Prof. Dr. Hans-Martin Henning
791. WE-Heraeus-Seminar, Bad Honnef, June 19th 2023

Transformation of Germany's energy system in the context of the EU Green Deal targets

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INSTITUT FÜR NACHHALTIGE TECHNISCHE SYSTEME
universität freiburg

Agenda

Introduction

Key drivers for the transformation of the energy system

Greenhouse gases and climate change

oben links: National Geographic, October 10th 2020 | oben rechts: BBC, May, 22nd 2020
unten links: Time, May 22nd 2020 | unten rechts: The Guardian, March 11th 2020

Energy imports and security of supply

oben: de.wikipedia.org/wiki/Europipe_(Pipeline)#/media/Datei:EuropipeII.jpg
unten: www.wikidata.org/wiki/Q52353566

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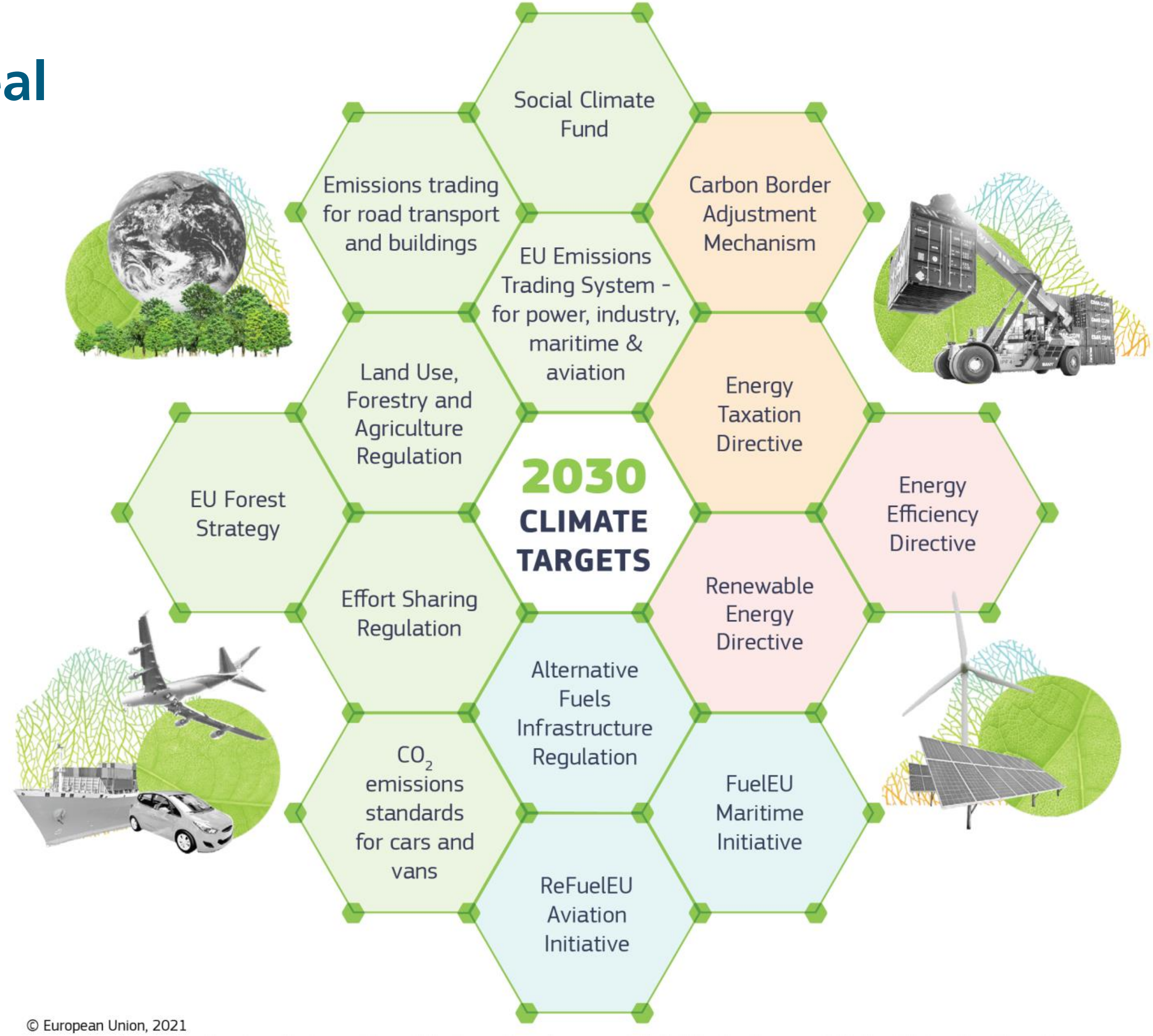
Introduction – European Green Deal

Delivering the European Green Deal

- **Climate neutrality by 2050**
- **Reduction of GHG emissions by 55 % compared to 1990 by 2030**
- **Up to 90 billion € for just transition**



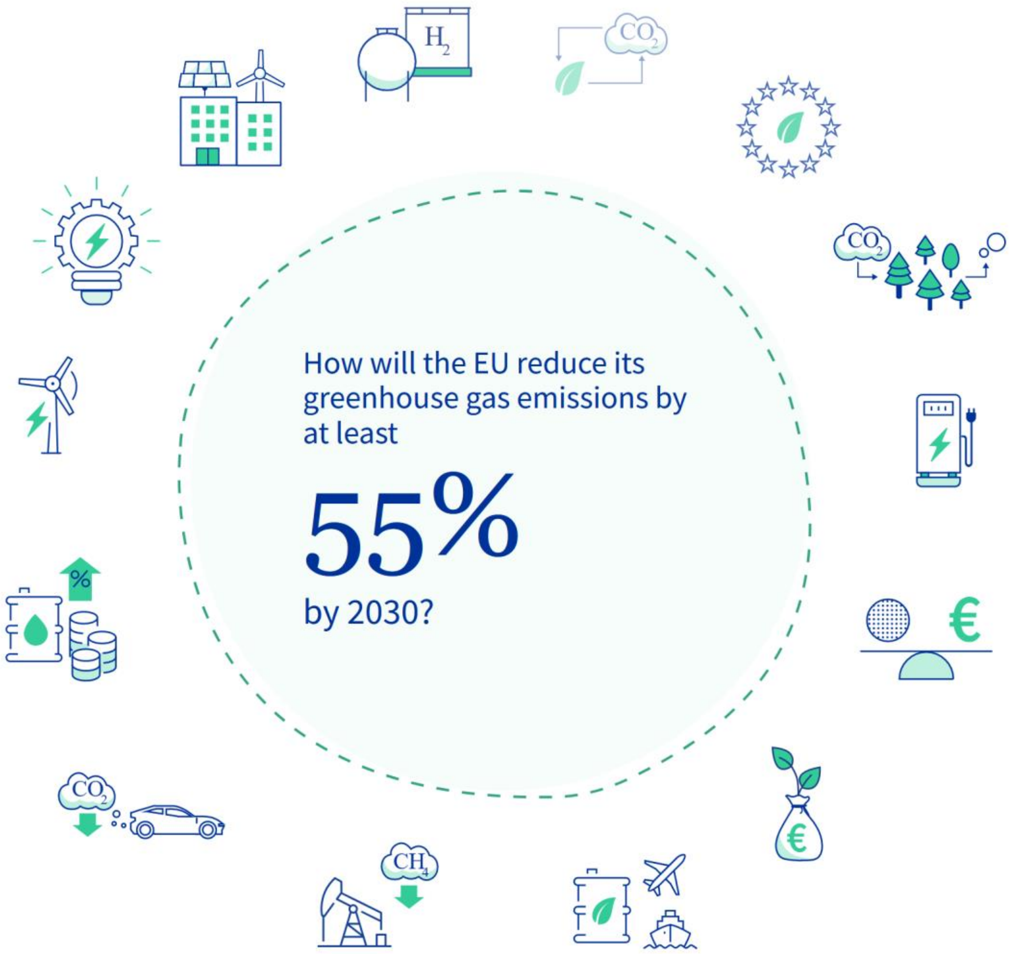
© European Union, 2021

Introduction – European Green Deal

Fit for 55 – Reducing net greenhouse gas emissions by 55% by 2030

Overview of aspects of “Fit for 55”:

- Reform of the European Emissions Trading Scheme
- A new emissions trading scheme for buildings and transport
- CO_2 border adjustment for individual indsutries
- Expansion of renewable energies
- Increasing energy efficiency
- Automotive: Fleet limits and charging infrastructure
- Land and forest as CO_2 sinks



https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

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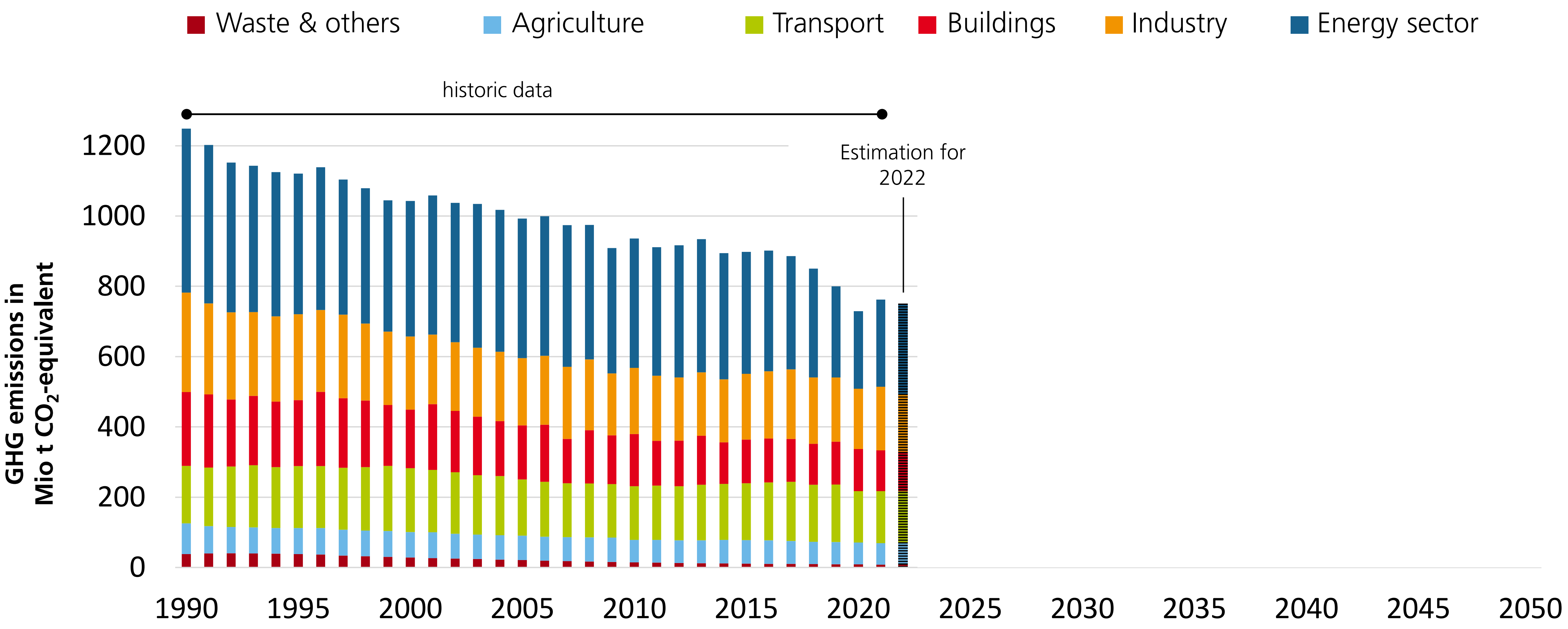
Introduction – Germany's Federal Climate Change Act (KSG)

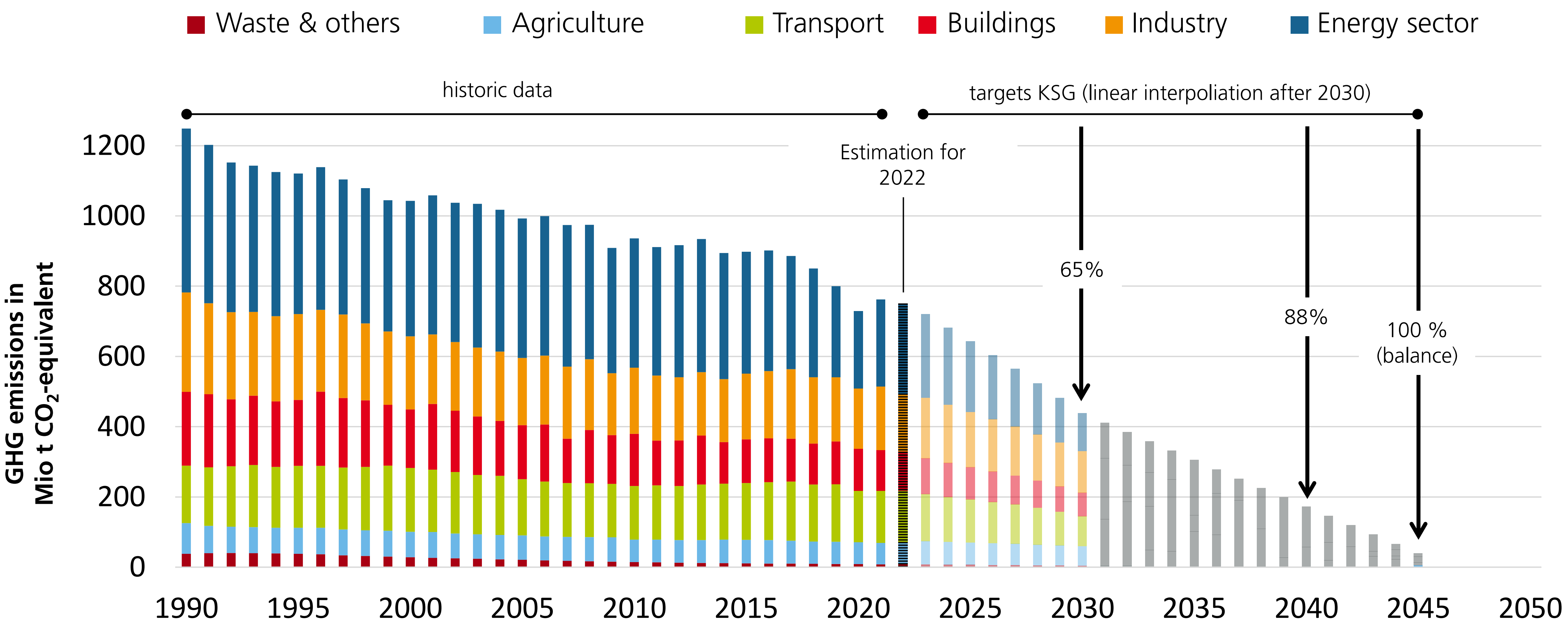
Germany's GHG Emissions – Historic Data and Targets



Historische Daten und VJS: Vorjahreschätzung (VJS) der deutschen Treibhausgas-Emissionen für das Jahr 2022. Umweltbundesamt, 15.3.2023

Introduction – Germany's Federal Climate Change Act (KSG)

Germany's GHG Emissions – Historic Data and Targets



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Agenda

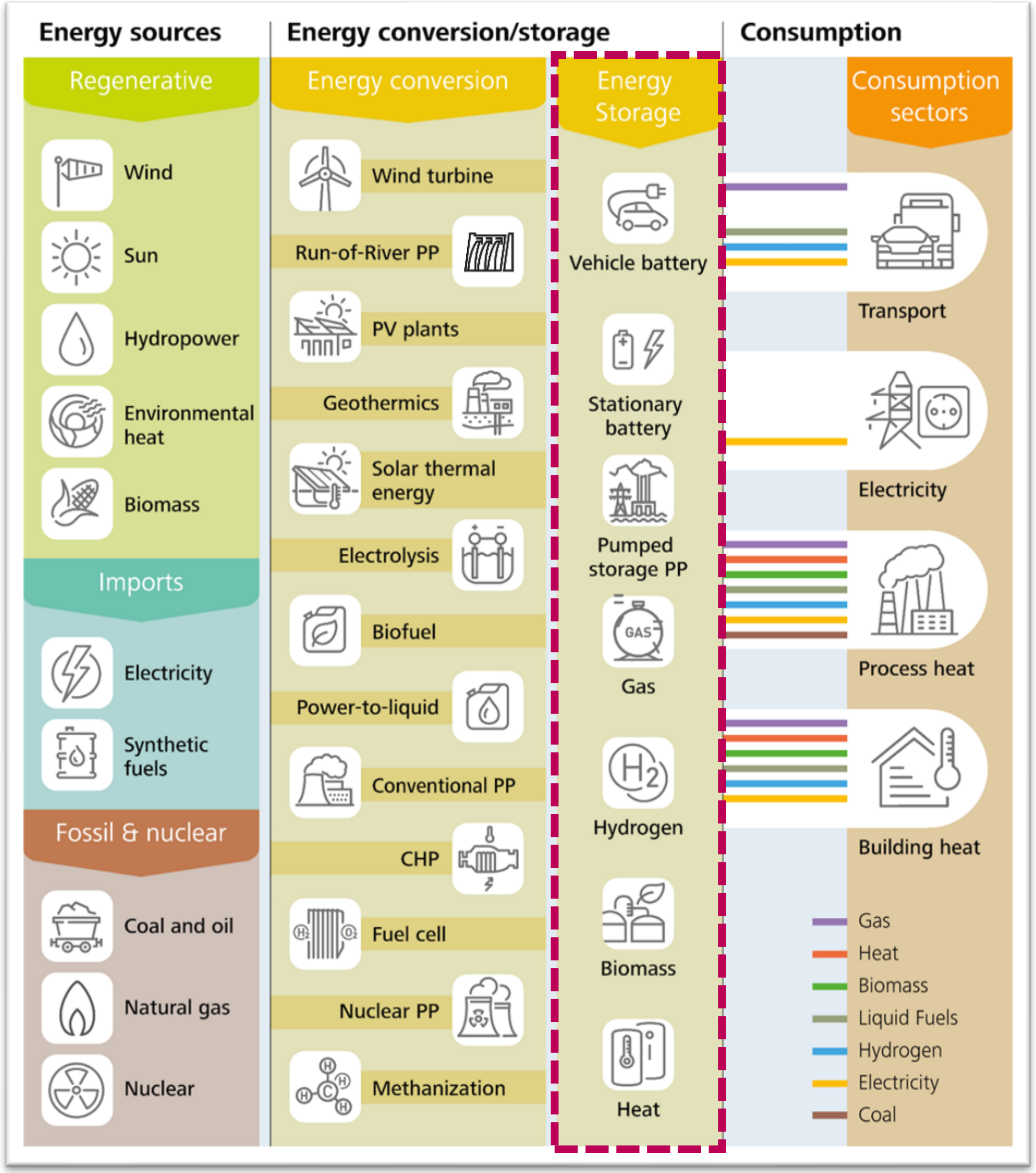
1. Introduction
2. **Energy system analysis**
3. Security of supply
4. Value chain and technology sovereignty
5. Conclusion

Energy System Analysis – Methodology

Renewable Energy Model »REMod«

Strictly model-based techno-economic optimization of transformation pathways

- Consideration of all end-use sectors and energy sources
- Comprehensive simulation of energy systems (hourly time scale)
- Mathematical optimization: Minimize total transformation cost in strict compliance with climate protection targets (year by year; climate neutrality in 2045)



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Energy System Analysis – Methodology

Methodology: Scenarios

Reference

cost-optimal path

- –

Persistence

Persistence on conventional technologies

- Transport: higher share of combustion engines in new passenger car registration
- Buildings: … gas boilers for new installations, fewer … ver renovation rate

Reduction of energy-related CO_2 emissions according to Federal Climate Change Act (climate neutrality 2045)

Non-Acceptance

Massive … against th… of wind tu… transmiss…

- Reduction of the expansion potential for wind energy
- Resistance against expansion of electric transmission grids
- Reduced grid expansion for electricity imports

Sufficiency

Energy savings and behavioral changes

- Decrease in energy consumption in all sectors (e.g. fewer kilometers driven, decrease in demand for electricity, energy efficiency)
- System-serving behaviour (e.g. vehicle-to-grid, buildings)

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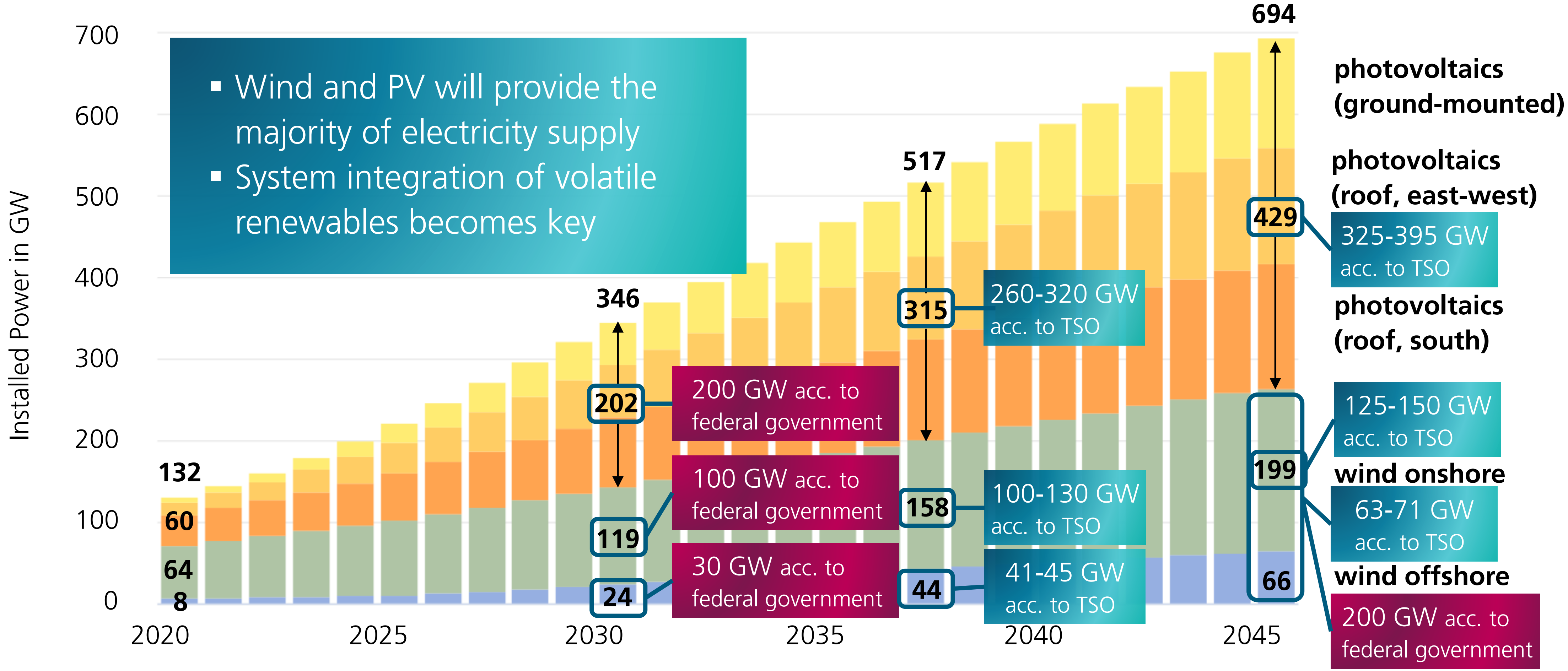
Energy System Analysis – Results

Expansion of solar PV and wind energy converters (Scenario Reference)



Studie: Fraunhofer ISE, Wege zu einem Klimaneutralen Energiesystem – Die deutsche Energiewende im Kontext gesellschaftlicher Verhaltensweisen, Update November 2021: Klimaneutralität 2045
Eröffnungsbilanz Klimaschutz des BMWK (13.01.2022). Szenariorahmen zum Netzentwicklungsplan Strom 2037 mit Ausblick 2045, Version 2023 (Januar 2022).

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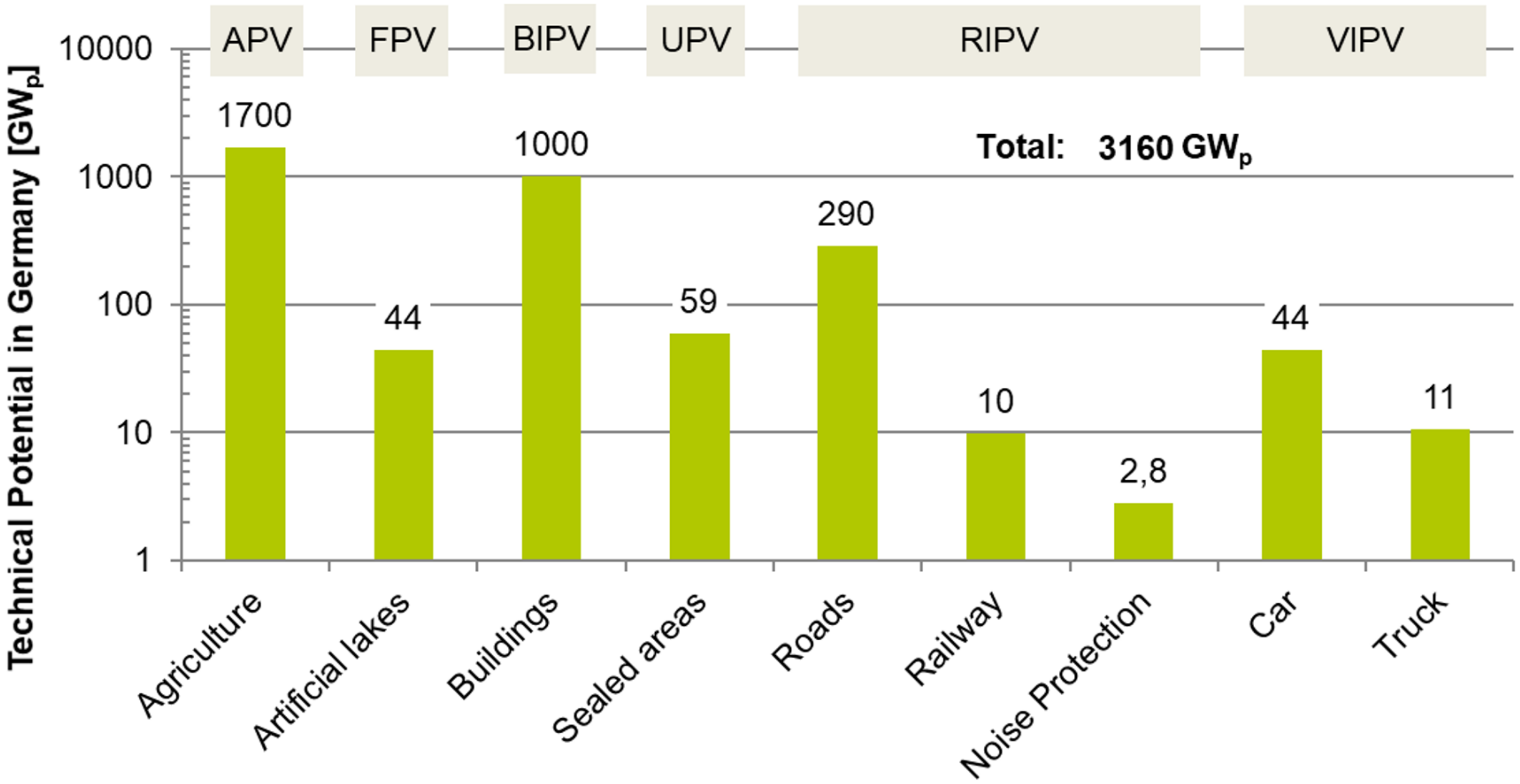
Energy System Analysis – Results

Integrated Photovoltaics – Potentials in Germany



APV	**Agri-Photovoltaik**
FPV	**Floating PV**
BIPV	**Building integrated PV**
UPV	**Urban PV**
RIPV	**Road integrated PV**
VIPV	**Vehicle integrated PV**

Energy System Analysis – Results

Primary energy by energy carriers or sources

Studie: Fraunhofer ISE, Wege zu einem Klimaneutralen Energiesystem – Die deutsche Energiewende im Kontext gesellschaftlicher Verhaltensweisen, Update November 2021: Klimaneutralität 2045.
Daten: https://energy-charts.info

Energy System Analysis – Results

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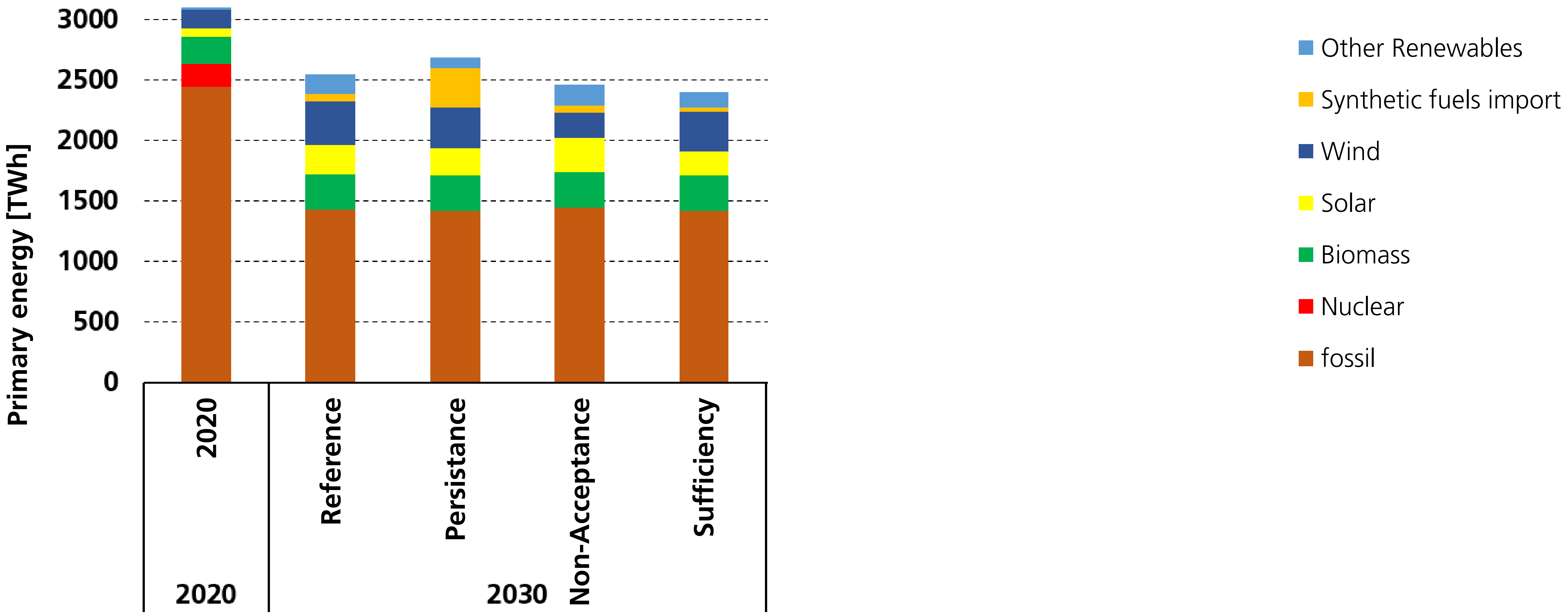

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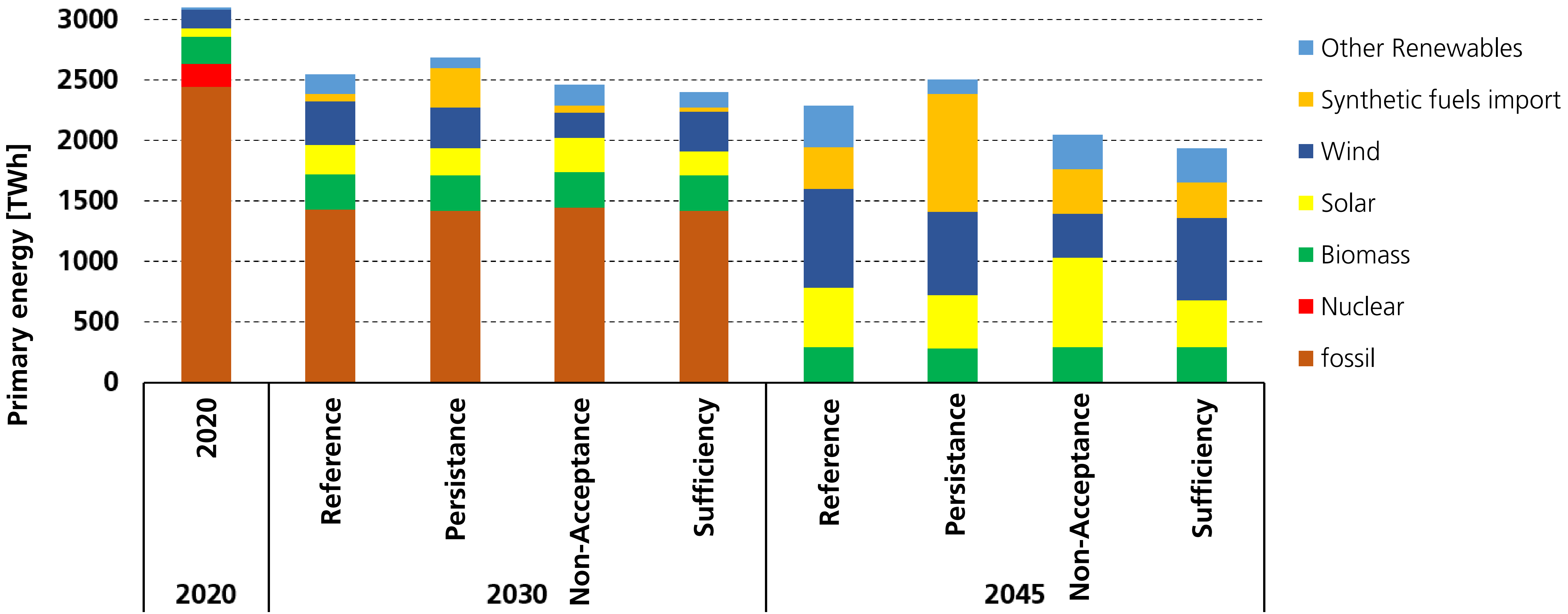

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Energy System Analysis – Results

Final energy use by sector

Studie: Fraunhofer ISE, Wege zu einem Klimaneutralen Energiesystem – Die deutsche Energiewende im Kontext gesellschaftlicher Verhaltensweisen, Update November 2021: Klimaneutralität 2045.
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Energy System Analysis – Results

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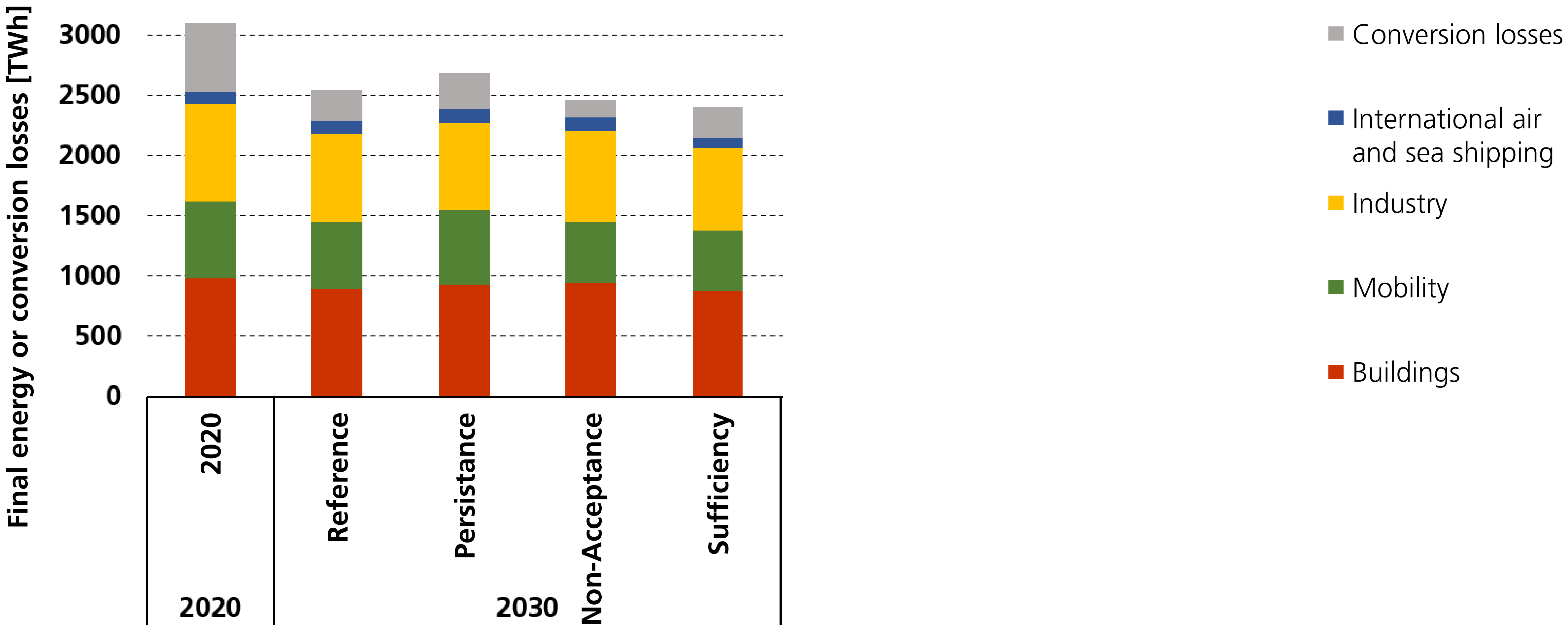

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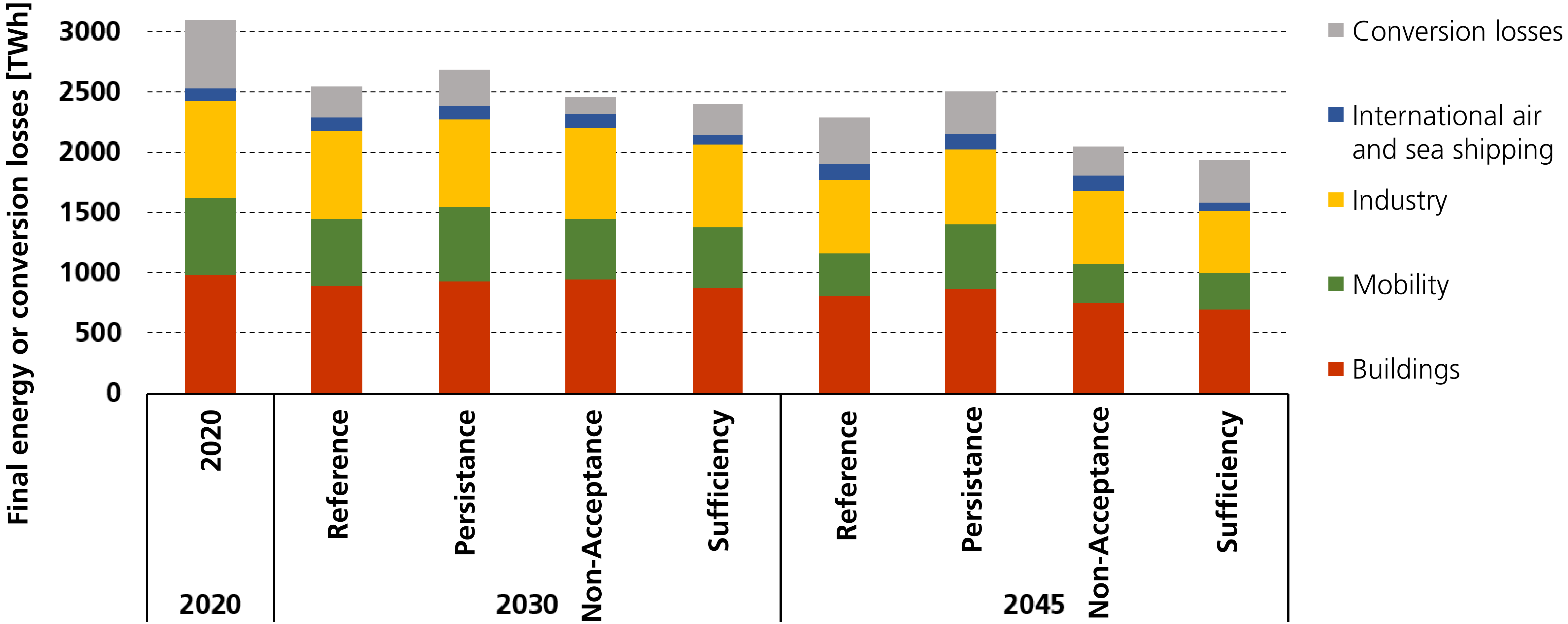

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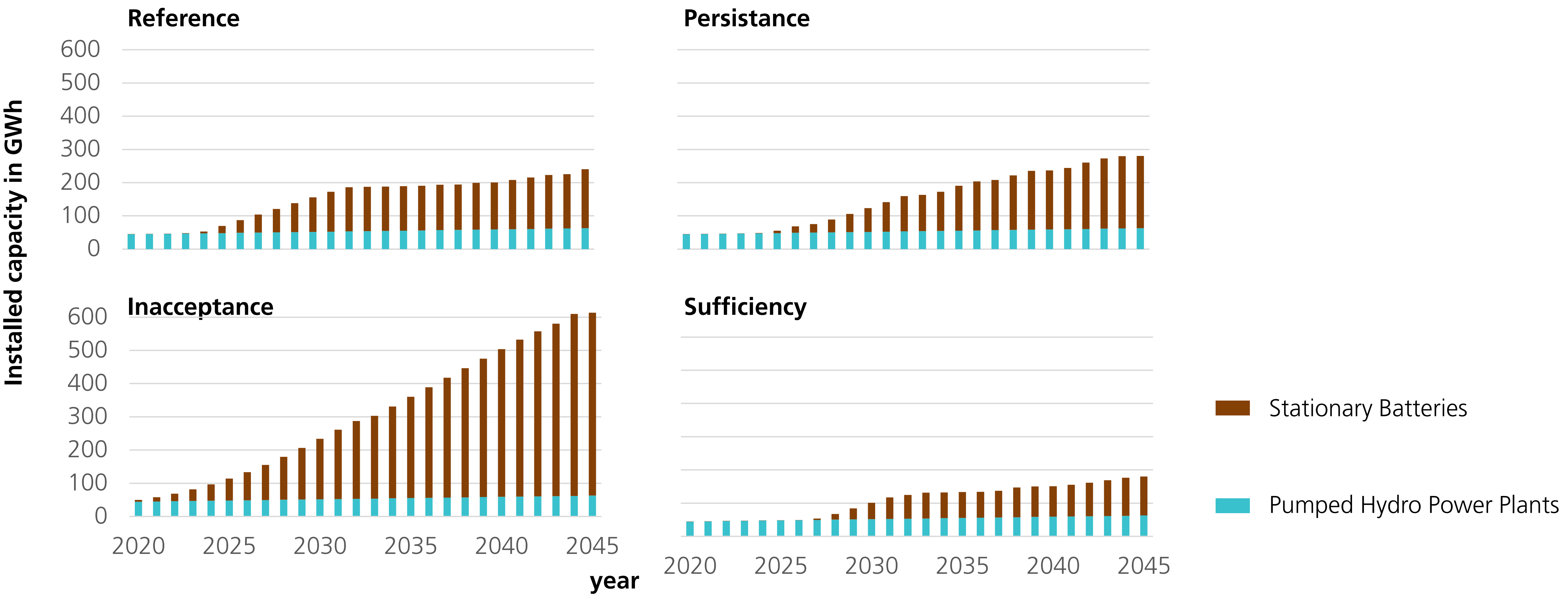
Energy System Analysis – Results

Installed capacity of staionary batteries and pumped hydro power plants



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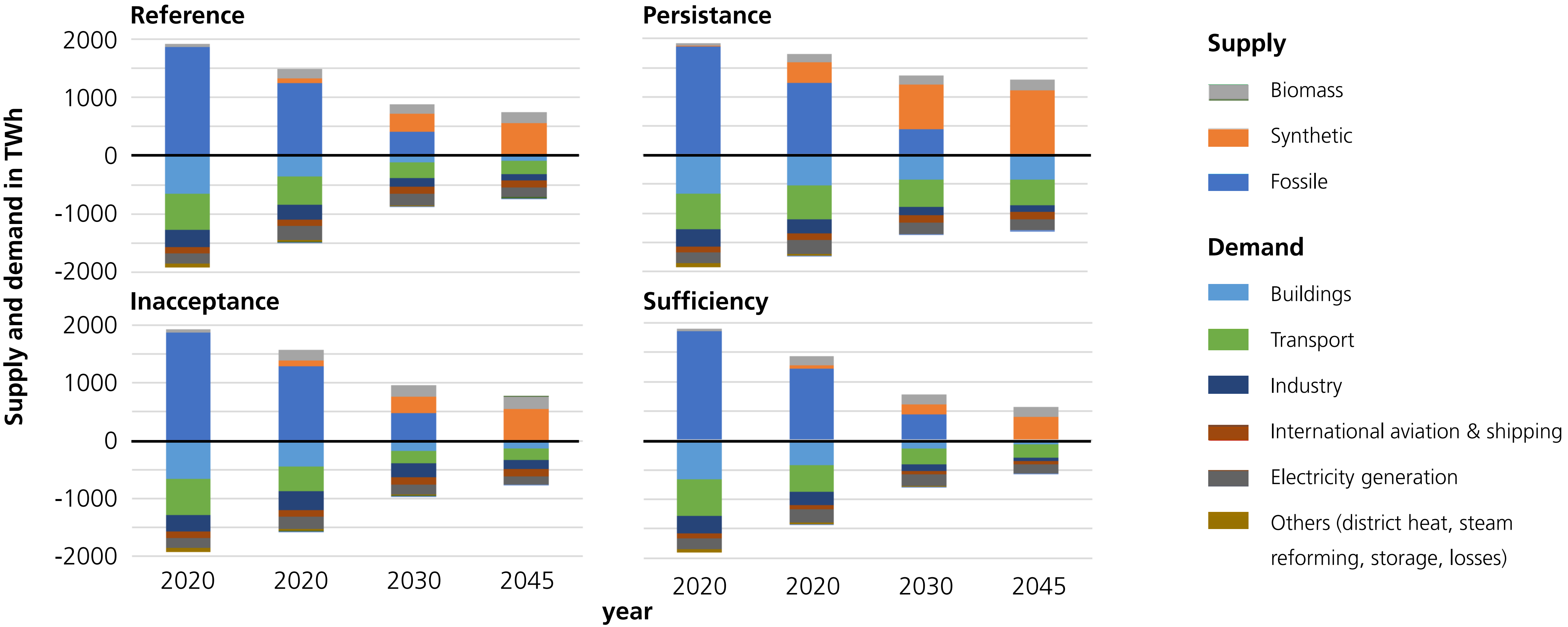
Energy System Analysis – Results

Supply and demand of fossile and synthetic energy carriers and biomass



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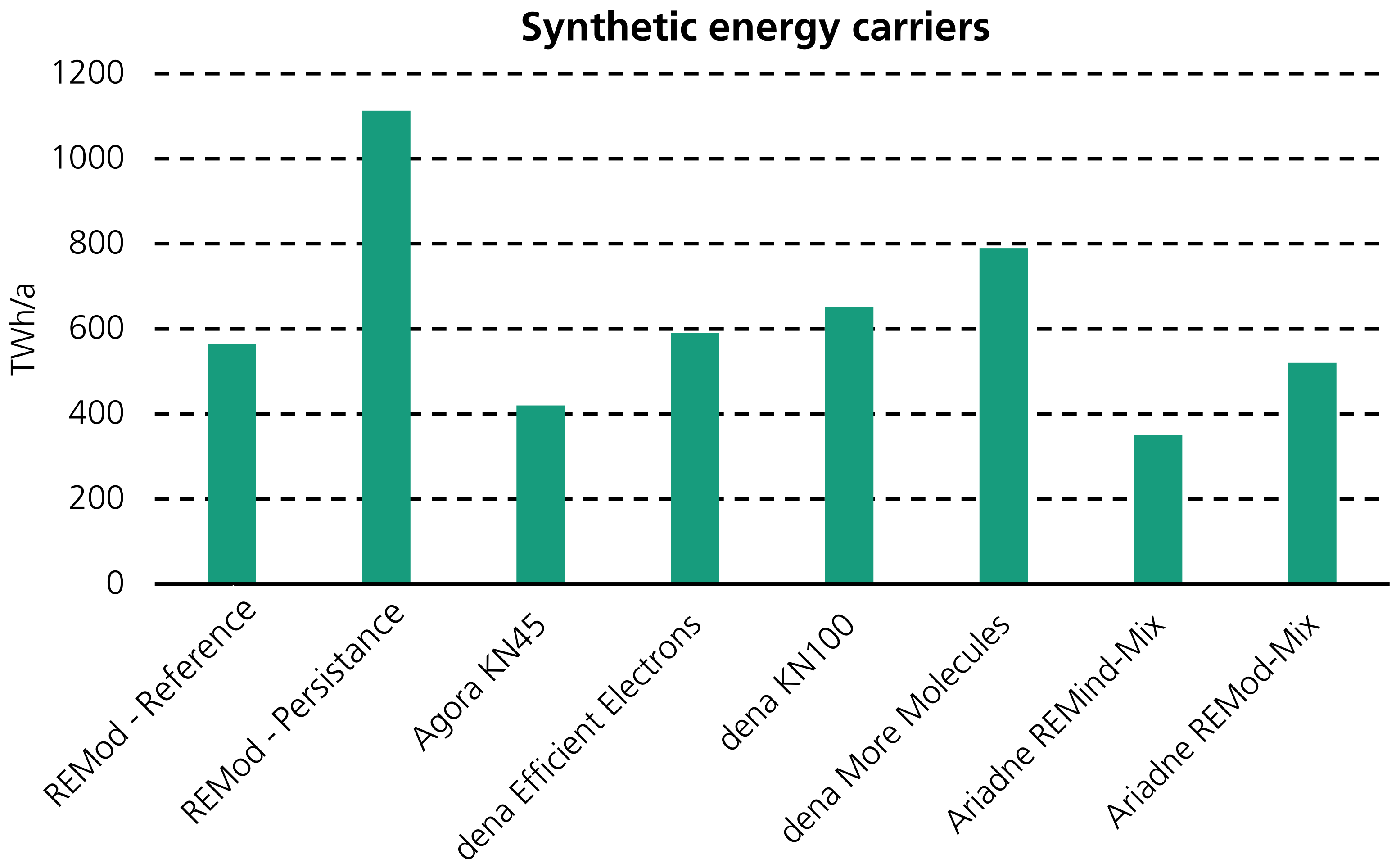
Energy System Analysis – Results

Comparison of current studies



- Range between different studies: below 400 TWh up to around 1100 TWh (without biomass)
- Robust range: 400-600 TWh
- »Persistance« represents an extreme scenario

Energy System Analysis – Results

Final energy: direct vs. indirect electrification

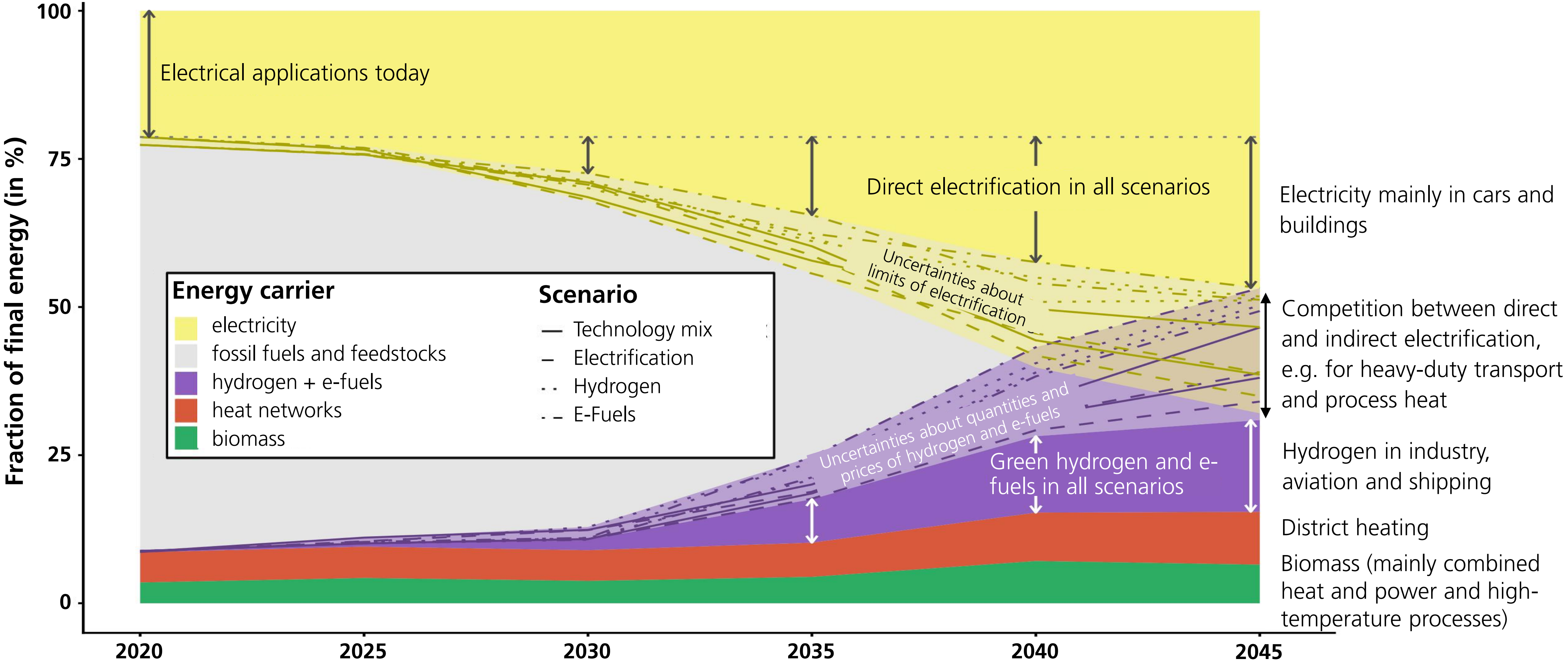


Figure translated from: Ariadne Kurzdossier 2021: Durchstarten trotz Unsicherheit, 16.11.2021, https://ariadneprojekt.de/publikation/eckpunkte-einer-anpassungsfaehigen-wasserstoffstrategie/

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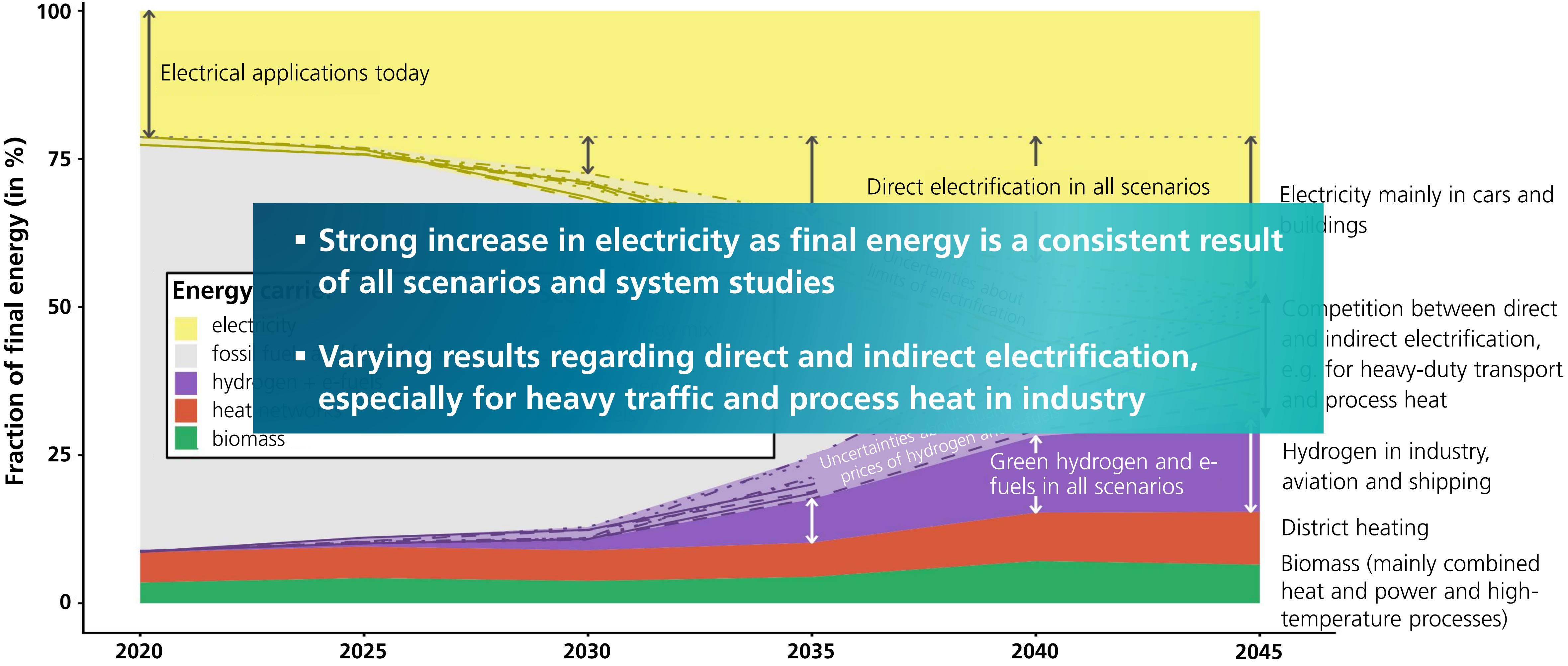
Energy System Analysis – Results

Final energy: direct vs. indirect electrification



- **Strong increase in electricity as final energy is a consistent result of all scenarios and system studies**
- **Varying results regarding direct and indirect electrification, especially for heavy traffic and process heat in industry**

Figure translated from: Ariadne Kurzdossier 2021: Durchstarten trotz Unsicherheit, 16.11.2021, https://ariadneprojekt.de/publikation/eckpunkte-einer-anpassungsfaehigen-wasserstoffstrategie/

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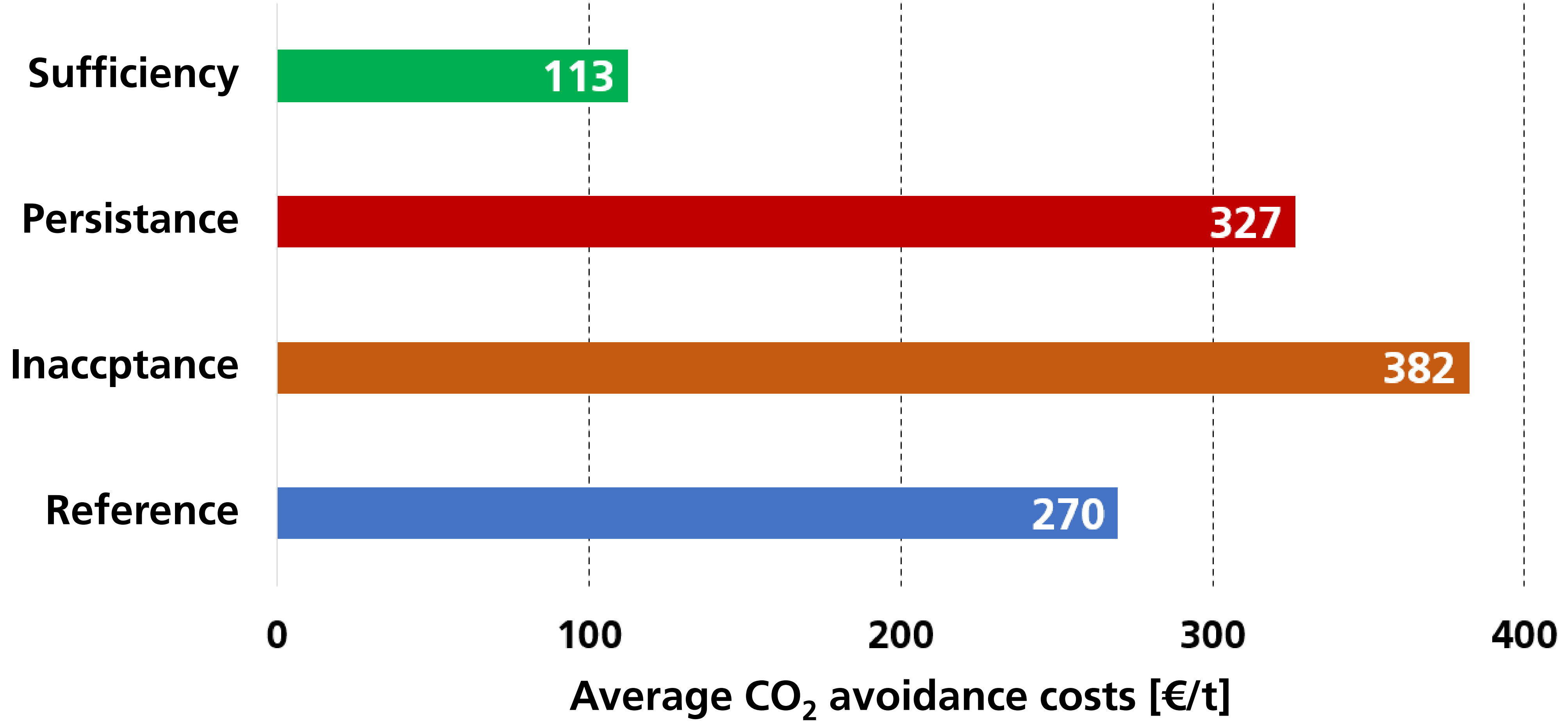
Energy System Analysis – Results

CO_2 avoidance costs – Comparison with business-as-usual scenario (no compliance with climate targets)



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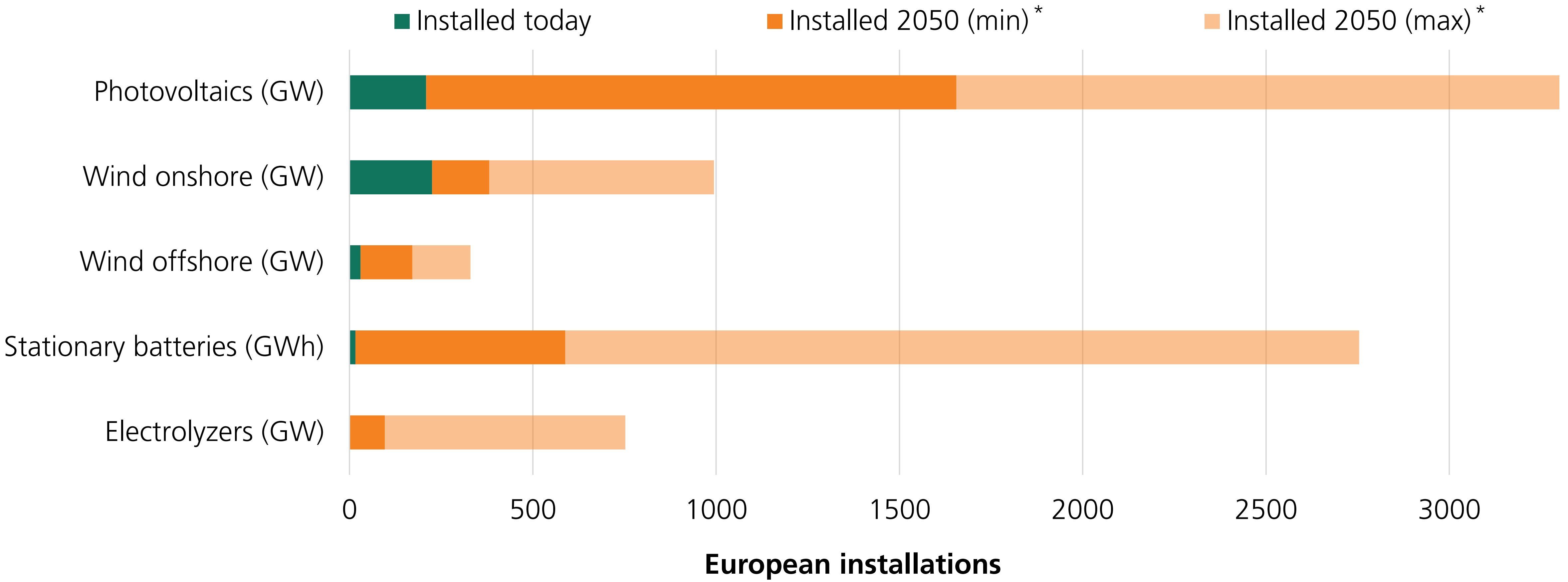
Energy System Analysis – Results

Extrapolation to Europe: Todays installations and estimated necessary installations



* Estimated from the REMod scenarios for Germany (mininum and maximum value of the four scenarios)

Energy System Analysis – Summary

- A successful energy transition requires a **significantly reduced share of chemical energy carriers** to approx. 400 - 600 TWh (today: almost 2500 TWh)
- The demand for electricity increases significantly – **electricity becomes the most important primary energy**
- There is **leeway for the composition of the final energy** in relation to the proportions of electrical energy and chemical energy carriers (hydrogen and its derivatives) ➔ A high proportion of chemical energy carriers requires an even greater and faster ramp-up in the global production of synthetic energy carriers and chemical products
- Therefore, a path of **direct electricity use** is recommended for applications wherever feasible
- Use of **hydrogen and other synthetic chemical energy carriers**, especially in the area of **no-regret applications** (chemical and raw materials industry, transport sector)
- **Energy efficiency and energy-saving behavior** leads to significantly lower amount of installed capacity for technical components and thus to lower investments and transformation costs

Agenda

1. Introduction
2. Energy system analysis
3. **Security of supply**
4. Value chain and technology sovereignty
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Security of supply

The four aspects of energy security

1 **Electrotechnical security of supply** (frequency and voltage stability, instantaneous reserve, ...)
➔ **Power electronics**

2 **Continuous coverage of electricity demand** with high shares of volatile renewables (“cold dark doldrums” or “kalte Dunkelflaute”) ➔ New paradigm of grid operation: **flexibilization, energy storage, controllable residual power plants**

3 Ensuring the **availability and affordability of imported energy sources** ➔ Increasing the share of **domestic energy sources**; diversification of imports

4 **Cyber security** of the flexible, digitized energy system
➔ **High standards for data communication, concepts for cyber resilience**

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Security of supply

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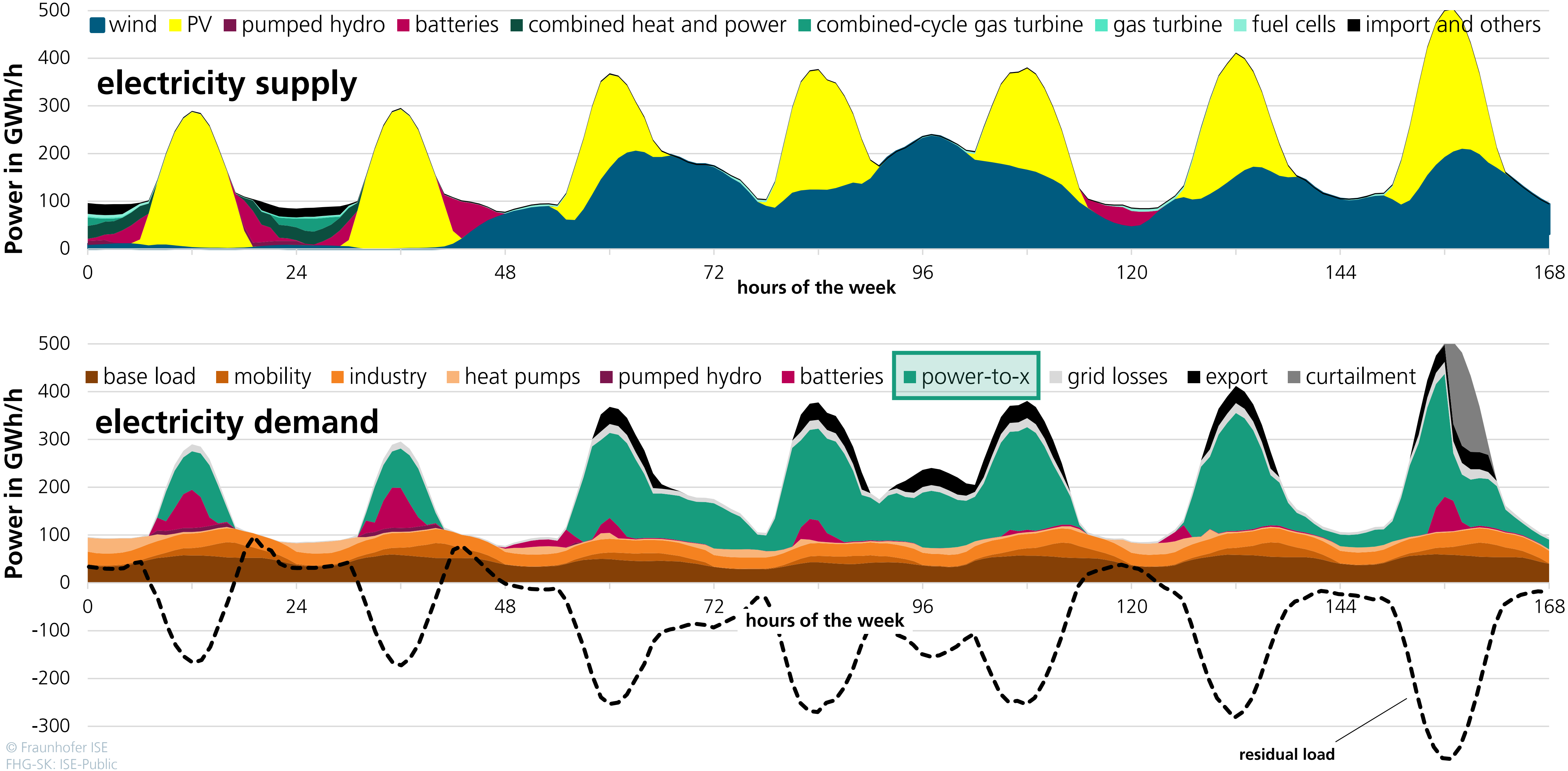
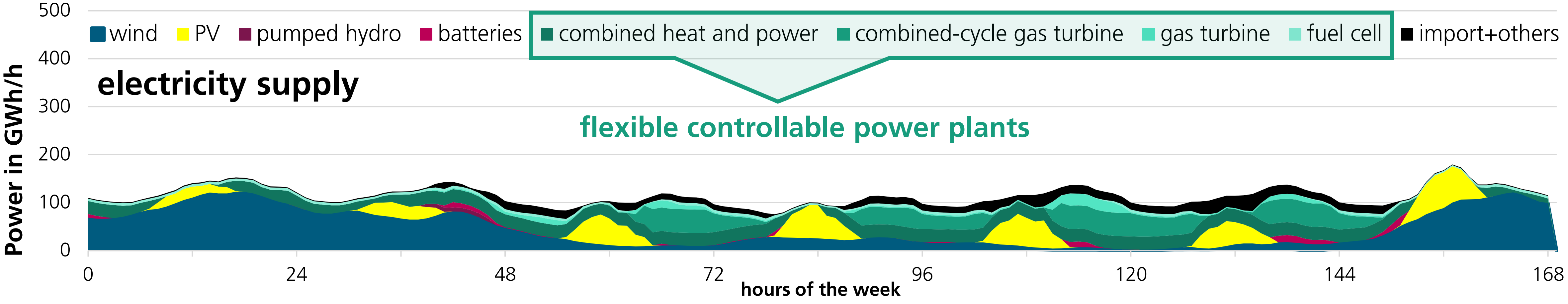
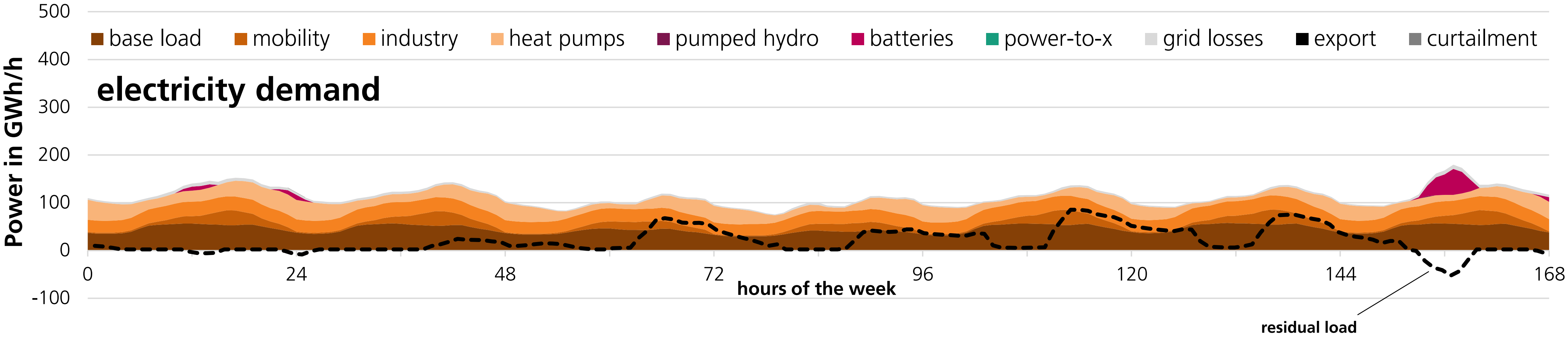
   ➔ **High standards for data communication, concepts for cyber resilience**

Electricity Supply and Demand in a Summer Week (Reference Scenario, 2045)



Electricity Supply and Demand in a Winter Week (Reference Scenario, 2045)





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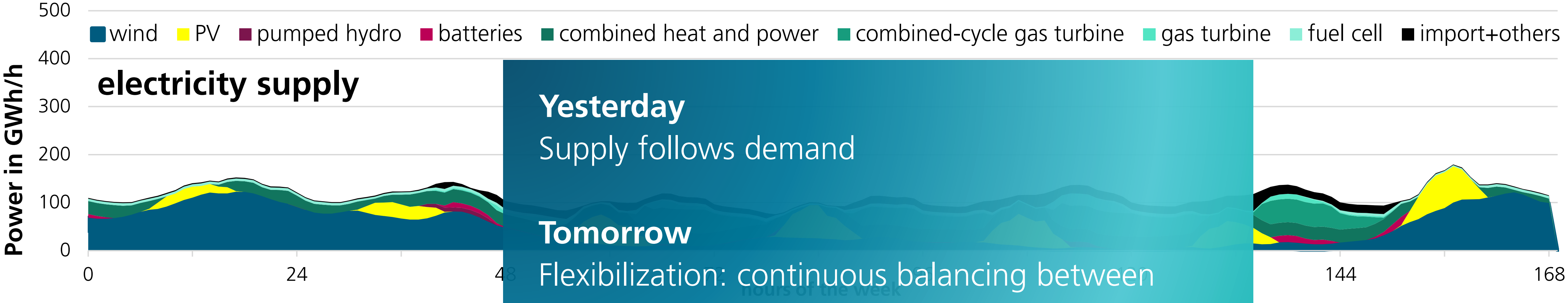


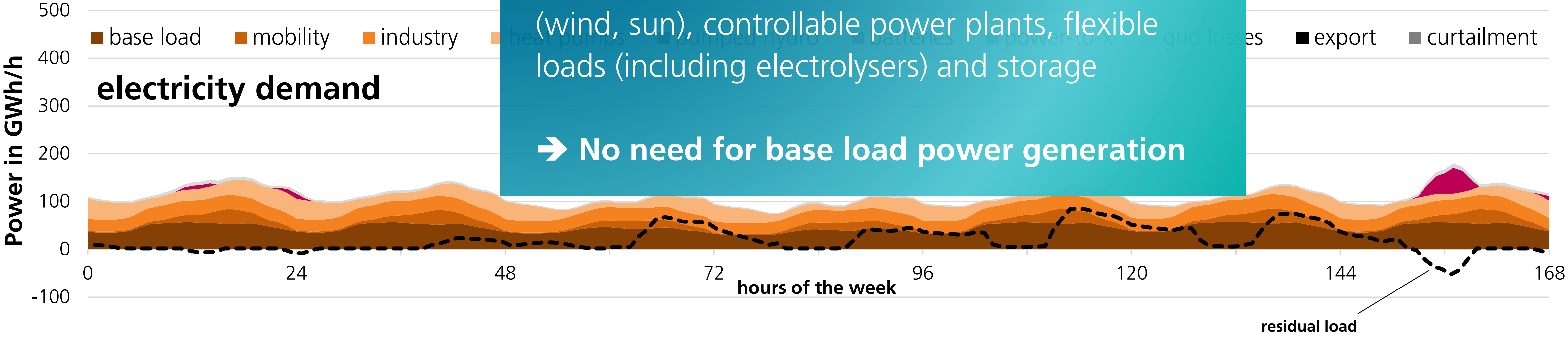
Yesterday

Supply follows demand

Tomorrow

Flexibilization: continuous balancing between power generation from renewable energies (wind, sun), controllable power plants, flexible loads (including electrolysers) and storage

➔ No need for base load power generation



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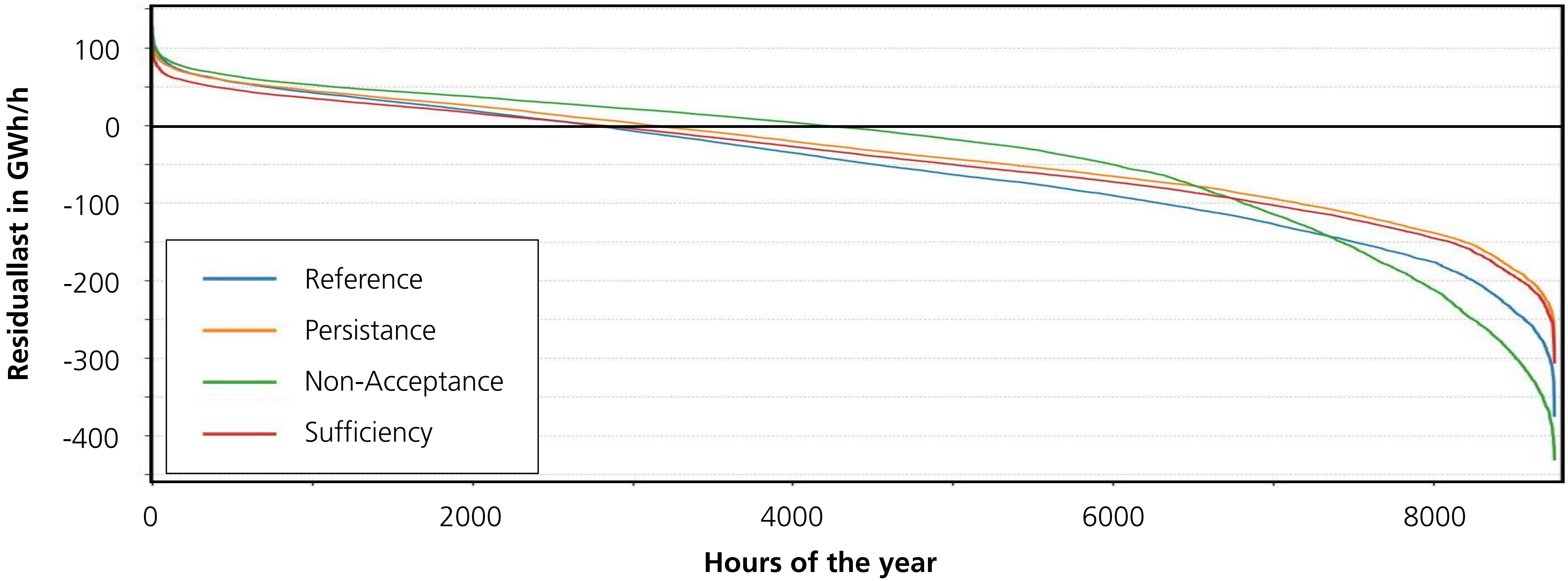
Security of supply: Continuous coverage of electricity demand

Annual duration curve



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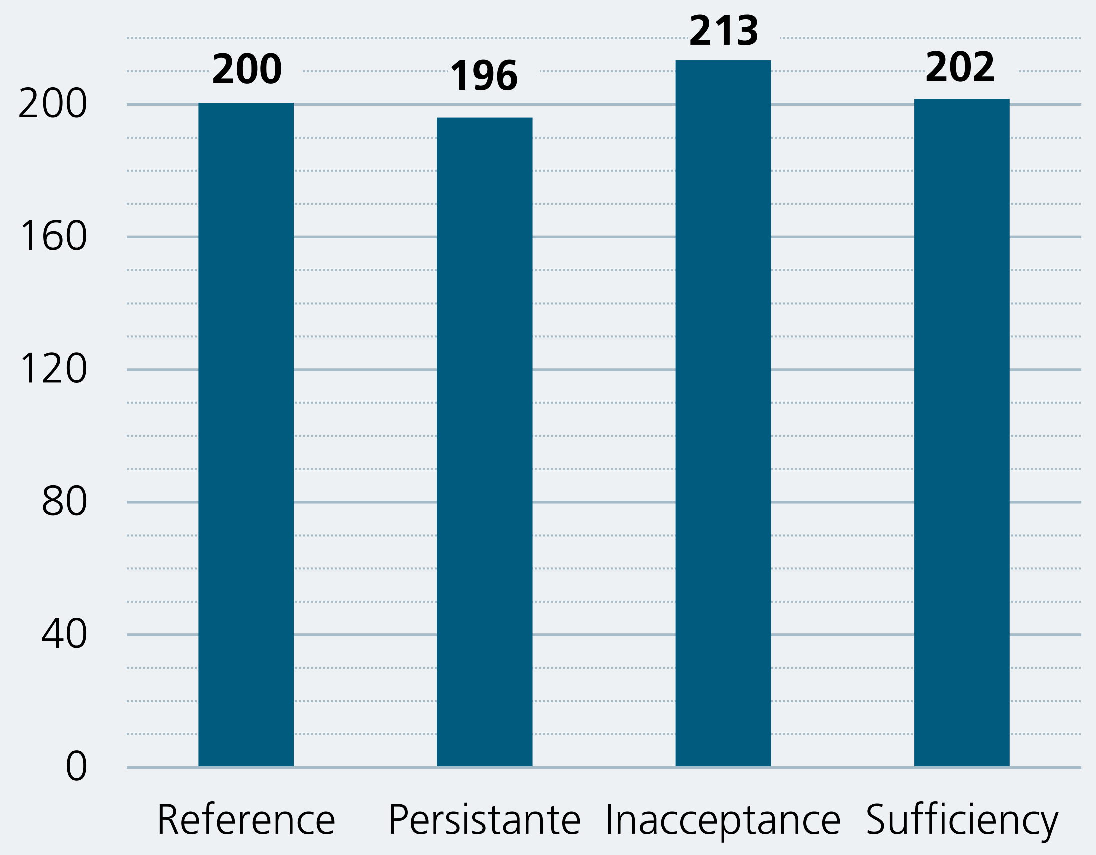
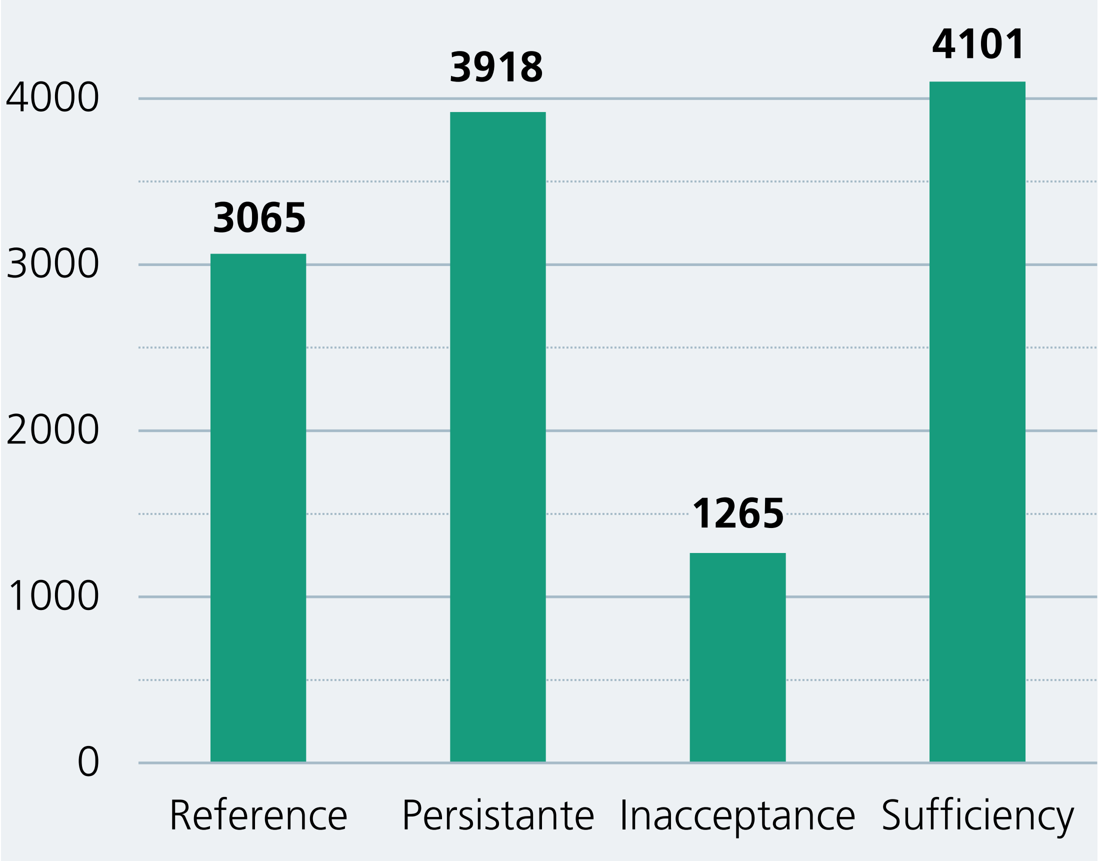
Security of supply: Continuous coverage of electricity demand

Full cycles of stationary batteries and full load hours of H_2 electrolysis

Full cycles stationionary batteries



Full load hours H_2 elektrolyzers



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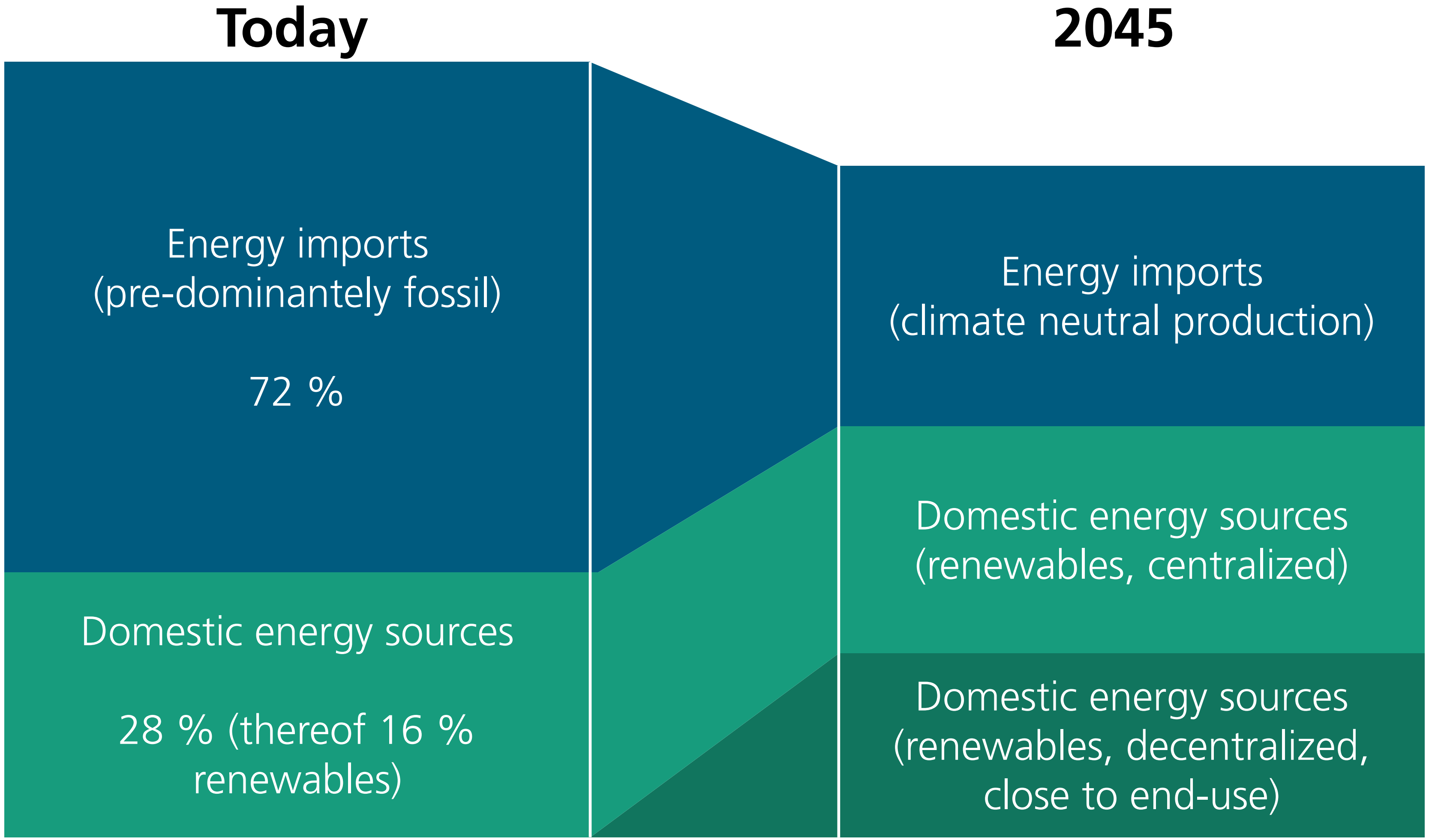
Security of supply: Dependency on energy imports

Transition to energy sovereignty: primary energy today (2020) and tomorrow (schematic)



- Reduction of primary energy consumption, even with future economic growth (efficiency, electrification)
- Reduction of energy imports due to higher production of domestic energy sources, especially electricity from photovoltaics and wind
- Strong growth in distributed, near-consumer generation in the built environment

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Agenda

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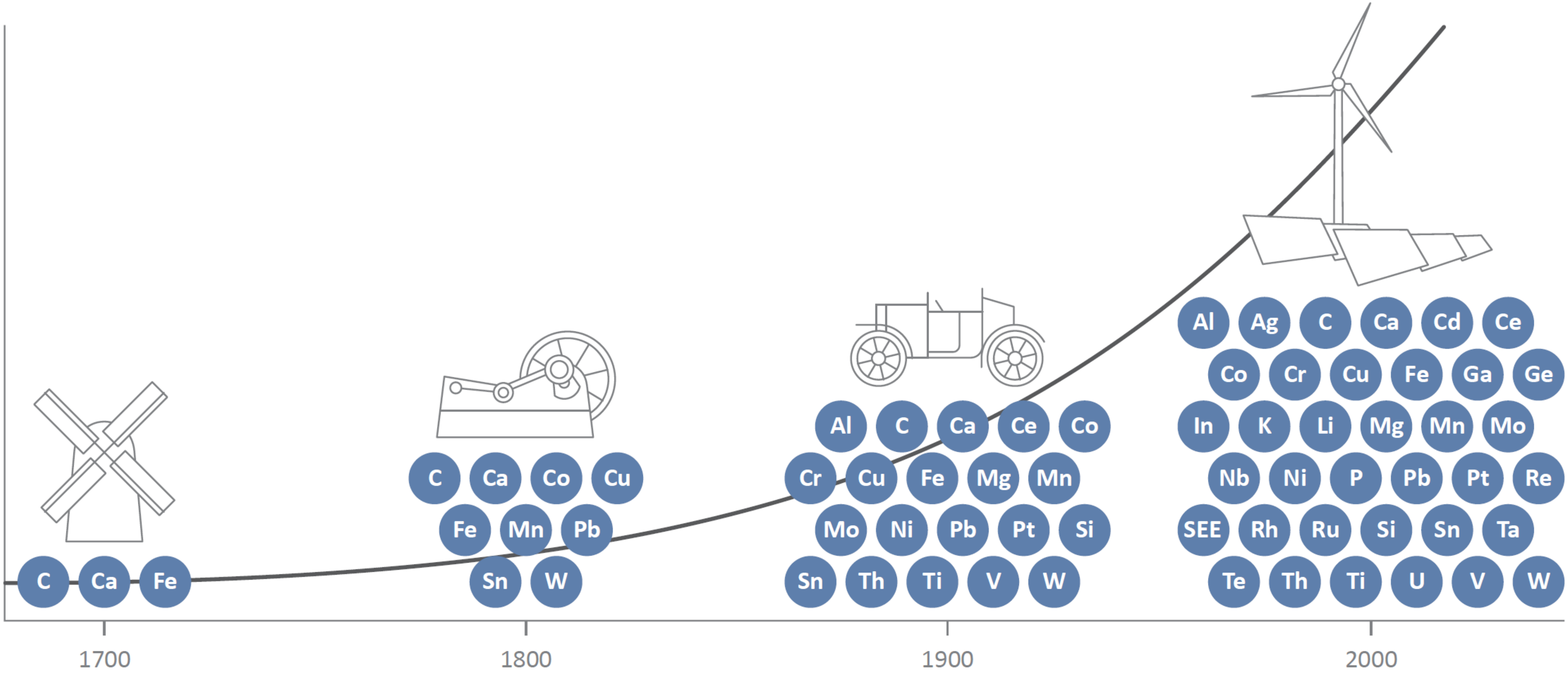
Value chain and technology sovereignty

High demand for metals and minerals



Angerer et al.: *Rohstoffe für die Energieversorgung der Zukunft: Geologie – Märkte – Umwelteinflüsse* (Schriftenreihe Energiesysteme der Zukunft), München 2016.

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Value chain and technology sovereignty

Raw materials: 2000% more Lithium is estimated in 2050 compared to 2020 overall use

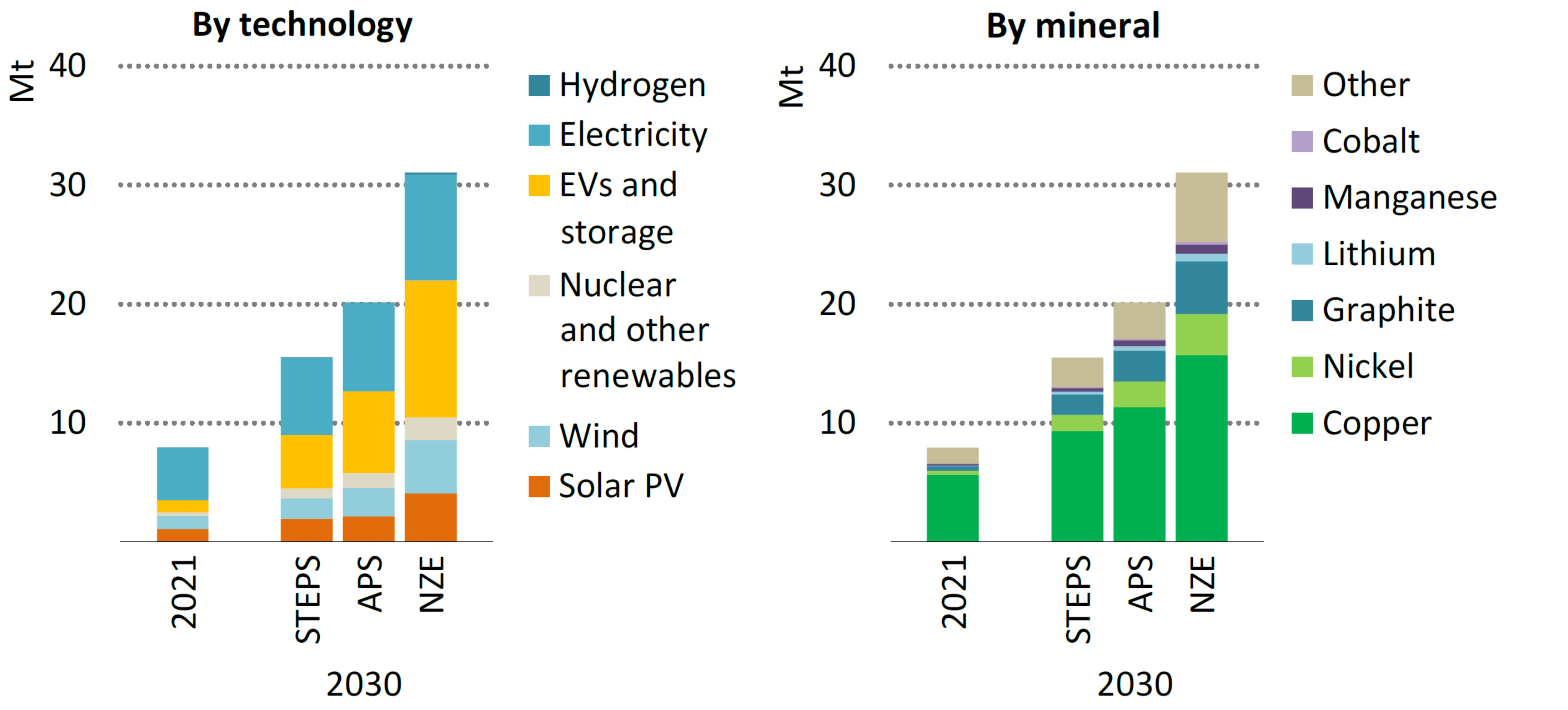
Lithium	2,109%	Silicon	62%
Dysprosium	433%	Terbium	62%
Cobalt	403%	Copper	51%
Tellurium	277%	Aluminium	43%
Scandium	204%	Tin	28%
Nickel	168%	Germanium	24%
Praseodymium	110%	Molybdenum	22%
Gallium	77%	Lead	22%
Neodymium	66%	Indium	17%
Platinum	64%	Zinc	14%
Iridium	63%	Silver	10%

% of metal amounts required in 2050 for clean energy technologies vs. 2020 overall use

Source: Metals Clean Energy (eurometaux.eu)

Value chain and technology sovereignty

Mineral Requirements for Clean Energy Technologies



- Strong increase in mineral requirements for clean energy technologies
- Particularly high growth for materials for electric vehicles (stationary storage probably < 10 % of »EVs and storage«)
- Renewable energies are responsible for about a quarter of the raw material requirements (in Mt)

IEA (2022), *World Energy Outlook 2022*, IEA, Paris, https://www.iea.org/reports/world-energy-outlook-2022
Notes: Mt = million tonnes; EVs = electric vehicles. Includes most of the minerals used in various clean energy technologies, but does not include steel and aluminium. See IEA (2021b) for a full list of minerals assessed

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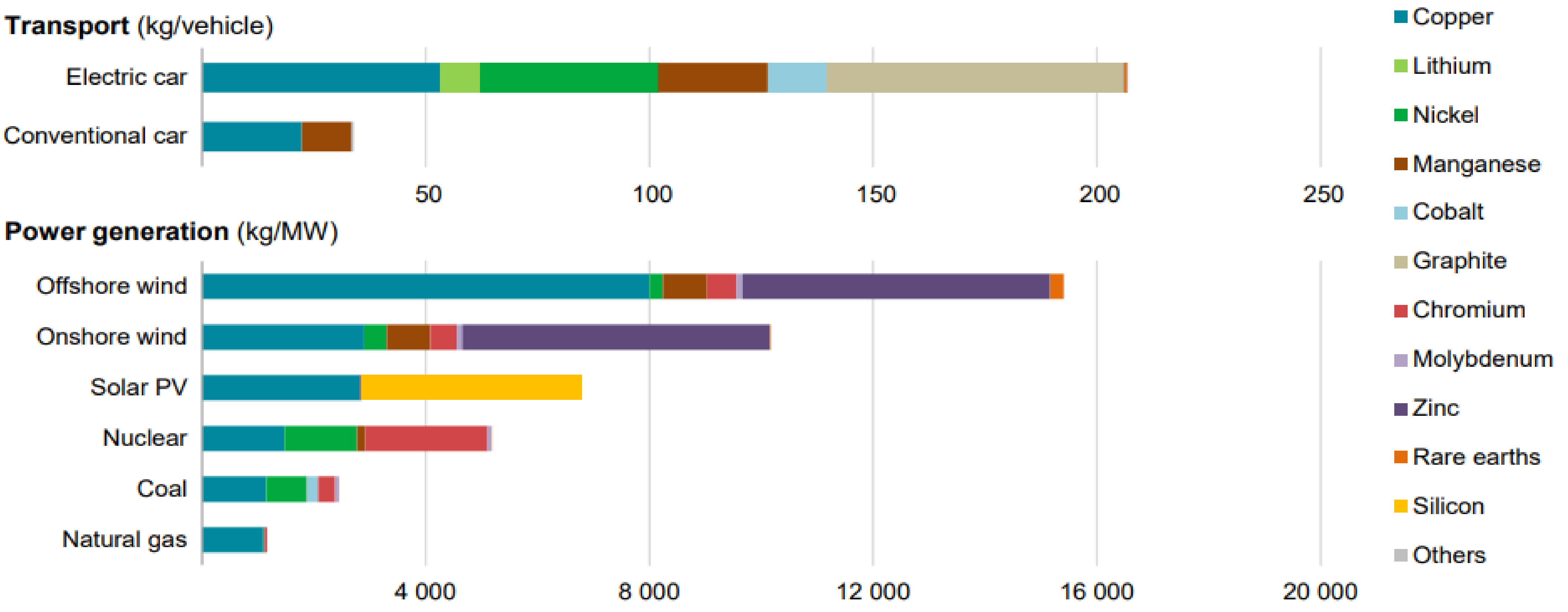
Value chain and technology sovereignty

Raw materials: Demand for selected technologies of the energy transition

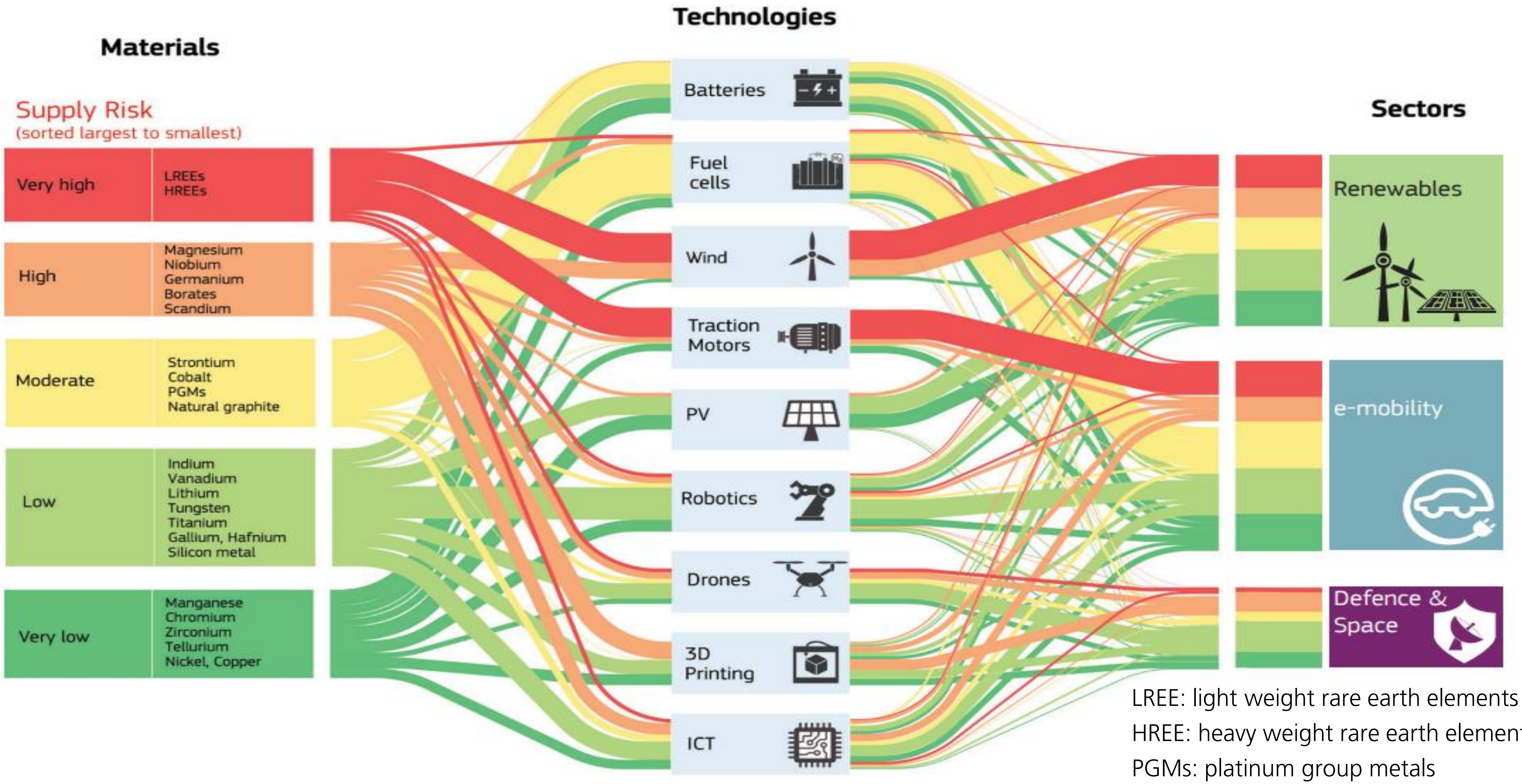


Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

Quelle: IEA, The Role of Critical Minerals in Clean Energy Transitions, 2021, Paris

Value chain and technology sovereignty

Raw materials: Requirements and Supply Risks of Selected Technologies of the Future Energy System



LREE: light weight rare earth elements
HREE: heavy weight rare earth elements
PGMs: platinum group metals

Closing material cycles is an indispensable prerequisite for a sustainable energy system

→ Circular Economy

Quelle: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020.

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Value chain and technology sovereignty

Key technologies of the future energy system

Global market size of $1.2 trillion for clean energy technologies in 2050*

Photo-voltaics	Wind (onshore, offshore)	Flexible power plants (H_2)	Hydro-gen techno-logies	Battery storage (mobile, stationary)	Heat pumps	Geo-thermal energy	Power electronics and grid techno-logies

Technology Sovereignty

Germany / Europe should be able to master and operate all steps of the value chain

- Strengthening of home markets in order to strengthen exports as well
- Reducing critical technology dependencies, but without striving for autonomy and turning away from international trade

*Net-Zero-Emissions-Szenario der IEA

Agenda

Conclusion

Transformation of energy systems towards renewable energies

- **Efficient use of energy, limitation of energy consumption** and **renewable energies** are the pillars of the transformation
- **Electricity is becoming the most important primary energy** and **flexibilization is becoming the new paradigm** of grid operation
- In the future, **system services** for the power grid will increasingly be provided by **power electronics components**
- The energy transition will substantially **reduce dependency on energy imports**
- **Increased demand for metals and minerals ➔ circular economy concepts** for all relevant technologies
- Policies towards **technological sovereignty** can **reduce dependencies** and **offer export opportunities**
- **Achieving** the politically agreed **climate protection targets requires a significant acceleration** of all measures and in all sectors

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Many thanks for your attendance…

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