IEA Modelling and Scenarios

3rd of October 2024

Energy, Mathematics and Theoretical Challenges

Institut Henri Poincaré, Paris

International Energy Agency

Overview

Scenario analysis in the World Energy Outlook

The *World Energy Outlook (WEO)* uses the latest available data to analyse energy, emissions and climate trends.

3 core scenarios

Where do existing policies take us?

STEPS

Stated Policies Scenario

What is the impact of announced net zero and other pledges if they are met in full?

APS

Announced Pledges Scenario

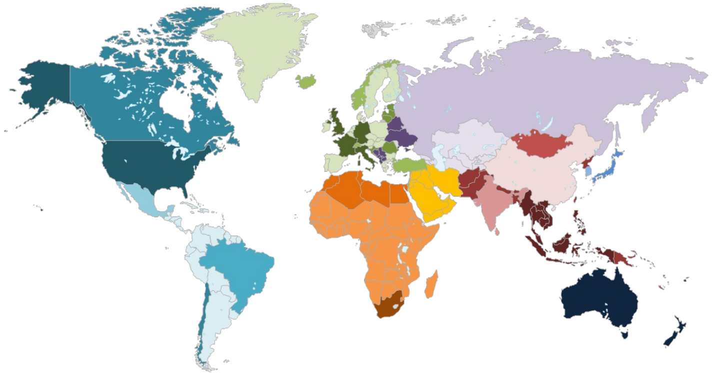
What is required for the energy sector to reach net zero CO_2 emissions by 2050?

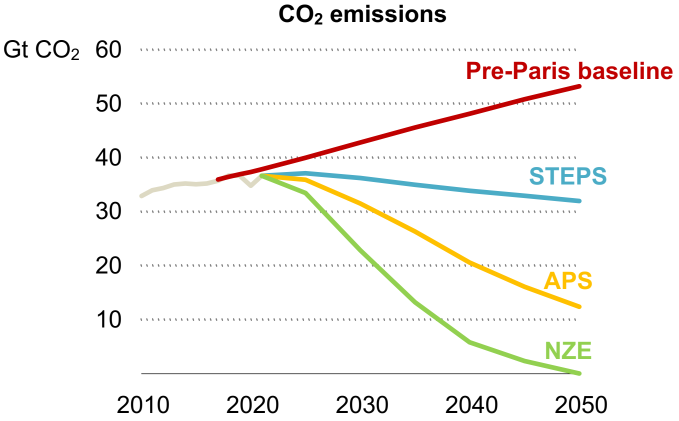
NZE

Net Zero Emissions by 2050 Scenario

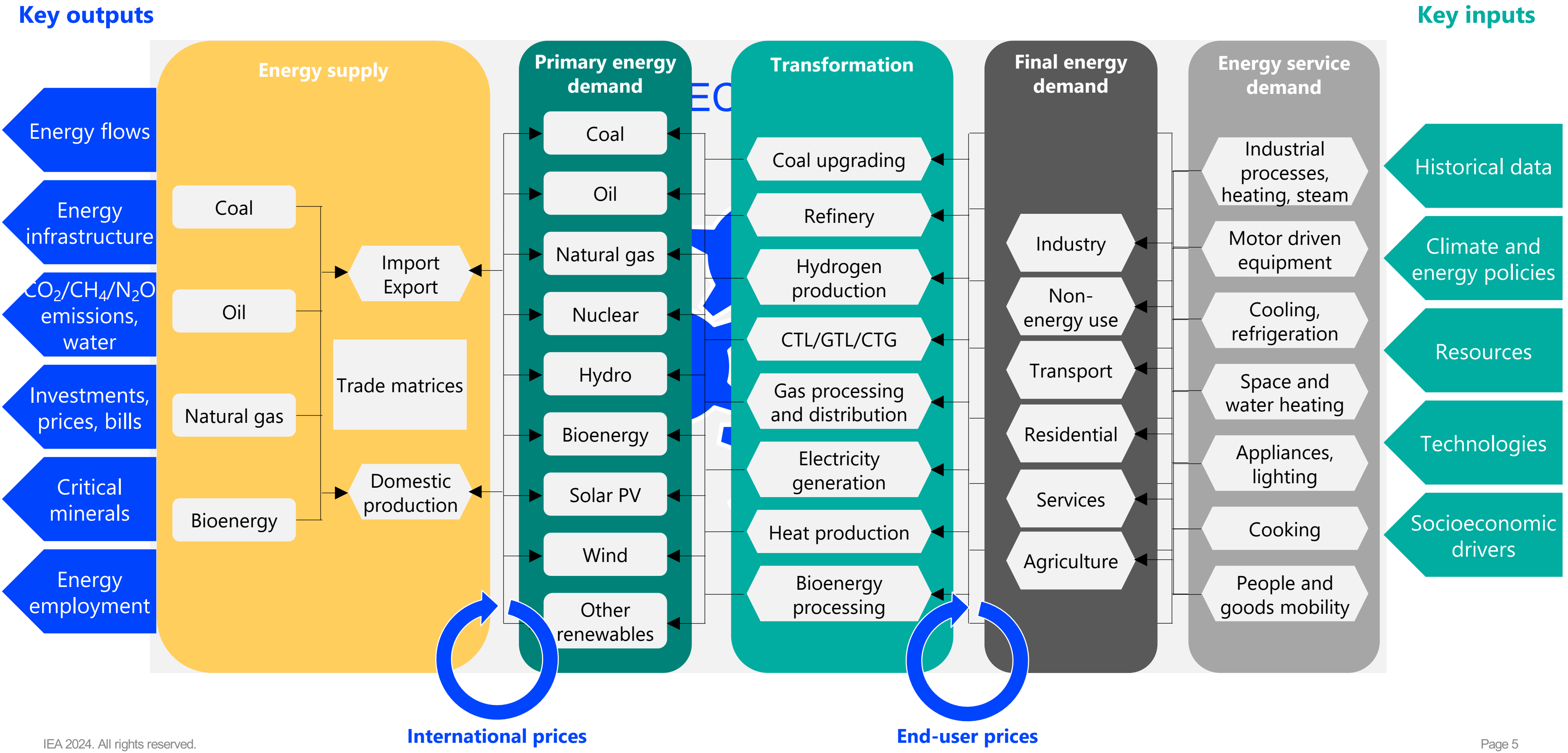
Main features of the Global Energy and Climate Model

- Large-scale simulation model
- Integrates WEM and ETP modelling frameworks
- Time frame: 1970 – 2050 (annual data)
- 26 demand regions:
  - 11 countries: Brazil, Canada, China, India , Indonesia , Japan , Korea, Mexico, South Africa, Russia, US
- Around 120 supply regions
- Technology and sectoral rich
- Includes IEA historical energy statistics and short-term energy market trends

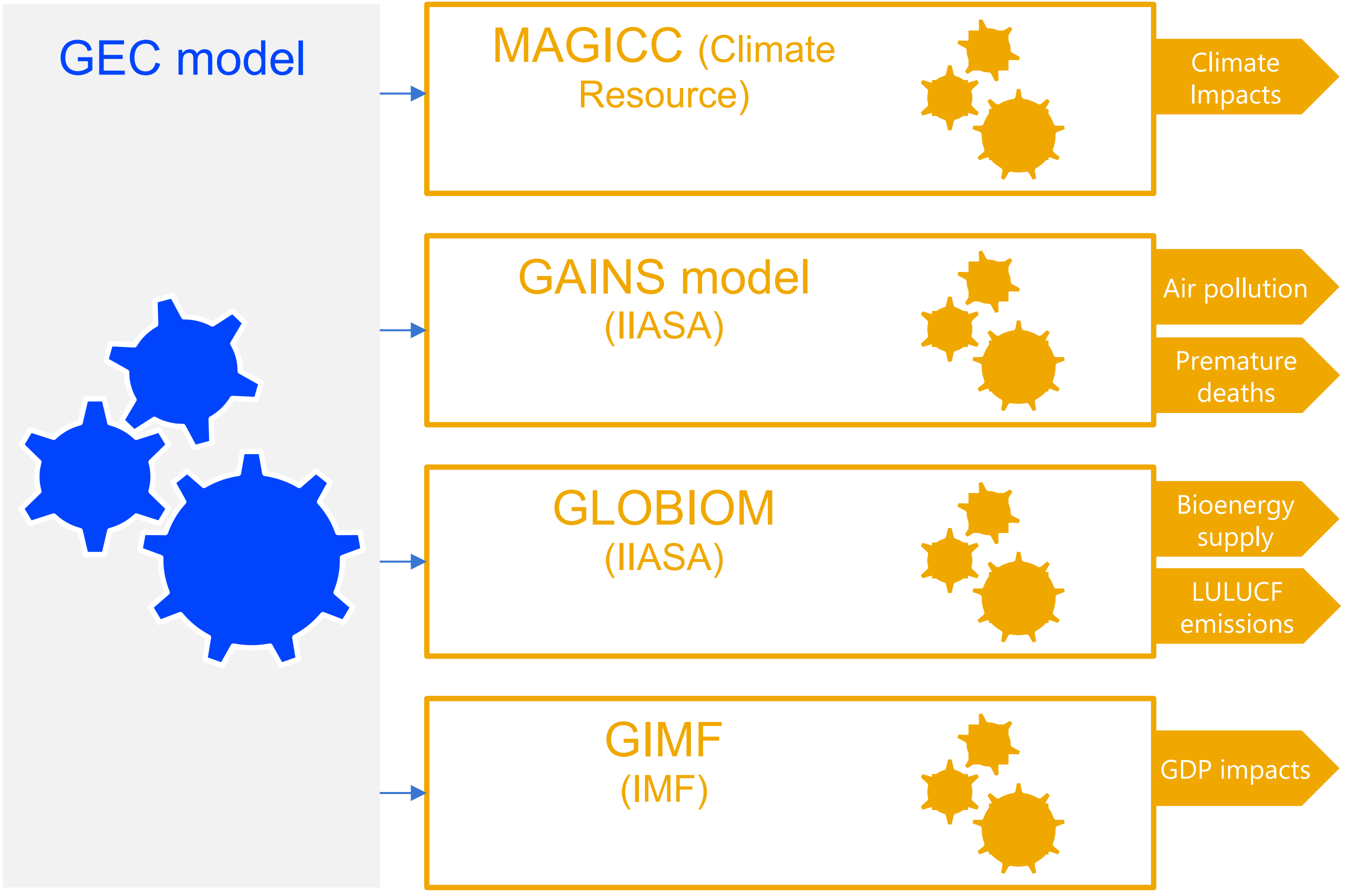


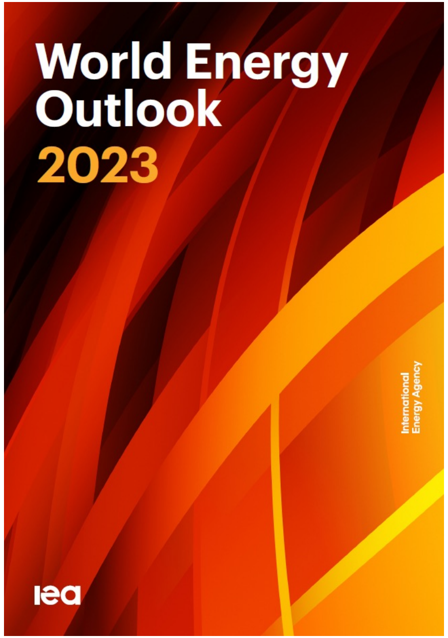


The Global Energy and Climate Model structure



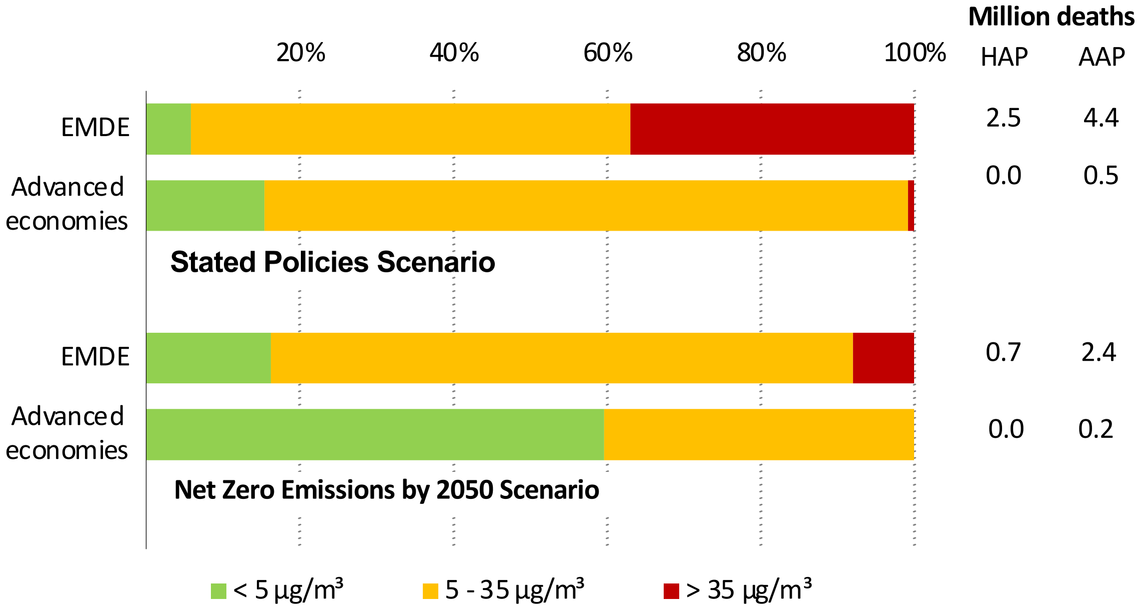
Connections with the international modelling community





NZE addresses the human and economic costs of air pollution

Share of people exposed to PM2.5 air pollution and associated premature deaths in 2030



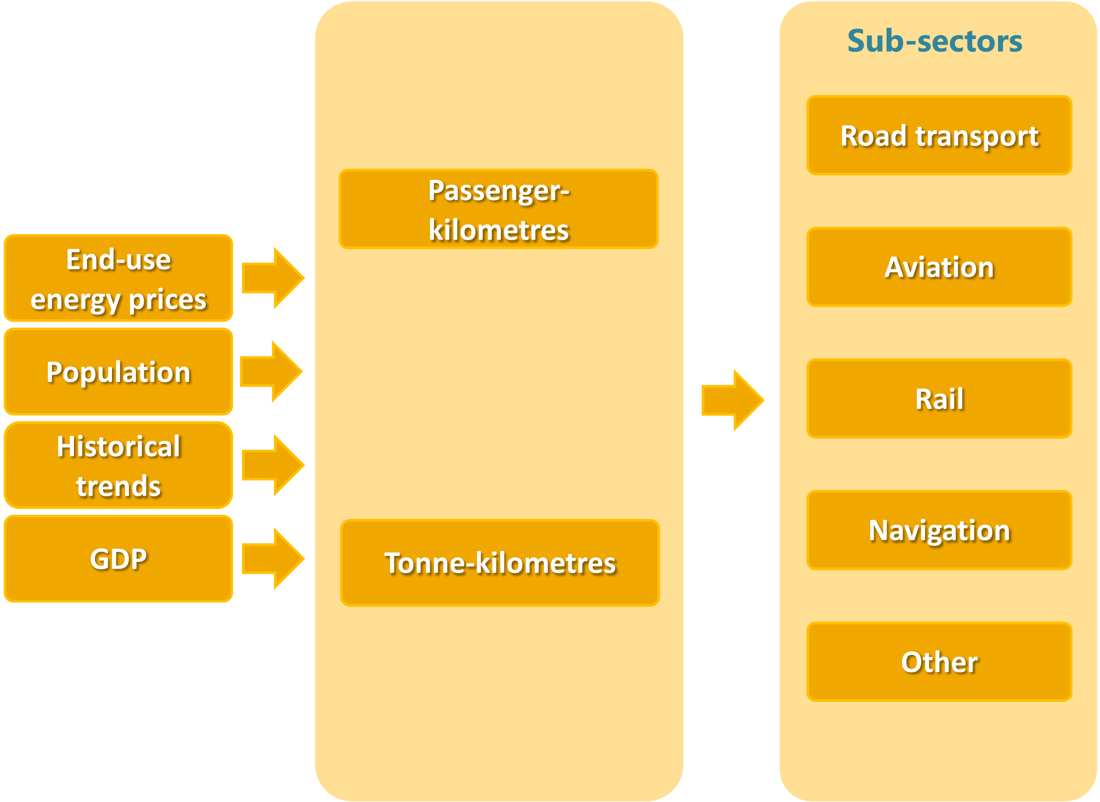
Exposure to the dirtiest air is cut by 75% by 2030, helping to reduce associated premature deaths by 3.6 million, predominately in emerging market and developing economies.

End-use sectors

Questions to be answered by the end-uses modules

- **How big is the need for new equipment in the future?**
  - What is the end-use service demand in the future? (impact of climate change)
  - How much equipment needs to be replaced?
- **What is the final energy demand for different end-uses?**
  - Which technologies are chosen to supply above estimated end-use demand?
  - How much is the final energy demand reduced by energy efficiency measures?
- **What are the resulting total final energy demand, CO2 emissions and investments?**

Example: Transport demand module



Transport demand module

Road transport

Passenger

- Cars
- Buses
- 2/3-wheelers

1. Projection of the stock
2. Adjustment of the mileage to road gasoline and diesel demand from EDC
3. Powertrain allocation (based on a weibull distribution)

Freight

- Light-duty trucks
- Medium-duty trucks
- Heavy-duty trucks

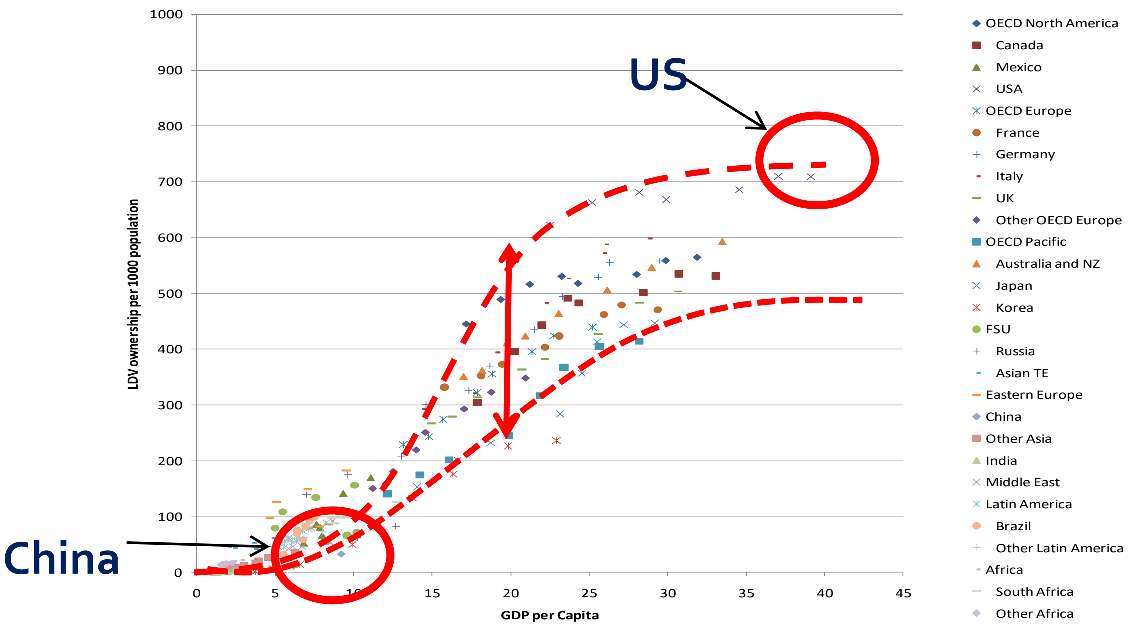
1. Projection of the activity (tonne-kilometres)
2. Split between the three modes
3. Adjustment of the mileage to road gasoline and diesel demand from EDC
4. Powertrain allocation (based on a weibull distribution)

Non-road transport

Aviation | Rail | Navigation | Other

- Navigation ← Econometric modelling adjusted to a detailed analysis performed in 2024
- Rail ← Econometric modelling by fuel type
- Aviation ← Aviation Integrated Model (profit max.) - UCL

How does vehicle ownership increase with GDP?



- Gompertz function:

$$V_t = y\, e^{a e^{b GDP_t}}$$

The wealthier people get, the more cars they buy – but how many really?

Powertrain choice

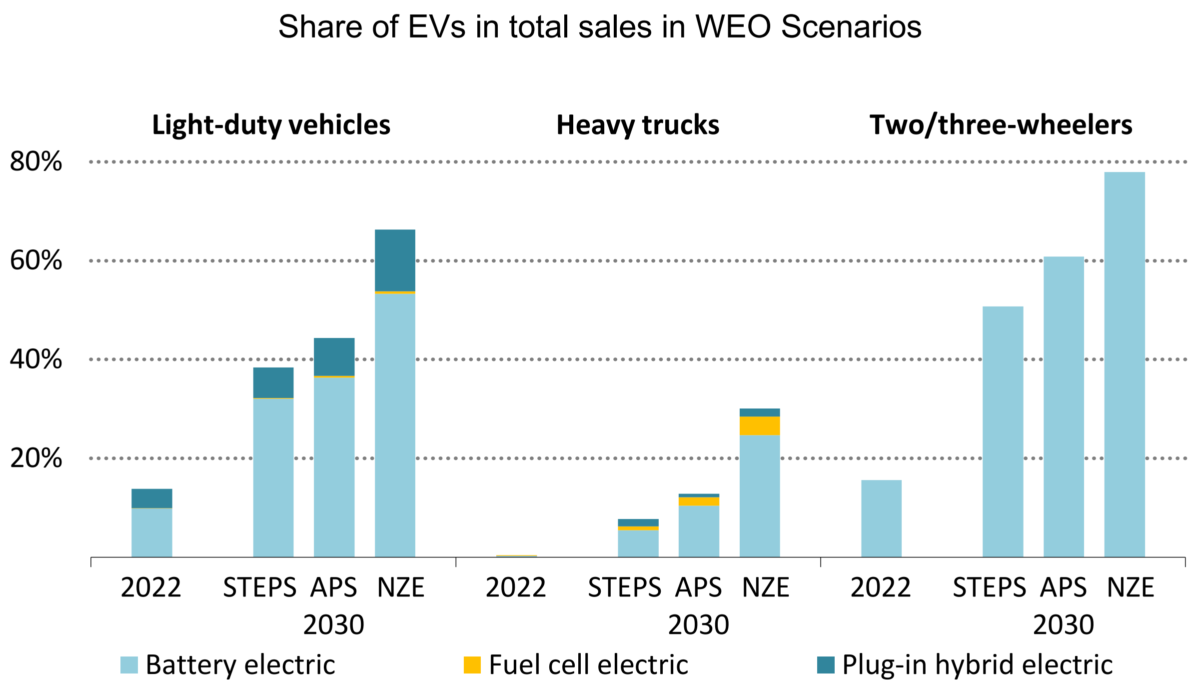
- Cost-benefit analysis (cost curves for each powertrain)

- Discrete choice theory (to mimic consumers preference) – logit model:

$$Share_j = \frac{b_j P_{PLDV_j}^{r_p}}{\sum_j \left(b_j P_{PLDV_j}^{r_p} \right)}$$

  - P_{PLDVj} is the annual cost of a vehicle (i.e. annualised investment, operation and maintenance costs as well as fuel use), r_p is the cost exponent that determines the rate at which a PLDV will enter the market, b_j is the base year share or weight of $PLDV_j$

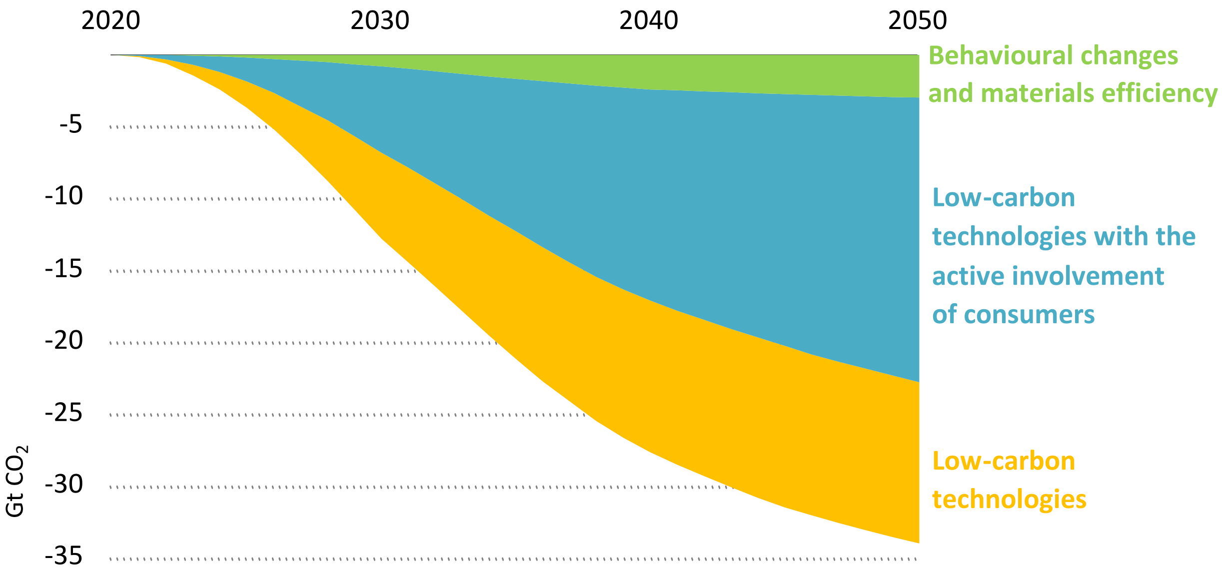
EVs play a decisive role in reaching net-zero targets



Battery electric vehicles dominate the market of light-duty vehicles and motorbikes in the Net Zero Emissions by 2050 scenario; FCEVs account around one fourth of heavy trucks sales in 2050

People will be involved in bringing about the transition

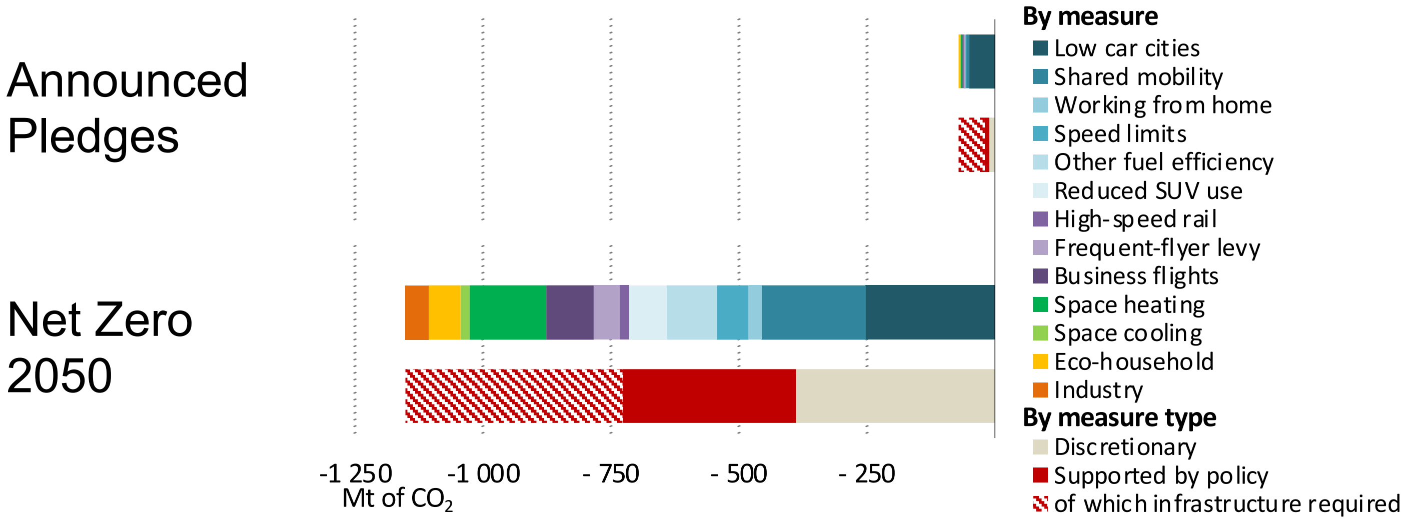
Role of technology and behavioural change in emissions reductions in the NZE



The majority of emissions reduction in NZE depend on consumer choices.

What's being done vs what could be done

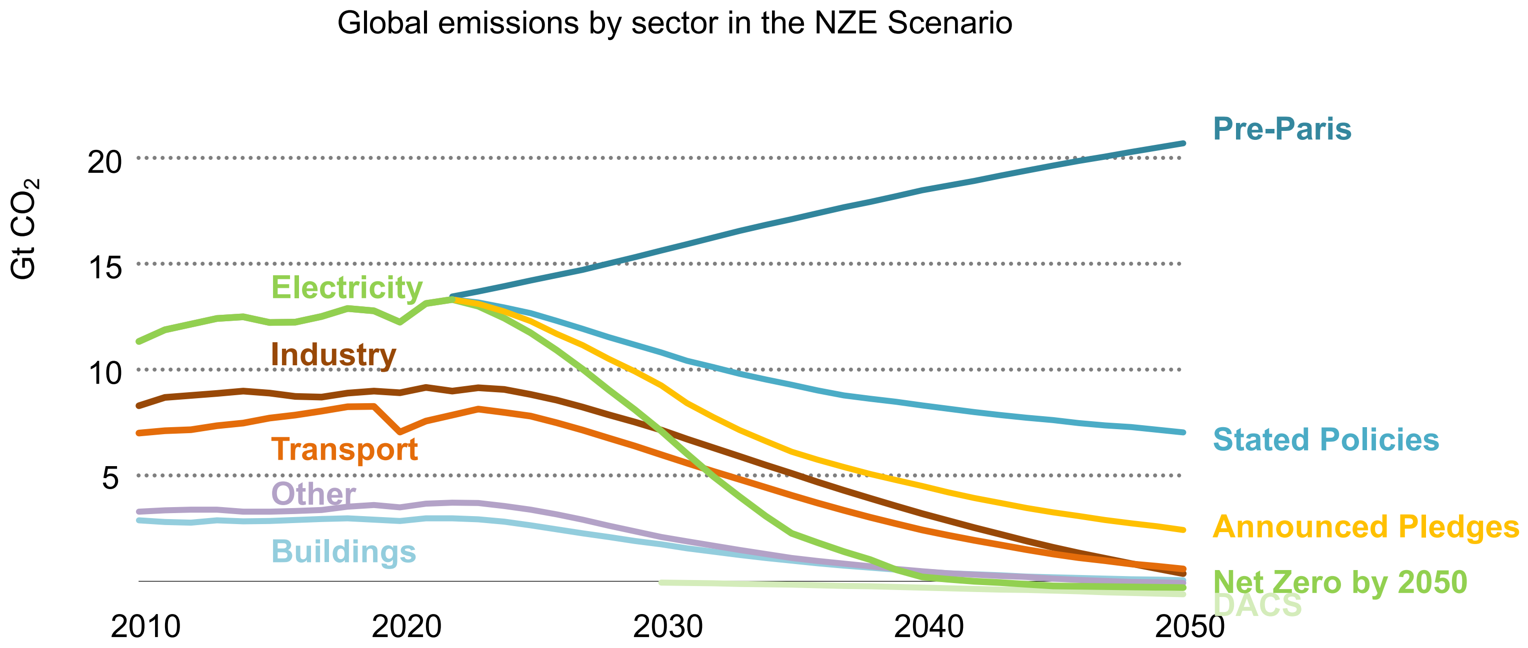
Reduction in CO_2 emissions from behavioural changes in 2035



Many behavioural change measures have been proven to work but they need policy support and, often, new infrastructure.

Power sector

Electricity leads the way to net zero



New policies & announced pledges pull emissions down and electricity is the first sector to reach net zero emissions, creating opportunities for electrification in other sectors to further drive down emissions

Power sector module

Inputs

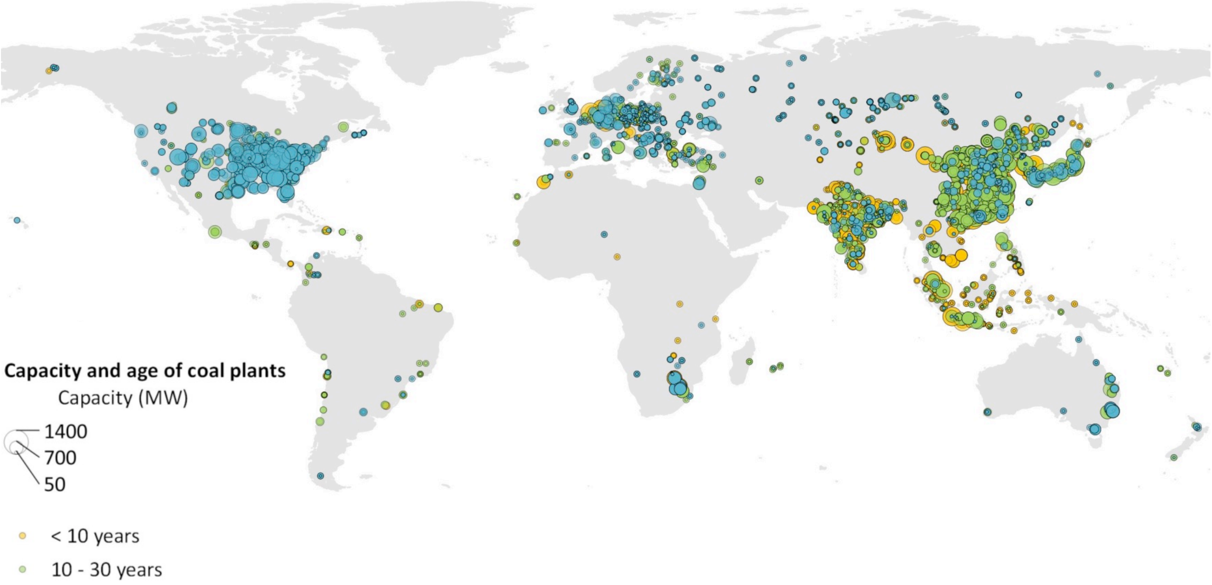
Historical data
- Capacity by year & tech
- Generation mix and losses
- Fuel consumption and CO_2 emissions

Techno-economic parameters
- Starting CAPEX and learning rates by tech
- Lifetime & efficiencies
- Grid elements & lengths
- RE capacity factors

Endogenous projections
- Electricity demand
- Fuel & CO_2 prices

Constraints
- Policies (e.g. RE targets)
- Technical, market or non-market limitations

Existing coal-fired power plants by age and size



What does the fleet of power plants look like tomorrow

Inputs	Key modules and calculations	Outputs

Inputs

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Key modules and calculations

Capacity additions mechanism

Electricity demand | Existing plants

load curve | Capacity margin | Retirements

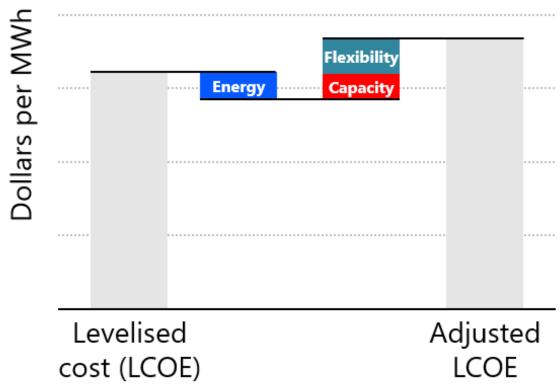
System adequacy overall needs

value-adjusted LCOE

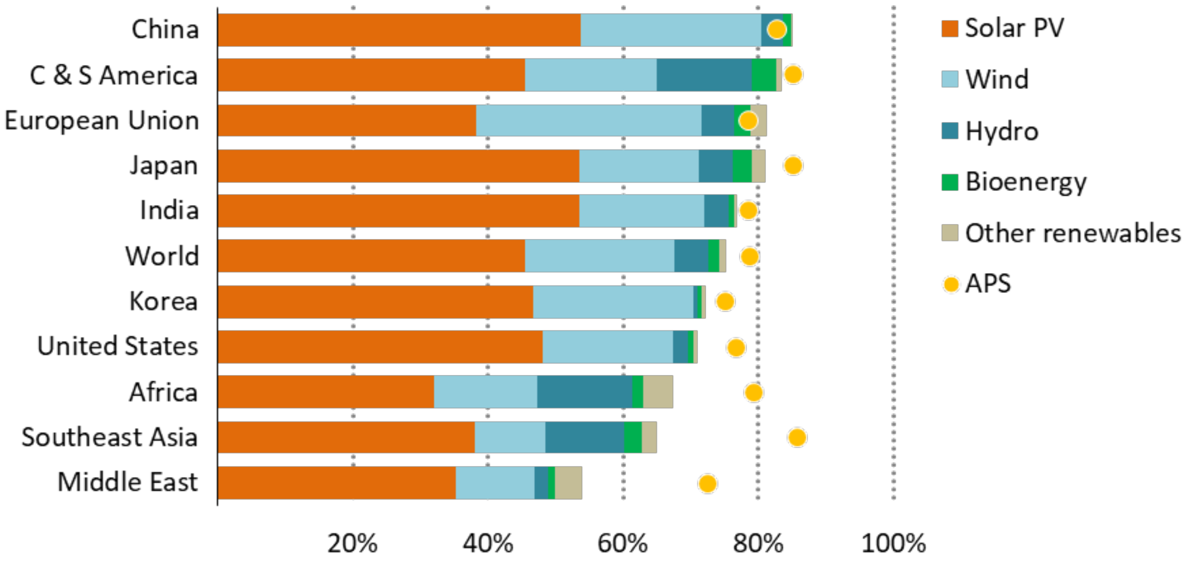
Capacity additions by technology

Outputs

Value-adjustments to the LCOE (illustrative)



Share of renewables in total power capacity additions by region in the STEPS, 2022-2050



Renewables account for the majority of capacity additions in all regions, with massive growth for solar PV and wind in all markets, followed by hydro in many

How is that fleet operated to meet electricity demand?

Inputs

Historical data
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- Generation mix and losses
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Techno-economic parameters
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Key modules and calculations

Capacity additions mechanism

Dispatch mechanism

Load curve → Merit order

Installed capacity → Capacity factors

Electricity generation by technology

Outputs

- Electricity generation by technology and age
- Installed capacity by technology and age
- Plant investment needs

Global implications of an electrifying future

Inputs

Historical data
- Capacity by year & tech
- Generation mix and losses
- Fuel consumption and CO_2 emissions

Techno-economic parameters
- Starting CAPEX and learning rates by tech
- Lifetime & efficiencies
- Grid elements & lengths
- RE capacity factors

Endogenous projections
- Electricity demand
- Fuel & CO_2 prices

Constraints
- Policies (e.g. RE targets)
- Technical, market or non-market limitations

Key modules and calculations

Capacity additions mechanism

Dispatch mechanism

Load curve → Merit order

Installed capacity → Capacity factors

Electricity generation by technology

→ Fuel inputs | CO_2 emissions | Electricity prices | T&D grids

Outputs

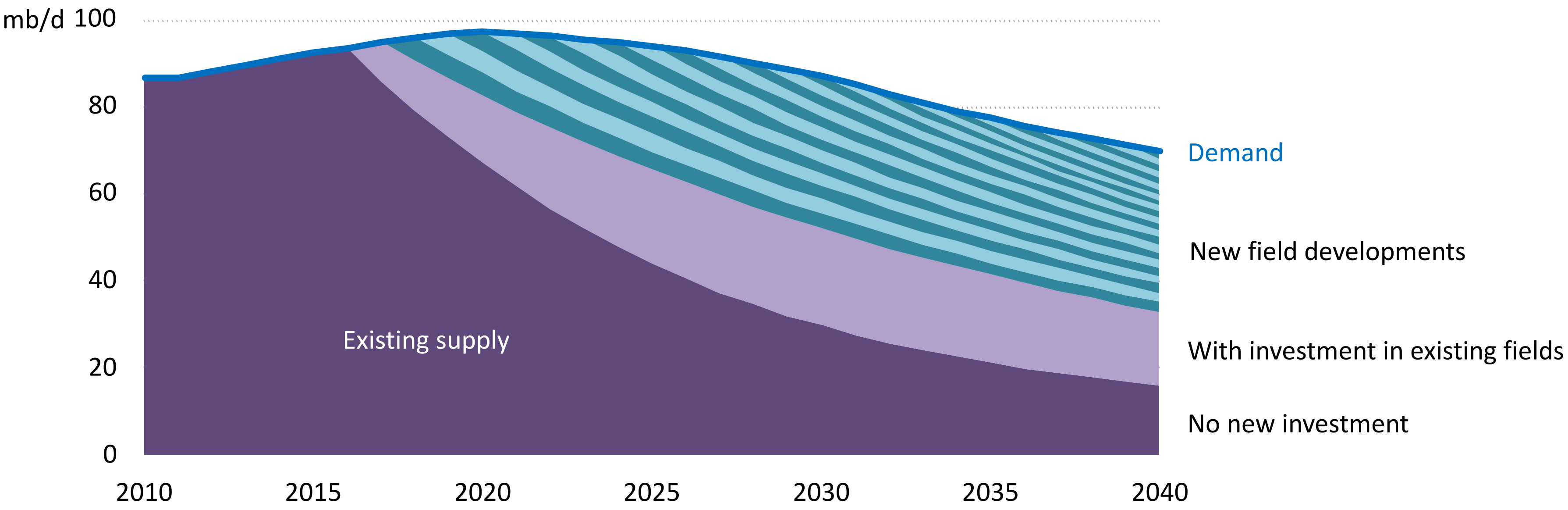
- Installed capacity by technology and age
- Plant investment needs

- Electricity generation by technology and age

- Fuel consumption and CO_2 emissions
- Electricity prices and bills
- T&D investment needs

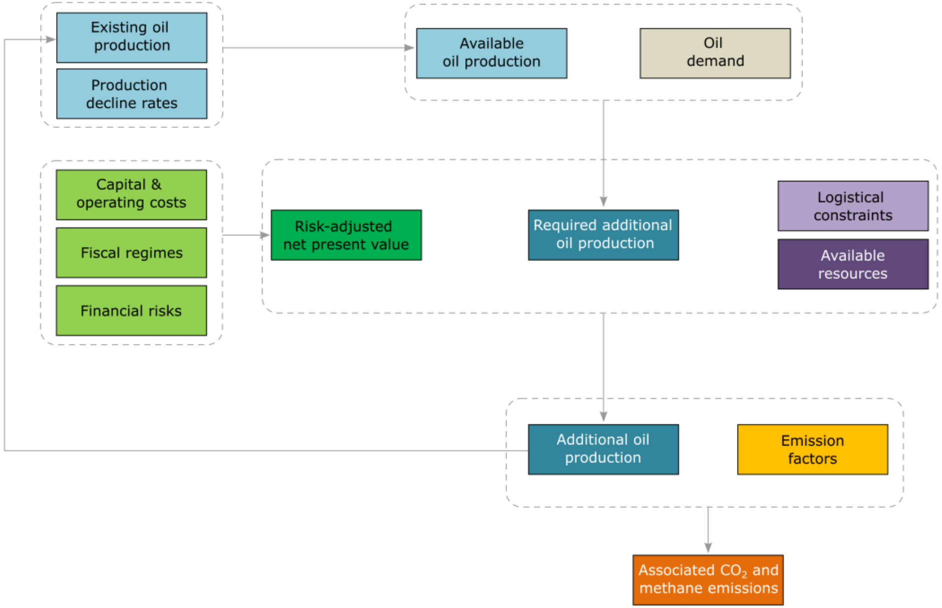
Oil & gas supply

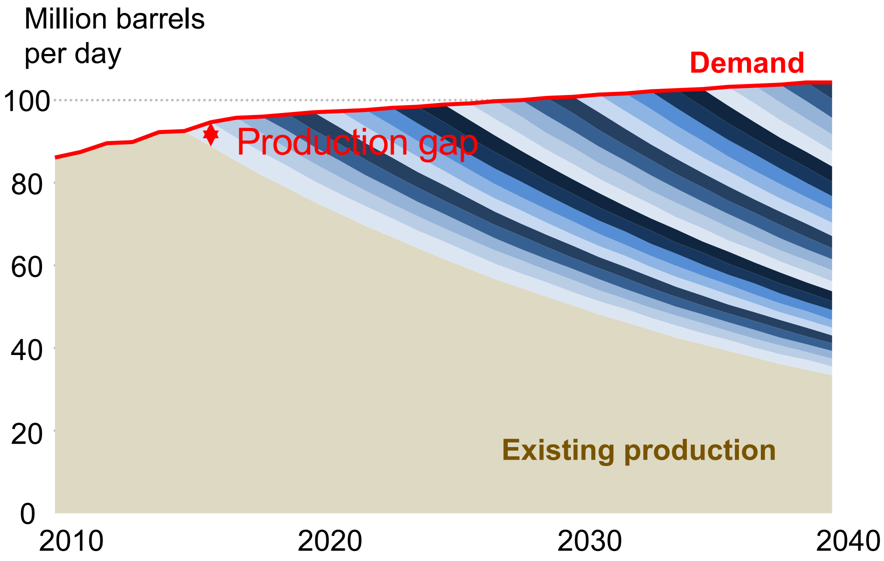
Modelling new upstream investment needs I



Current production declines, creating a gap with demand that must be filled with new investments

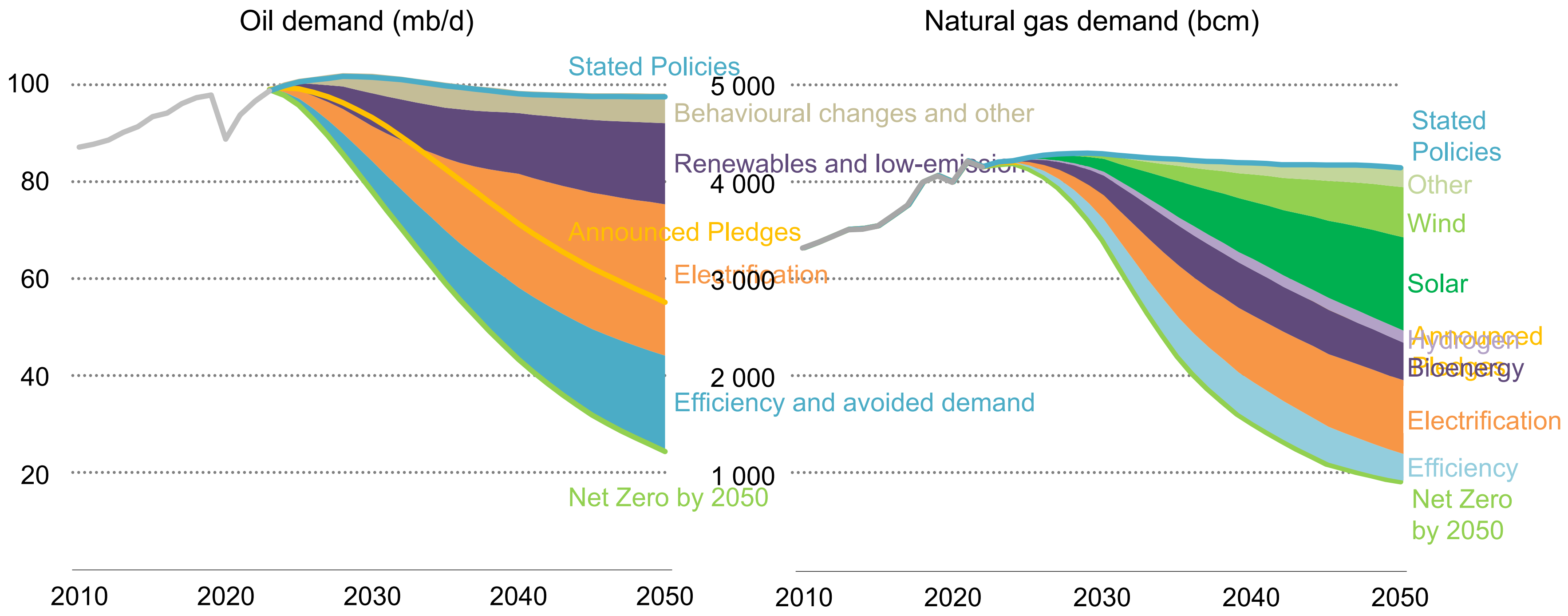
Modelling new upstream investment needs II





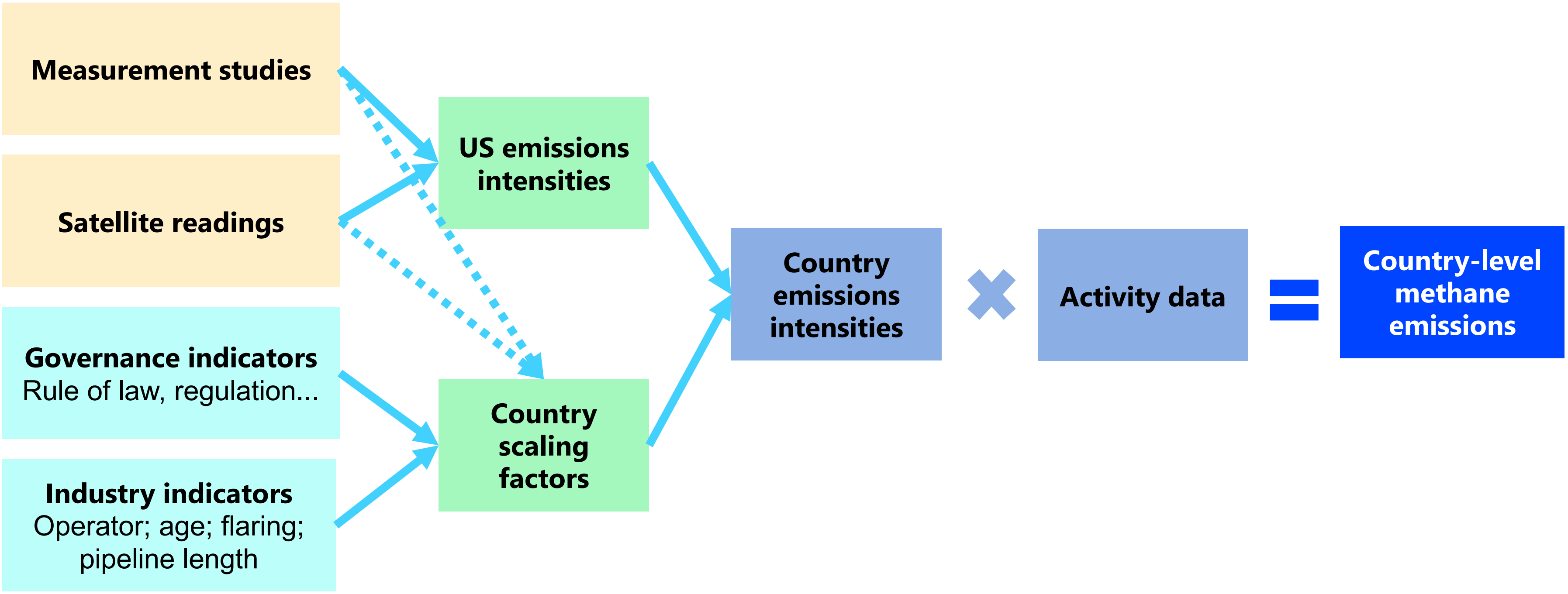
Hydrocarbon prices are calculated endogenously from demand and NPV

Twin peaks, but what lies beyond?



Today's momentum behind clean energy transitions is sufficient to generate peaks in oil and gas demand by 2030, but much more needs to be done to bring demand down in ways that meet national & global climate goals

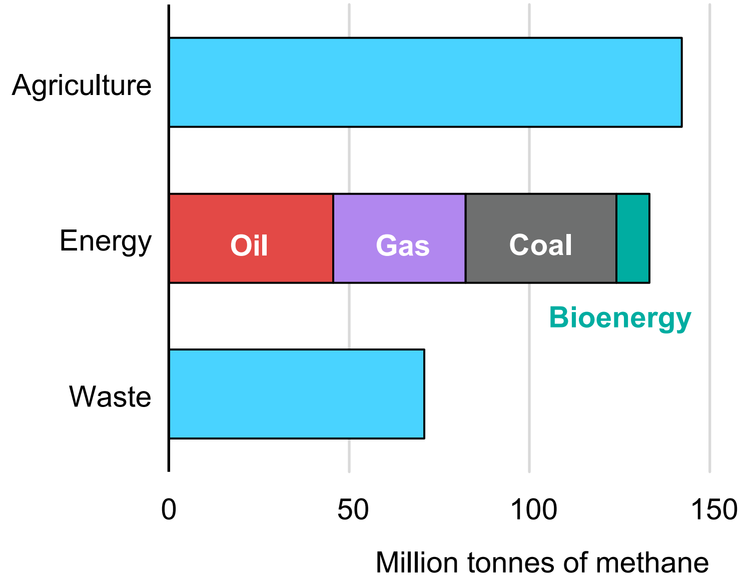
Methodological approach for oil and gas methane emissions

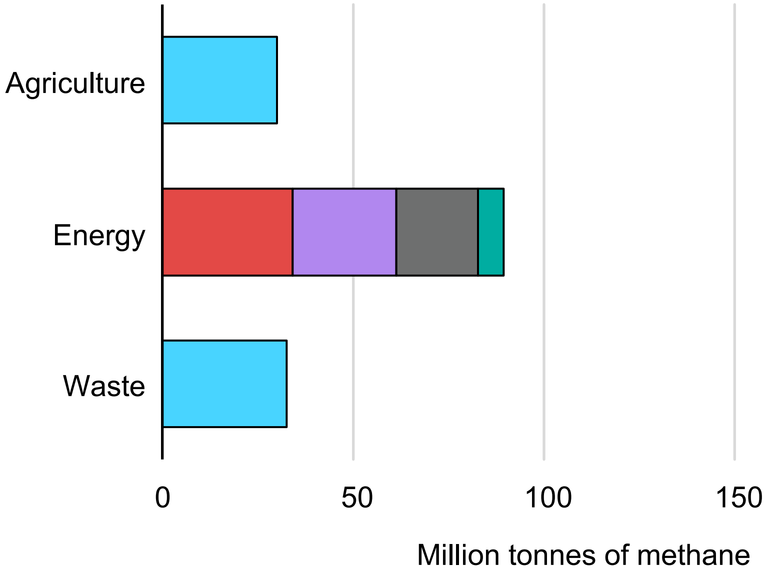


Our estimates take into account a range of auxiliary data that is calibrated to match available measurement data

There is a huge opportunity to cut oil and gas methane emissions

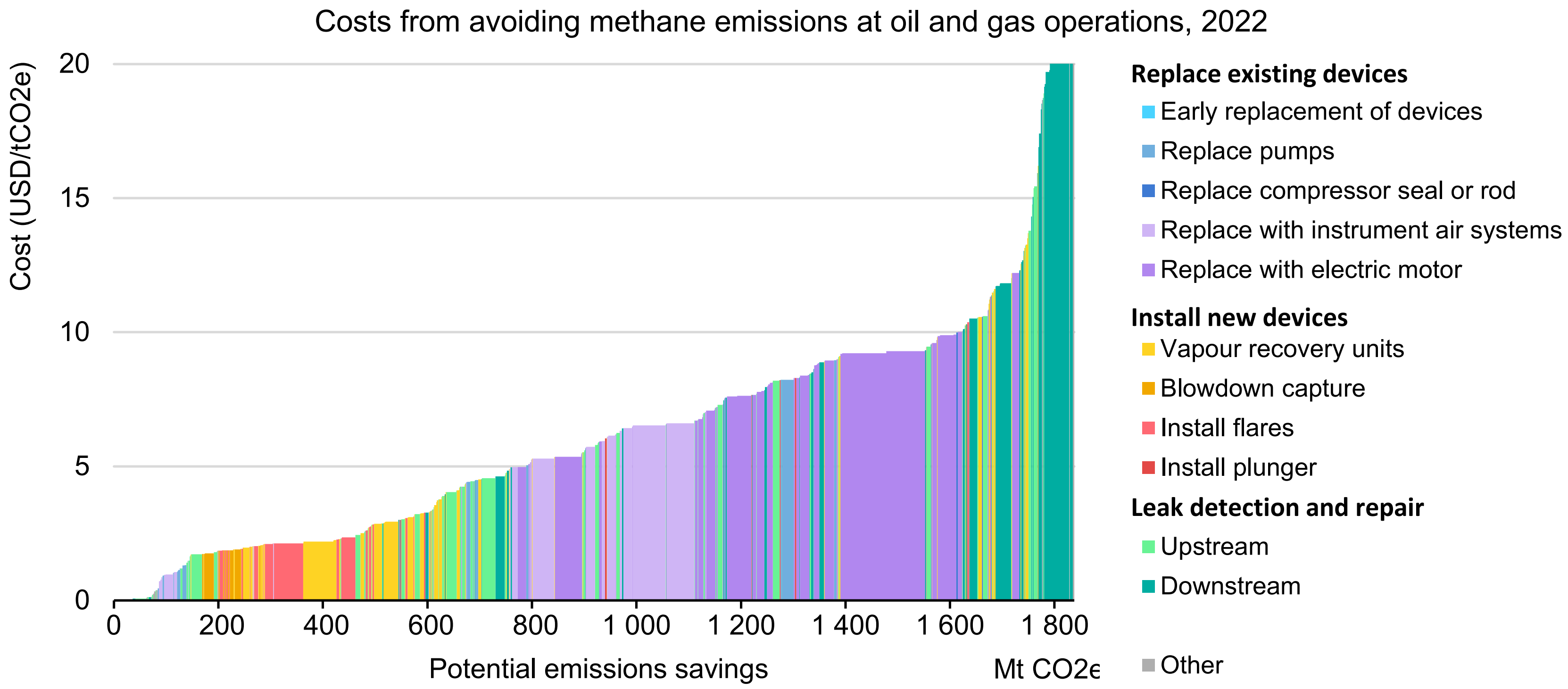
Main sources of methane from human activities





The energy sector is responsible for nearly 40% of total methane emissions from human activity today

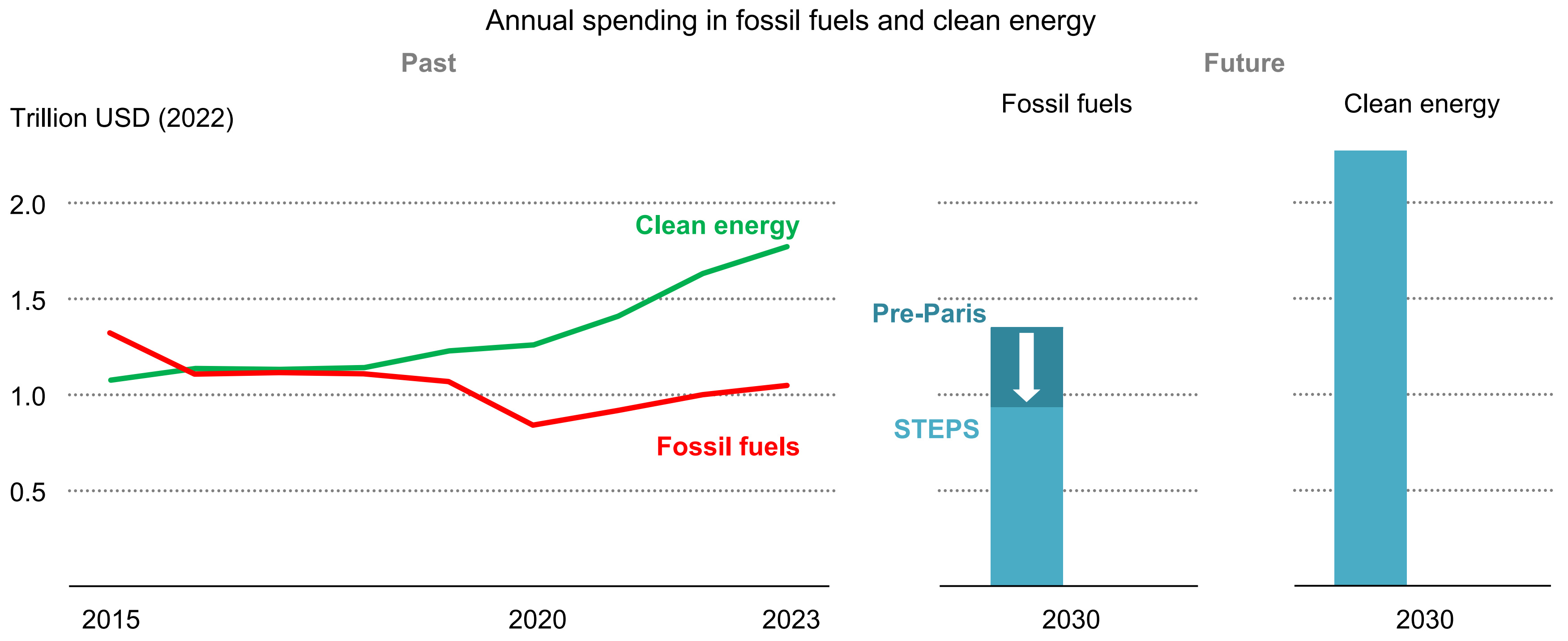
It is incredibly cheap to cut methane (irrespective of gas prices)



Almost all available abatement measures would be cost effective in the presence of an emissions price of only 15 USD/tCO2-eq (without revenue from gas sales)

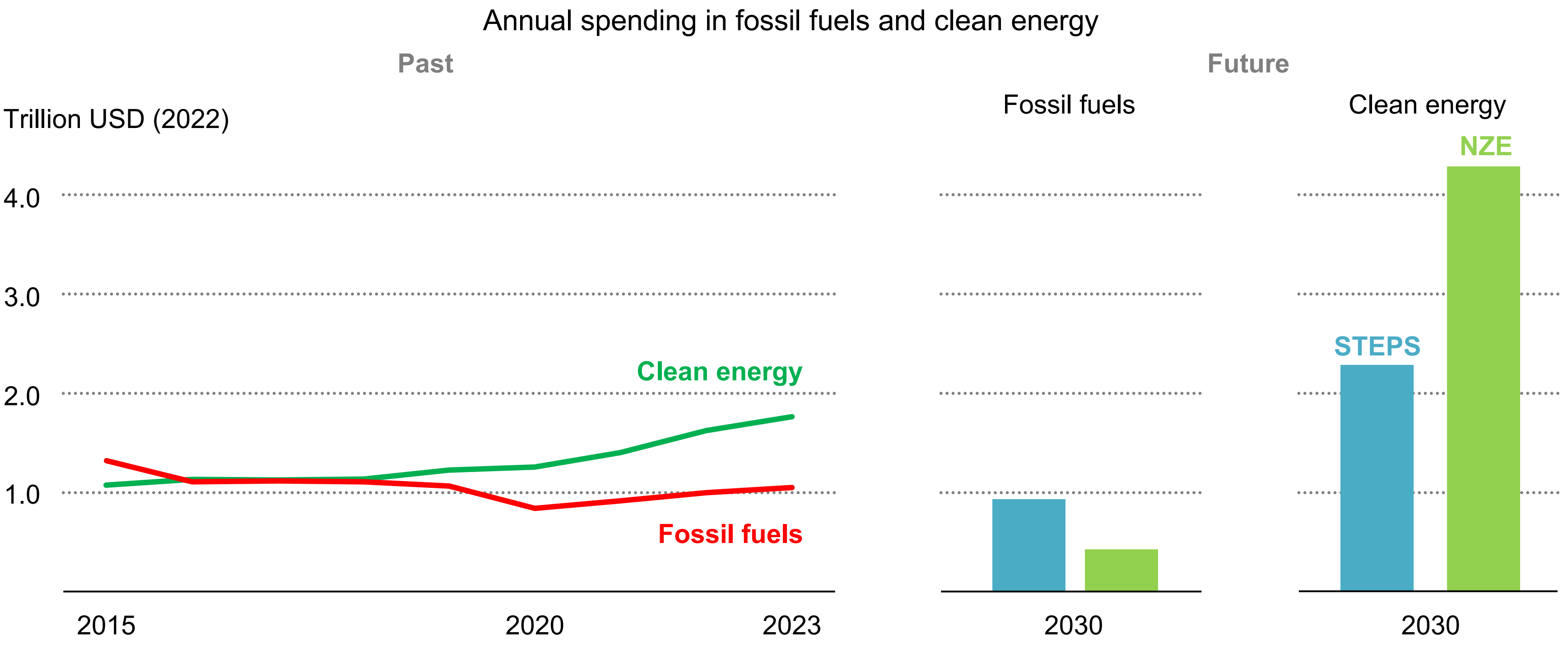
Clean energy transitions

New dynamics for energy investment



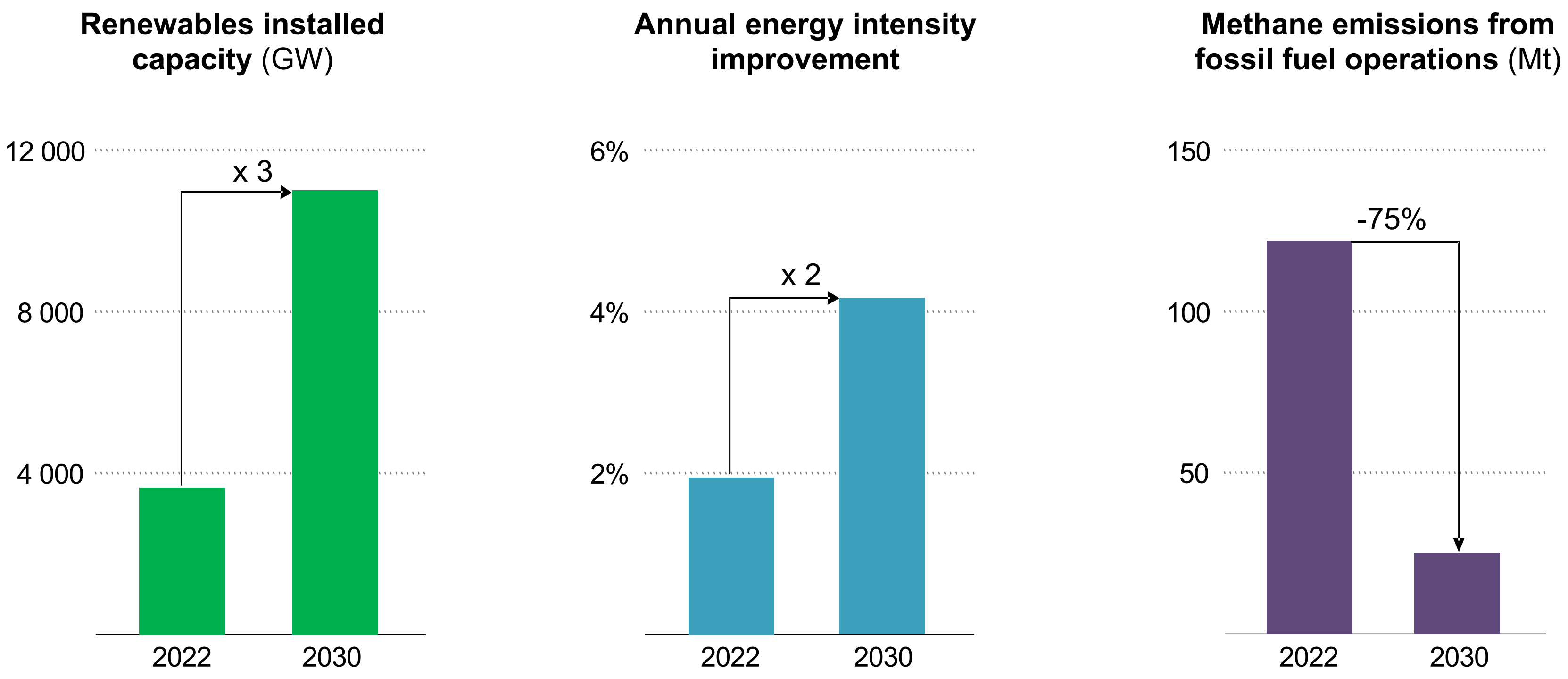
Fossil fuel investment today is in line with levels needed in the STEPS.
Today, every dollar spent on fossil fuels sees USD 1.8 spent on clean energy.

New dynamics for energy investment



Fossil fuel investment today is in line with levels needed in the STEPS.
Today, every dollar spent on fossil fuels sees USD 1.8 spent on clean energy. This rises to USD 10 in 2030 in the NZE.

We have the tools to go much faster



Energy-related greenhouse gas emissions peak by 2025 and decline by nearly 40% from today to 2030. Proven solutions available today deliver over 80% of what is needed this decade.

A roadmap to net zero by 2050