



Energy
Transitions
Commission



Abundant clean energy for all: the technological opportunity

Adair Turner

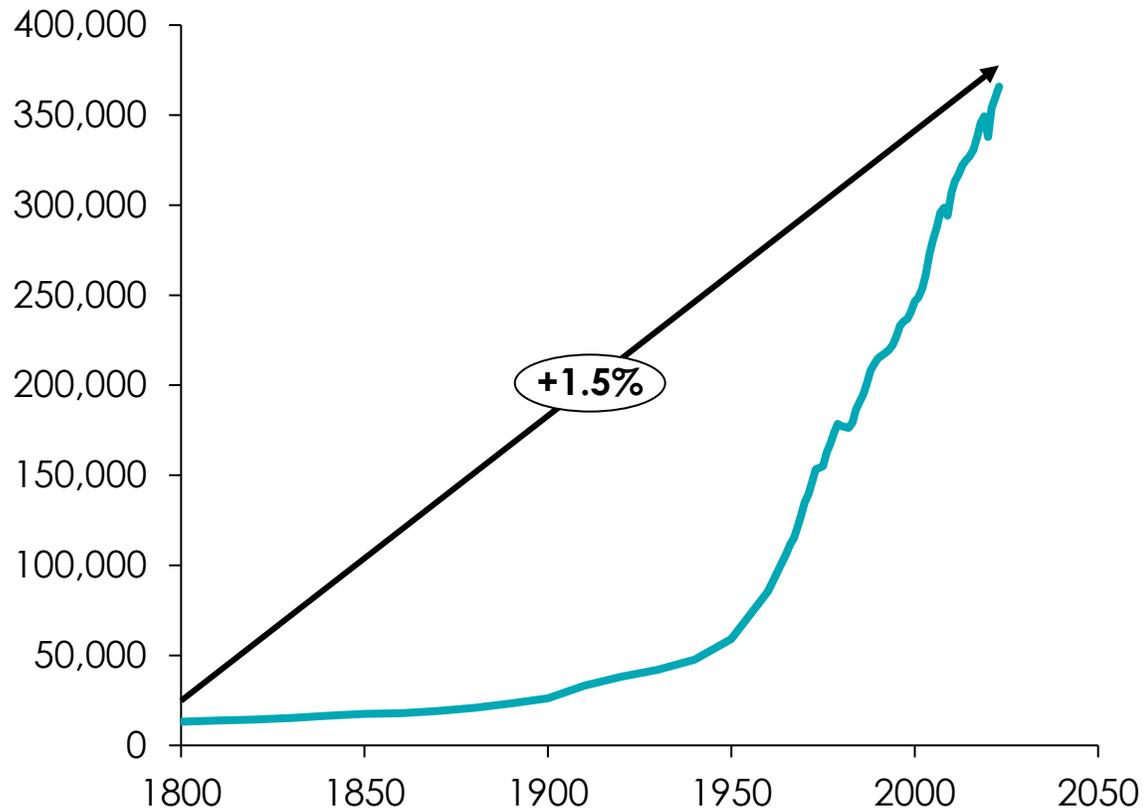
Chair, Energy Transitions Commission

The Global School of Sustainability at LSE

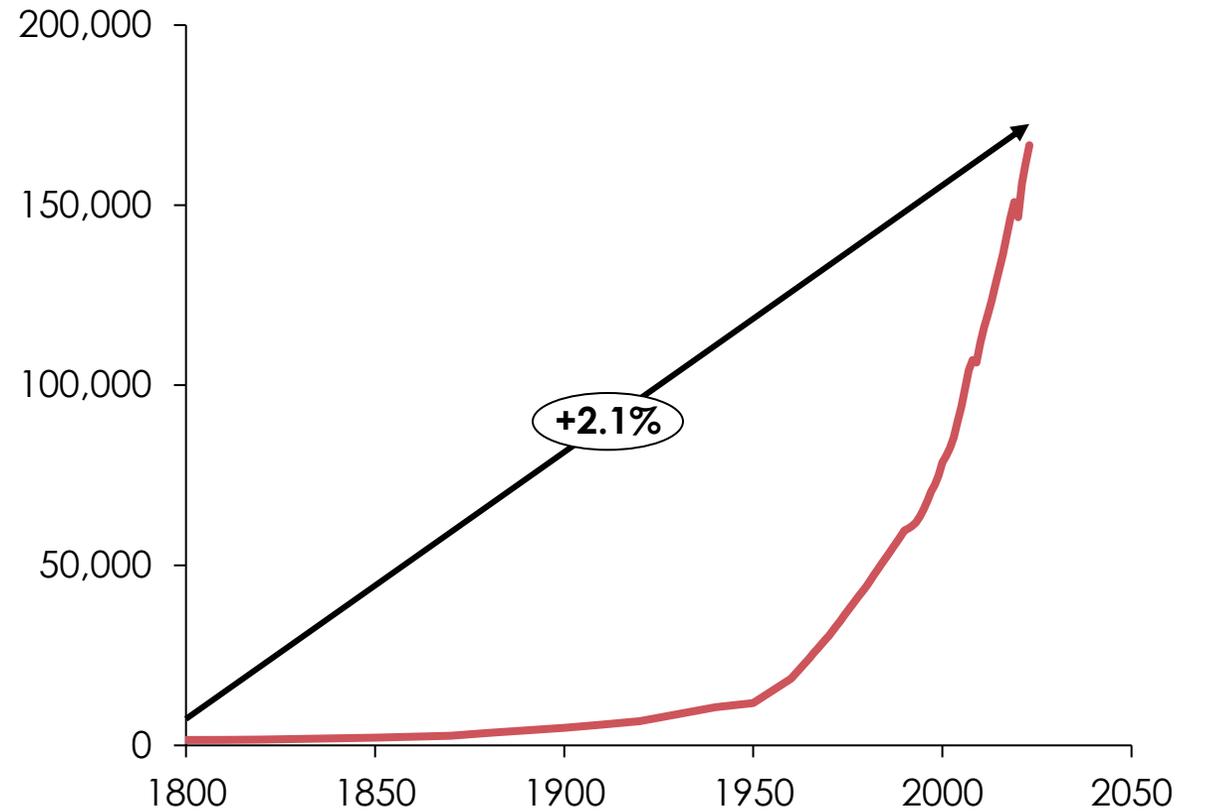
27th January 2026

Total GDP vs. Energy Demand, 1800-2023

Primary Energy (TWh)



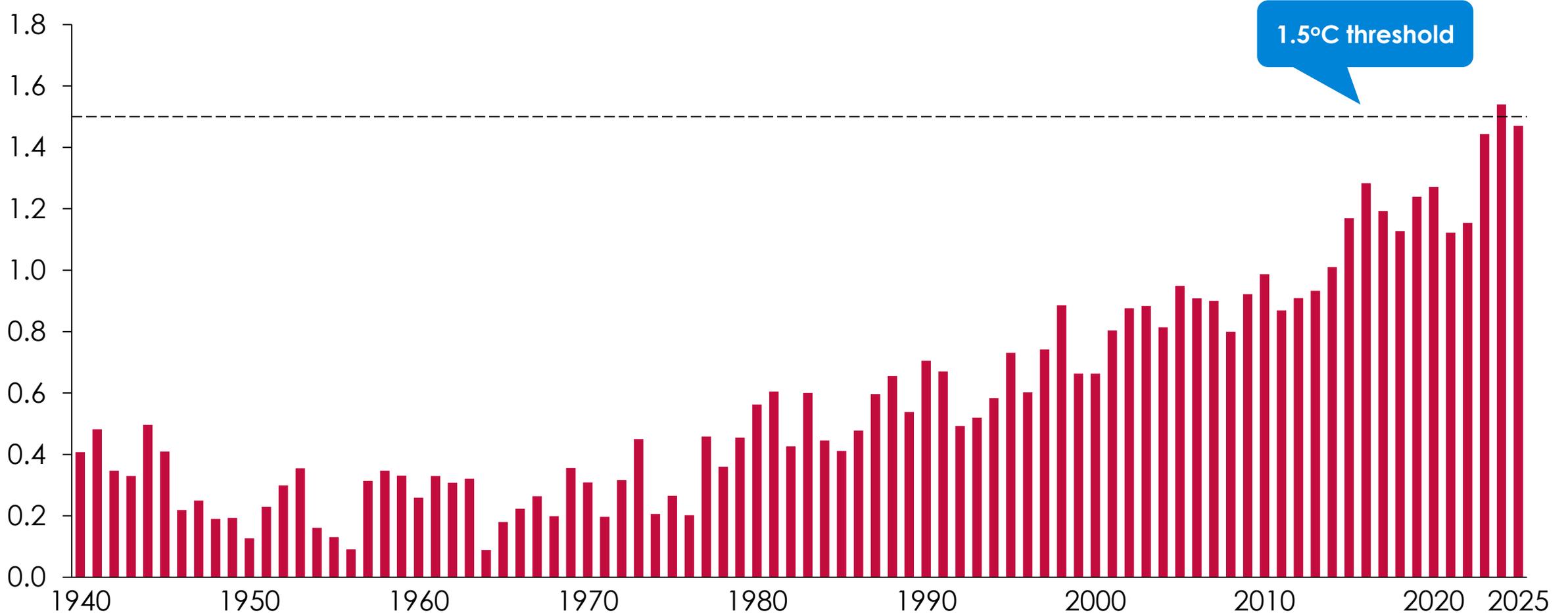
GDP (2021 USD Billion)



Source: ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system.*

Global surface temperature increase above pre-industrial level

°C above pre-industrial levels; Reference period: pre-industrial (1850-1900)



Source: Copernicus (Accessed Jan 2026), *Global climate highlights 2024*, NOAA global temperature.

Extreme weather summer 2023



California



China



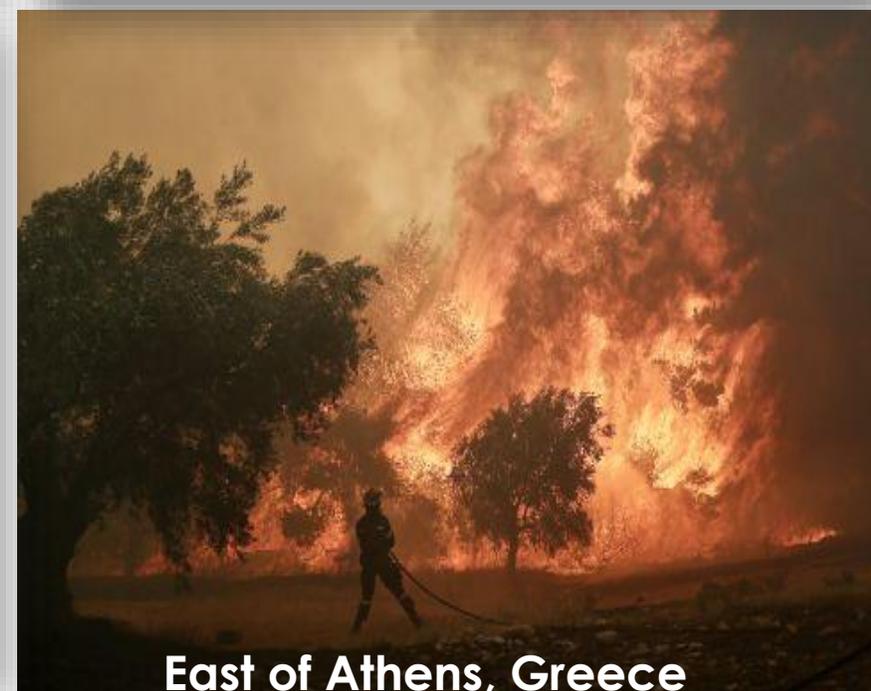
China



Pakistan



River Po at Castel San Giovanni



East of Athens, Greece

Extreme weather summer 2024



Extreme weather in the past 18 months

Jan 2025



Los Angeles, USA

Sep 2025



Valencia, Spain

Nov 2025



Pakistan

Jan 2026



Australia

Jan 2026

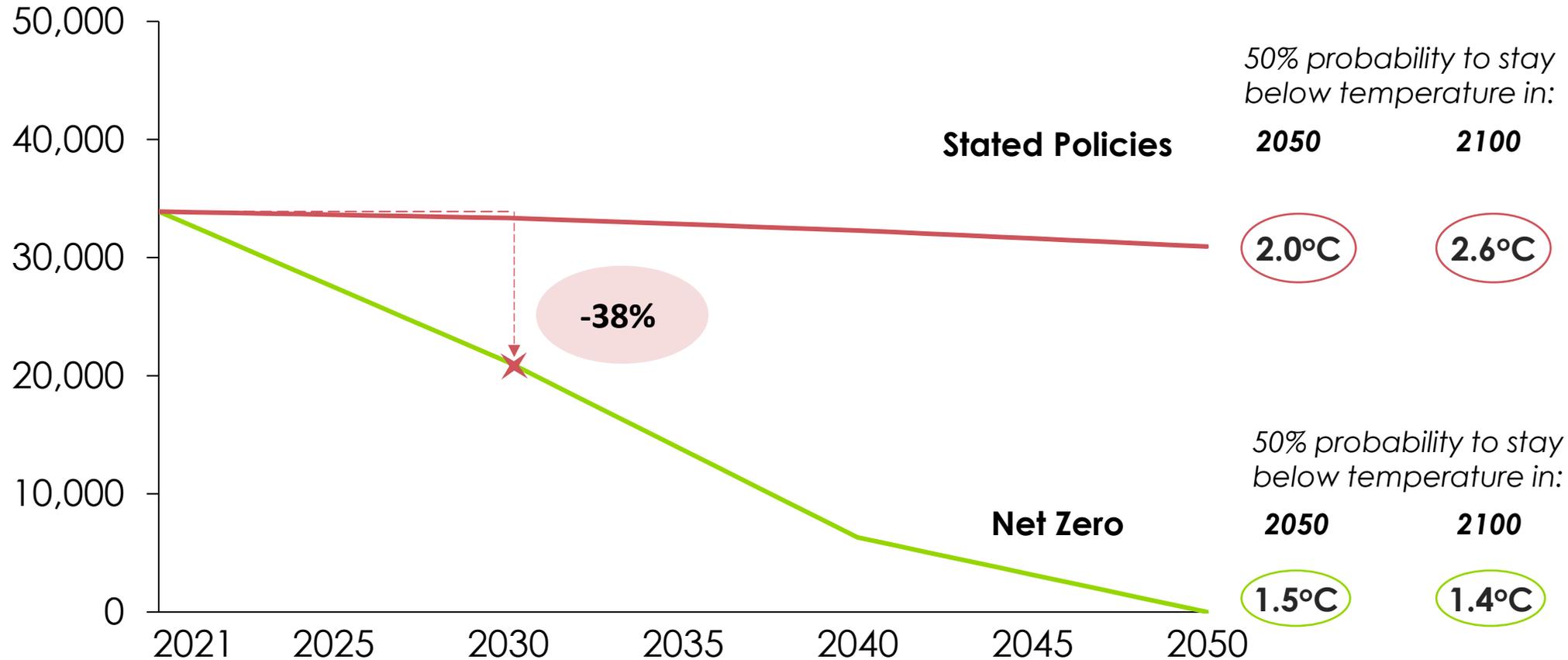


Mozambique



IEA emission scenarios 2021 and implied peak temperature

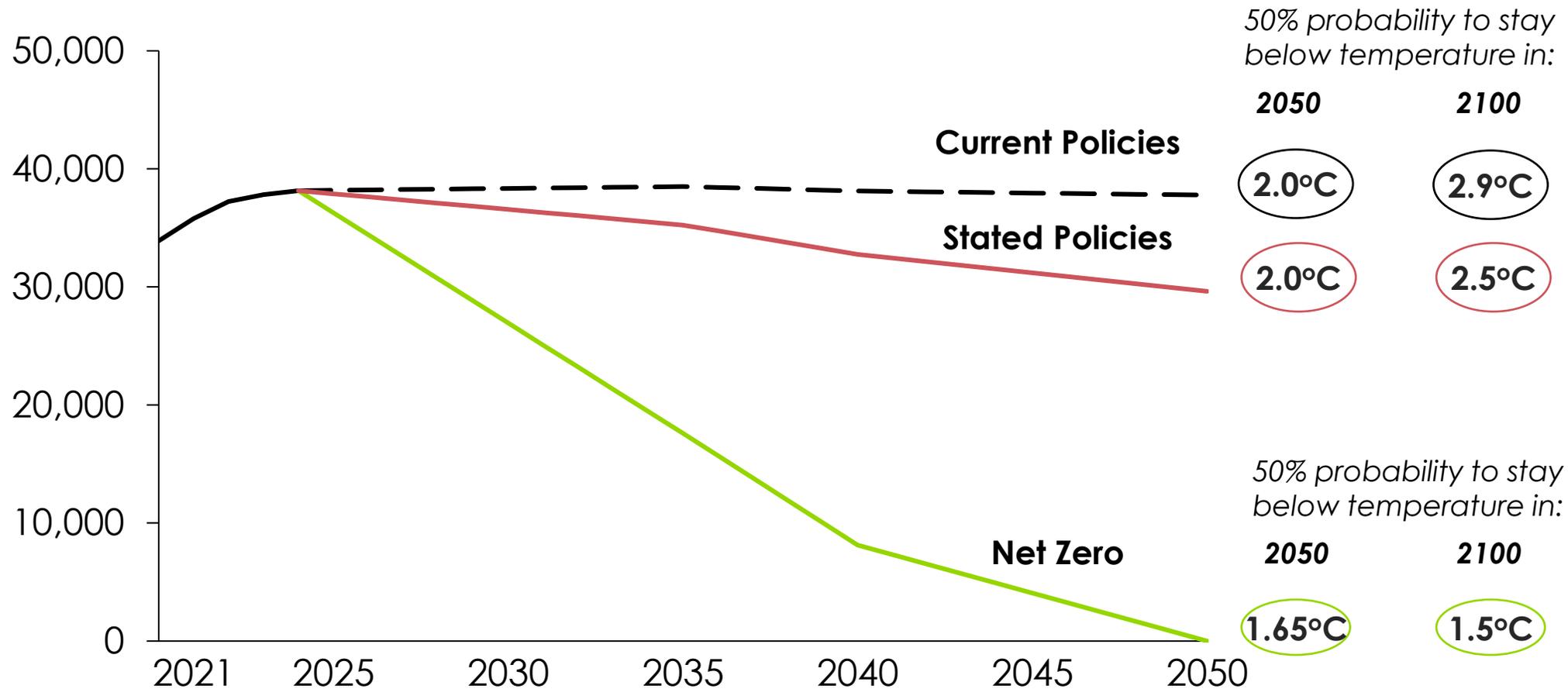
Energy-related Mt CO₂



Note: IEA Scenarios have emissions interpolated between 5-10 years, using Stated Policies: A.4a; Net Zero: Table A.4d.
Source: IEA (2021), *World Energy Outlook 2021*.

IEA emission scenarios 2024 and implied peak temperature

Energy-related Mt CO₂



Note: IEA Scenarios have emissions interpolated between 5-10 years; using Current Policies: A.4a; Stated Policies: A.4b; Net Zero: Table A.4c.
Source: IEA (2025), *World Energy Outlook 2025*.

Calls for a "pragmatic" reset of climate ambition

Dan Yergin, Atul Arya and Peter Orszag

The Troubled Energy Transition – how to find a pragmatic way forward



Key points

Growing energy demand, energy security concerns and very large transition costs make rapid transition impossible; fossil fuels still essential to prosperity and will take long time to replace

Temperature assumption

~2.4°C

Bill Gates

Three tough truths about climate



"we should measure success by our impact on human welfare more than our impact on the global temperature-"

No chance of <2°C, can deal with consequences of 3°C

Michael Liebreich

The pragmatic climate reset



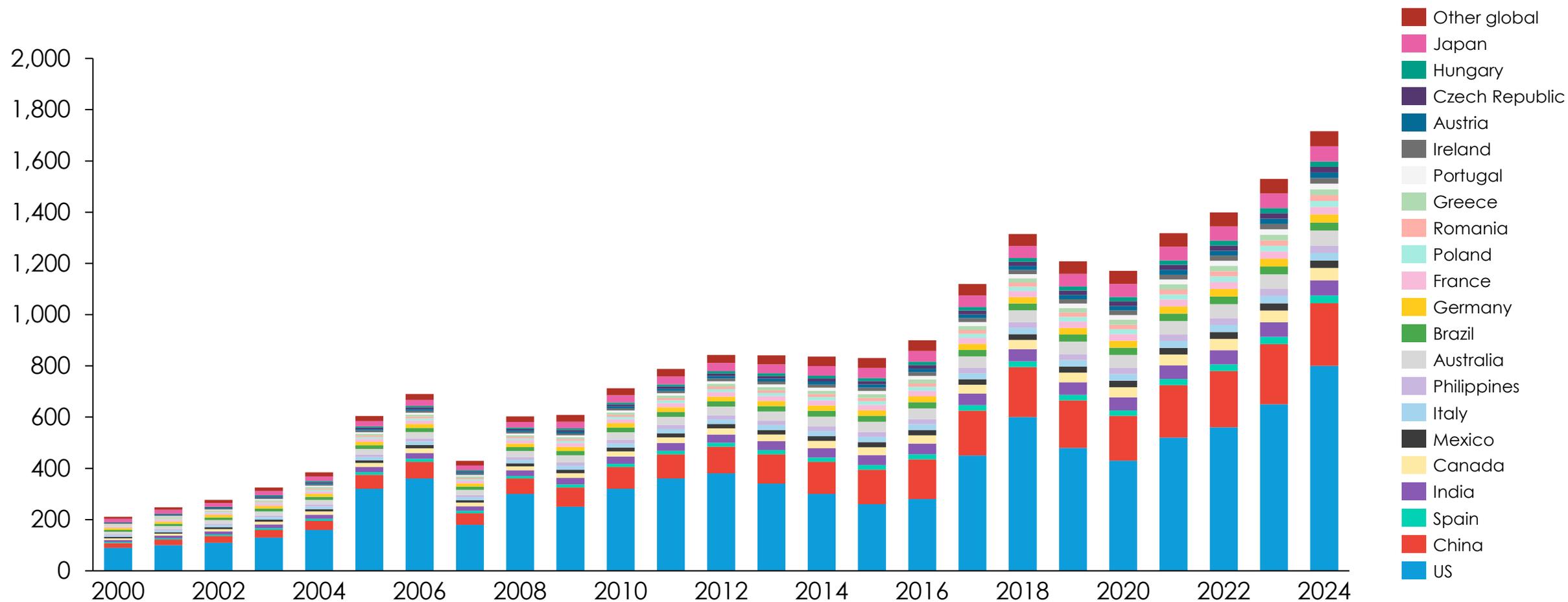
1.5°C was always impossibly costly objective – adopted without analysis
"It's time to switch back to the hard 2°C target which was at the heart of the Paris Agreement "

**1.8°C-3.5°C
But ideally <2°C**



Annual climate damages plus climate related government spending

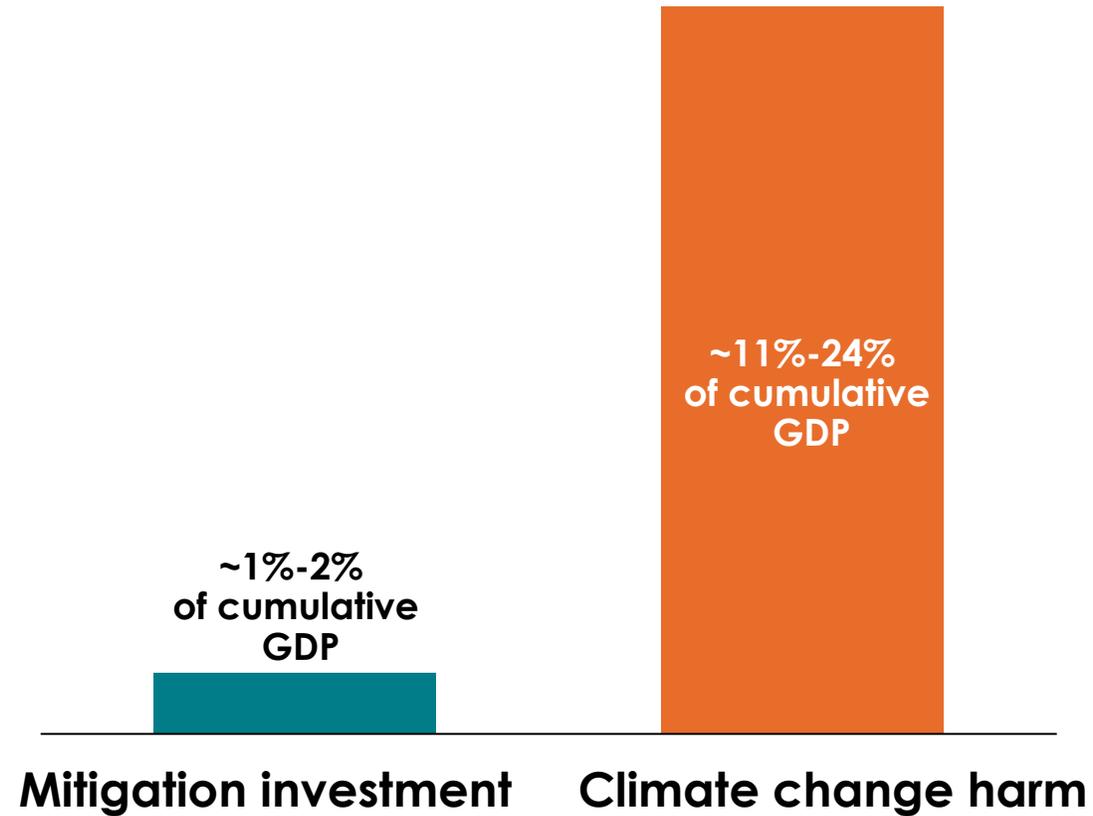
\$ billions



Note: Climate damages include insured and uninsured damages to property and climate-related government spending (including drainage grants, disaster prevention and recovery, environmental protection and agricultural insurance subsidies).
Source: BNEF (2025), *Adaptation and Resilience: The New Investment Imperative*

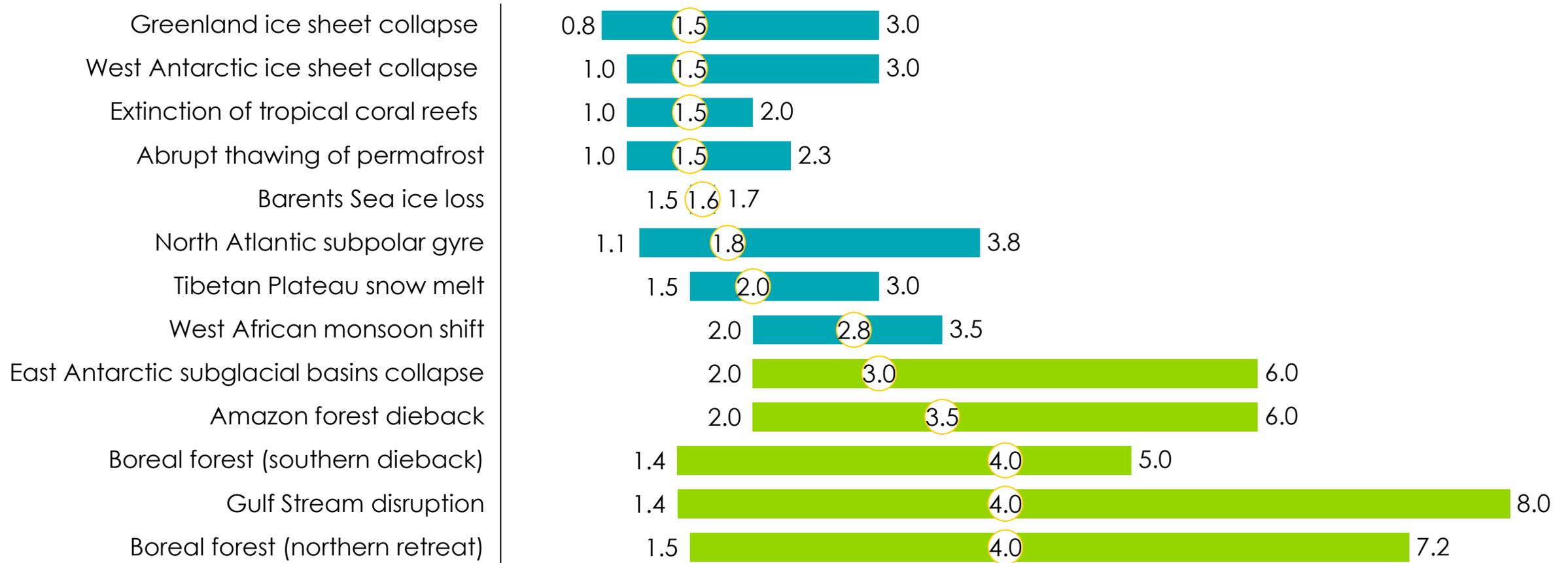


Mitigation costs vs climate change harm 2025-2100: comparing 2°C vs 3°C world



Temperature ranges at which tipping points may occur

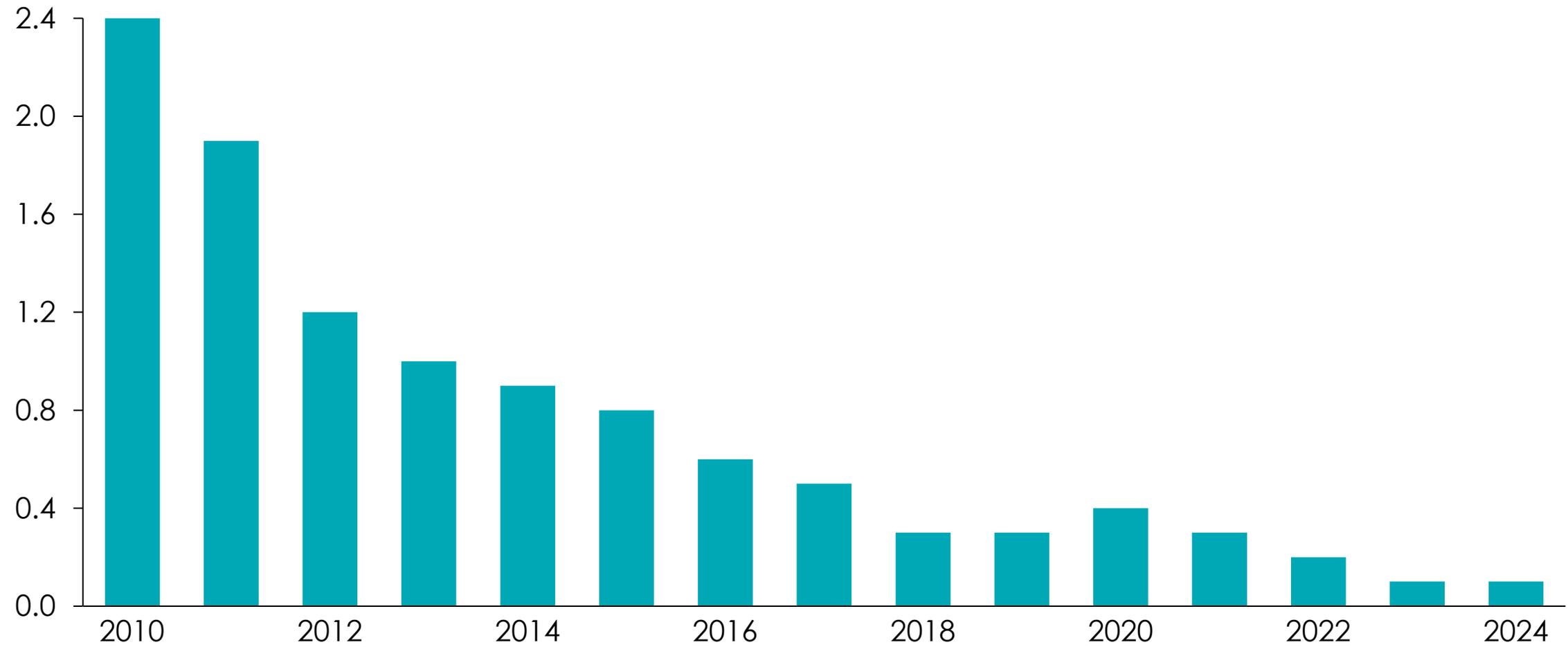
°C increase relative to pre-industrial era



Source: Science (2022), Exceeding 1.5°C global warming could trigger multiple climate tipping points.

Solar PV module costs

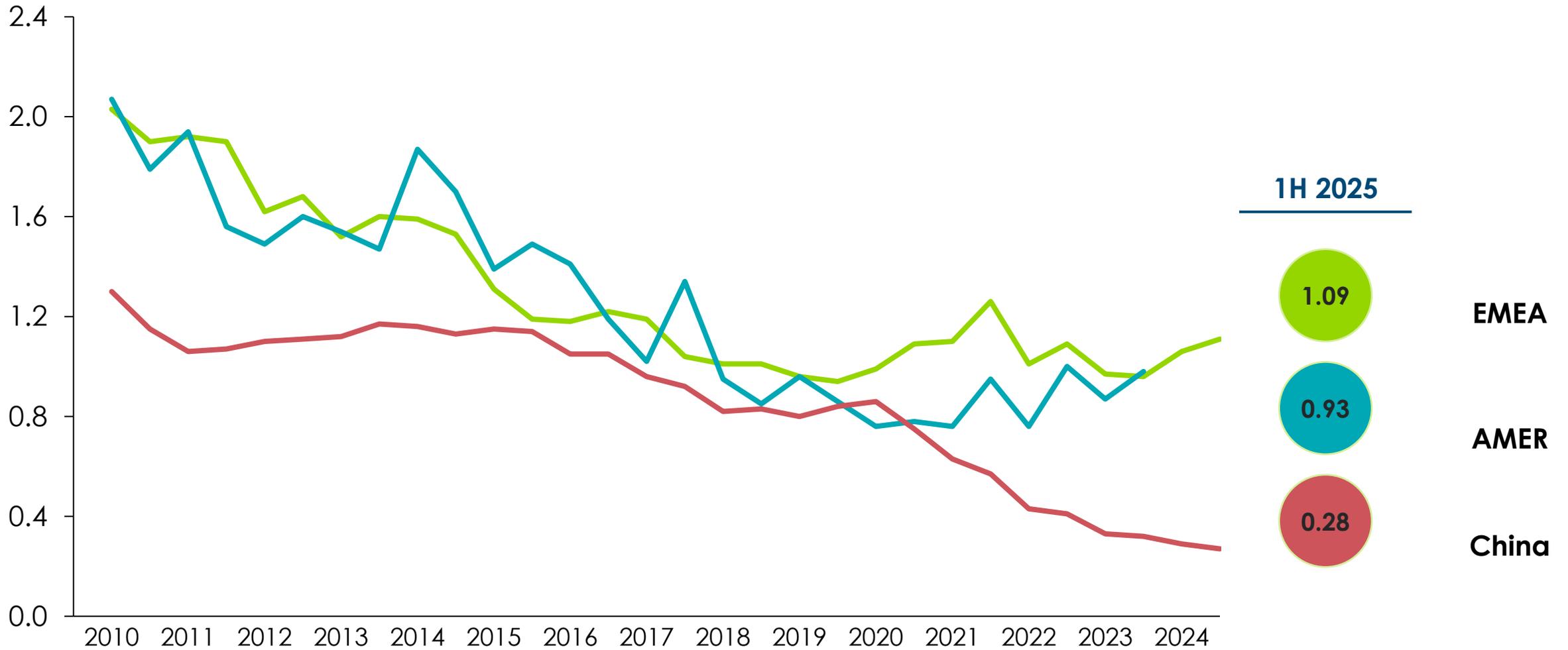
\$ per watt



Note: Module element of benchmark capex for a typical fixed-axis utility-scale PV project.
Source: BNEF (March 2025), *Solar Modules Are Cheap and Will Become Even Cheaper*

Wind turbine prices by region, 2010-2025

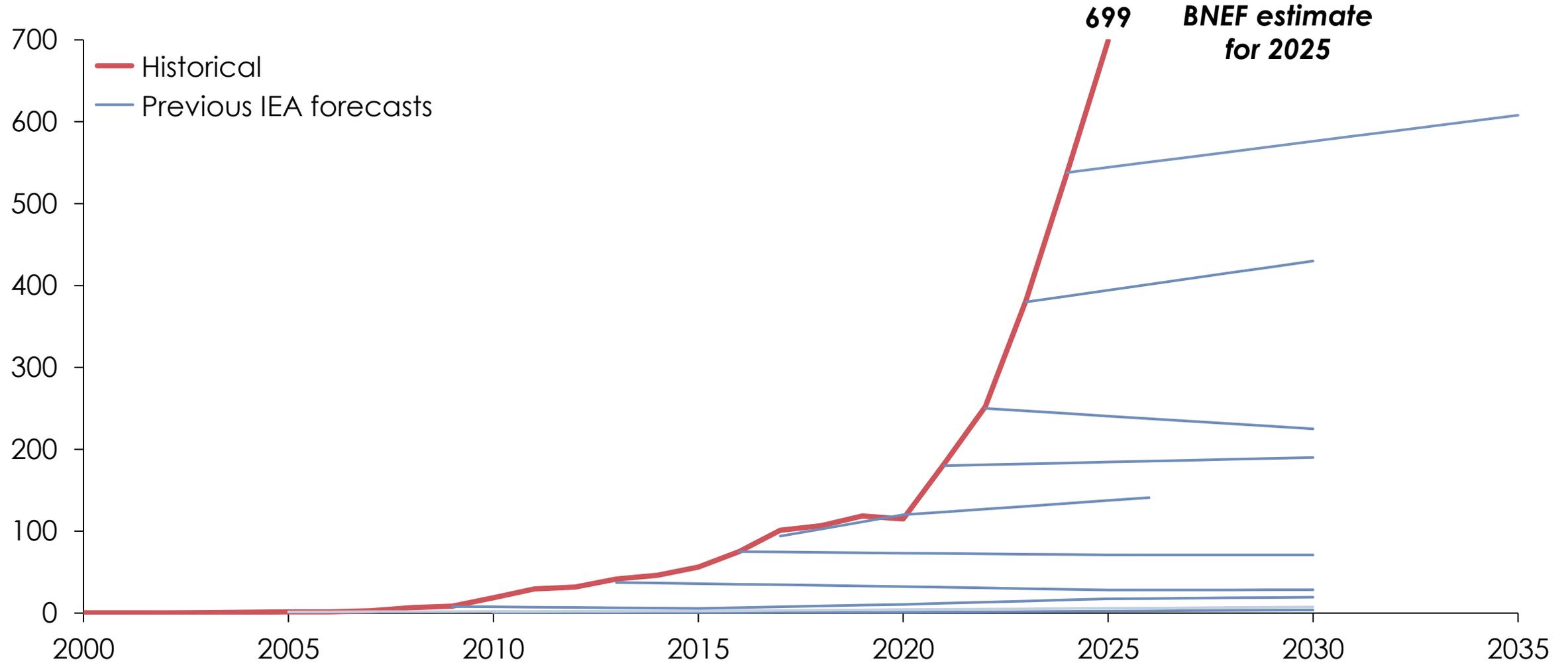
\$ million/MW, 2025 real



Source: BNEF (2025), Wind Turbine Price Index 1H 2025: Still on the Rise; U.S. Bureau of Labor Statistics (2025), Consumer Price Index for All Urban Consumers (CPI-U), All Items, US City Average, Not Seasonally Adjusted.

Annual solar PV installations compared to IEA forecasts

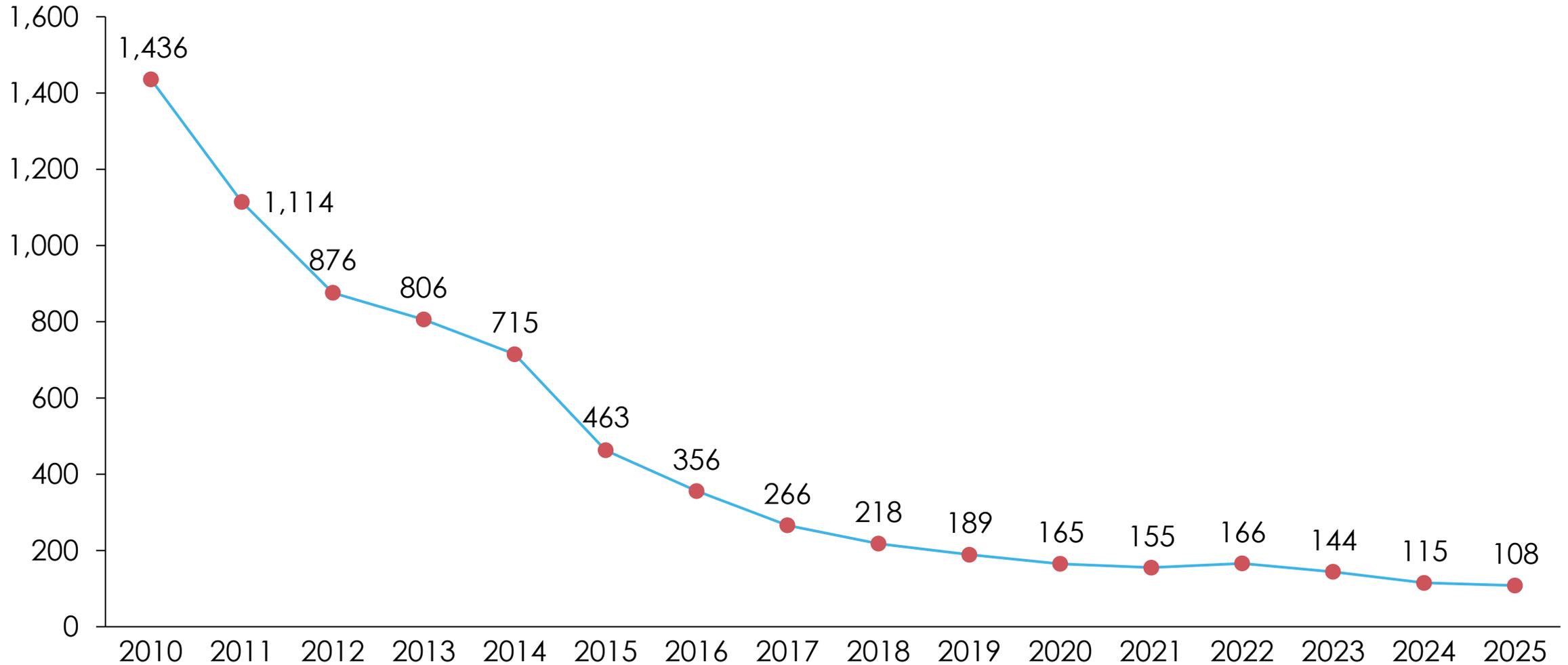
GW



Source: IEA (Various), IEA New Energy Outlook; BNEF (2025), Global Installed Capacity

Lithium-ion battery price survey results: global average pack price - BNEF

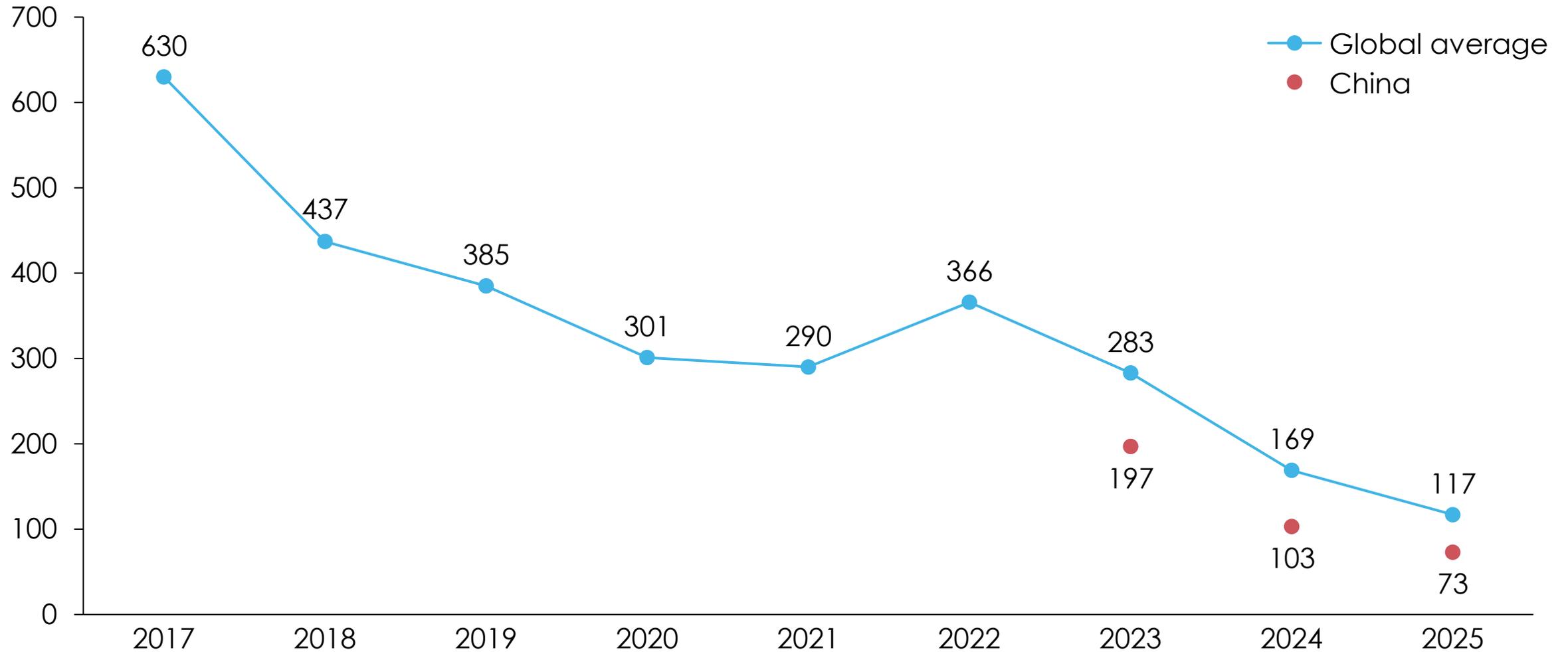
\$/kWh, real 2024



Source: BNEF (2025), *Lithium-ion battery price survey* December 2025

Prices for turnkey energy storage systems 2016-25 - BNEF

\$ per kilowatt-hour, usable (real 2025)

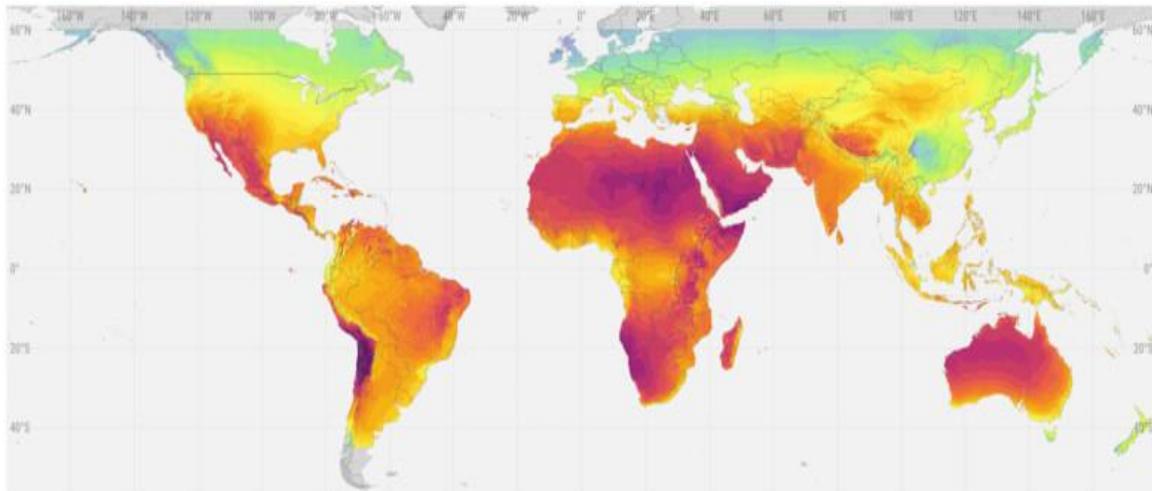


Source: BNEF (2025), Energy Storage Systems Cost Survey 2025

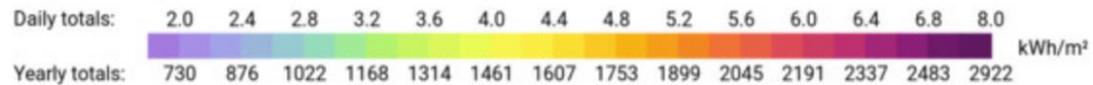
The global sunbelt and the high latitude wind belt

Solar irradiation intensity

Long-term yearly average of daily and yearly GHI totals

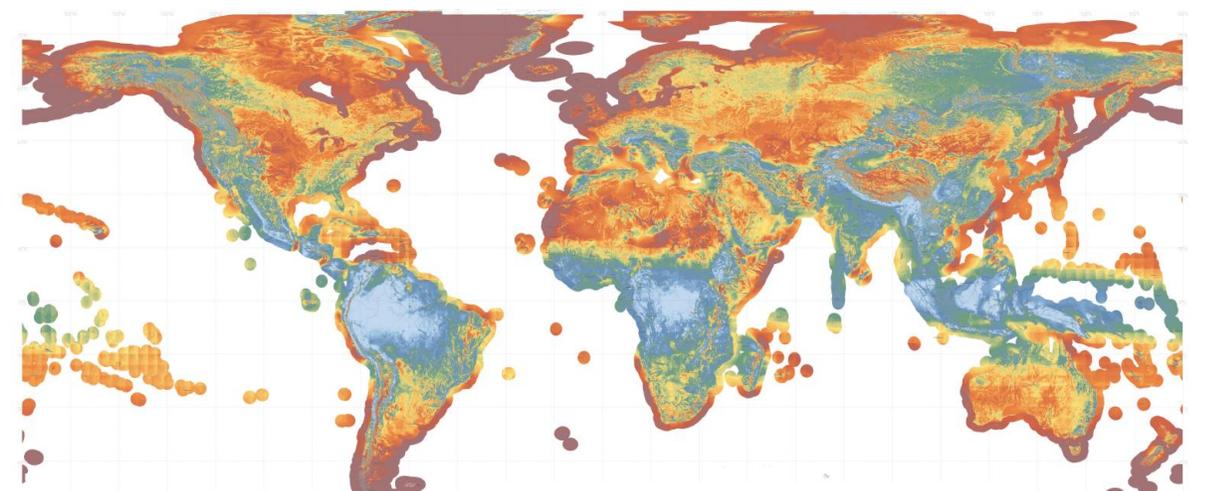


Long-term average of GHI



Wind power density

Mean wind power density at 100 m above surface level



Mean Wind Speed @ 100m - [m/s]

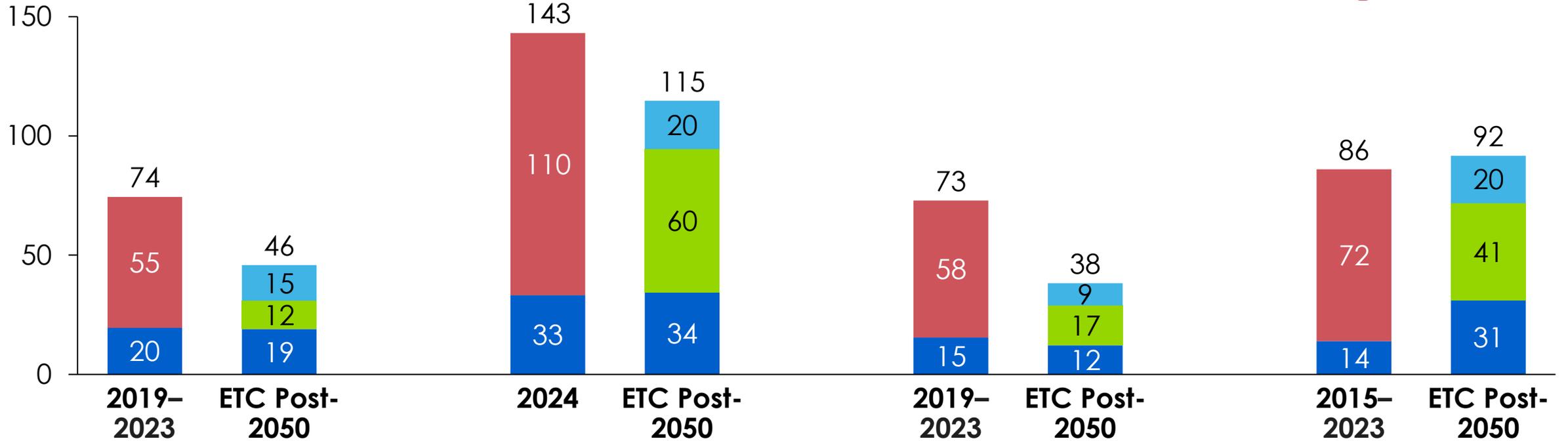


Note: GHI refers to Global Horizontal Irradiance - the total amount of solar radiation received on a horizontal surface.
Source: World Bank (2023), *Global Solar Atlas*; World Bank (2023), *Global Wind Atlas*.

Total system costs (generation, balancing, and grids), recent vs post-2050

\$/MWh (real 2024\$)

■ Average wholesale power prices
 ■ Balancing costs
 ■ Wind/solar
 ■ T&D costs



"Sunbelt" regions

"Windbelt" regions

Mixed Climate

Mild/Mediterranean

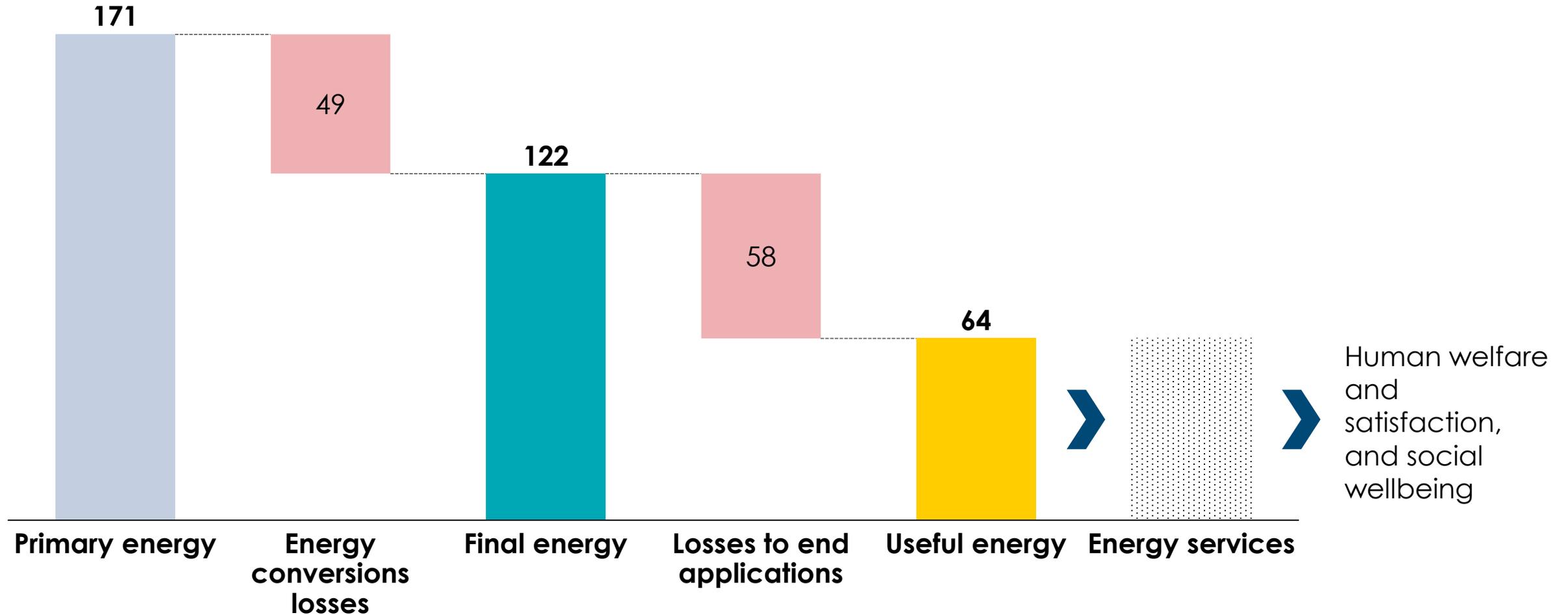


Note: T&D = Transmission and distribution.

Source: ETC (2025), Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems

Global energy flows

000 TWh, 2023



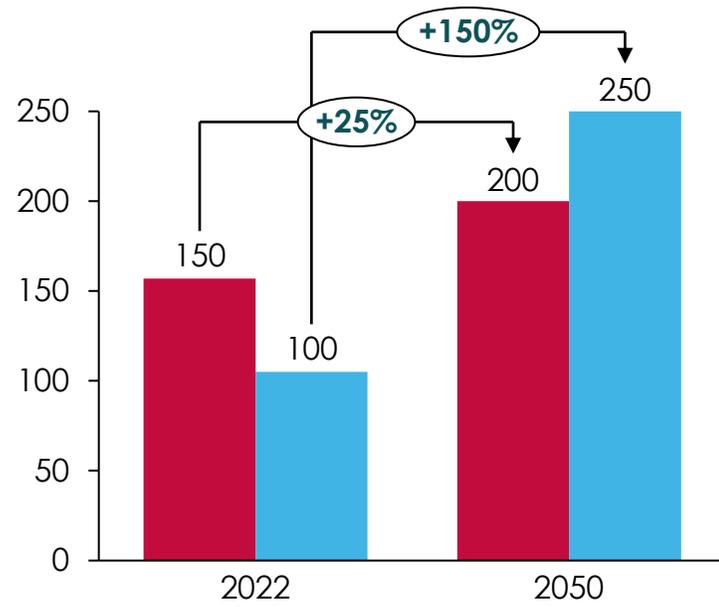
Source: ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system*

Likely growth in energy services

Heated and cooled floor area demand

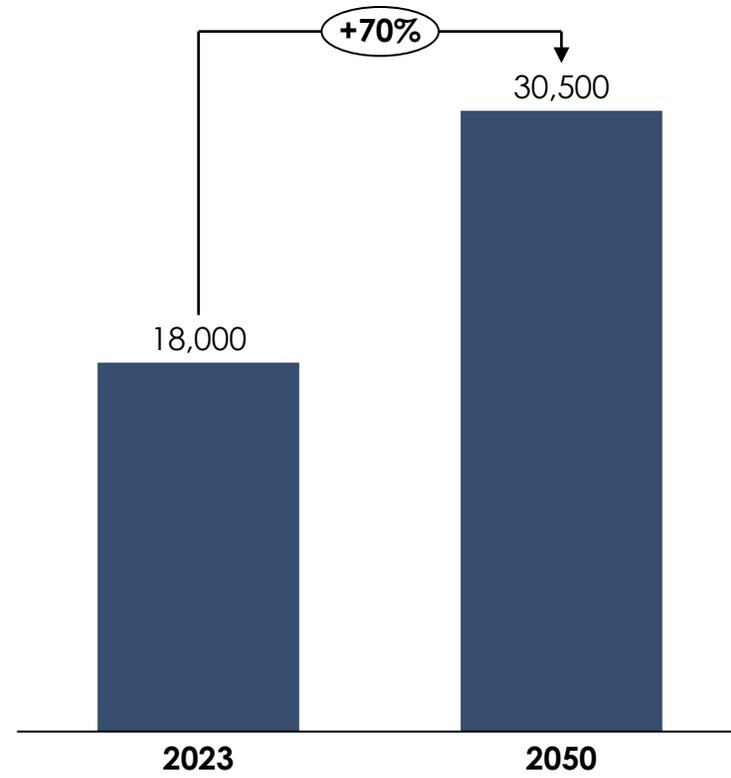
Billion m²;

- Cooled floor area
- Heated floor area (space heating)



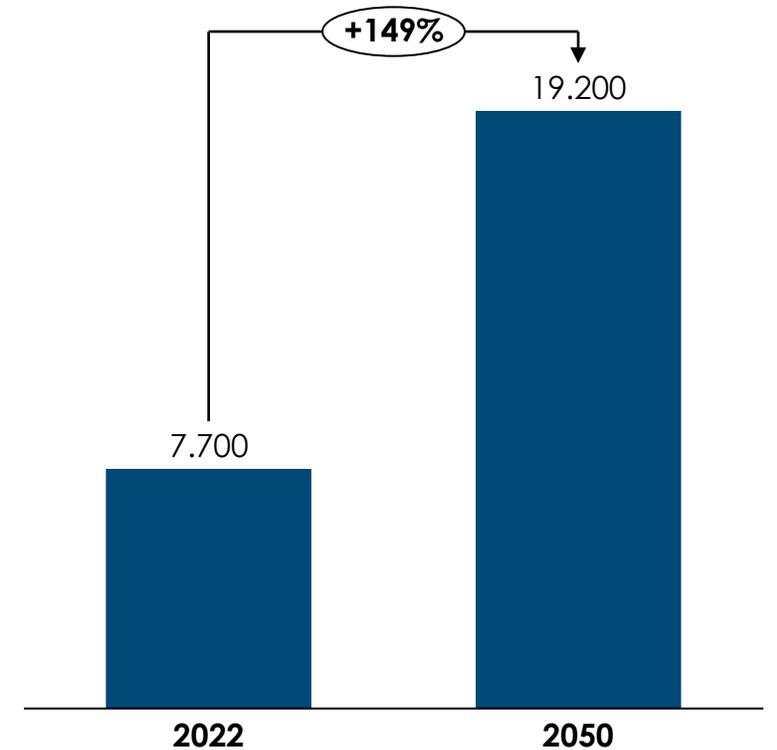
Passenger road transport demand

Billion km;



Aviation demand

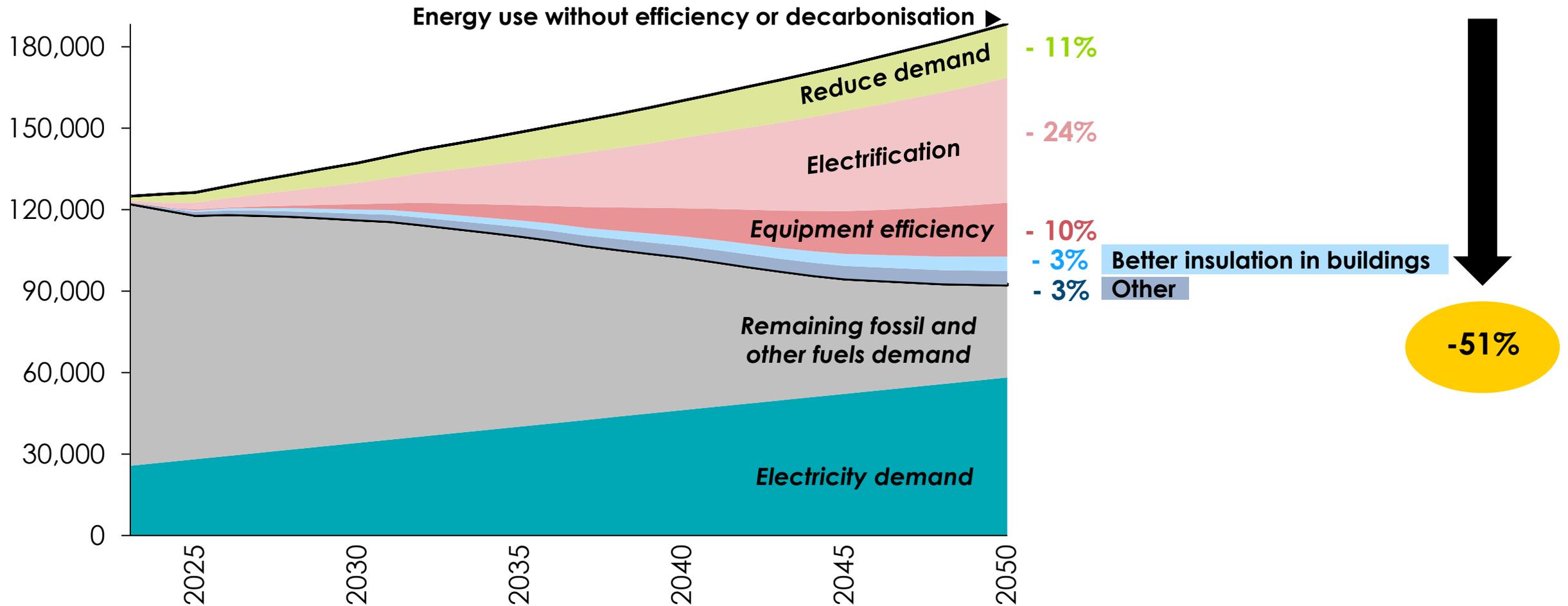
Billions revenue passenger km (RPK)



Note: Revenue passenger km represents the number of paying passengers carried on scheduled flights multiplied by the number of km those seats were flown.
Source: ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system*.

Final energy demand 2020-50: energy efficiency through electrification

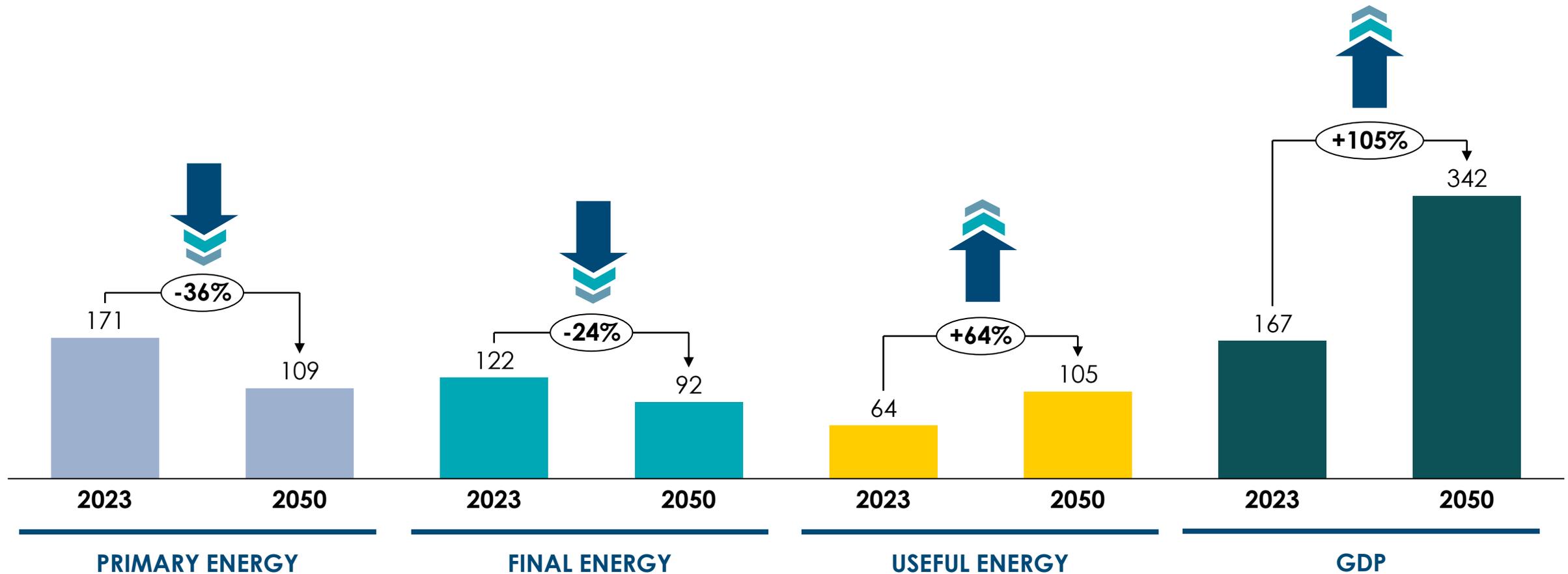
TWh



Source: ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system*

Rising energy services with falling inputs – the electrification effect

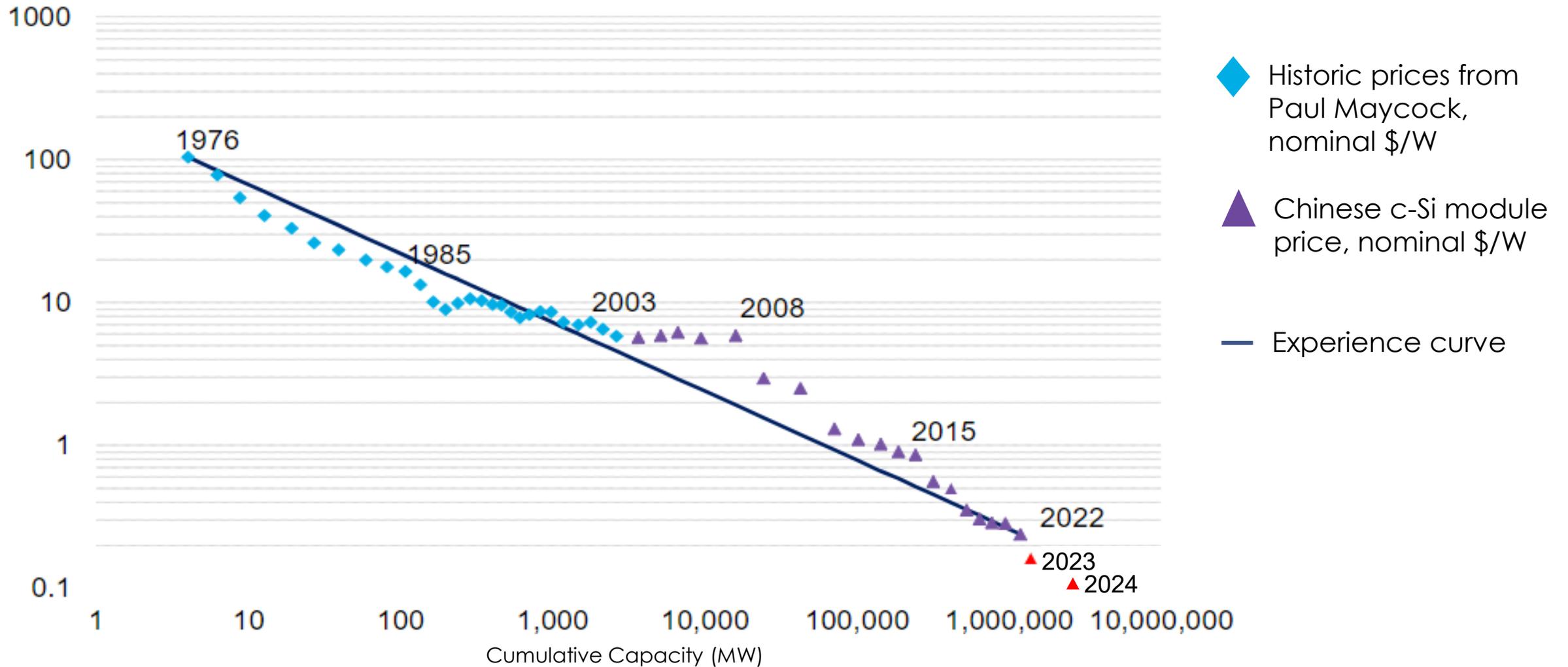
Energy in 000 TWh; GDP in constant 2021 Trn US\$



Source: ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system*

Price of solar PV panels

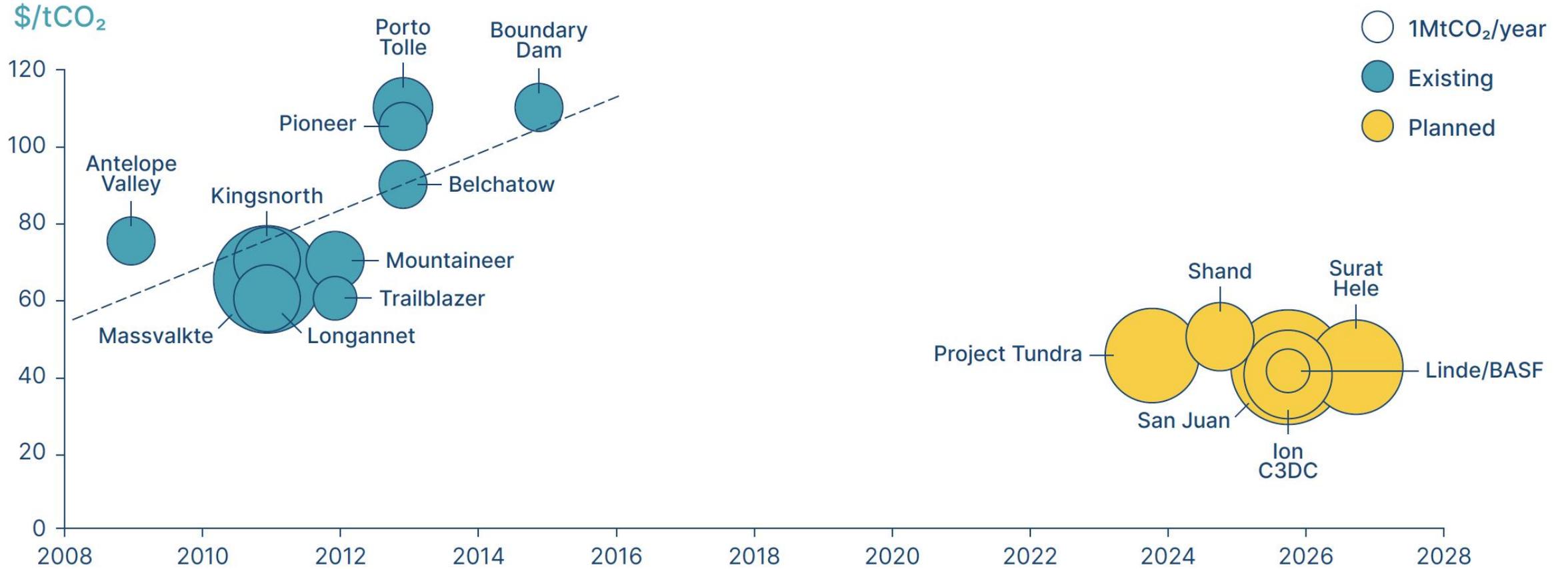
\$ per peak watt; real 2023 \$



Source: Our World in Data (2025), Solar photovoltaic panel prices

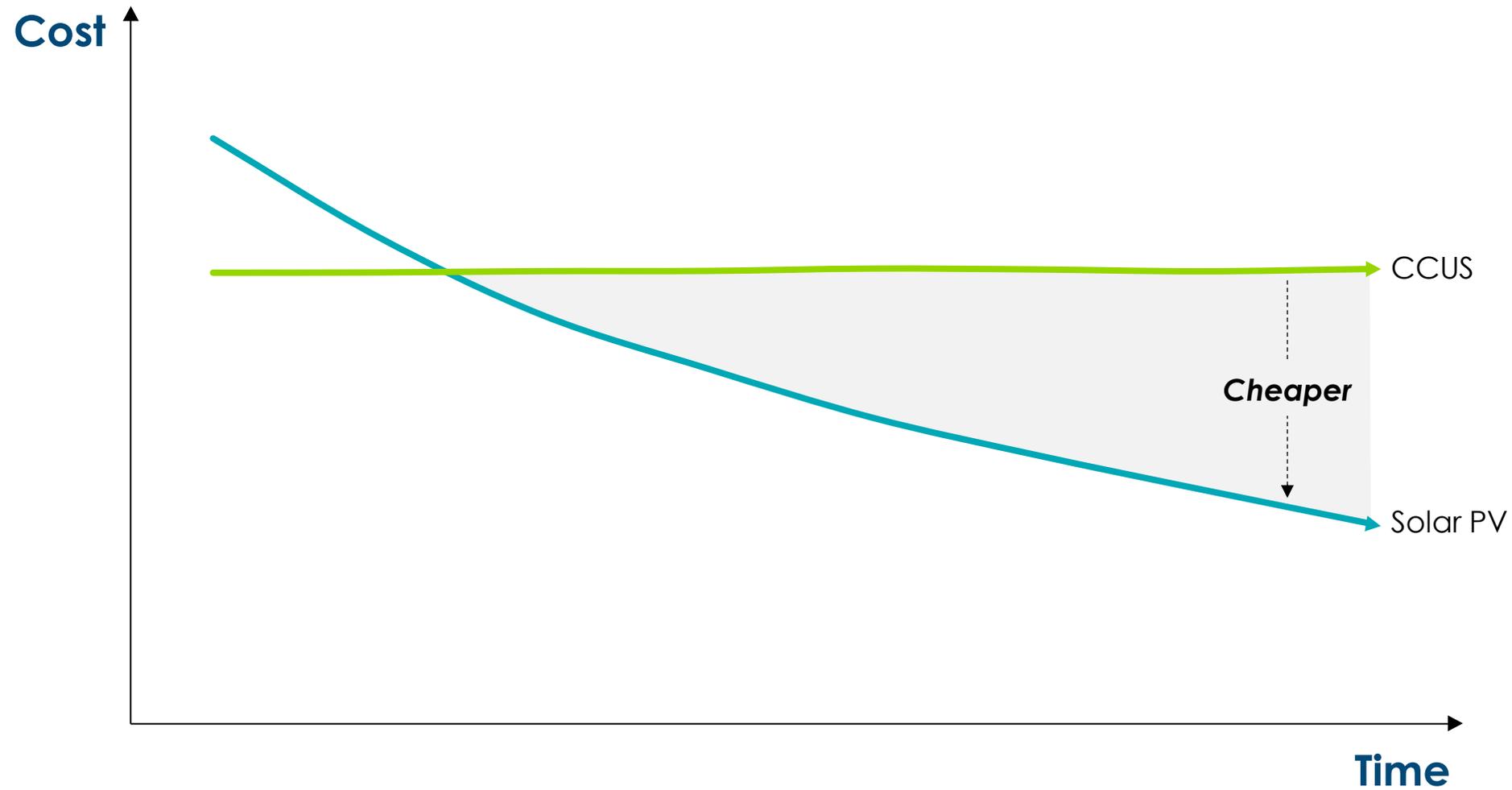
CCUS project costs: 2008-25

\$/tCO₂



Source: ETC (2022), Carbon Capture, Utilisation and Storage in the Energy Transition: Vital but Limited

Solar PV vs carbon capture costs: 2008-25



A clear pattern is emerging in technology cost reduction

Fastest
cost
reduction

Solar PV, EVs and
batteries



- Mass produced in large-scale, replicable factories
- Easily transported
- Easily deployed / installed

Heat pumps



- Mass produced in large factories
- Easily transported
- Complex installation

Wind



- Turbines supply chains very complex, scale of production is orders of magnitude smaller than PV/batteries
- Higher degree of customisation for projects
- Transport and installation more complex

Electrolyser and
green H₂



- Can be mass produced, but balance of system costs and specific project complexities important

CCUS



- Customised engineering design and deployment

Large-scale nuclear

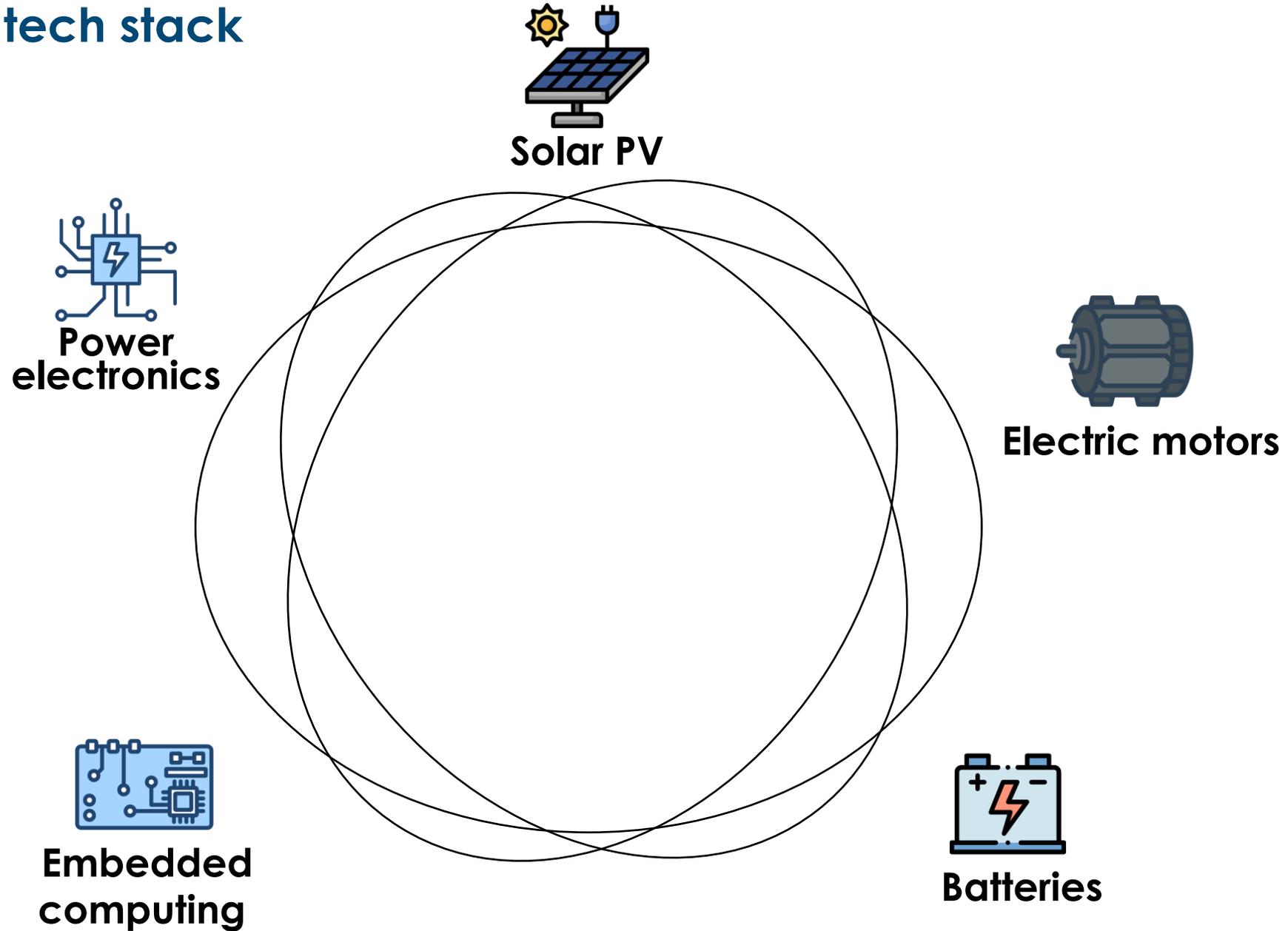


- Hugely complex large-scale systems

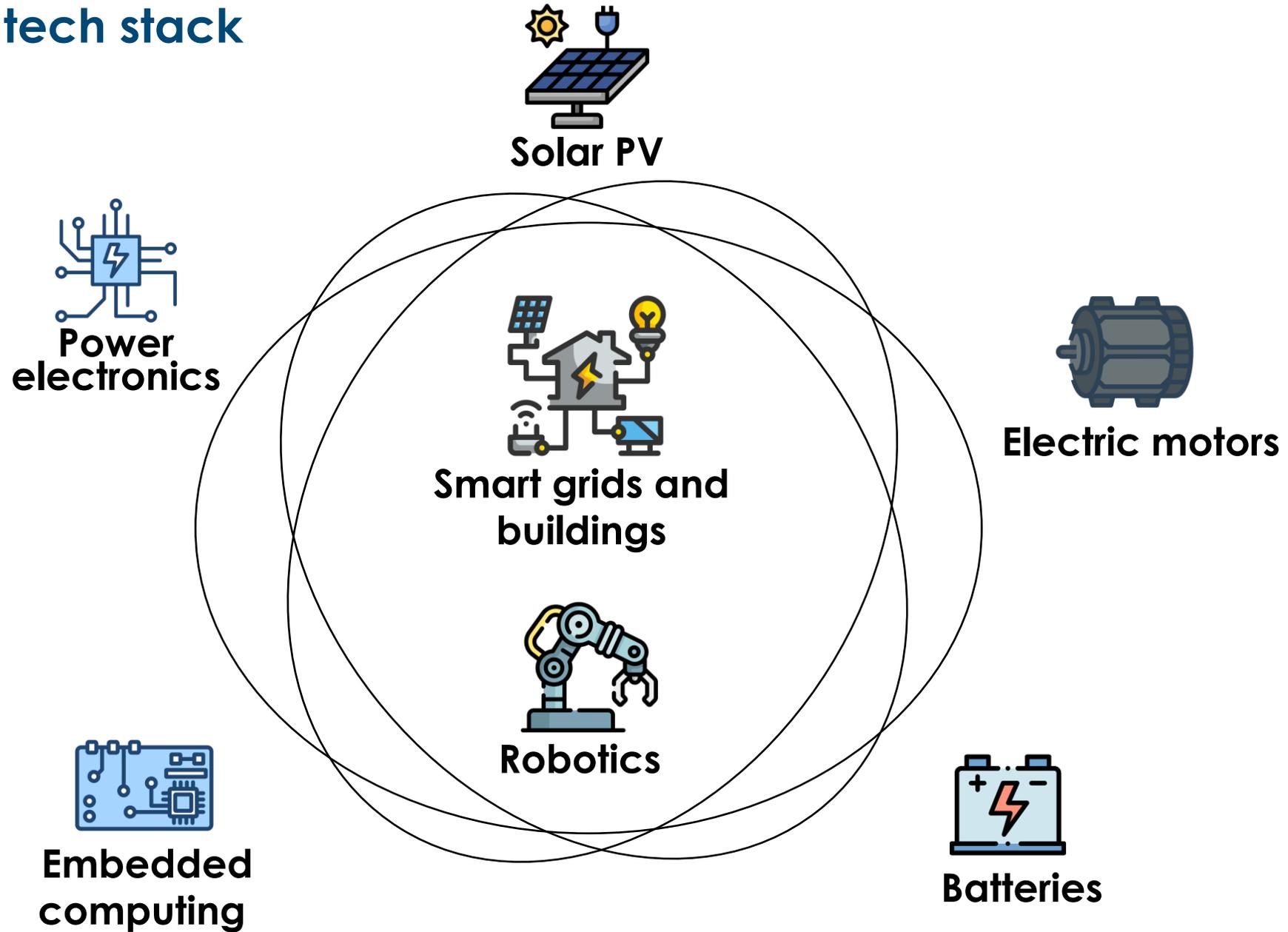
Slower/nil
cost
reduction



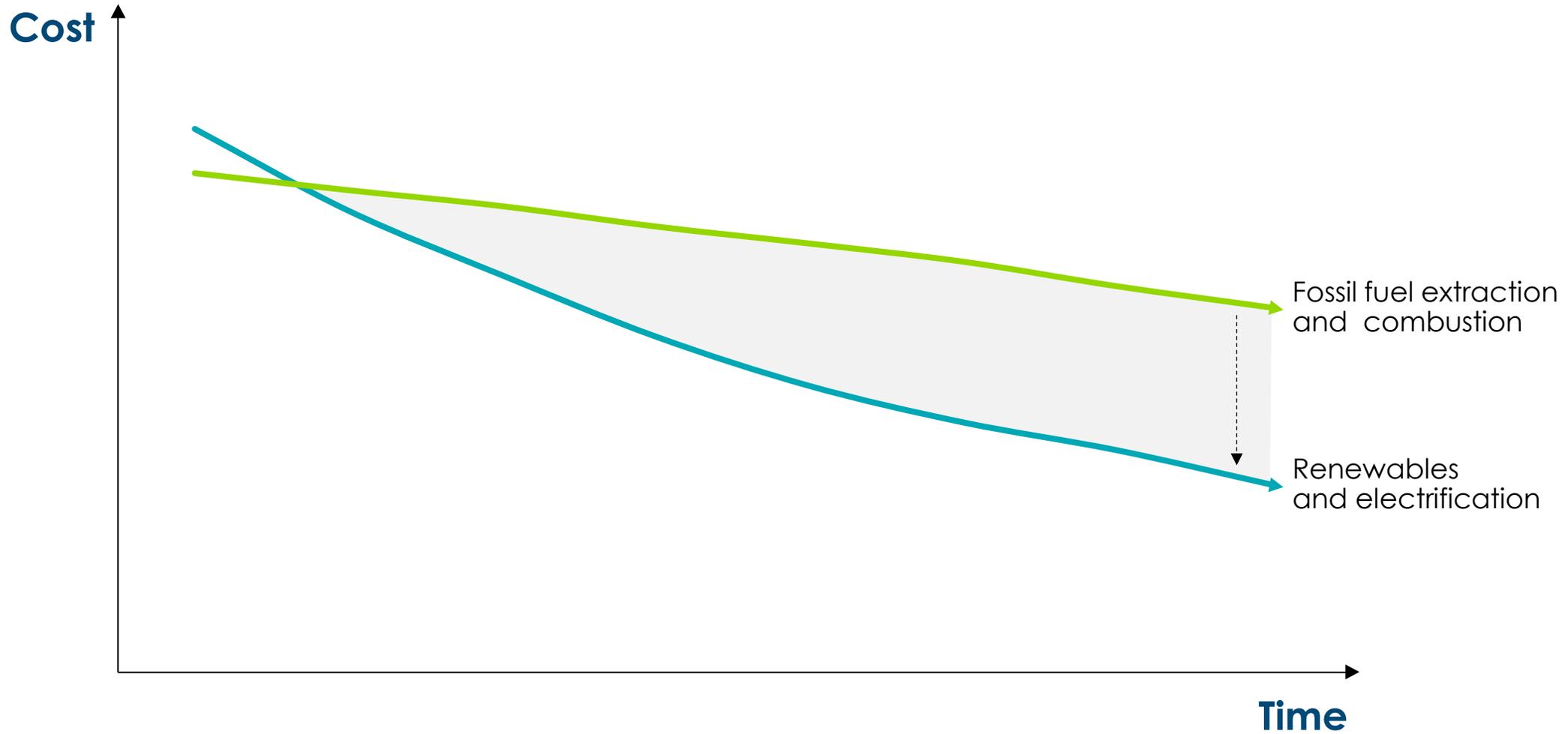
The electro tech stack



The electro tech stack

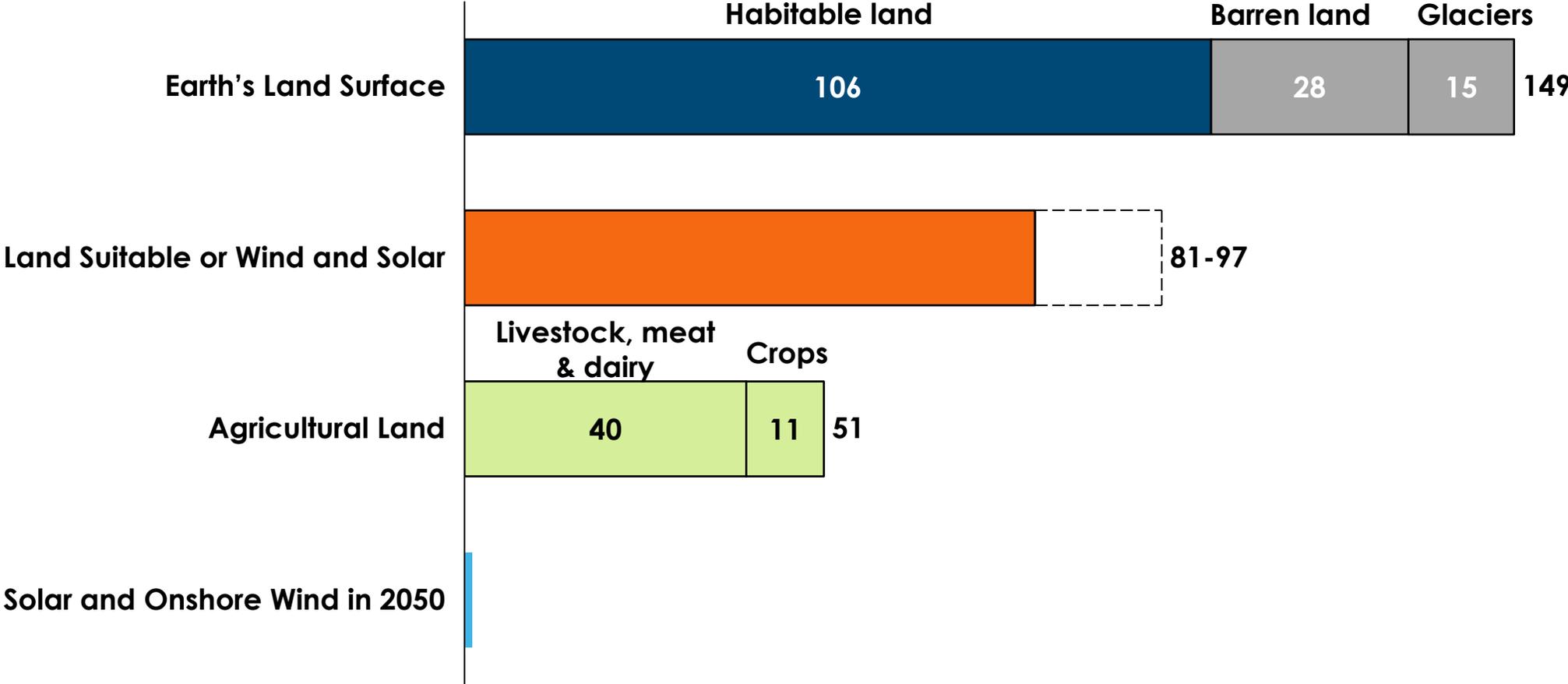


Electro tech vs fossil fuels



Land use by type

Million km²



Source: Source: ETC (2023), *Material and Resource Requirements for the Energy Transition*

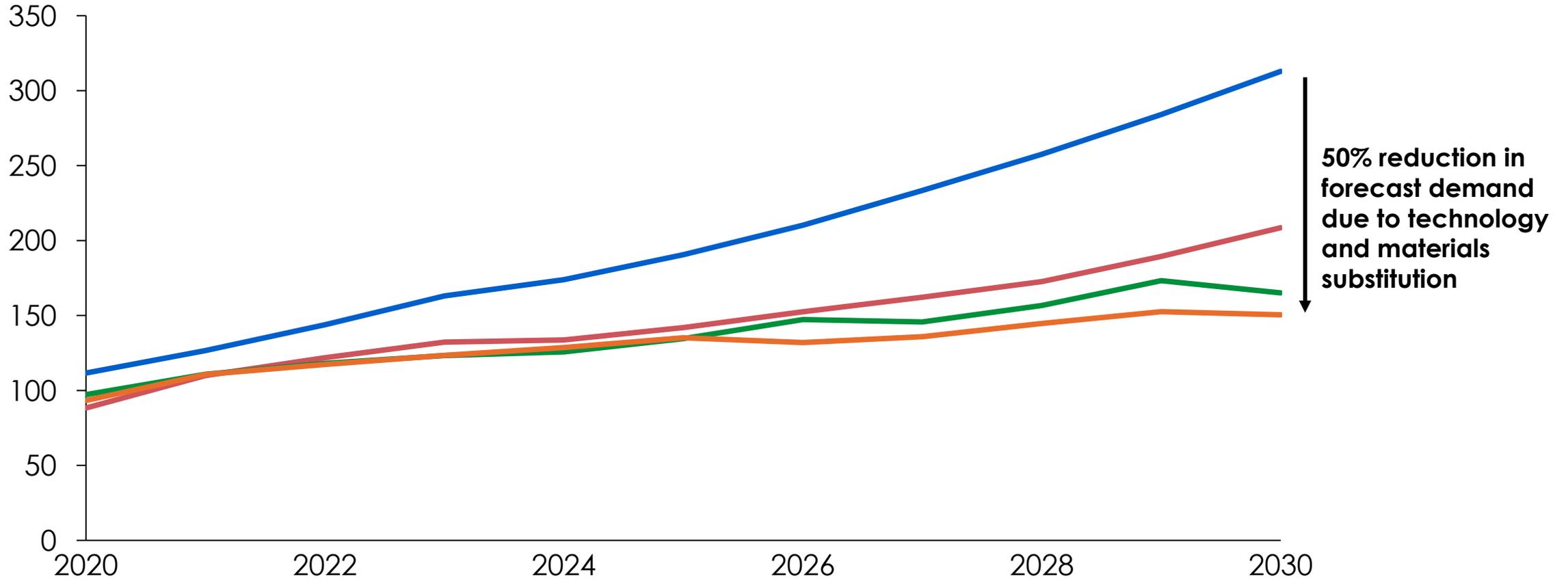
Agri PV



Projected cobalt demand in successive BNEF projections

Thousand metric tonnes

— BNEF forecast, 2019 — BNEF forecast, 2020 — BNEF forecast, 2021 — BNEF forecast, 2022



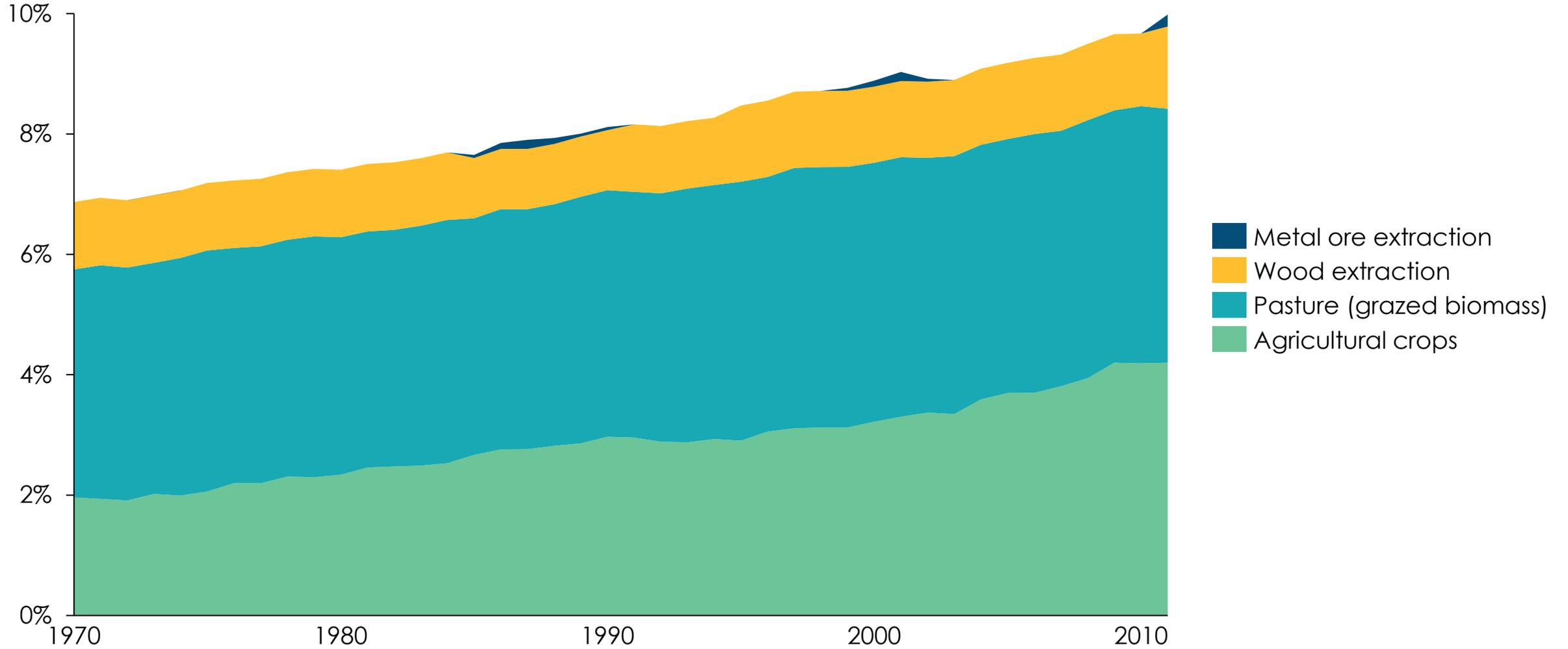
50% reduction in forecast demand due to technology and materials substitution



Note: Ratio of prices is adjusted to account for higher conductivity (a ratio of 1.66:1 Cu:Al). A value above 1 indicates aluminium is favoured over copper. Source: BNEF (2022), *Long-term electric vehicle outlook*; BNEF (2021), *Copper and aluminium compete to build the future power grid*.

Global biodiversity loss by cause

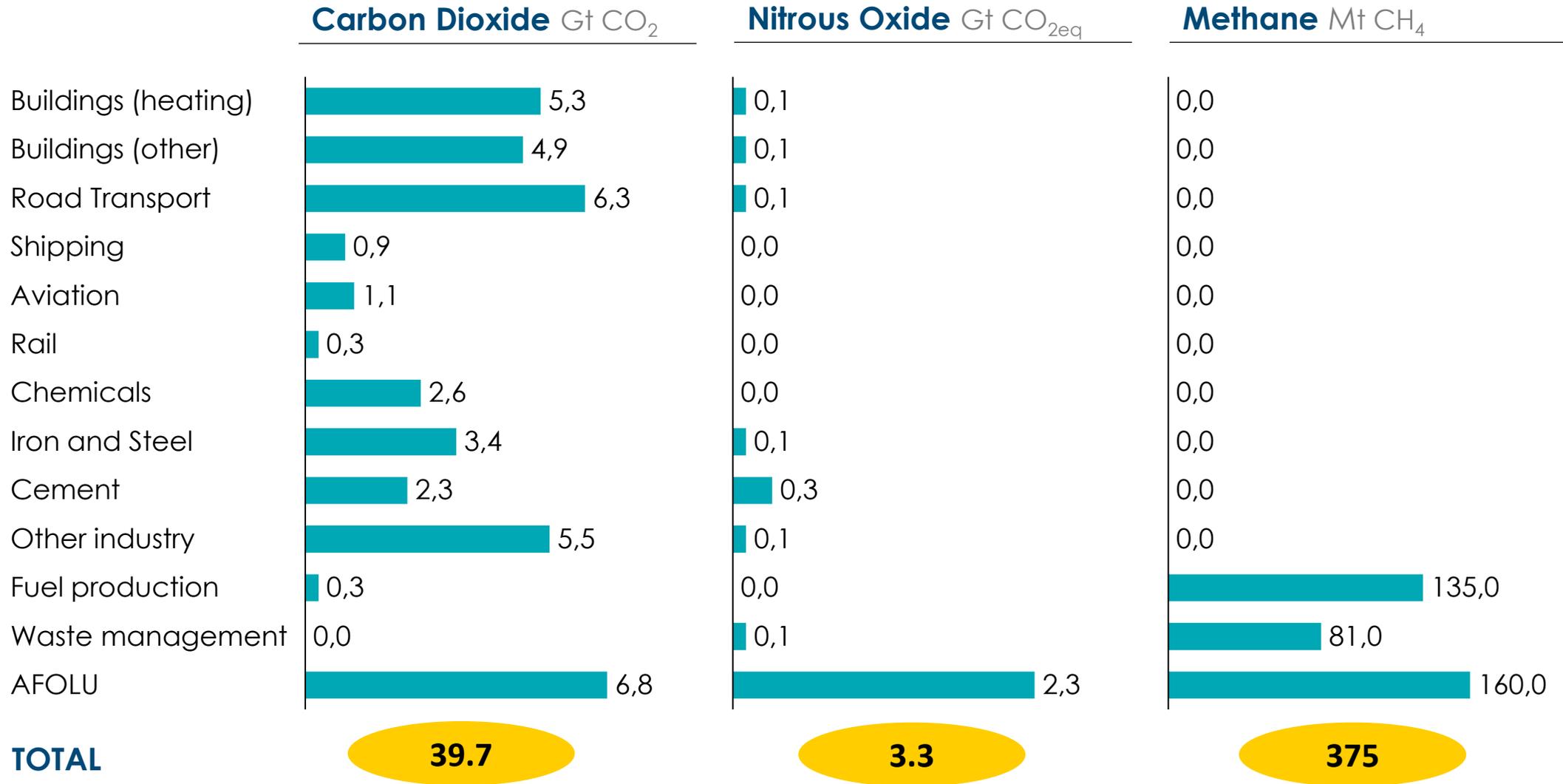
% of global species loss



Note: Does not include indirect impacts on land use, for example development of roads for mining sites which lead to other economic activities requiring deforestation.
Source: ETC (2023), Material and Resource Requirements for the Energy Transition



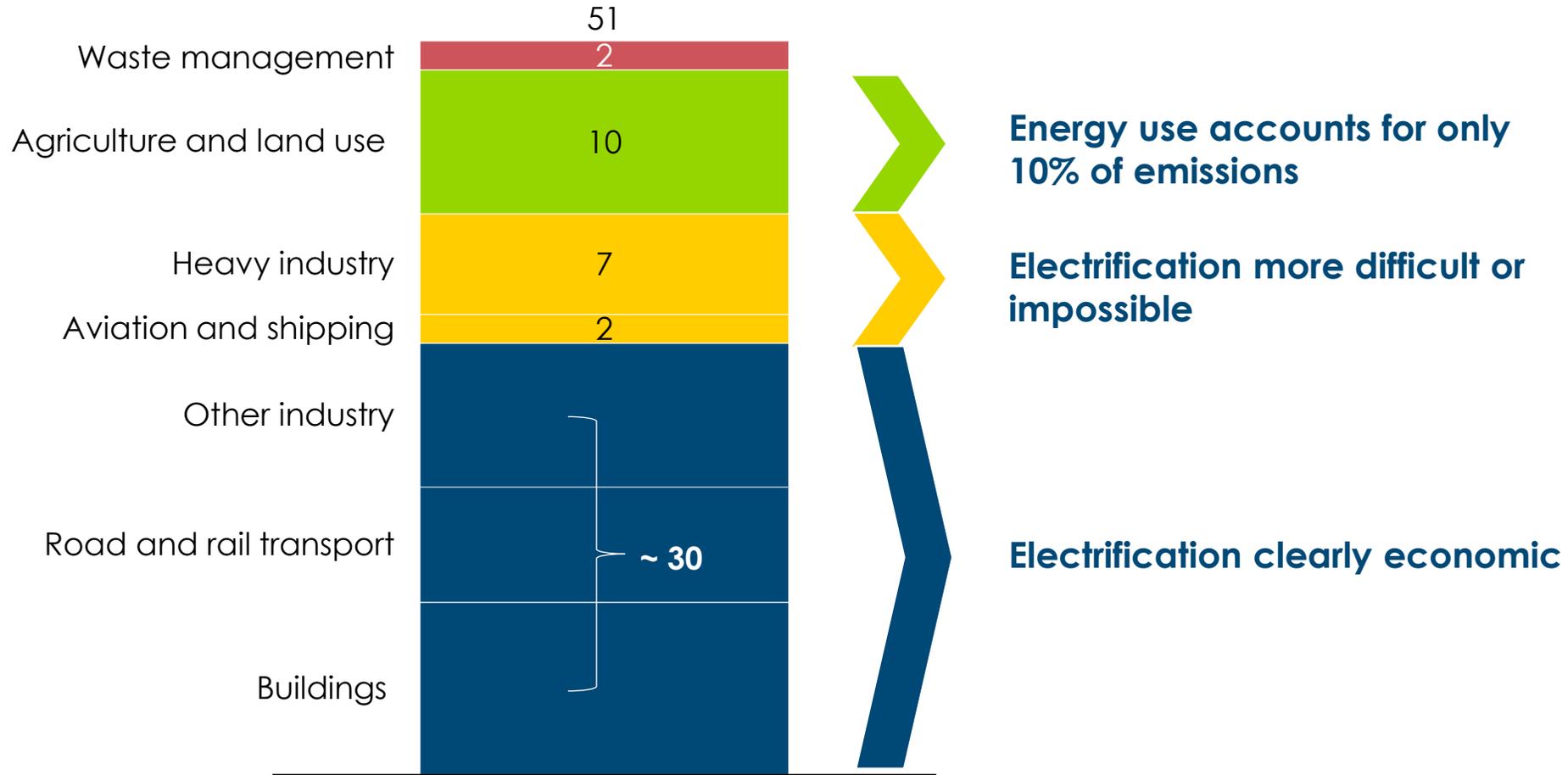
Greenhouse Gas Emissions, 2020



Source: ETC (2022), Mind the Gap

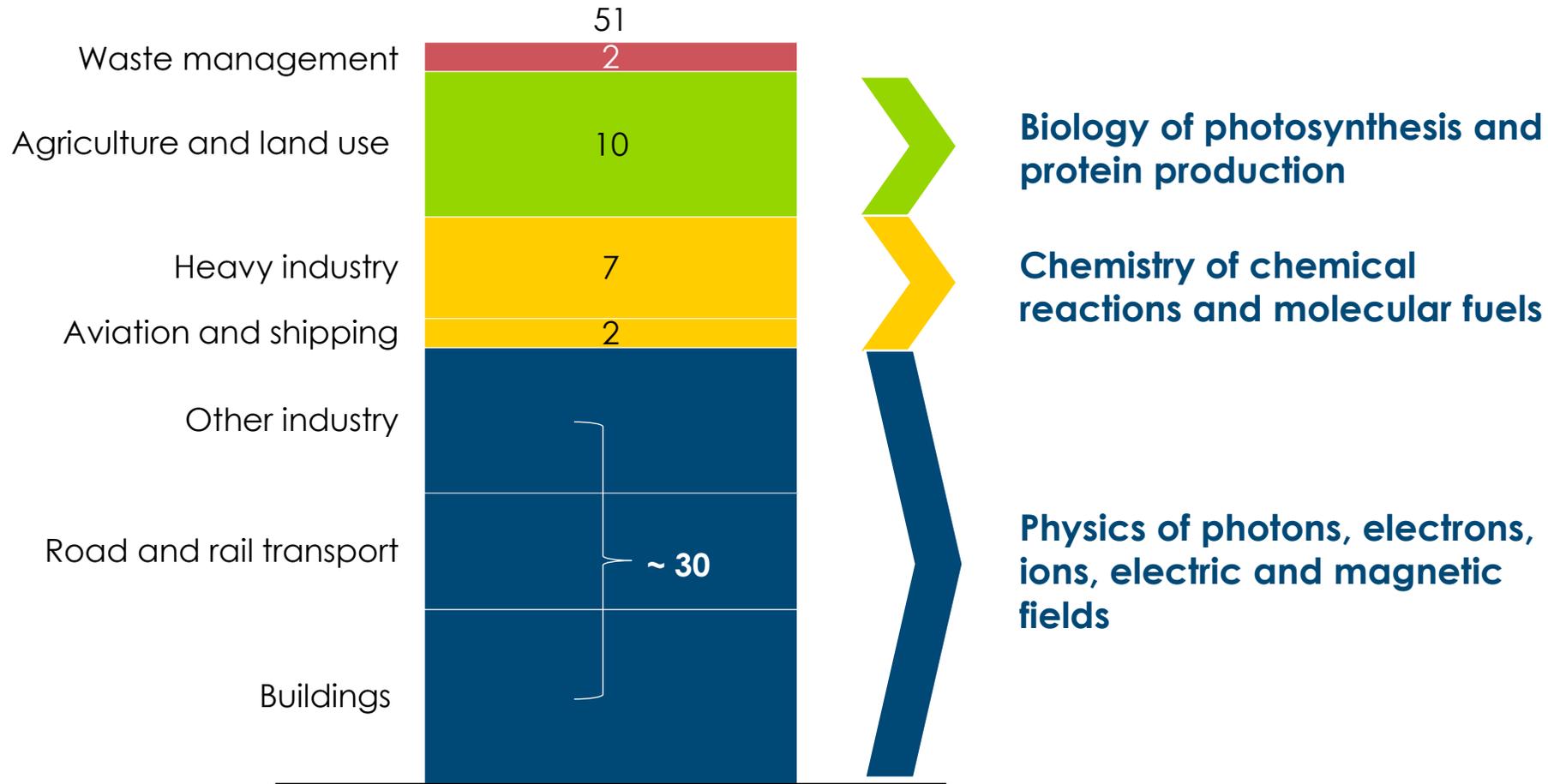
GHG emission by broad sector

Gt CO_{2eq}



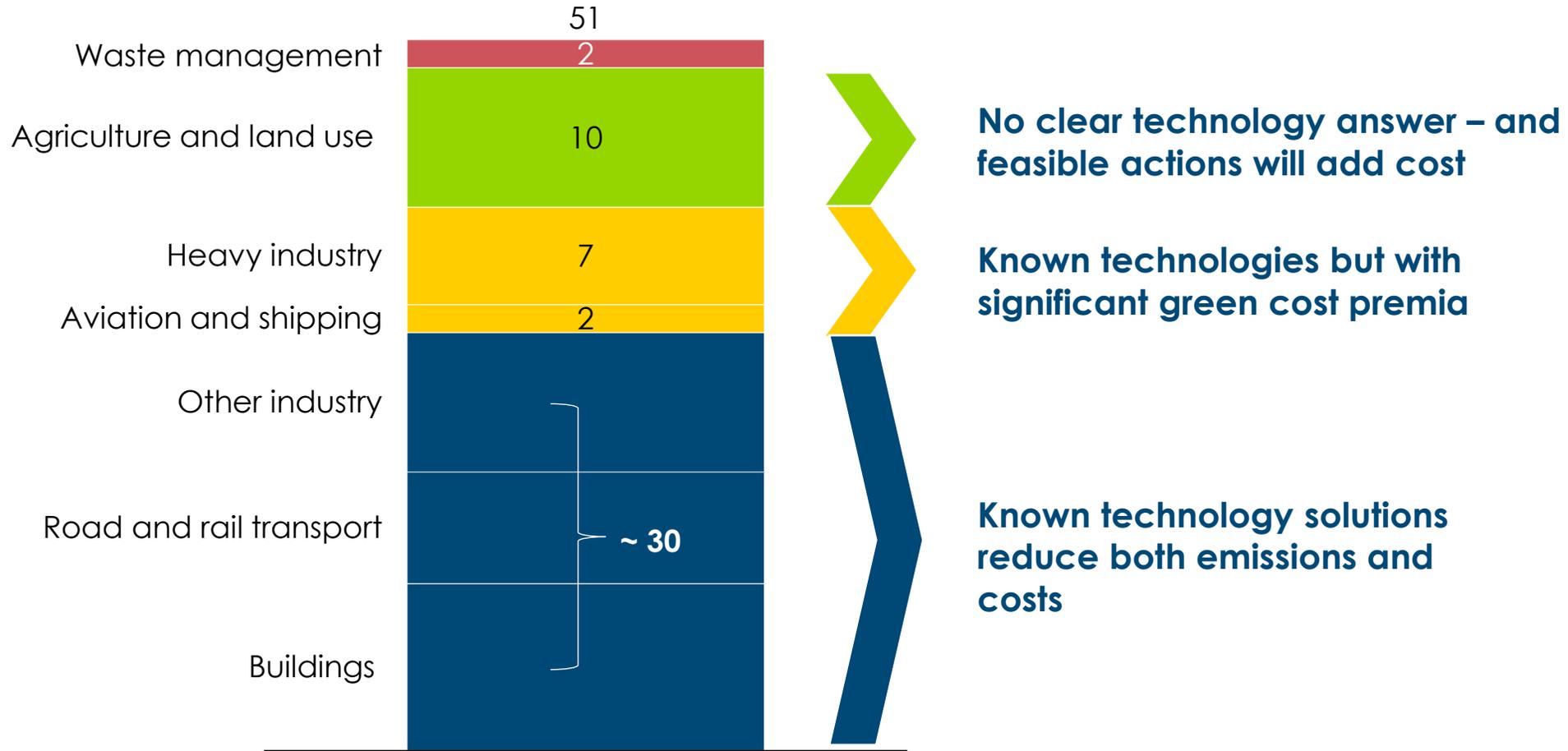
GHG emission by broad sector

Gt CO_{2eq}



GHG emission by broad sector

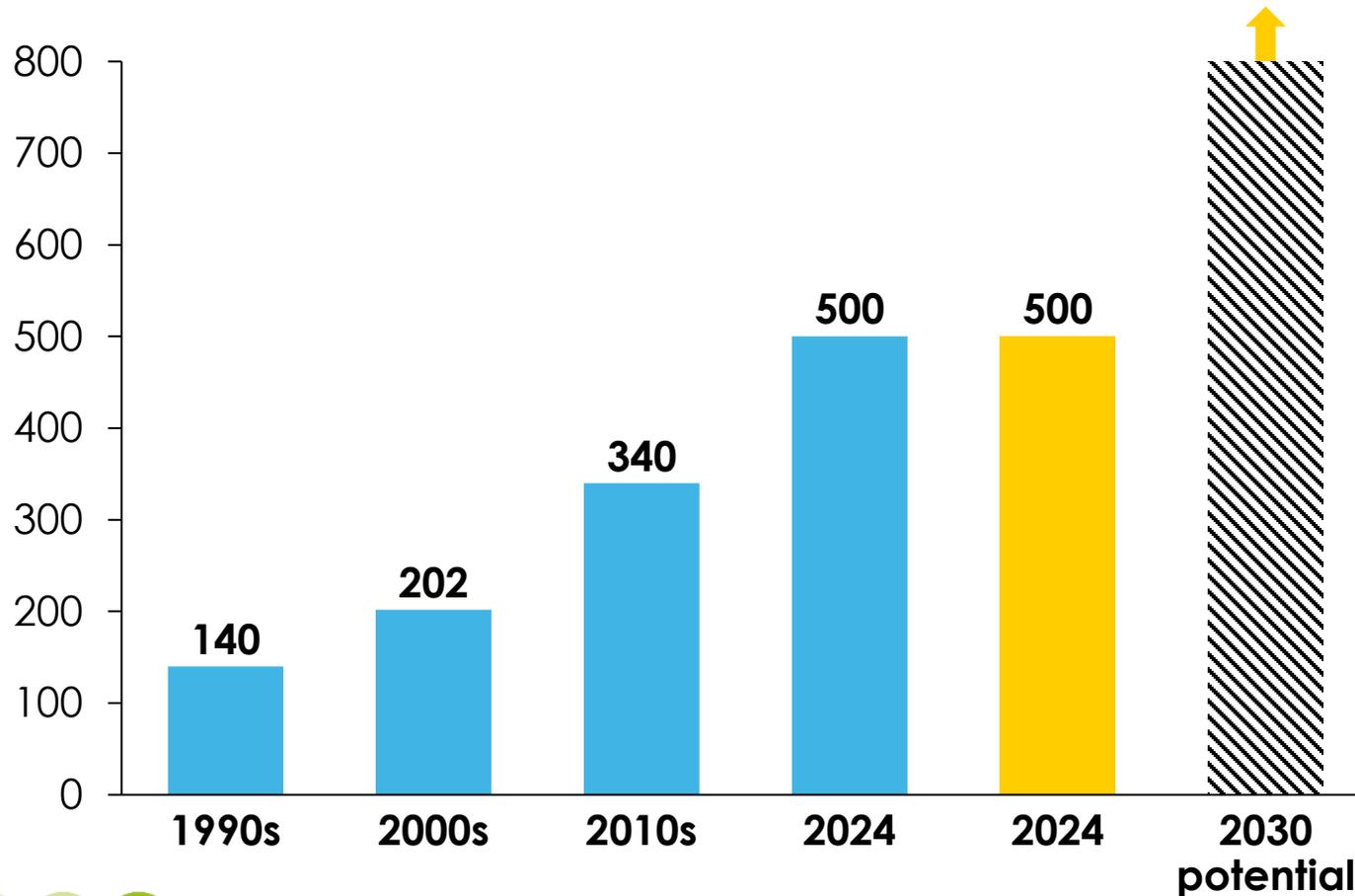
Gt CO_{2eq}



Top-tier battery cell energy density over time

Gravimetric densities, Watt-hours/kg

■ Lithium-ion (liquid) ■ Solid-state (multiple chemistries)



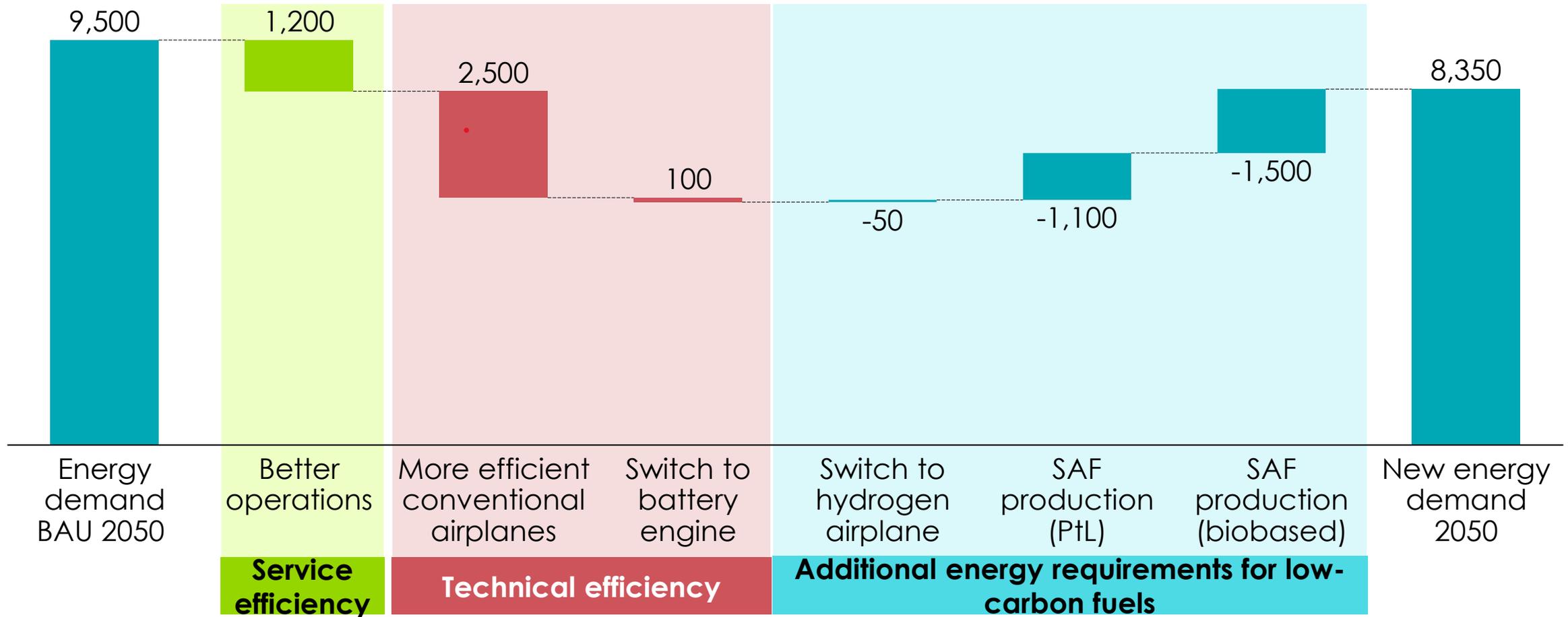
Feasible sector application

- Short-haul passenger aircrafts
Medium-haul shipping
- Shorter-haul aviation
- Shorter-haul shipping, Heavy trucks
- Light trucks
- Passenger cars
- Consumer electronics



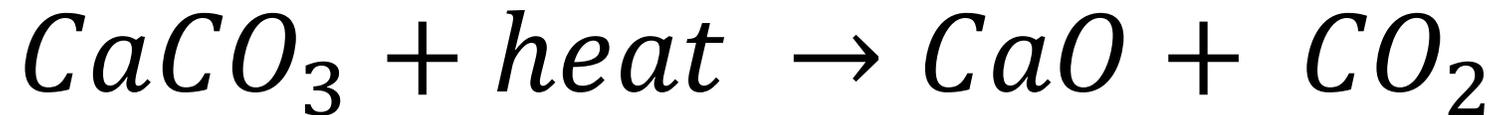
Aviation sector primary energy demand in 2050

TWh

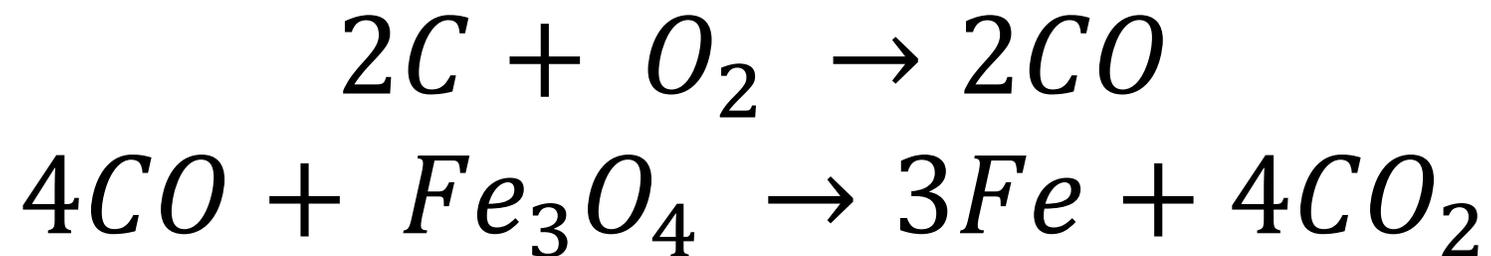


Note: BAU = Business as Usual; SAF = Sustainable Aviation Fuel; PtL = Power to liquids.
 Source: Schäfer, A. (2019), "Technological, economic and environmental prospects of all-electric aircraft"; ETC (2022), Making Net-Zero Aviation Possible.

Cement



Iron



Heavy industry decarbonisation technologies

Iron and steel



- Hydrogen as reduction agent
- CCS
- Electrolysis/ electrowinning

Cement



- CCS
- New cementitious materials

Plastics



- New carbon atom sources – bio or direct air capture
- CCS
- Mechanical or chemical recycling
- Sustainable end of life storage



The green premium in heavy industry decarbonisation

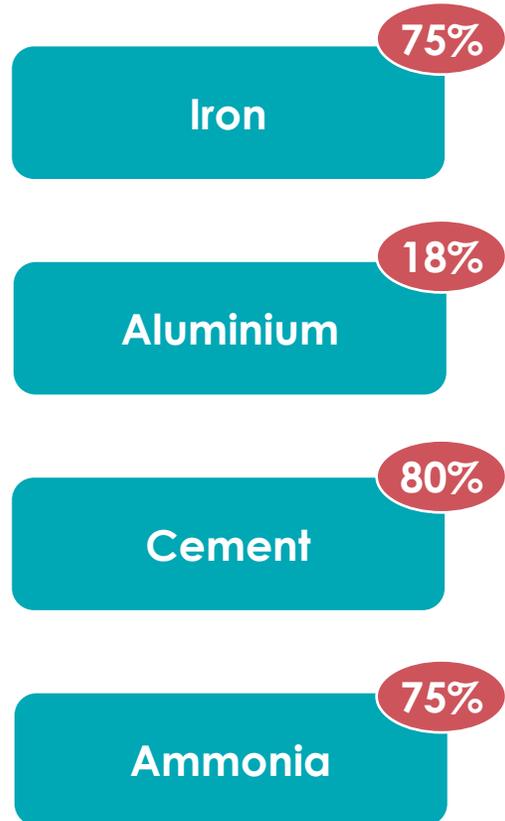
Cost premia from decarbonisation

x%

y%

z%

Clean Commodity Production



Note: Assumes 100% cost pass through, costs are based on productions in low-cost regions of Europe.
Source: Systemiq analysis for the ETC, ETC (2020), *Making Mission Possible*.

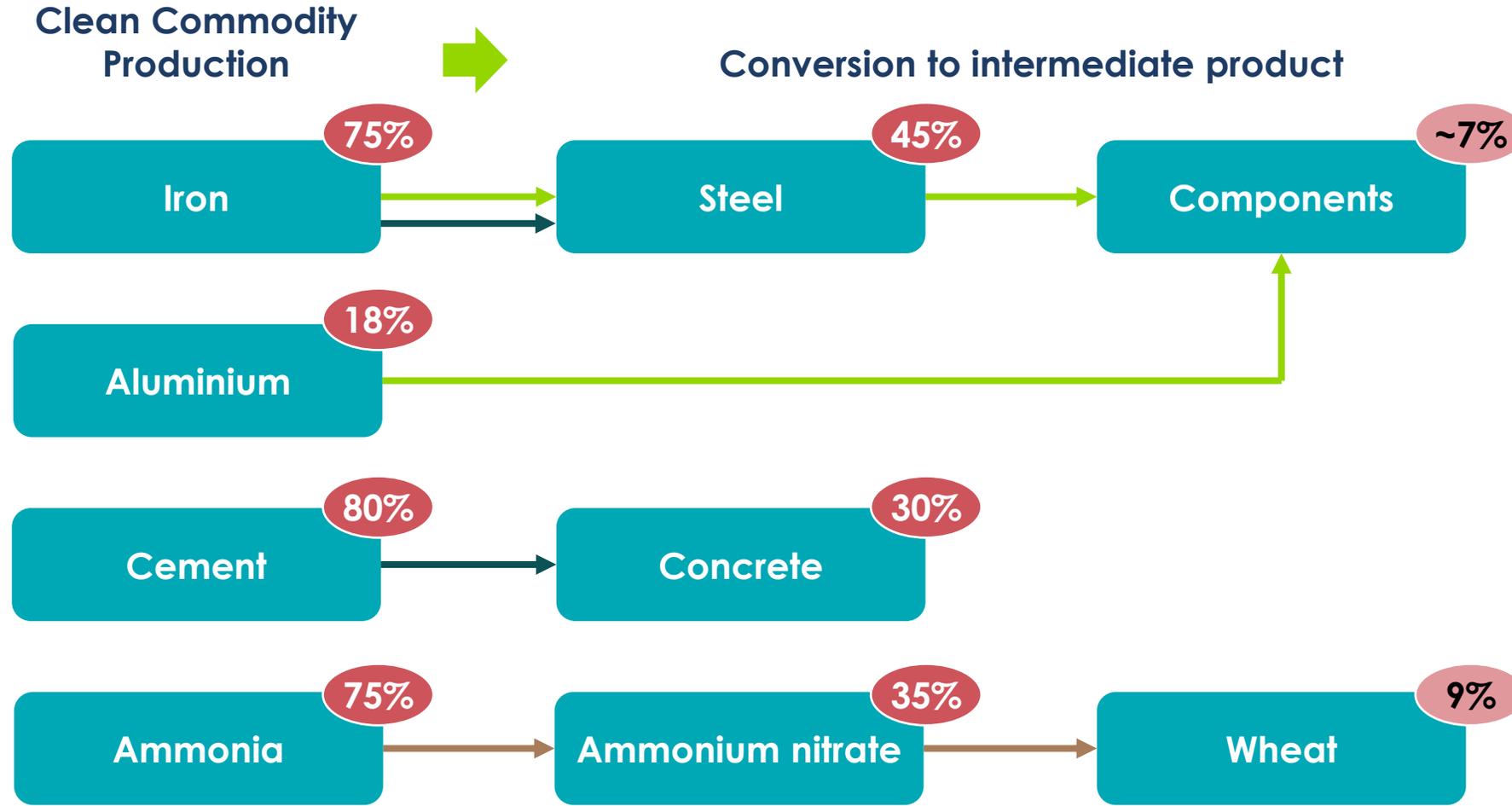
The green premium in heavy industry decarbonisation

Cost premia from decarbonisation

x%

y%

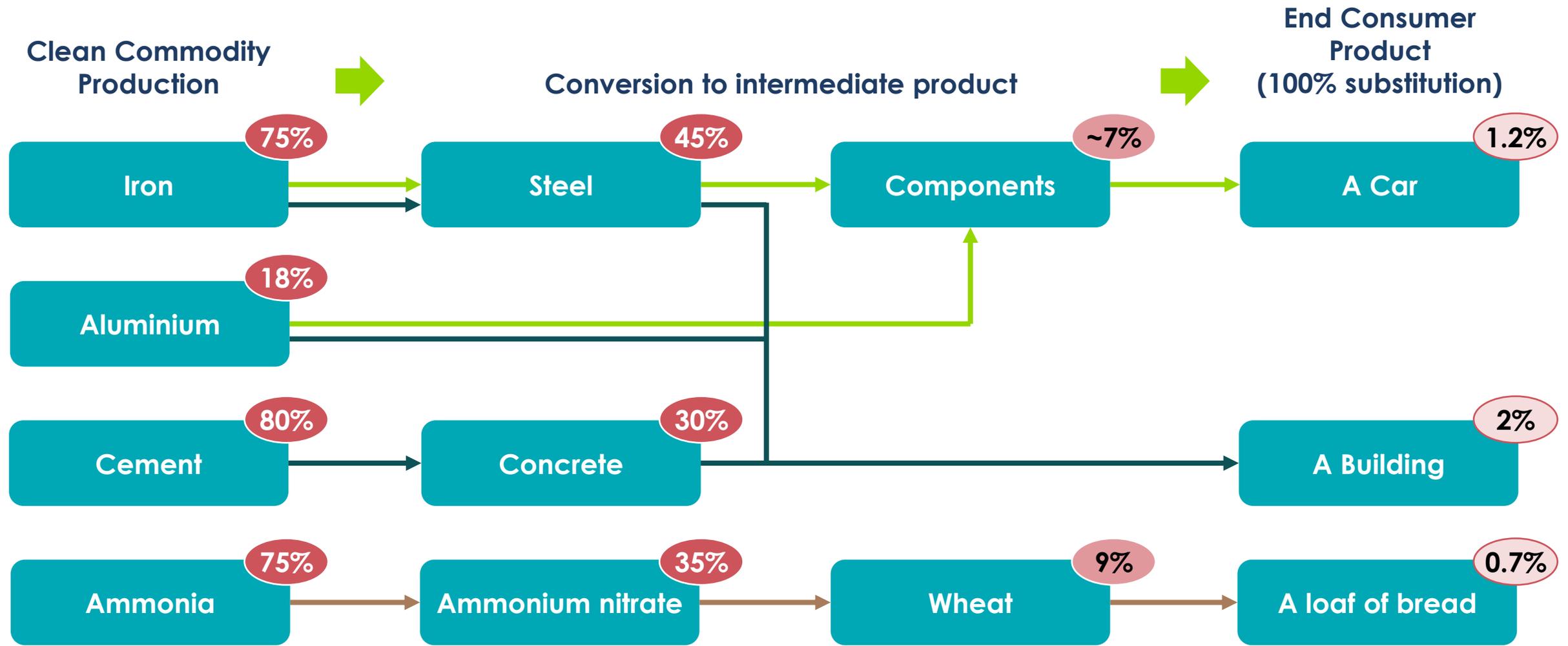
z%



Note: Assumes 100% cost pass through, costs are based on productions in low-cost regions of Europe.
Source: Systemiq analysis for the ETC, ETC (2020), *Making Mission Possible*

The green premium in heavy industry decarbonisation

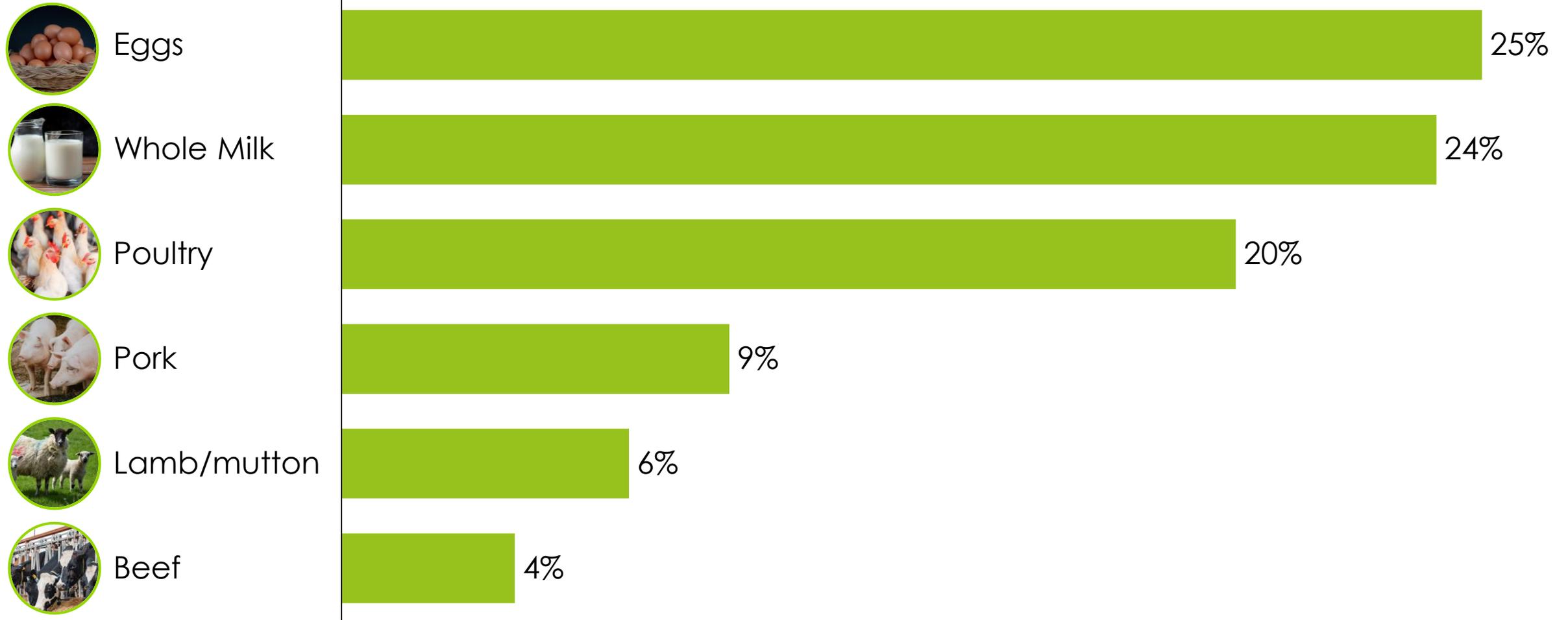
Cost premia from decarbonisation
 x% y% z%



Note: Assumes 100% cost pass through, costs are based on productions in low-cost regions of Europe.
 Source: Systemiq analysis for the ETC, ETC (2020), *Making Mission Possible*.

Protein efficiency of meat and dairy production

% of protein inputs as feed effectively converted to animal product



Source: Global Environmental Change, Volume 41, Alexander et al. (2016). *Human appropriation of land for food: the role of diet.*

Relative efficiency: road transport vs meat

Solar to motion



x



=

13.5%

Solar to animal protein



x



=

0.04%



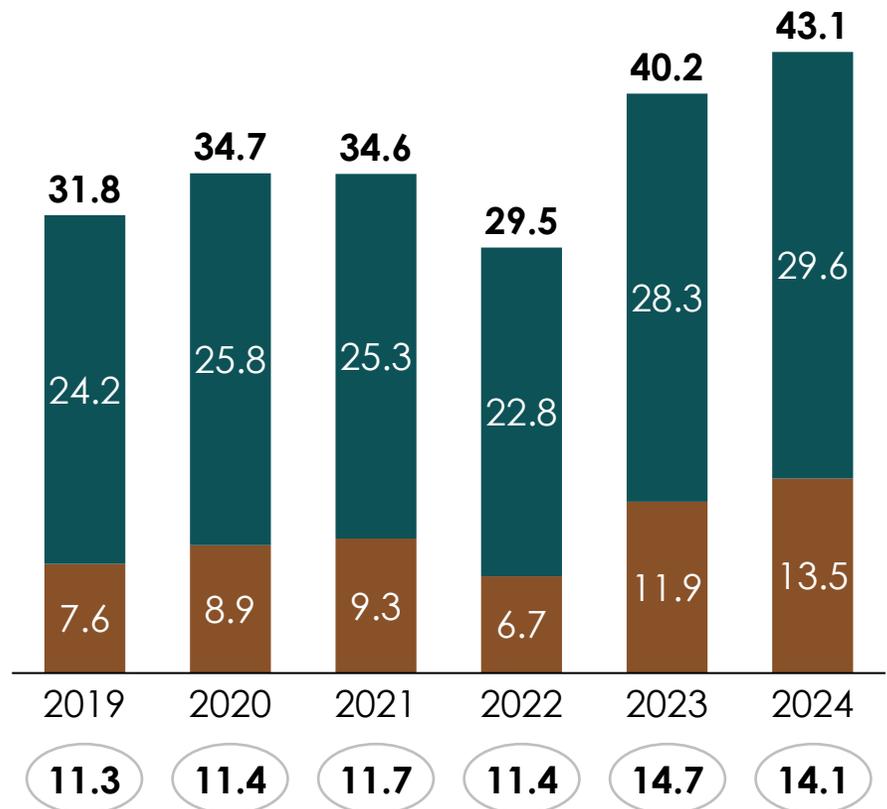
Global tree loss trends and drivers

Global annual tree cover loss, 2019-2024

Mha

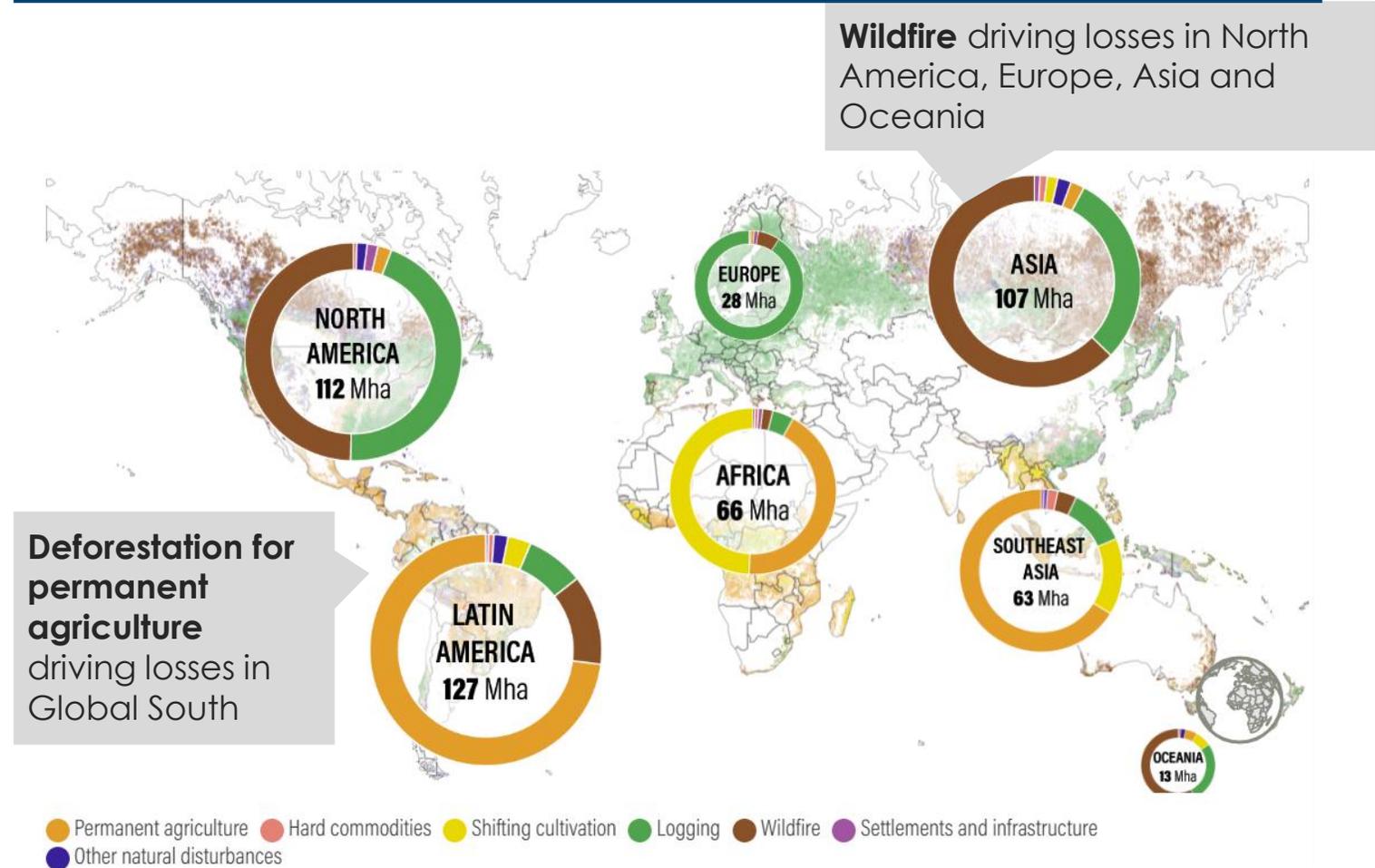
Loss due to all other factors* Loss due to fire

XX.X Related Gt of CO₂e emissions



Tree cover loss by dominant driver, 2001-2024

Regional Results

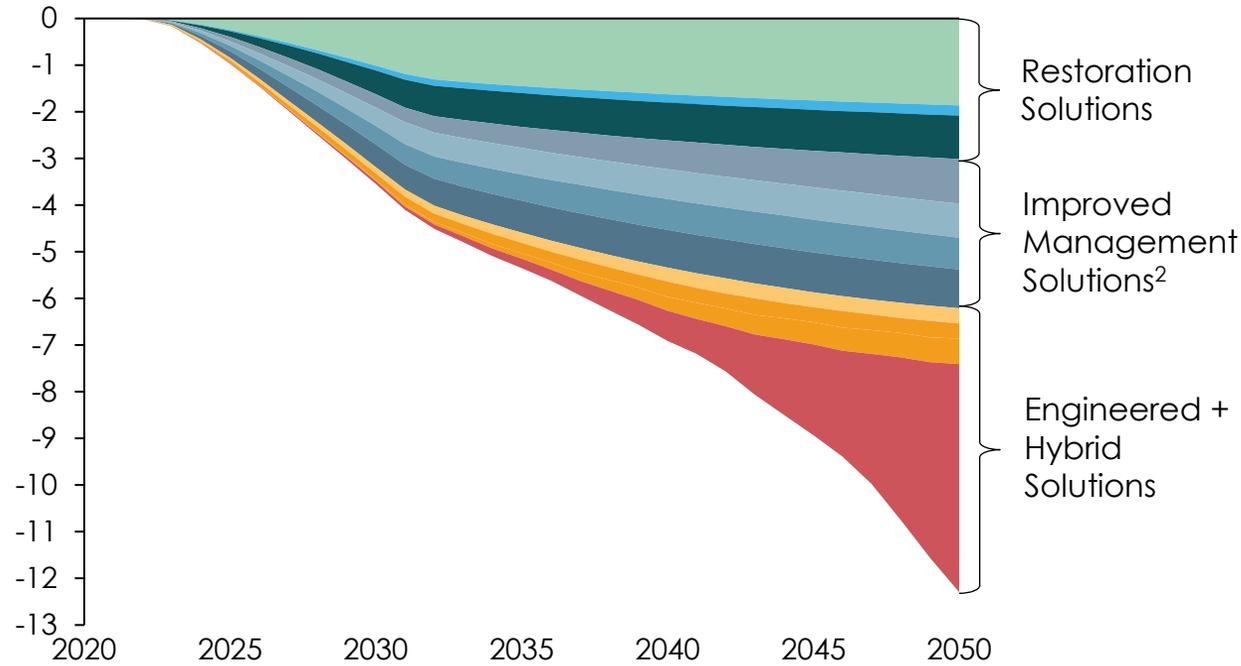


Note: Other factors of loss include manmade and other natural disturbances, such as landslide, insect damage, storms and changing rivers.
 Source: WRI (2025), *New Data Shows What's Driving Forest Loss Around the World*; Global Forest Watch.

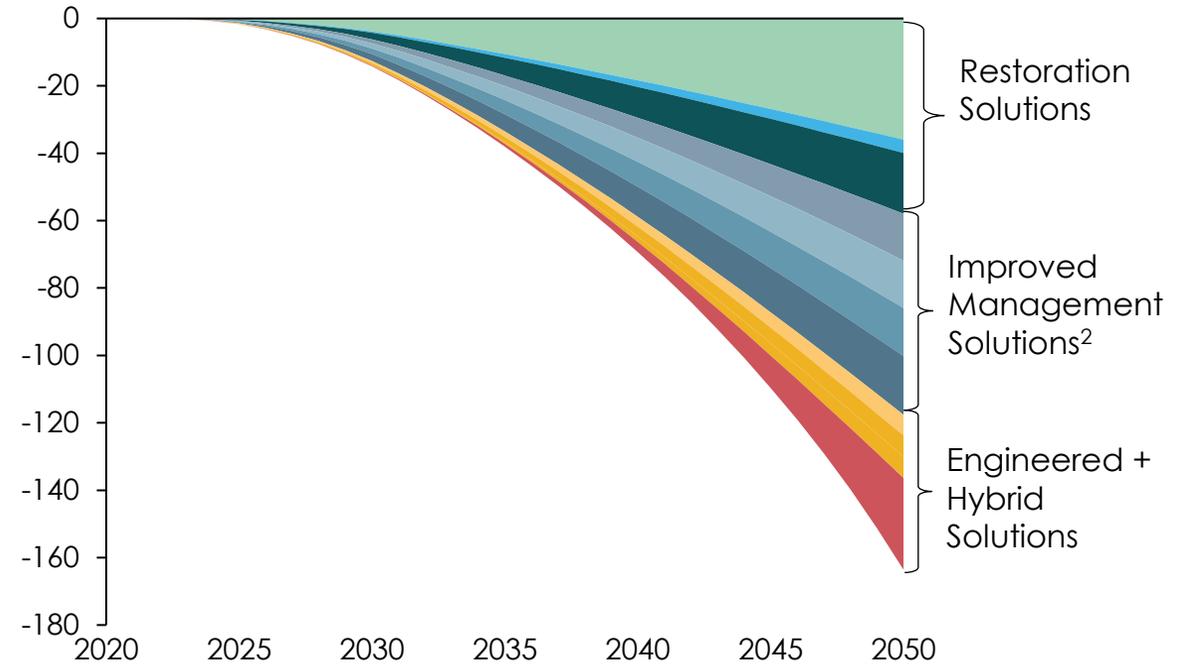
Required removals for a 1.5C temperature limit estimated by ETC in 2022

CO₂ ONLY

Potential ramp-up of CDR, GtCO₂/year, global



Cumulative CDR 2020-2030, GtCO₂, global



NCS: Restore

- Restore forests
- Restore Blue carbon
- Restore drained peatlands

NCS: Manage

- Improve forest management
- Agroforestry
- Enhance soil carbon sequestration in croplands
- Enhance soil carbon sequestration in grazing lands

Hybrid and engineered approaches

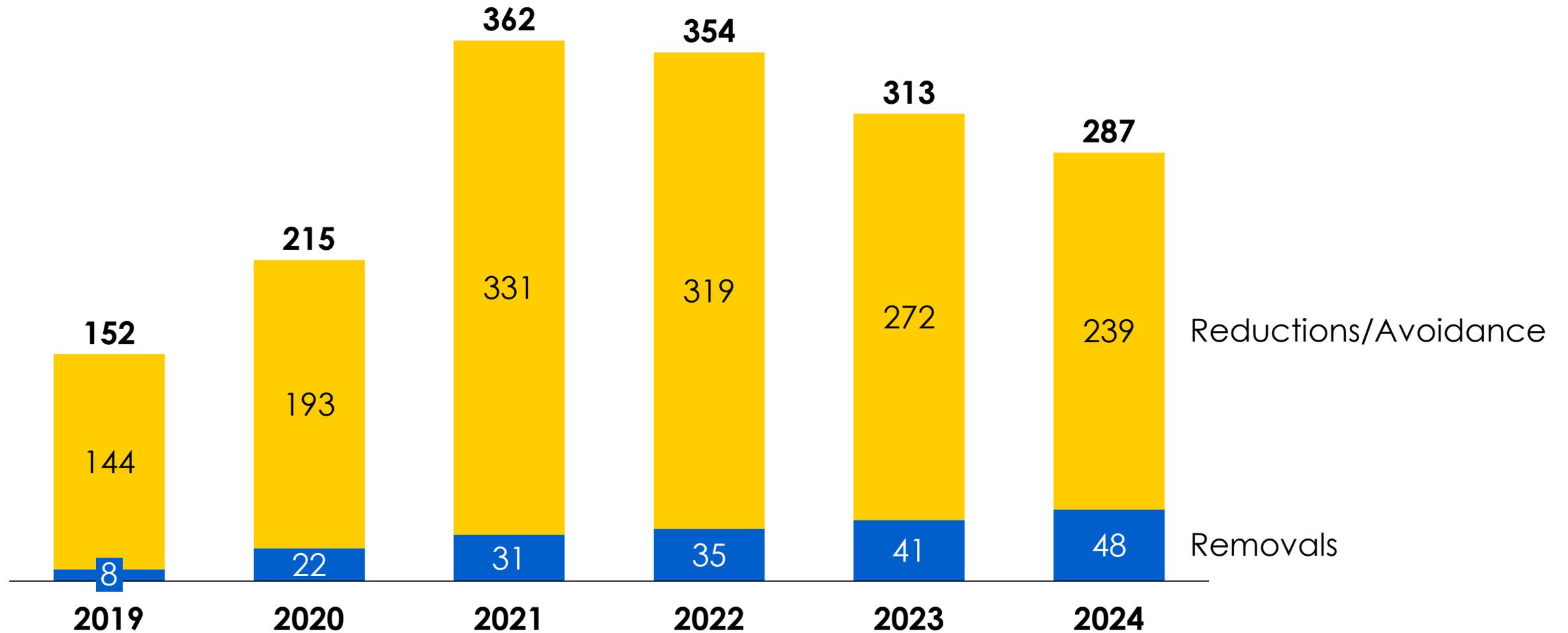
- Apply biochar
- BECCS
- DACCS



Source: ETC (2022), *Mind the Gap: How Carbon Dioxide Removals Must Complement Deep Decarbonisation to Keep 1.5°C Alive*

Volume of carbon credit issue/purchase by type

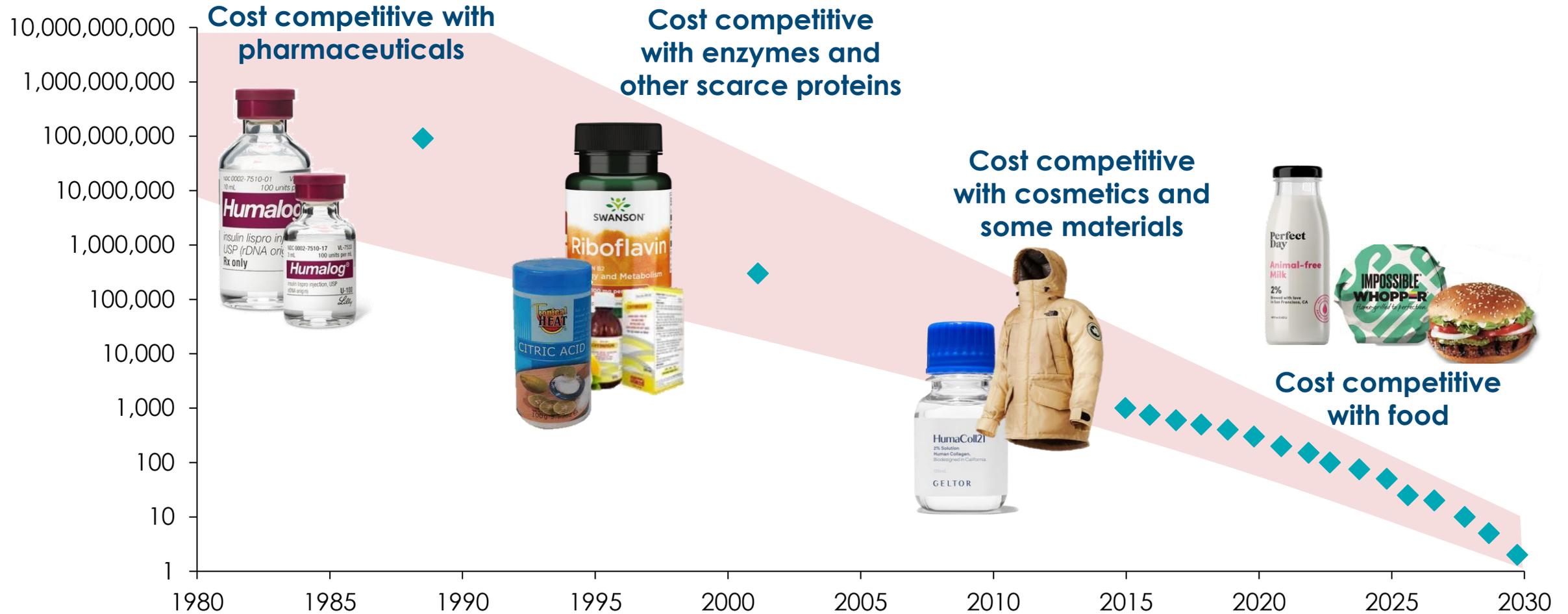
Million tonnes



Source: Group of 30 (2025), Carbon Pricing and Markets: Enabling Efficient Emission Reductions

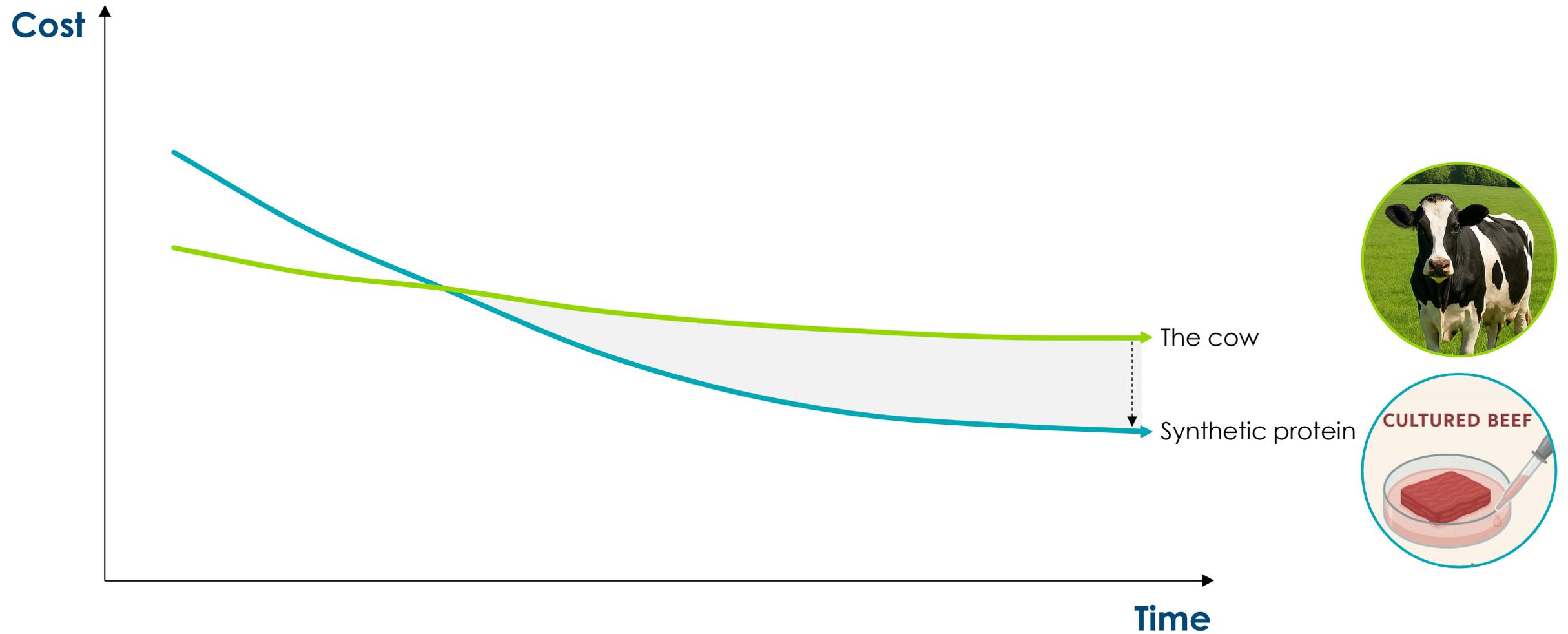
Precision fermentation proteins

Log (2018 \$/kg protein)



Source: Rethink X (2019), *Rethinking Food and Agriculture*.

Synthetic protein vs the cow



GHG emission by broad sector

Gt CO_{2eq}

