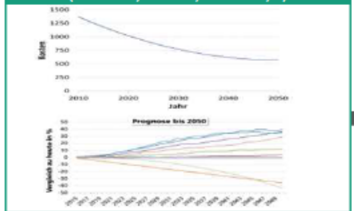
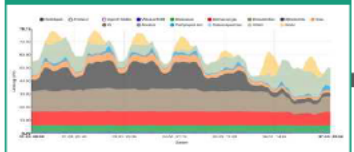
REMod – Cross-sectoral energy system modelling

CO_2-target

Data input
(Tech. costs, life times, efficiencies, ...)



Hourly profiles (demand, weather)



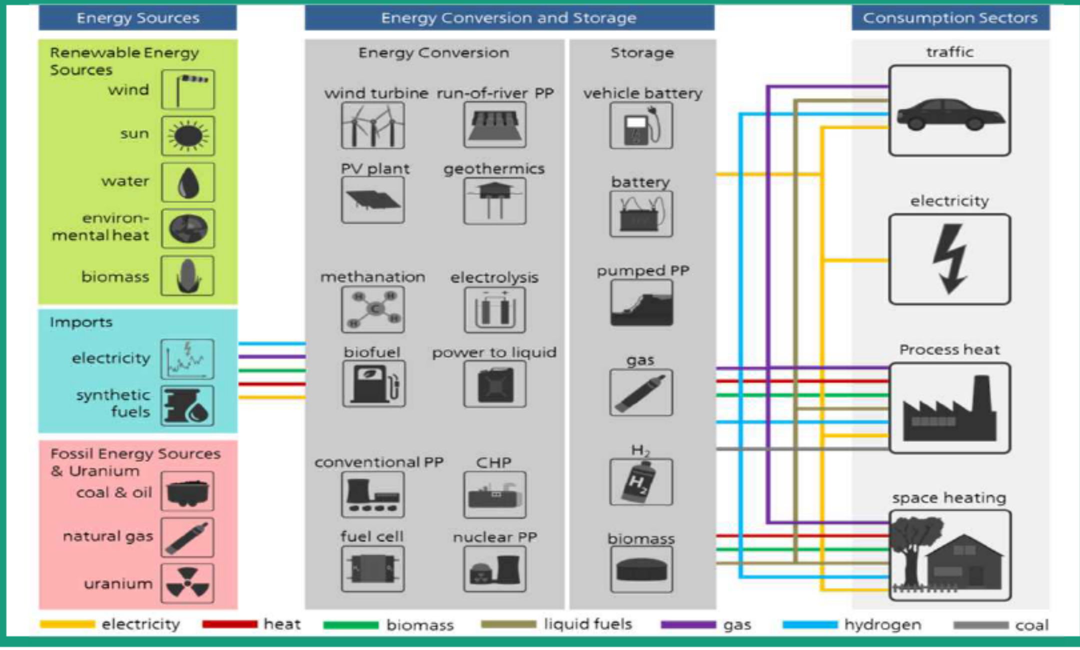
Energy converters today
(all sectors)

Target function: Minimization of total system costs

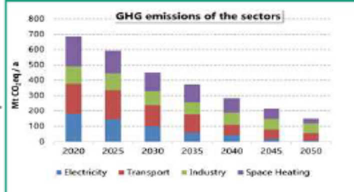
Hourly optimization. Non-linear.

All energy sources, converters, storages and consumption sectors

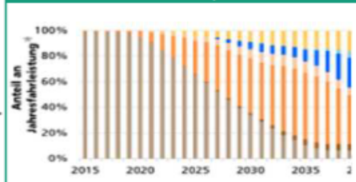
Boundary conditions: Security of supply and CO_2 emissions



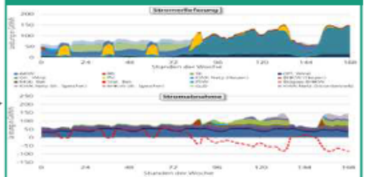
GHG emissions per sector



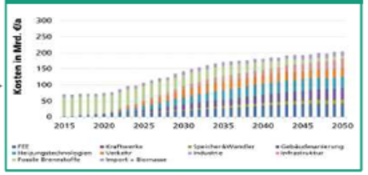
Energy converters until 2050 (all sectors)



Sector-coupled operating results



System costs of transformation



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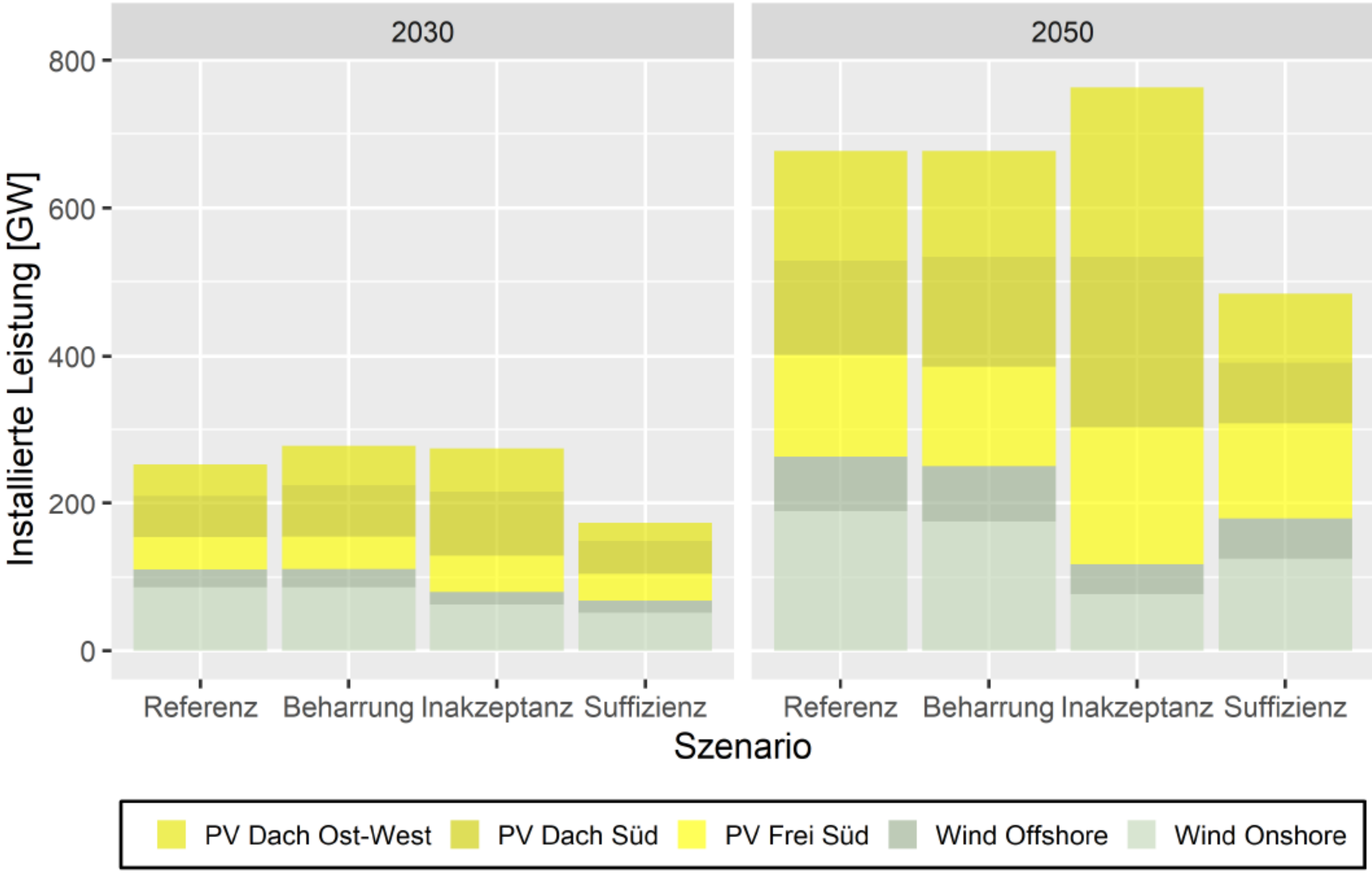
Cost-optimized Scenarios

Installed Photovoltaic Capacity for 2030 and 2050 in Germany

Outcome is differenciated according to the basic assumptions



 Source: Fraunhofer ISE

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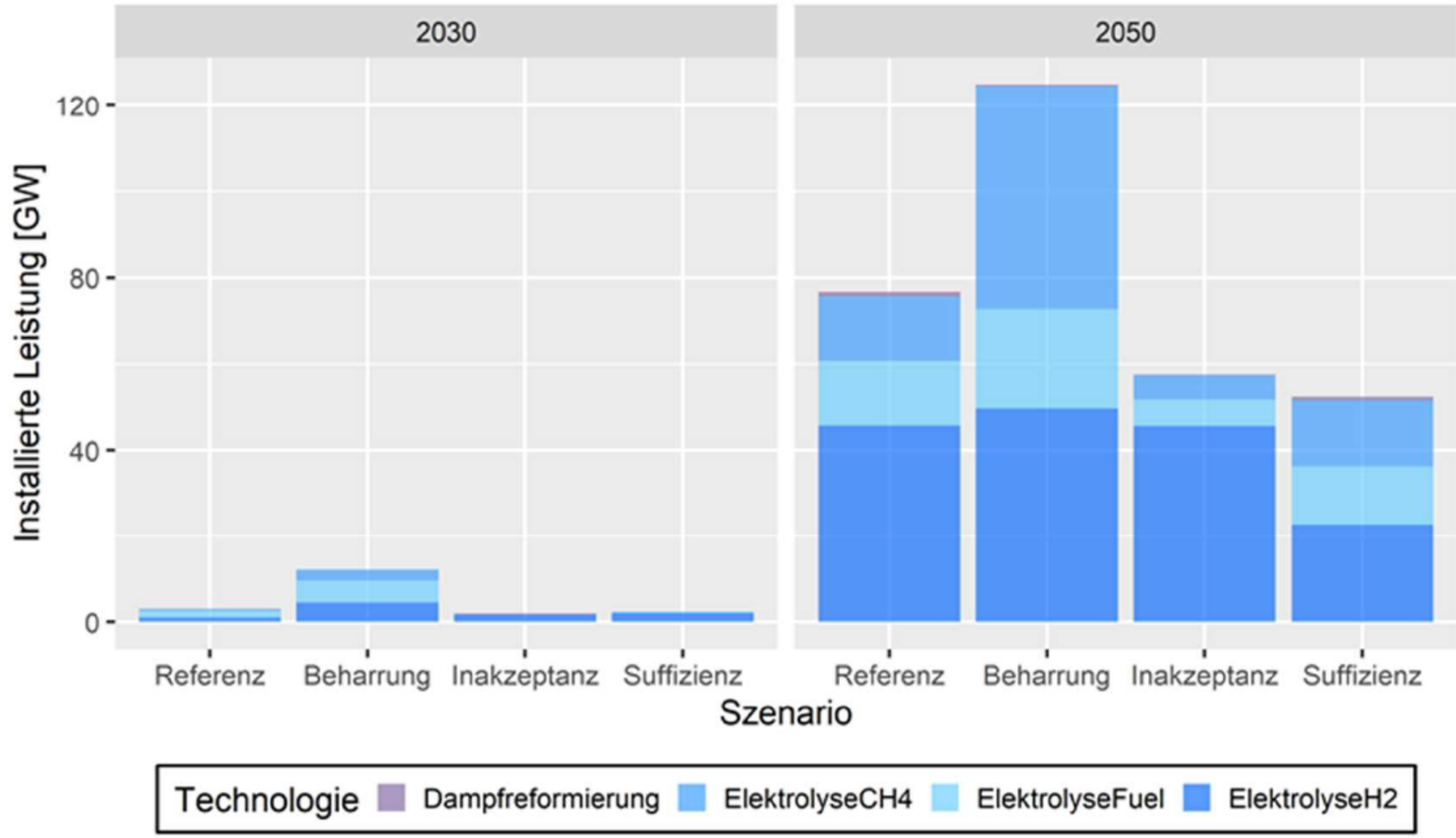
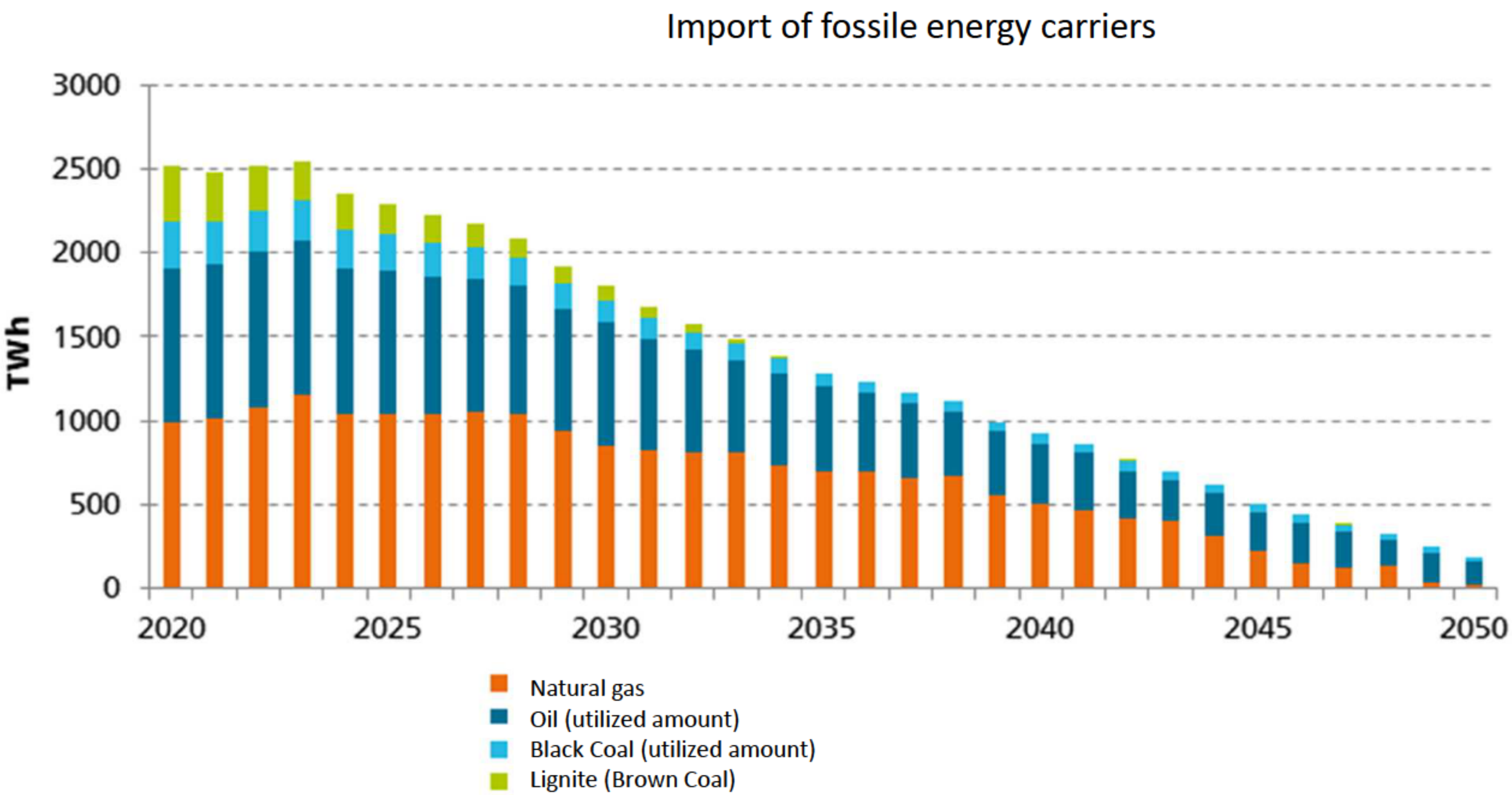
Cost-optimized scenarios:
Cumulative Installed Electrolyzer Capacity in Germany



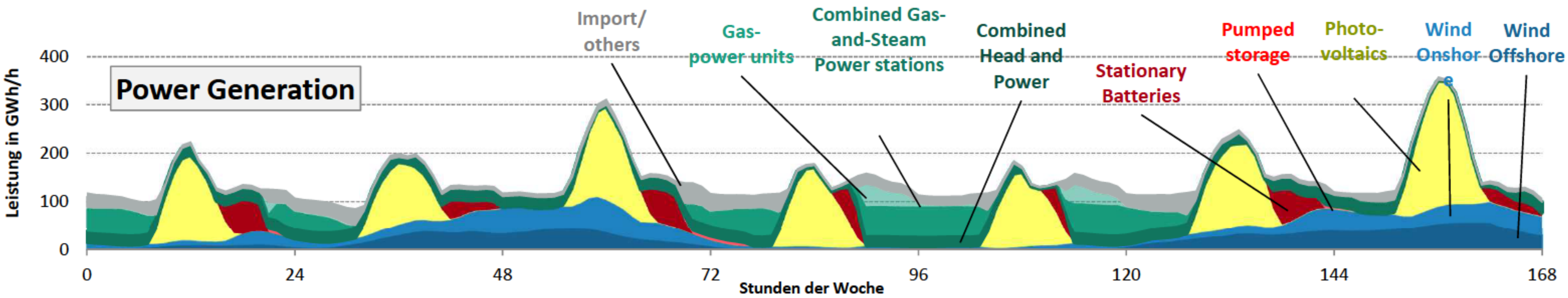
 Source: Fraunhofer ISE

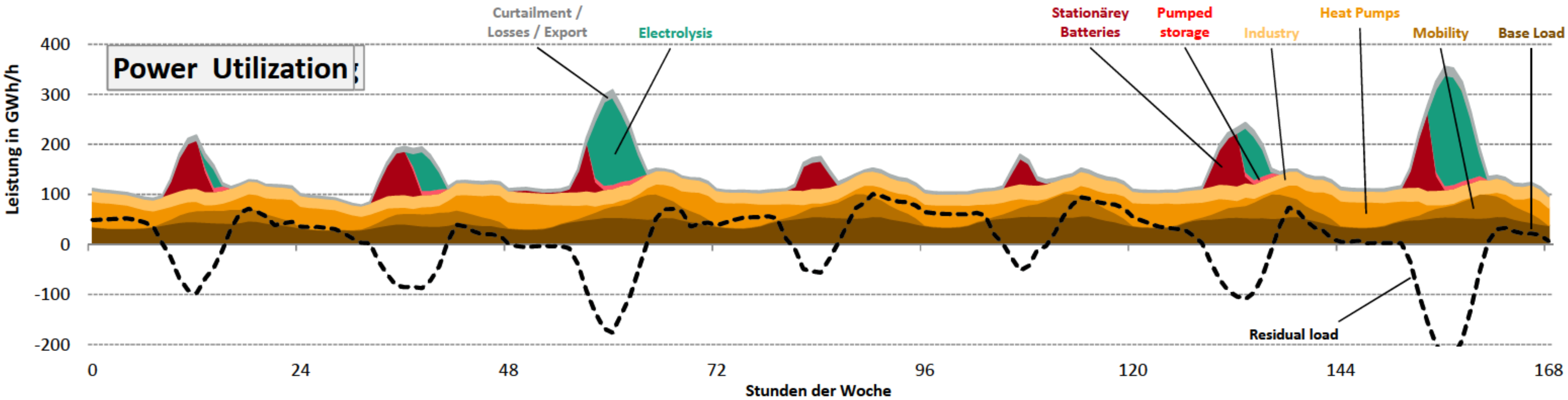
Utilized Amounts of Fossile Energy Carriers



 Source: Fraunhofer ISE

Electricity Production in Germany – Example: Winter week in 2050





Daten: P. Sterchele, „Analysis of Technology Options to Balance Power Generation from Variable Renewable Energies ", Dissertation (2019)

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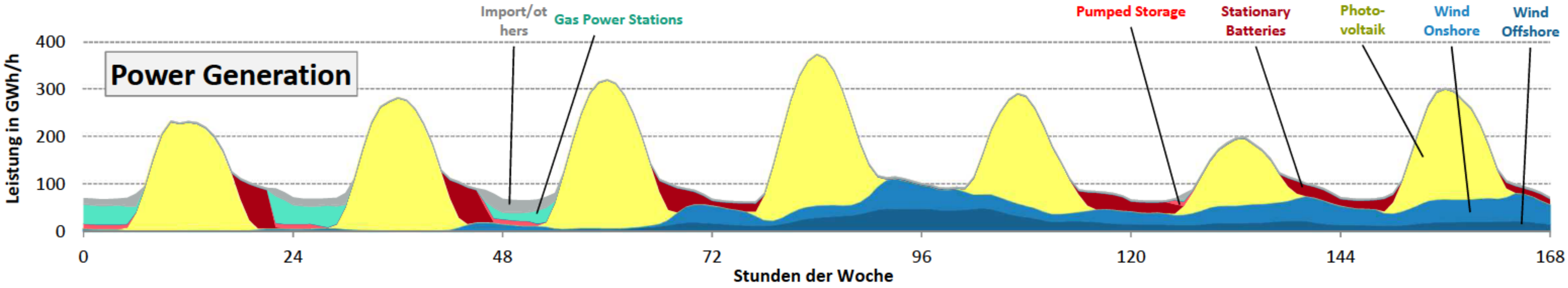
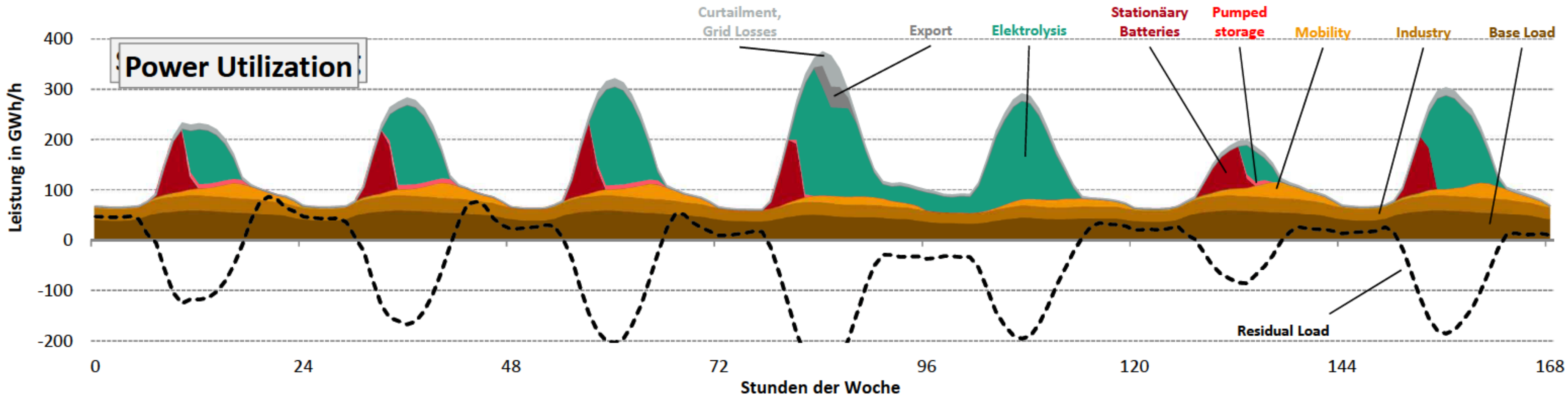
Electricity Production in Germany – Example: Summer week in 2050





Daten: P. Sterchele, „Analysis of Technology Options to Balance Power Generation from Variable Renewable Energies “, Dissertation (2019)

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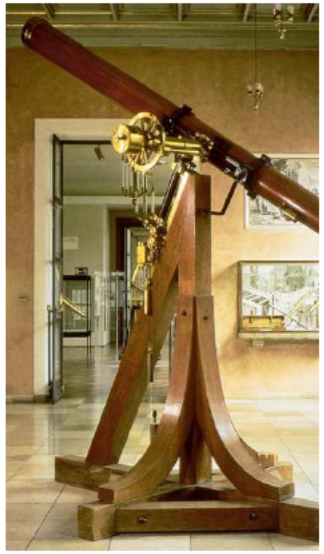
Research

The Fraunhofer-Gesellschaft
Largest Organization for Applied Research in Europe

- **72 institutes and research units** with total staff more than 26,600
- More than **€2.5 billion annual research budget**, of which around €2.1 billion is generated through contract research
  - Roughly 70 percent of contract research is generated on behalf of industry and publicly funded research projects.
  - Roughly 30 percent is contributed by the German federal and state governments in the form of base funding.
- **International cooperation throughout the world**



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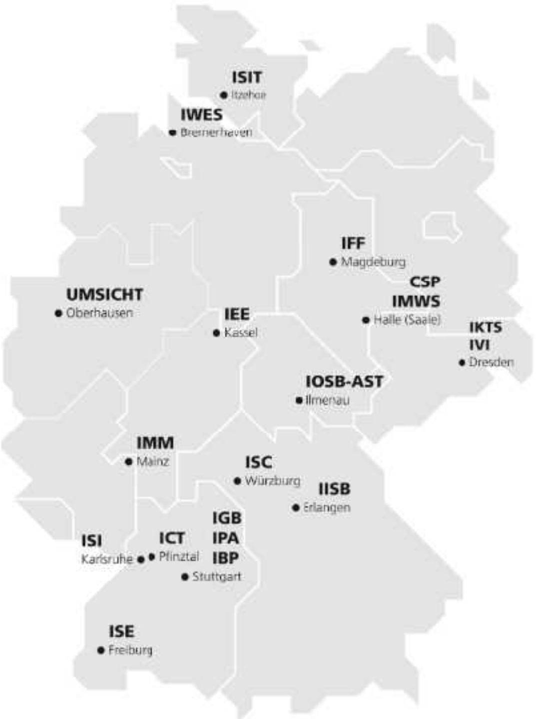
Fraunhofer Fields of Research

Energy Research at Fraunhofer

Fraunhofer Energy Alliance Comprising the Competence of 18 Institutes



Energy generation

- Solar thermal energy
  Photovoltaics
- Wind energy
- Bioenergy
- Hydropower
- Geothermal energy

Energy storage

- Battery cells
- Hydrogen / Fuel cells
- Mechanical
- Thermal
- Energy Harvesting

Energy efficiency

- Efficient production technology
- Mobility
- Interconnecting grids
- Energy conversion
- Energy distribution
- Energy usage

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Energy Research at Fraunhofer
Central Challenges of the Energy Transition

Core results of basic studies* on the feasibility of the energy transition in Germany by 2050:

1. Develop **renewable energies** faster
2. **Ensure supply**: Make consumption more flexible, provide controllable power plants
3. Develop market and technologies for renewable **synthetic energy sources**
4. Switch to a new **technology mix in transport**
5. Comprehensive, energy-efficient and faster renovation of **buildings**
6. Avoid **industrial emissions** — with efficiency, renewable energies and new processes
7. **Holistic control** of the energy transition to facilitate investments

*dena: "Study Integrated Energy Transition" (07/2018)
BDI: "Climate Paths for Germany" (01/2018)
acatech/Leopoldina/Akademienunion: "Energy Systems of the Future" (11/2017)

Fraunhofer Institute for Solar Energy Systems ISE

Research for the Energy Transformation

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Directors

Prof. Dr. Hans-Martin Henning

Prof. Dr. Andreas Bett

Staff

ca. 1300

Scientists, engineers, students

Budget 2019 (prelim.)

Operation	93,5 Mio. EUR
Investment	10,6 Mio. EUR
Total	104,1 Mio. EUR

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Areas of Concentration

Total staff >1200

Annual turnover about 90 Mio €

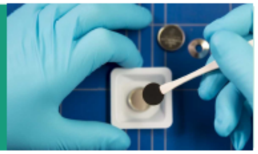
ENERGY TECHNOLOGIES AND SYSTEMS
Prof. Dr. Hans-Martin Henning

PHOTOVOLTAICS
Dr. Andreas Bett

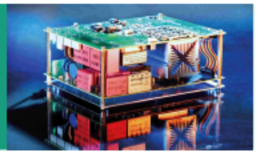
Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes

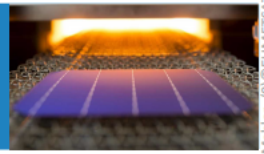
Hydrogen Technologies and Electrical Energy Storage



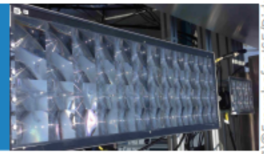
Power Electronics, Grids and Smart Systems



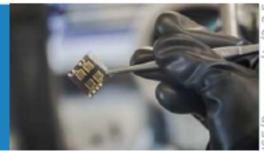
Silicon Photovoltaics



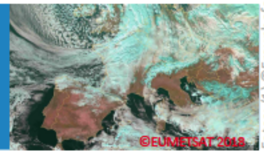
III-V and Concentrator Photovoltaics



Emerging Photovoltaic Technologies



Photovoltaic Modules and Power Plants



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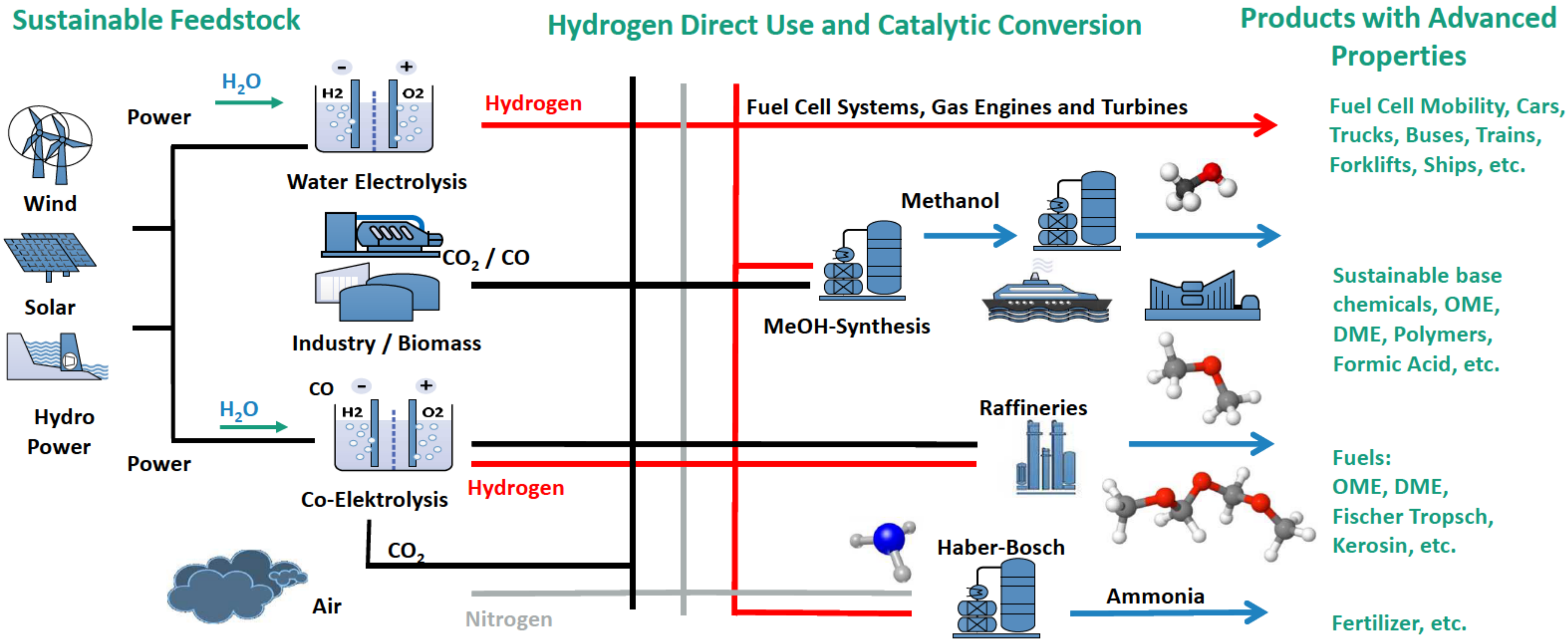
Internationality

Sustainable Fuels an Chemicals

Power-to-X



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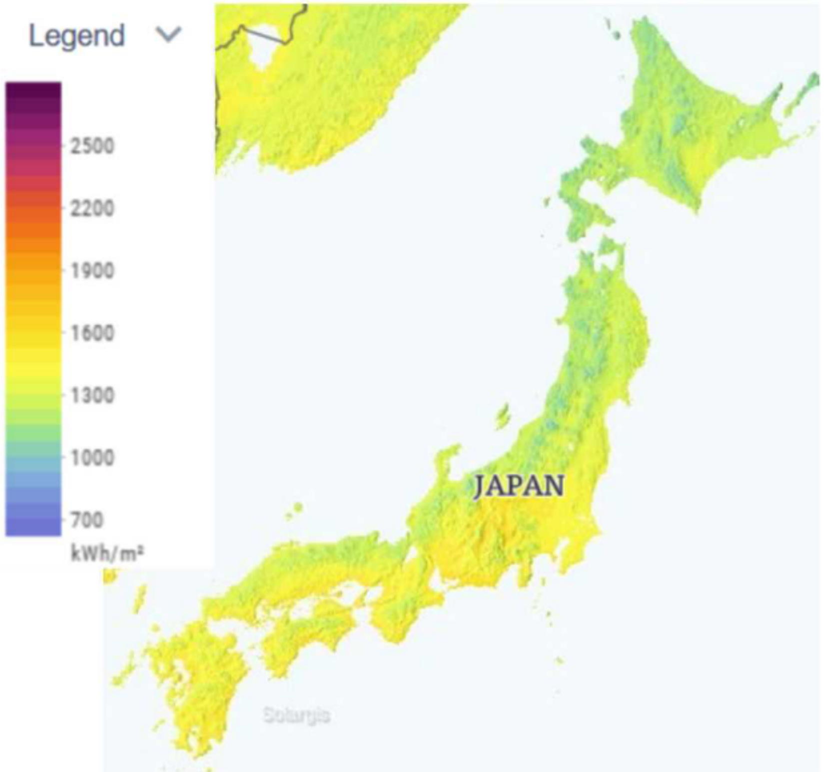
Combined Solar and Wind Power Potential of Japan

Japan: High potential for energetic self-sufficiency

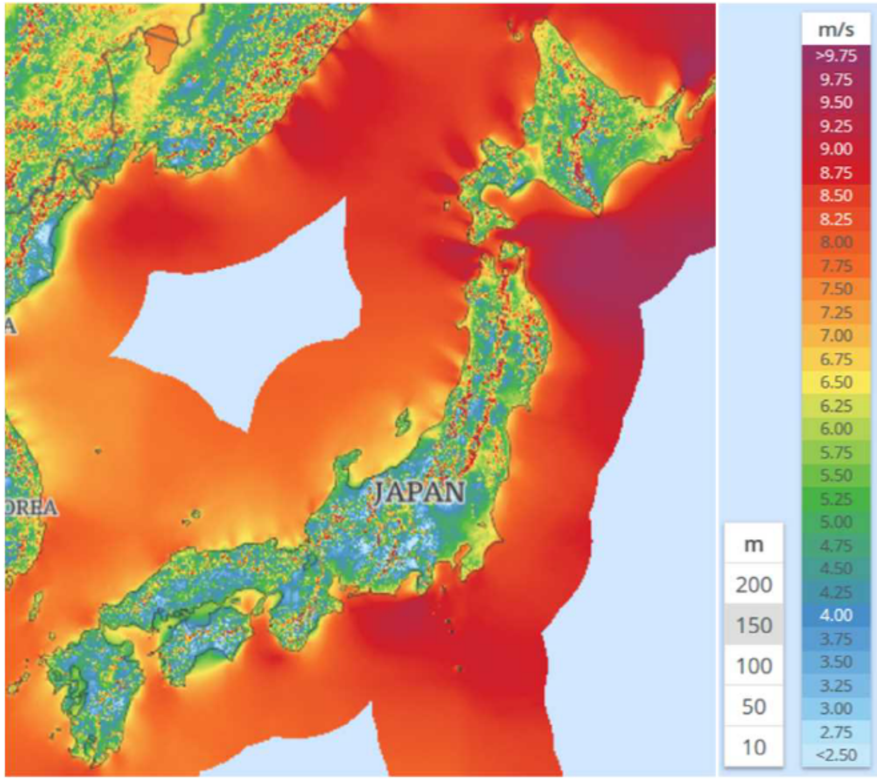
Heat map of solar power



Source: GSA 2.0, Solargis, World Bank Group (*)

Note: Global Horizontal Irradiation (GHI), [kWh/m²] per year

Heat map of wind power



Source: GWA 3.0, DTU, World Bank Group (*)

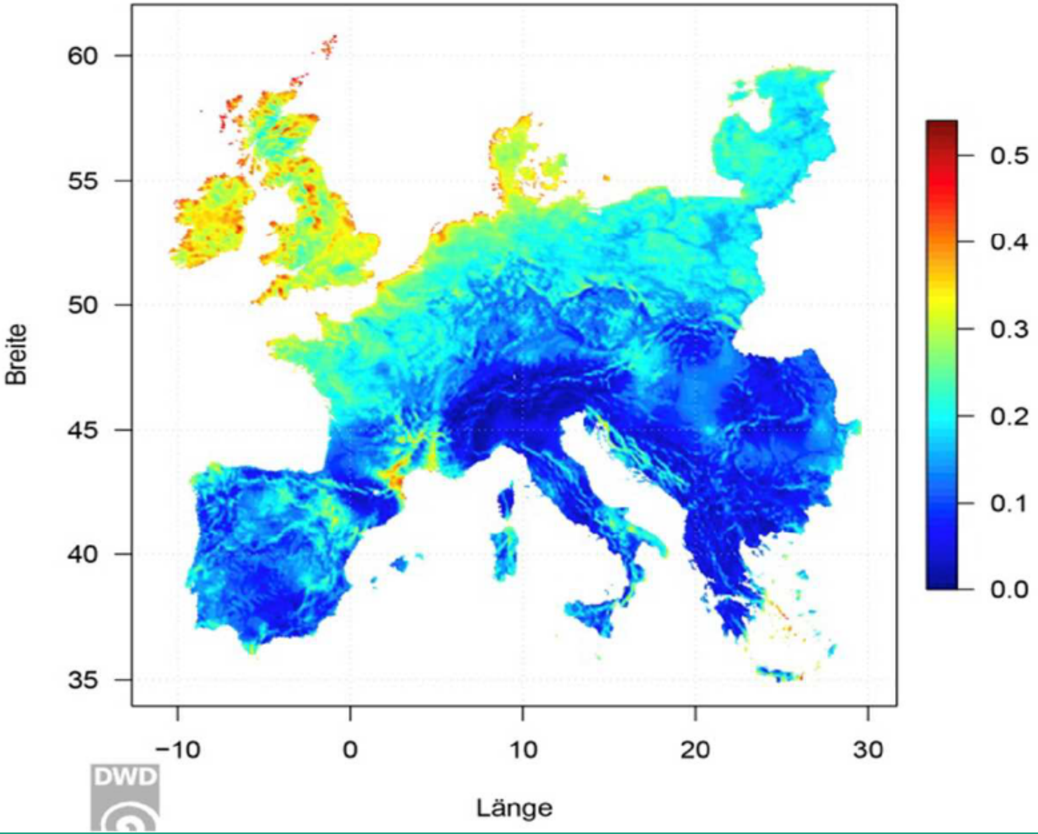
Note: Wind Speed at 100m, [m/s]

* maps obtained from https://globalsolaratlas.info and https://globalwindatlas.info

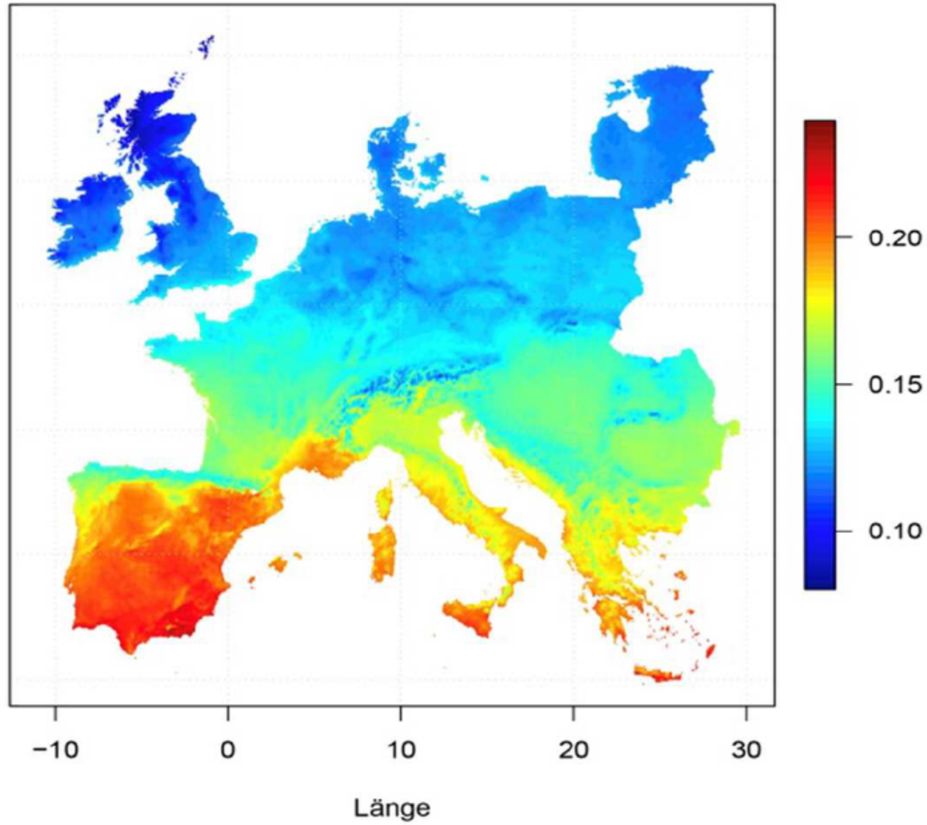
Averaged Capacity Factor for Wind and Solar Energy in Europe

1995 bis 2015

Wind



Solar



 Source: dwd.de/klima

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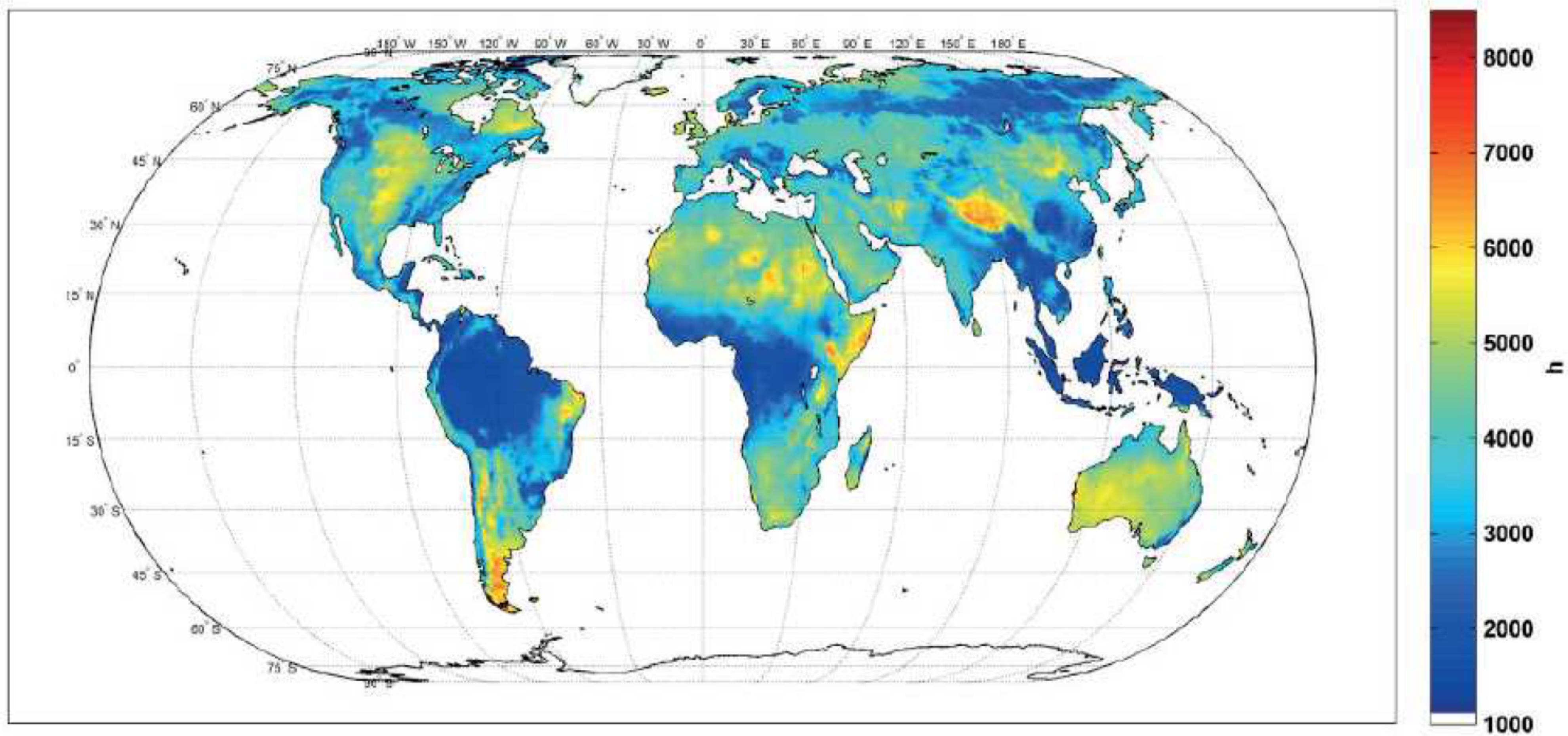
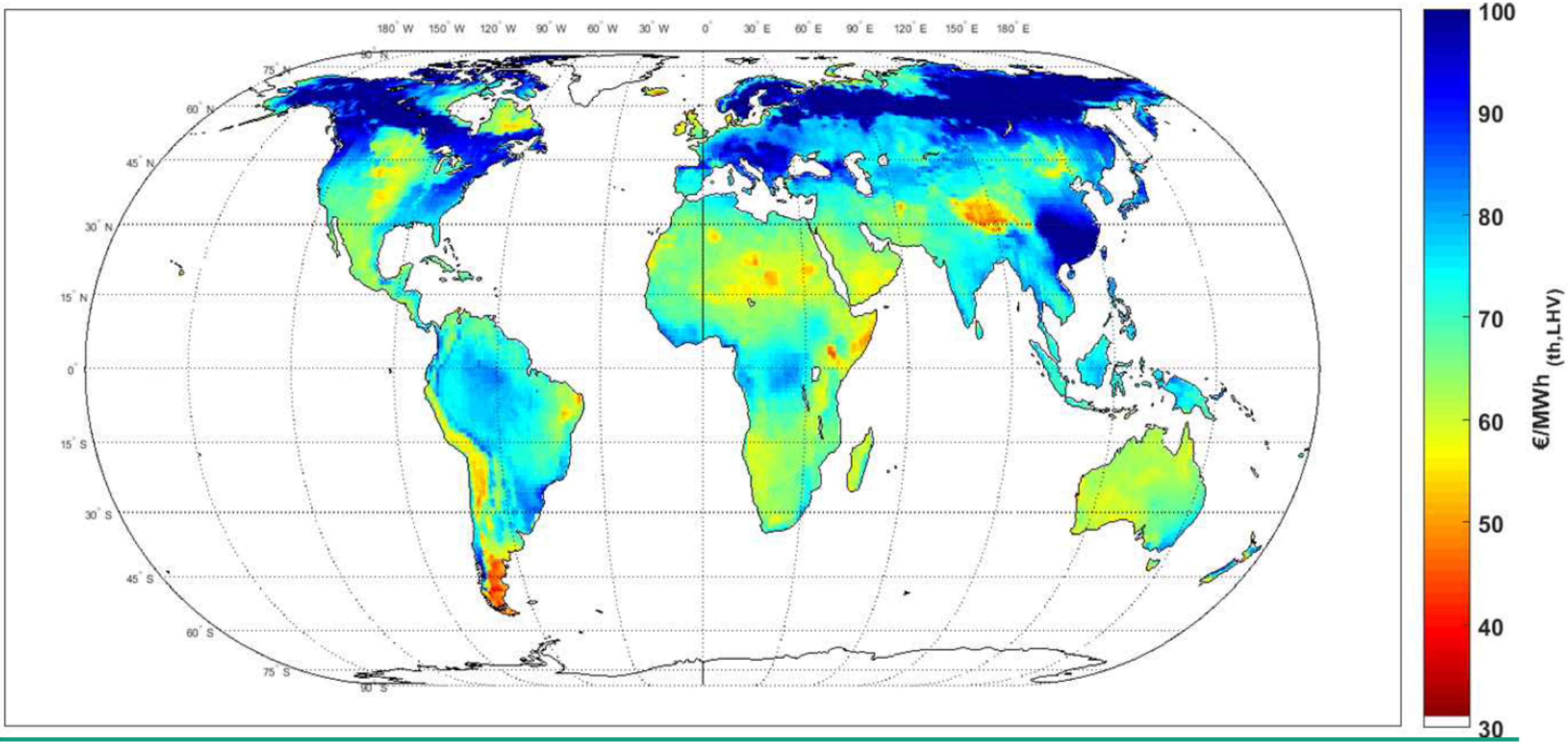
Full Load Hours of Photovoltaic and Wind Power Plants Combined



 Source: IEA (2017) Renewables

Identification of potential hydrogen supplier countries

Levelised cost of on-site green hydrogen production



 Source: Jensterle et al. 2019 (LUT-model)

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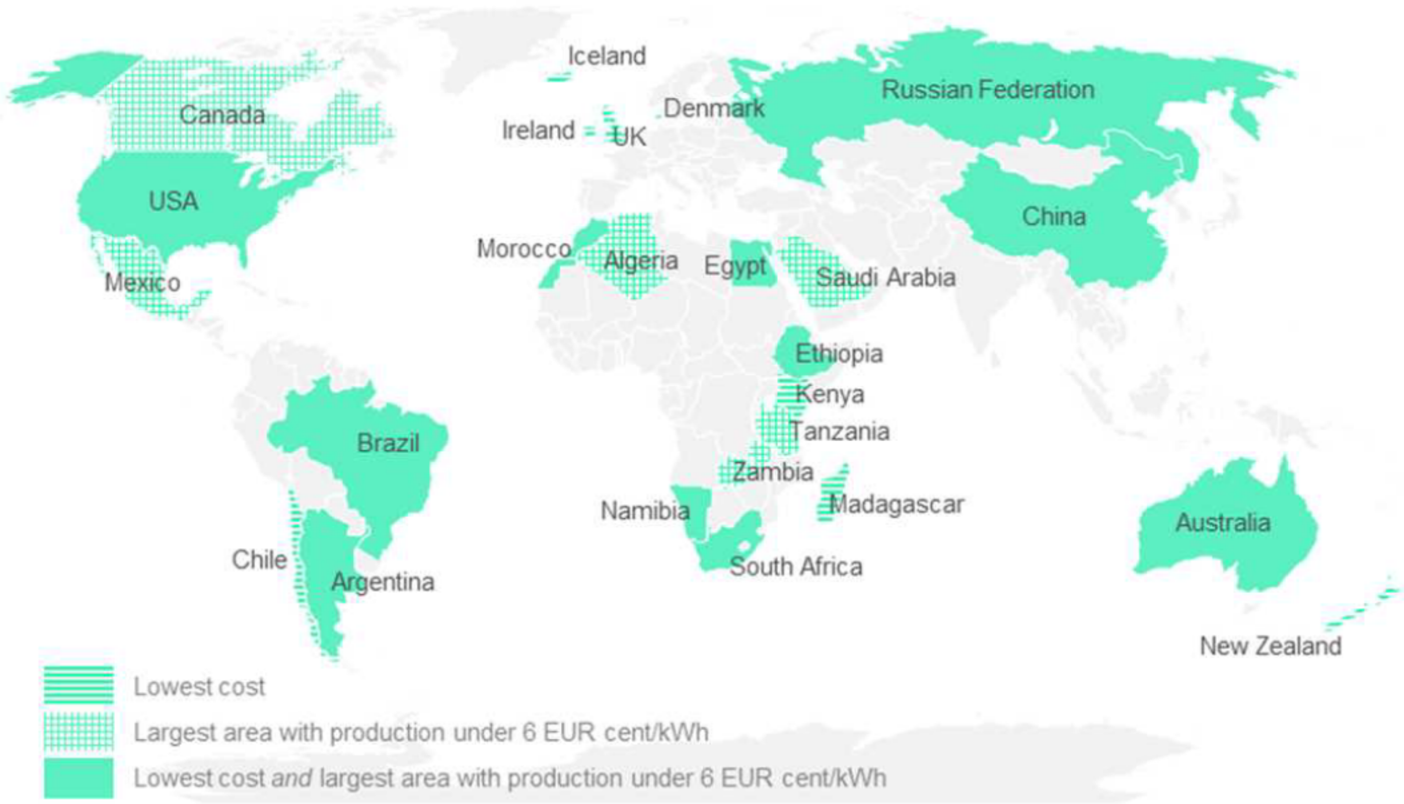
Identification of potential hydrogen supplier countries



Lowest costs and biggest production potential (top10):

- Argentina
- Australia
- Brazil
- China
- Egypt
- Morocco
- Namibia
- Russia
- South Africa
- United States

Source: Jensterle et al. 2019 (LUT-model)

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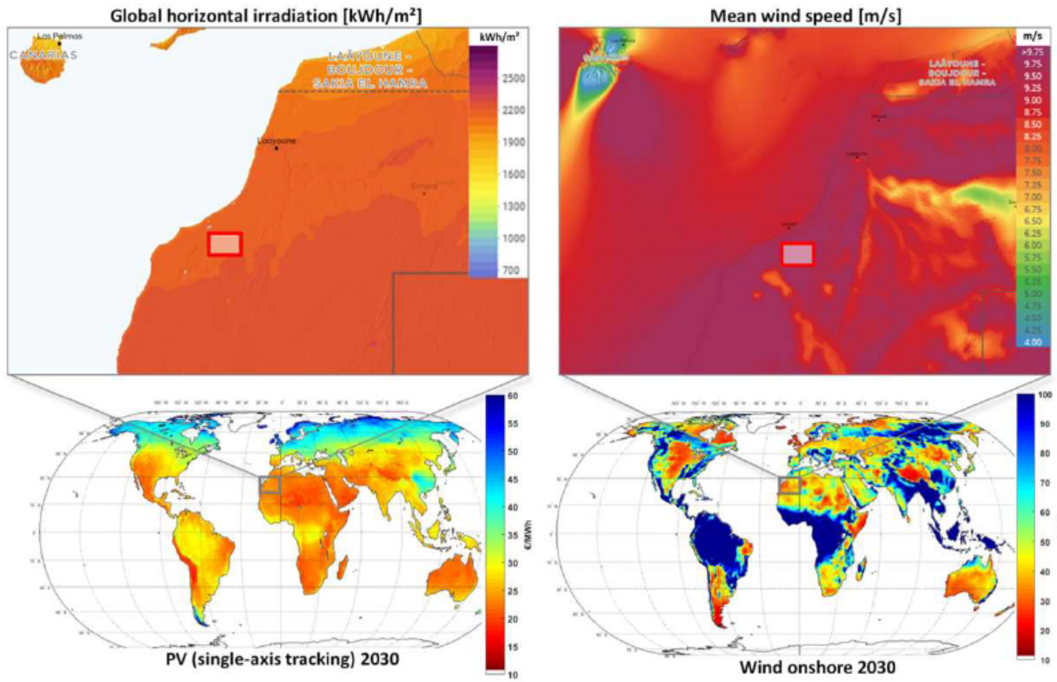
High Demand for Renewable Energy

Import of PtX products as one promising pathway

- “The import of PtX products from countries with high renewable energy potentials to countries with high energy demand presents a promising pathway.”
- **Which PtX energy carriers qualify suitable for long-distance transport?**
  - Methane, methanol, ammonia, liquefied hydrogen and hydrogen bound in LOHC*
  - Energy and cost efficiency
  - Influence of fluctuating renewables
  - Case study for transport Marocco → Germany



Source: Hank et al. 2020 – based on Fasihi et al. 2020

Source: Hank et al. 2020 - Energy efficiency and economic assessment of imported energy carriers based on renewable electricity - SUBMITTED

*LOHC: Liquid Organic Hydrogen Carriers

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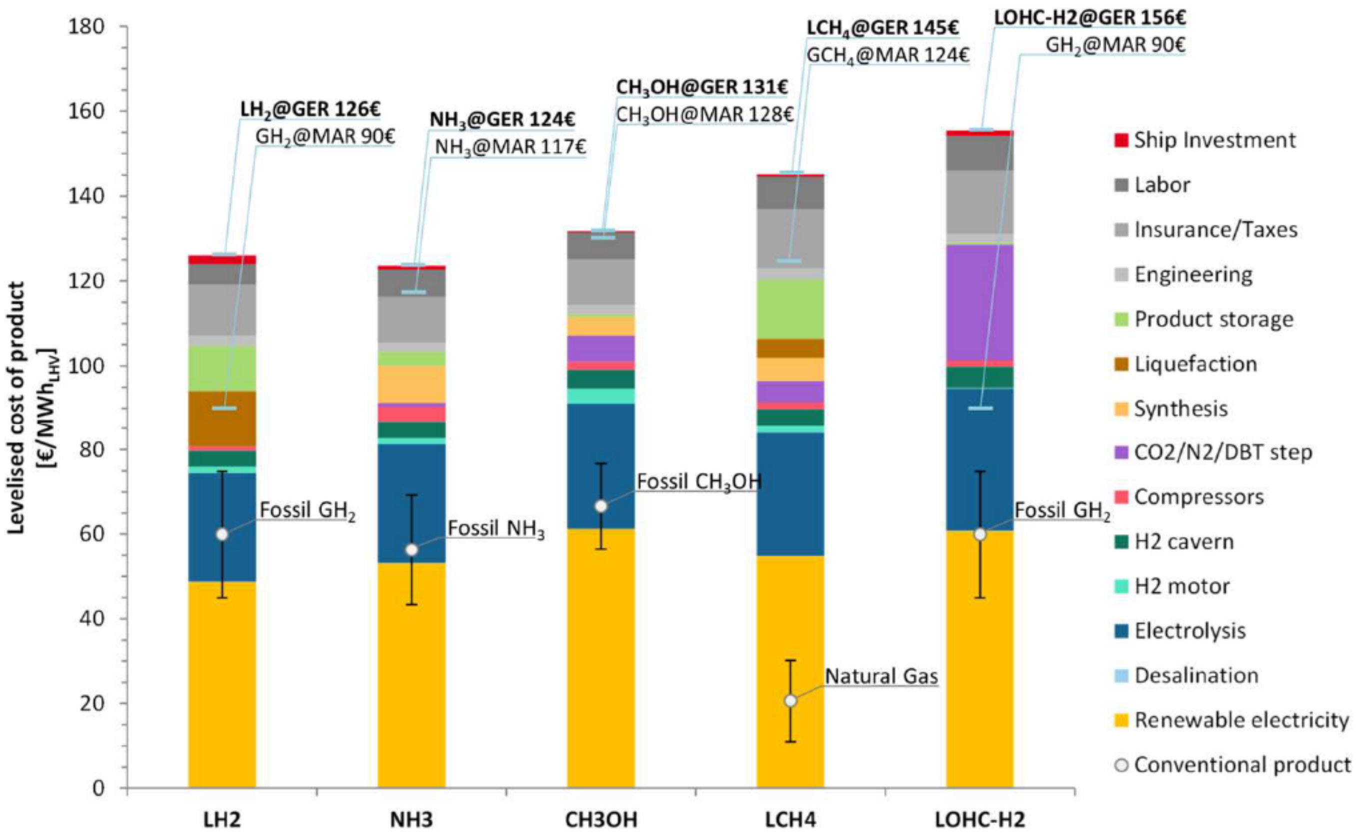
High Demand for Renewable Energy

Import of PtX products as one promising pathway



- **Production costs**: 124 – 156 € per MWh
- **Ship transport** does not significantly affect costs and efficiency of the PtX pathways (MAR to GER ~ 4000km)
- **Water provsion via desalination** with negligible impact on pathway efficiency and costs
- High initial investment for **LOHC-medium** (DBT)
- **Boil-off** of LH2 is considered to be used in a H2-gas motor

 Source: Hank et al. 2020 - Energy efficiency and economic assessment of imported energy carriers based on renewable electricity - Accepted

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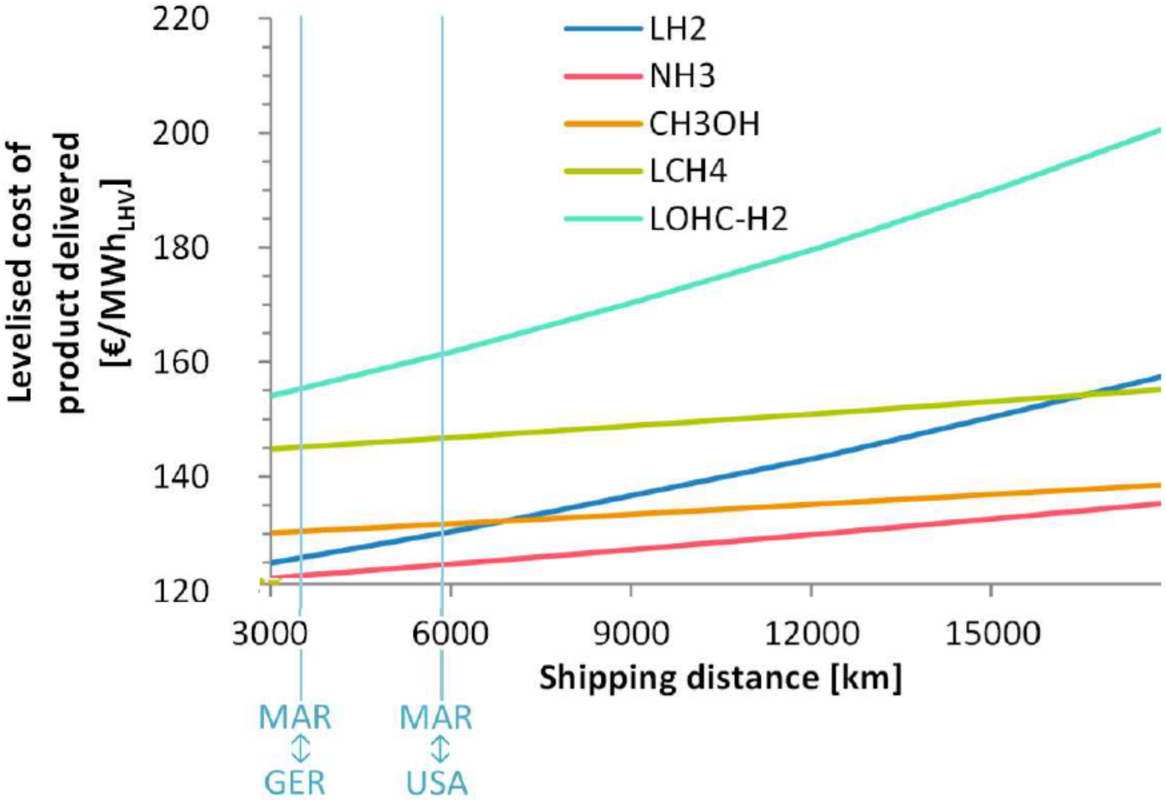
High Demand for Renewable Energy

Germany: Import of PtX products as promising pathway



- **Production costs** between: 124 – 156 € per MWh
- **Ship transport** does not significantly effect costs and efficiency of the PtX pathways (MAR to GER ~ 4000km)
- **Energy density** of transported energy carrier is the important parameter
- Longer transport distances increase the **cost difference between energy carriers** (JPN to AUS ~ 6600 km)

 Source: Hank et al. 2020 - Energy efficiency and economic assessment of imported energy carriers based on renewable electricity - Accepted

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Conclusions

Global trade of renewable energy is required and is beginning now

- The transformation of energy systems in line with GHG emission targets **is technically feasible**
- **National politics must develop clear pathes and targets** for GHG neutrality and set-up an **effective regulatory framework** (taxes, levies, incentives, etc.) to achieve the targets
- The **importance of electric energy is increasing** and renewables (solar, wind) will be dominant
- **Renewable Electricity in Power-to-X Applications** is increasing
  - **Coupling of sectors:** electricity use (directly, indirectly) for heat, chemistry and mobility
  - Large scale conversion of renewable electricity into **synthetic energy carriers** (H2, liquid fuels)
  - **Transformation is cost competitive** if CO_2 emissions appropriately penalized
- **Internationally harmonized and certified standards** with a strong governance frameworks are needed for hydrogen-based energy carriers and chemicals
- **International research cooperations and energy partnerships** are a prerequisite for faster progress, longterm trading relationships and a secure investment environment

Thank You for Your Attention

Fraunhofer Institute for Solar Energy Systems

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