ENERGY for the FUTURE – Energy Transition

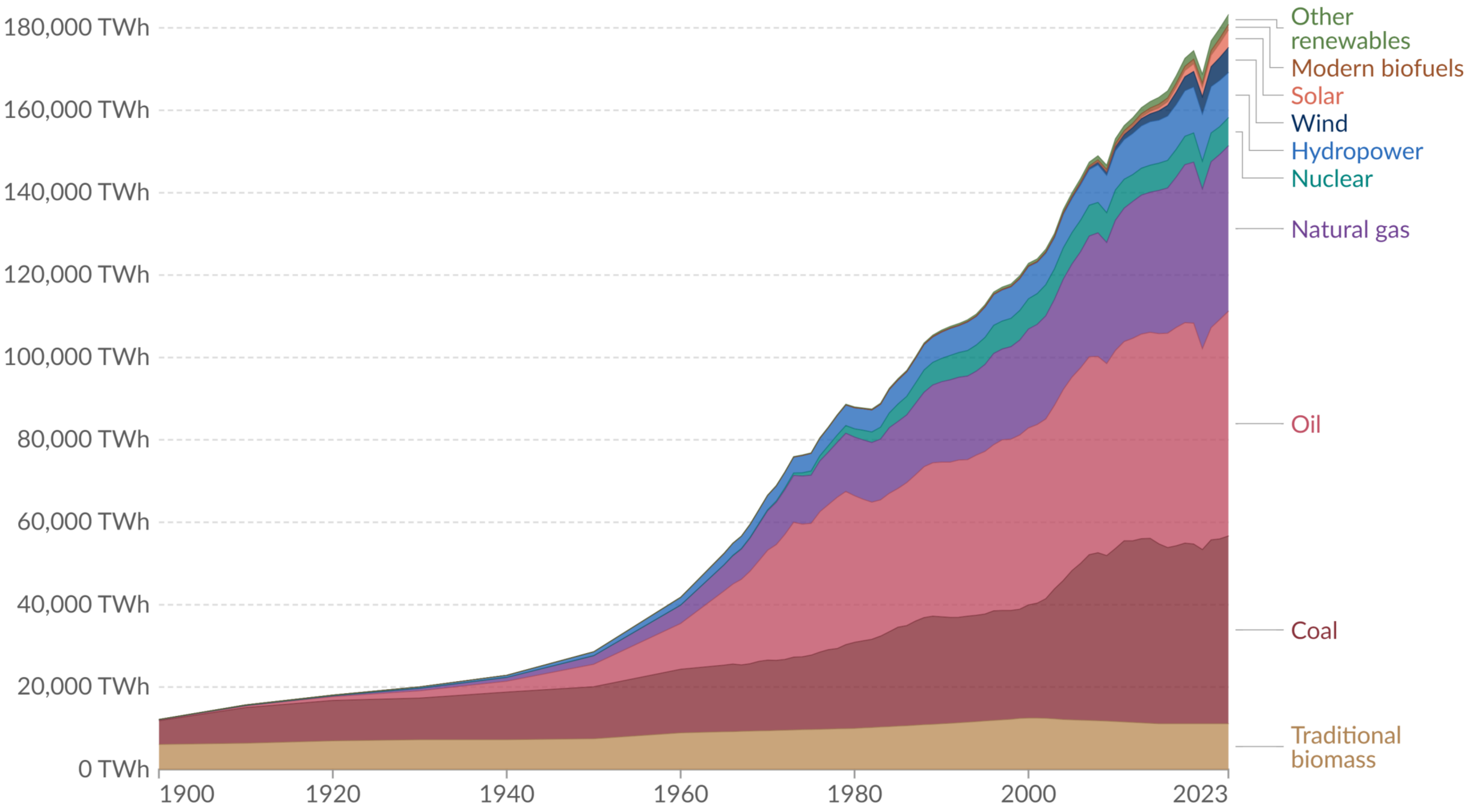
- **Affordable**
- **Abundant**
- **Reliable and Resilient**
- **Clean, with a Low Carbon Footprint**
- **Mitigate Climate Change**
- **CCUS & CCS**

Prof. Arne Graue

Department of Physics and Technology
University of Bergen
Norway

Global primary energy consumption by source

Primary energy[1] is based on the substitution method[2] and measured in terawatt-hours[3].



Data source: Energy Institute - Statistical Review of World Energy (2024); Smil (2017)

World Population by Country

#	Country (or dependency)	Population (2023)	Yearly Change	Net Change	Density (P/Km²)	Land Area (Km²)	Migrants (net)	Fert. Rate	Med. Age	Urban Pop %	World Share
1	India	**1,428,627,663**	0.81 %	11,454,490	481	2,973,190	-486,136	2.0	28	36 %	17.76 %
2	China	**1,425,671,352**	-0.02 %	-215,985	152	9,388,211	-310,220	1.2	39	65 %	17.72 %
3	United States	**339,996,563**	0.50 %	1,706,706	37	9,147,420	999,700	1.7	38	83 %	4.23 %
4	Indonesia	**277,534,122**	0.74 %	2,032,783	153	1,811,570	-49,997	2.1	30	59 %	3.45 %
5	Pakistan	**240,485,658**	1.98 %	4,660,796	312	770,880	-165,988	3.3	21	35 %	2.99 %
6	Nigeria	**223,804,632**	2.41 %	5,263,420	246	910,770	-59,996	5.1	17	54 %	2.78 %
7	Brazil	**216,422,446**	0.52 %	1,108,948	26	8,358,140	6,000	1.6	34	88 %	2.69 %
8	Bangladesh	**172,954,319**	1.03 %	1,767,947	1,329	130,170	-309,977	1.9	27	41 %	2.15 %
9	Russia	**144,444,359**	-0.19 %	-268,955	9	16,376,870	-136,414	1.5	39	75 %	1.80 %

Source: **Worldometer** (www.Worldometers.info)

CO_2 Emissions by Country

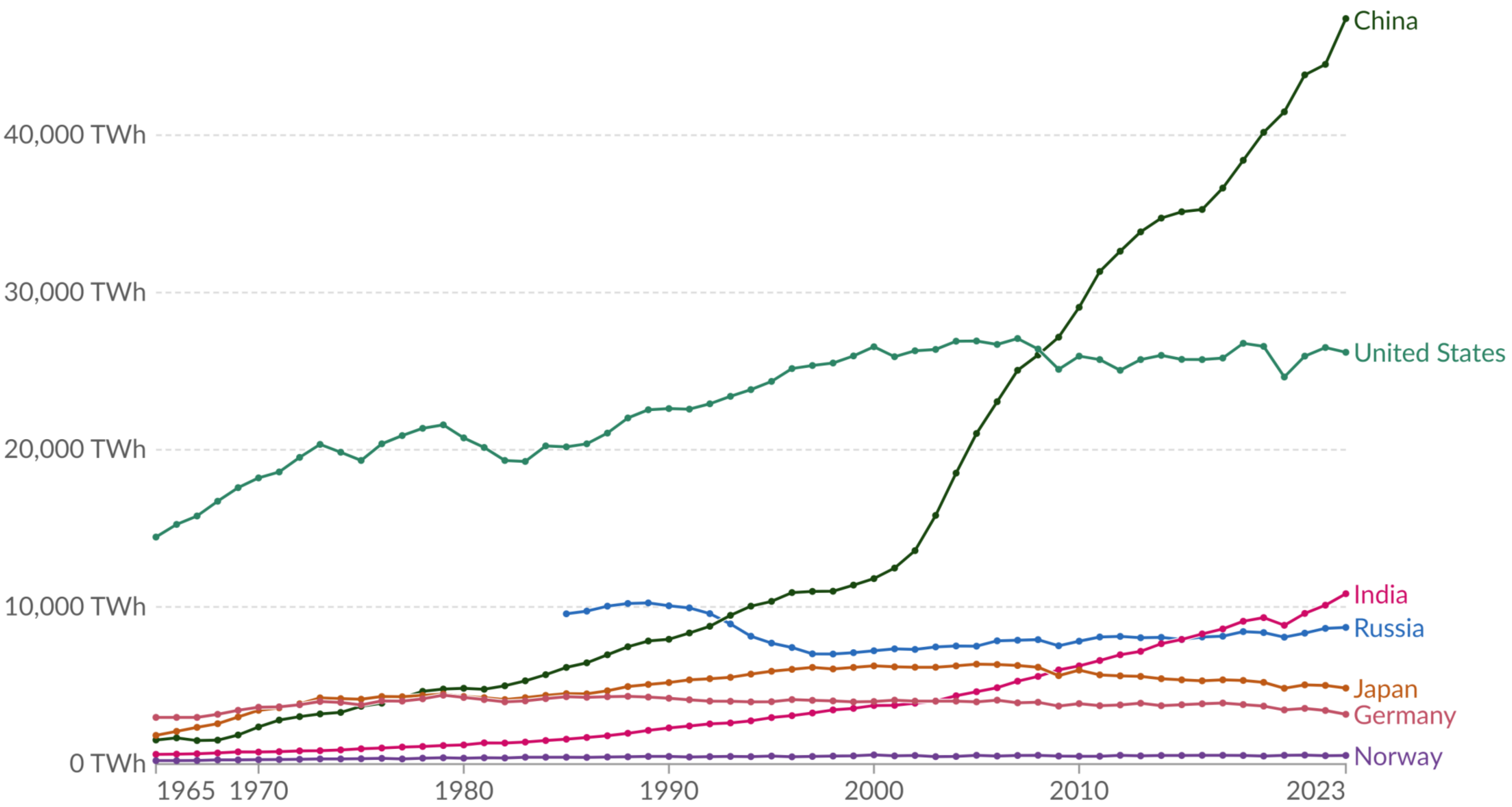
#	Country	CO_2 Emissions (tons, 2016)	1 Year Change	Population (2016)	Per capita	Share of world
1	China	10,432,751,400	-0.28%	1,401,889,681	7.44	29.18%
2	United States	5,011,686,600	-2.01%	327,210,198	15.32	14.02%
3	India	2,533,638,100	4.71%	1,338,636,340	1.89	7.09%
4	Russia	1,661,899,300	-2.13%	145,109,157	11.45	4.65%
5	Japan	1,239,592,060	-1.21%	126,993,857	9.76	3.47%
6	Germany	775,752,190	1.28%	82,331,423	9.42	2.17%
7	Canada	675,918,610	-1.00%	36,113,532	18.72	1.89%
8	Iran	642,560,030	2.22%	83,306,231	7.71	1.80%
9	South Korea	604,043,830	0.45%	51,309,984	11.77	1.69%
10	Indonesia	530,035,650	6.41%	261,850,182	2.02	1.48%
11	Saudi Arabia	517,079,407	0.92%	33,416,270	15.47	1.45%
12	Brazil	462,994,920	-6.08%	206,859,578	2.24	1.29%

Source: **Worldometer** (www.Worldometers.info)

Primary energy consumption

Our World in Data

Primary energy[1] consumption is measured in terawatt-hours[2], using the substitution method[3].

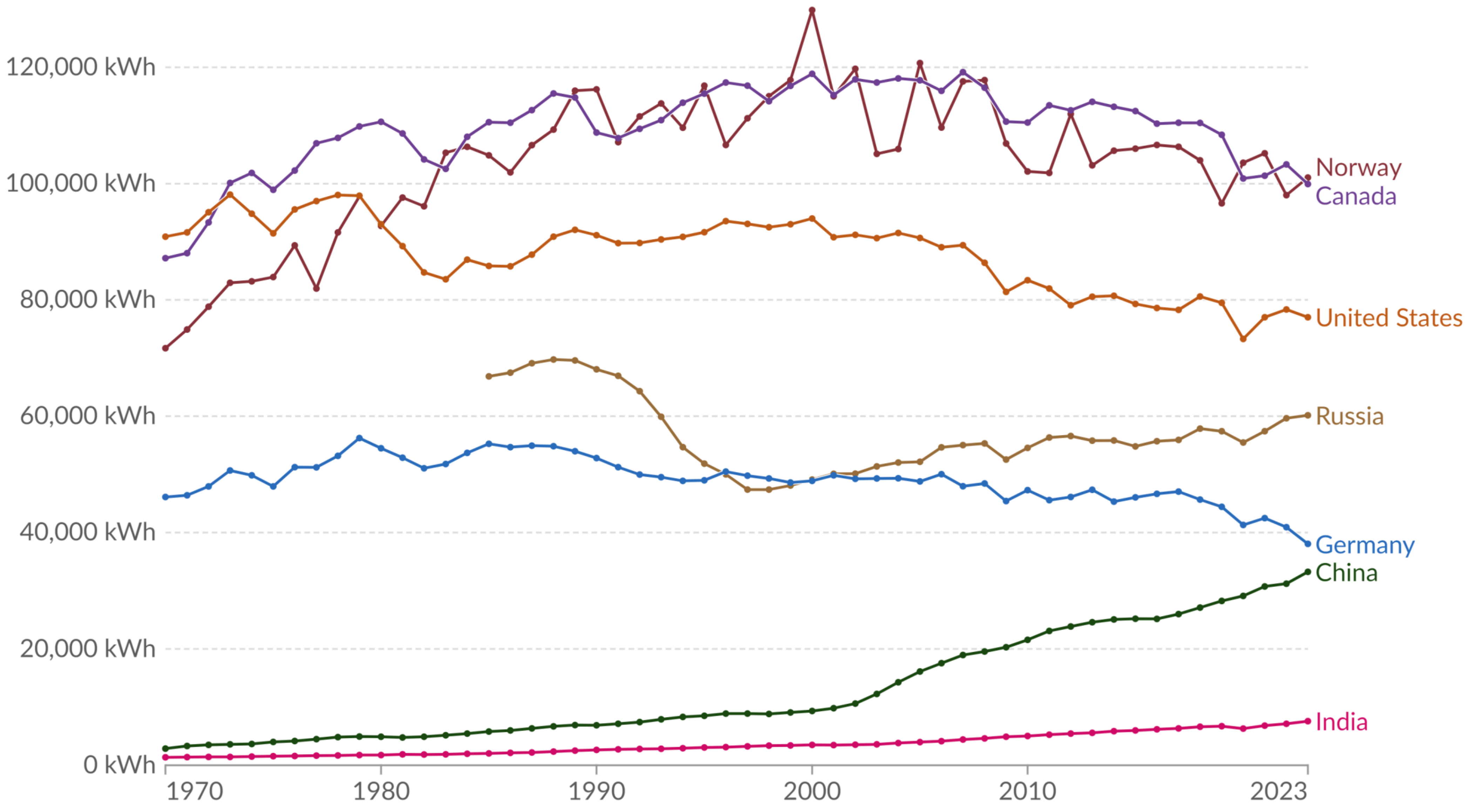


Data source: U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2024)

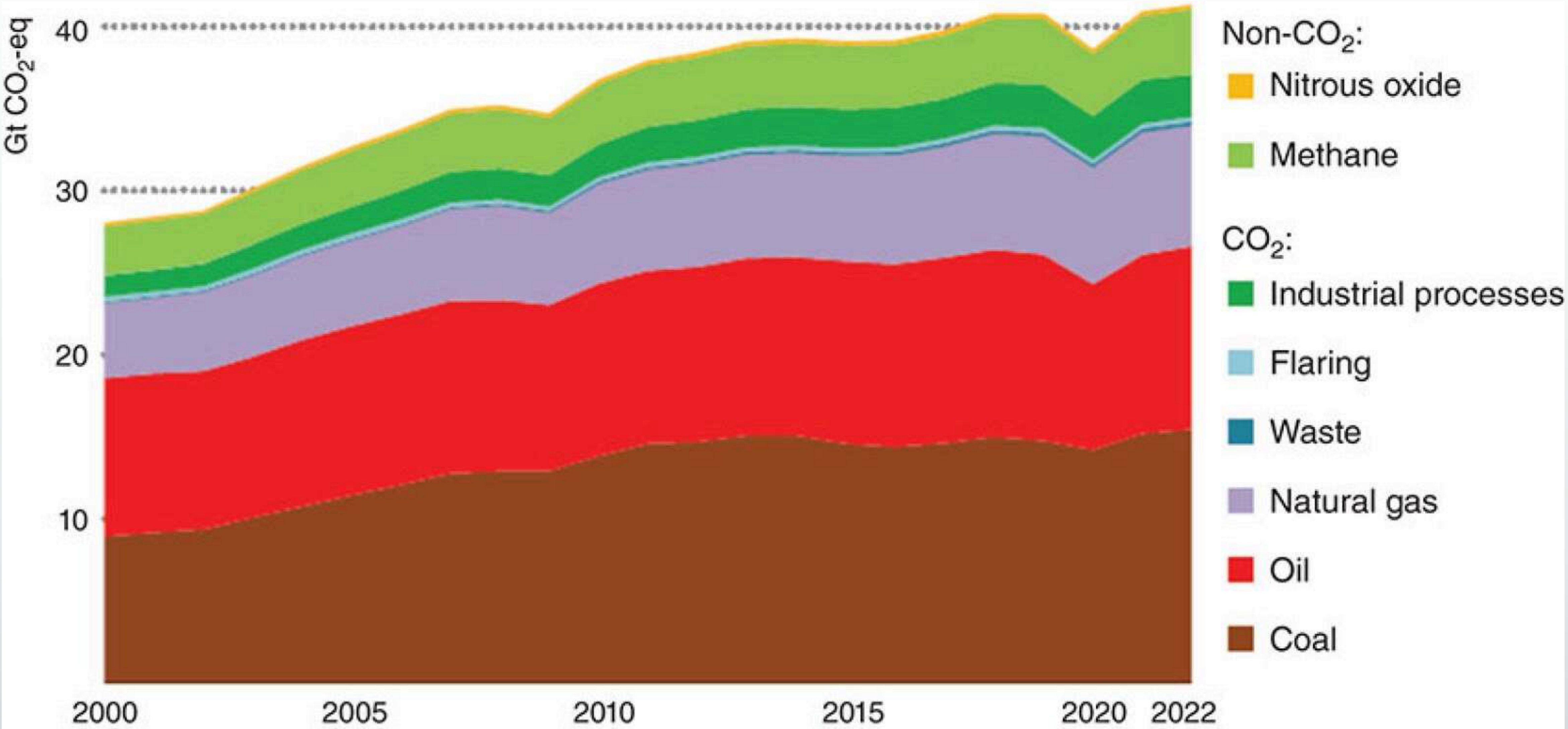
Note: Data includes only commercially-traded fuels (coal, oil, gas), nuclear and modern renewables. It does not include traditional biomass.

Energy use per person

Measured in kilowatt-hours[1] per person. Here, energy refers to primary energy[2] using the substitution method[3].



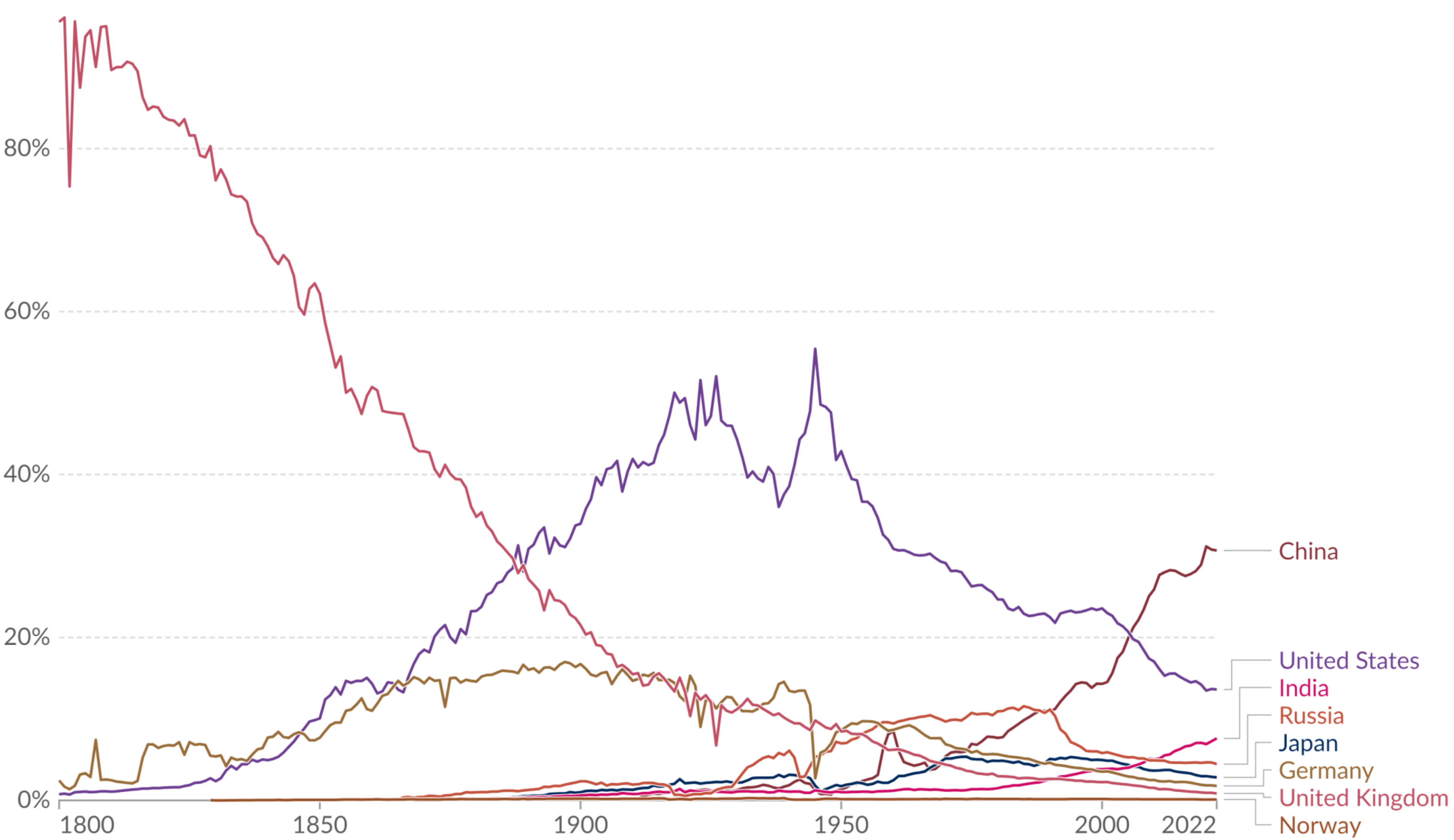
Global Energy-Related Green House Gas Emissions 2000-2022



International Energy Agency (2022), World Energy Outlook 2022, IEA, Paris

Share of global CO_2 emissions

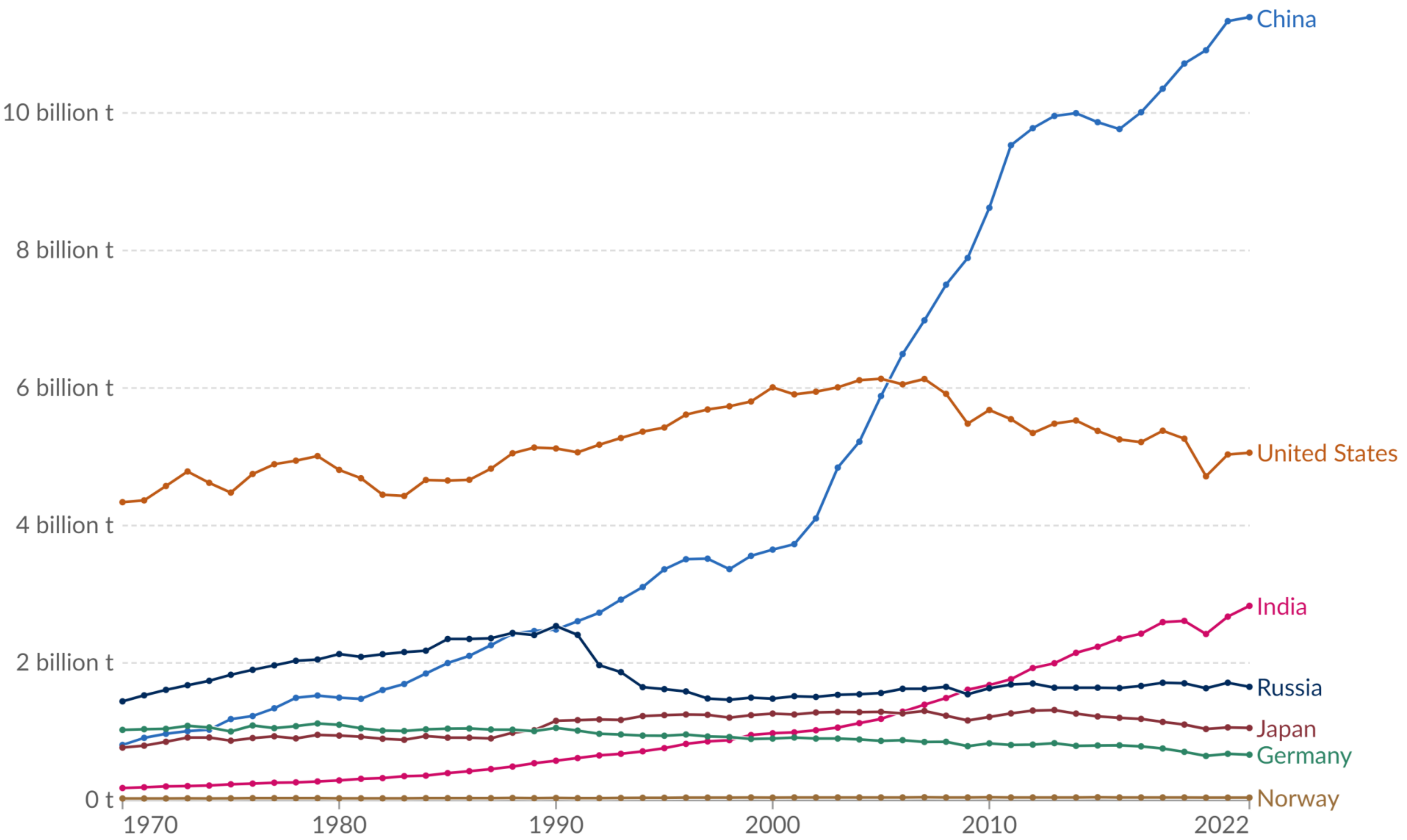
Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.



Data source: Global Carbon Budget (2023)

Annual CO_2 emissions

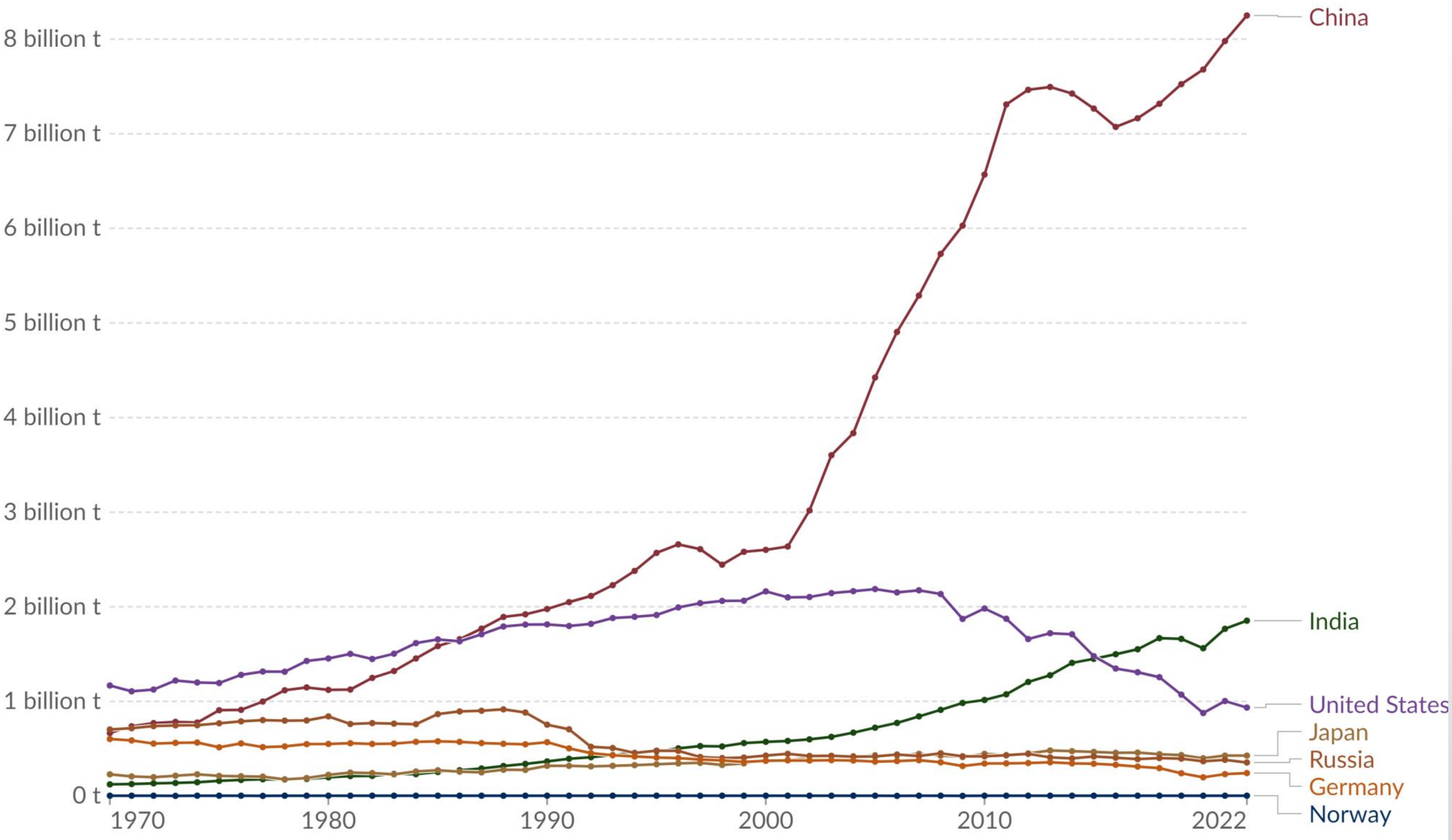
Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.



Data source: Global Carbon Budget (2023)

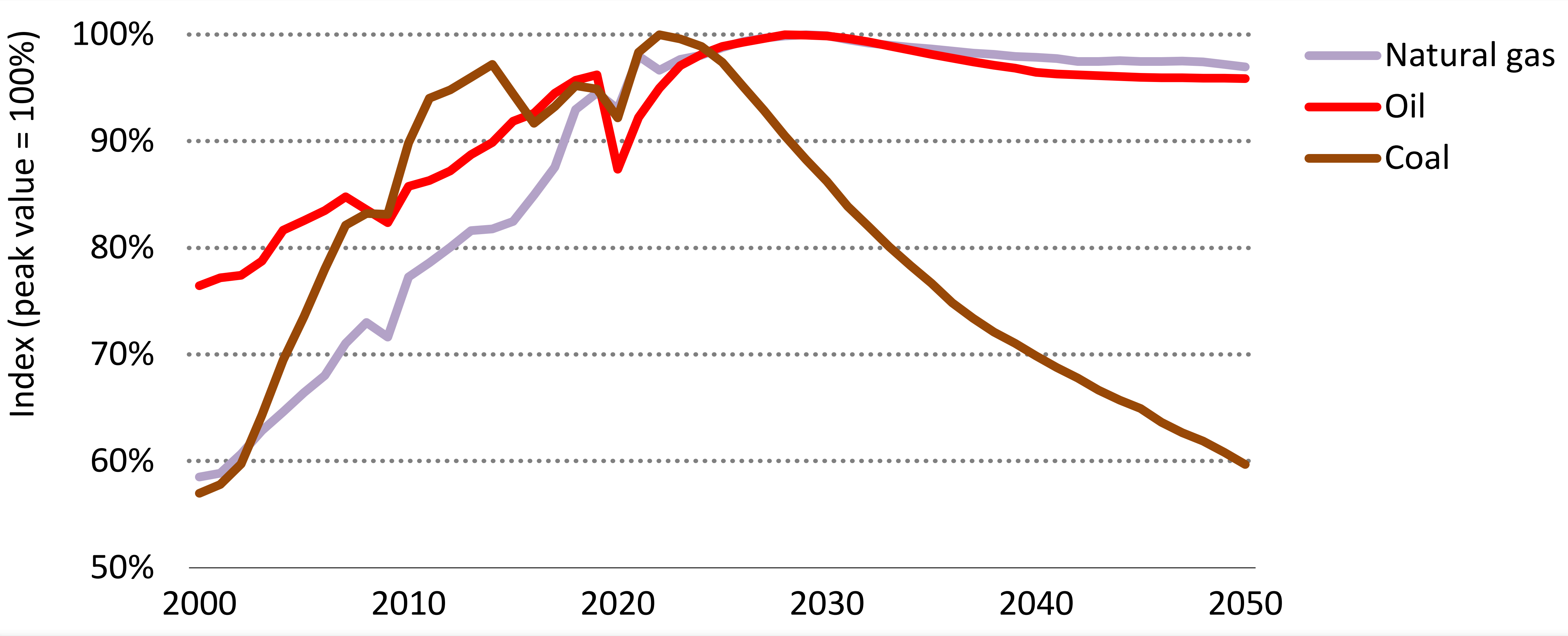
Annual CO_2 emissions from coal

Annual emissions of carbon dioxide (CO_2) from coal, measured in tonnes.



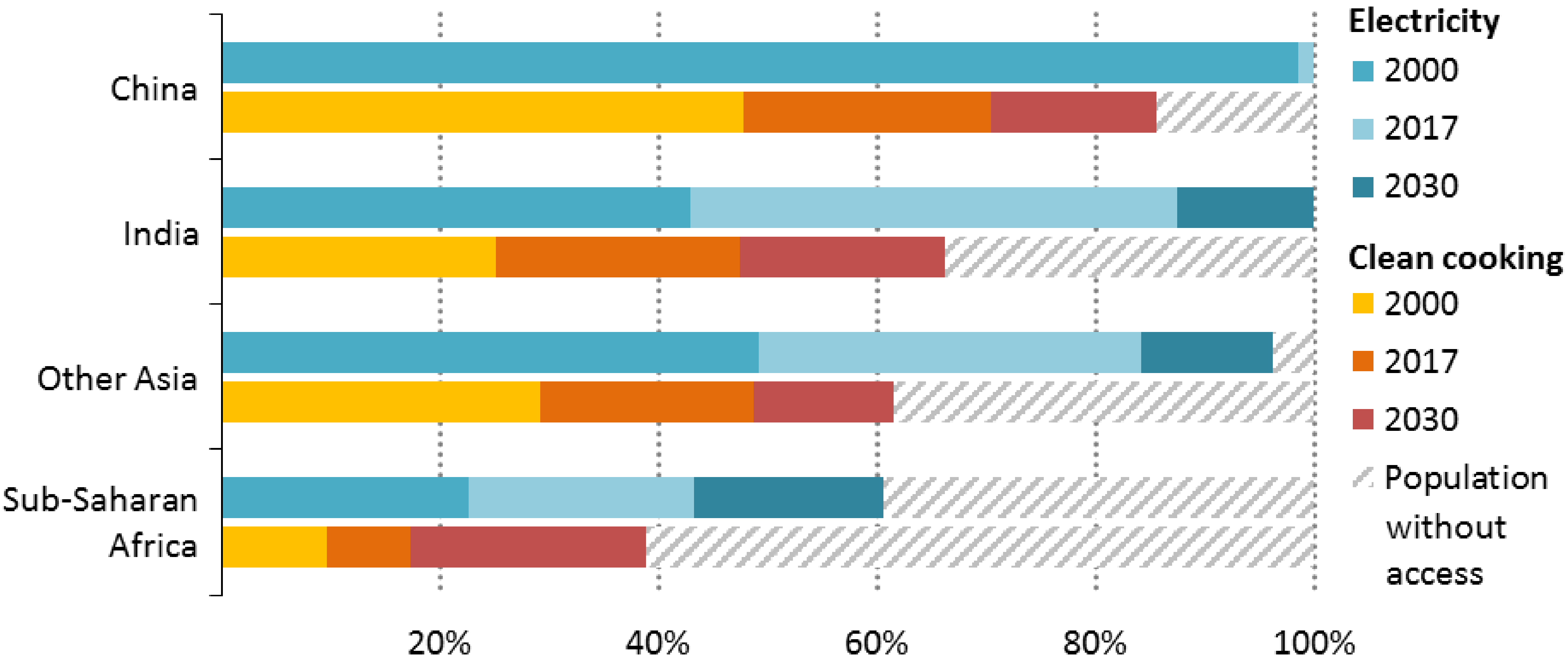
Data source: Global Carbon Budget (2023)

Fossil fuel consumption by fuel in the STEPS, 2000-2050



International Energy Agency (2023), World Energy Outlook 2023, IEA, Paris

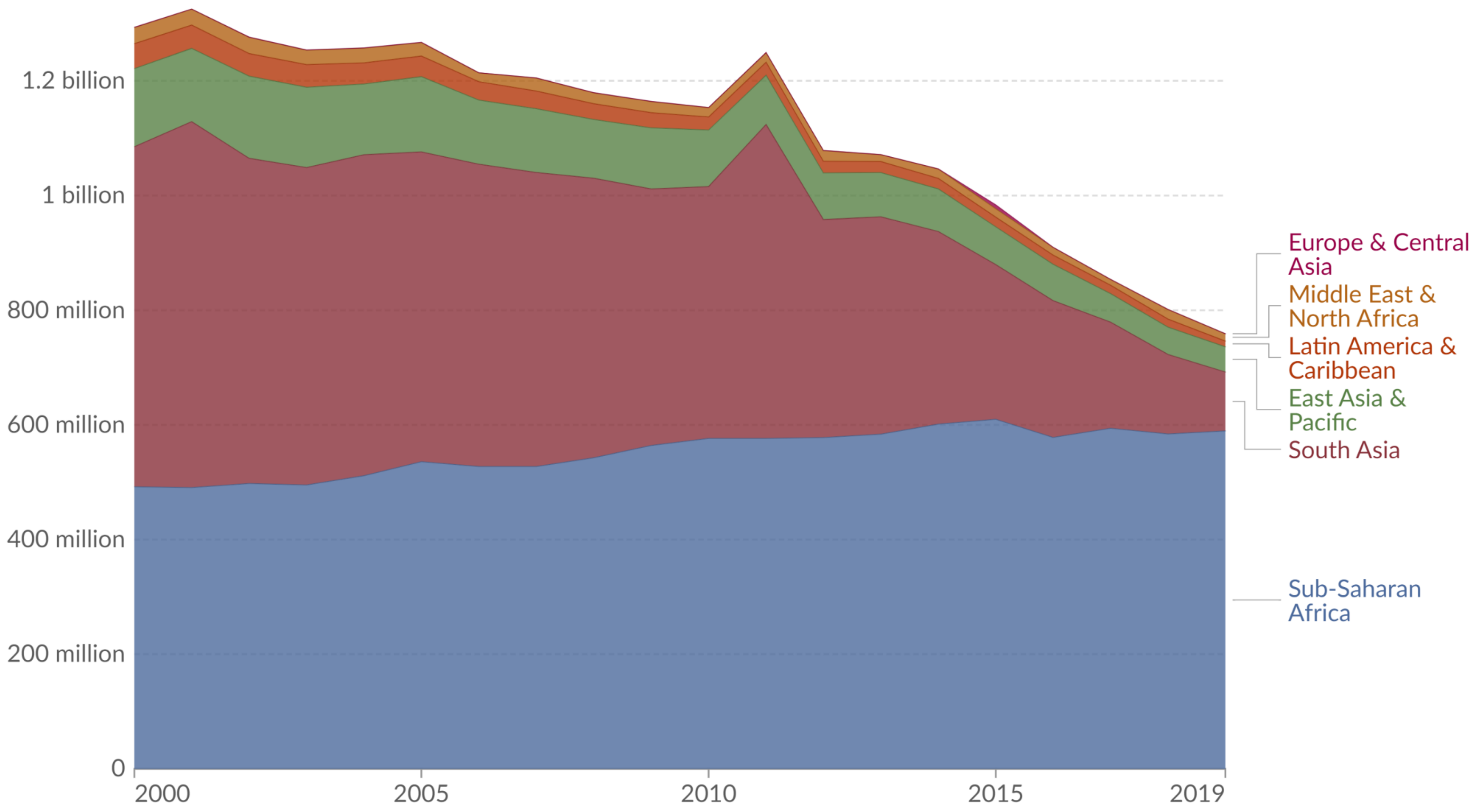
Access to electricity and clean cooking in the New Policies Scenario



International Energy Agency (2018), World Energy Outlook 2018, OECD/IEA, Paris

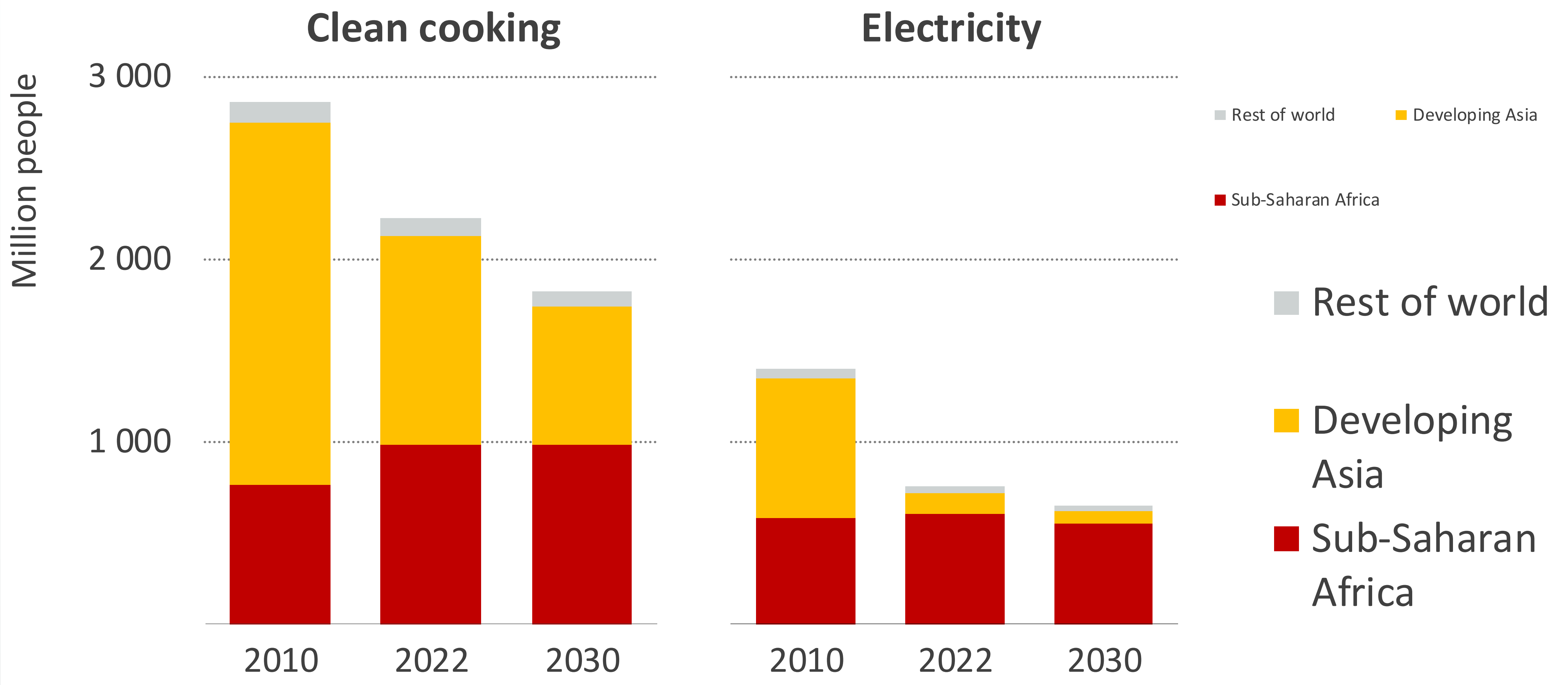
Number of people without access to electricity

Having access to electricity is defined in international statistics as having an electricity source that can provide very basic lighting, and charge a phone or power a radio for 4 hours per day.



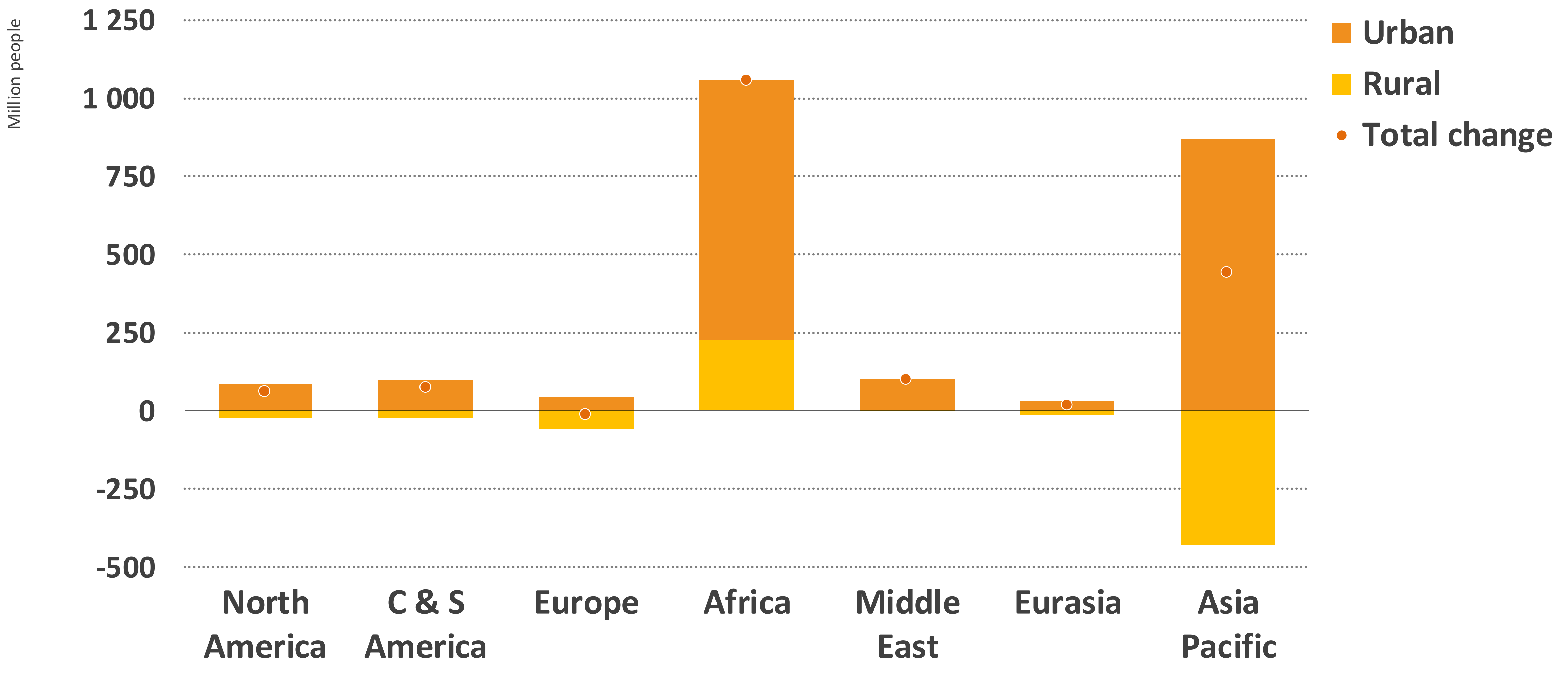
Data source: World Bank

Population without access to modern energy in the STEPS



International Energy Agency (2023), World Energy Outlook 2023, IEA, Paris

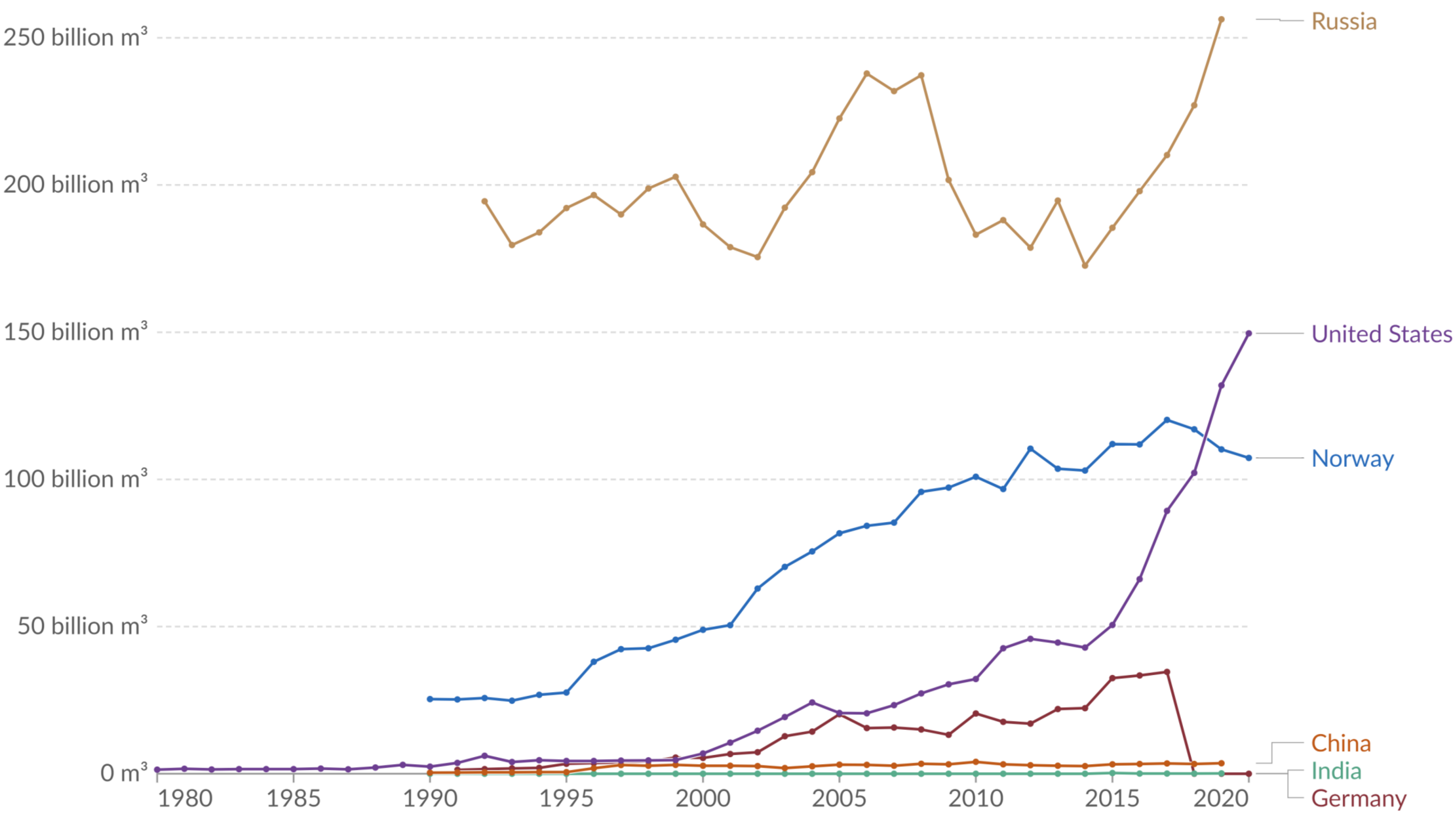
Change in population in urban and rural areas by region to 2050



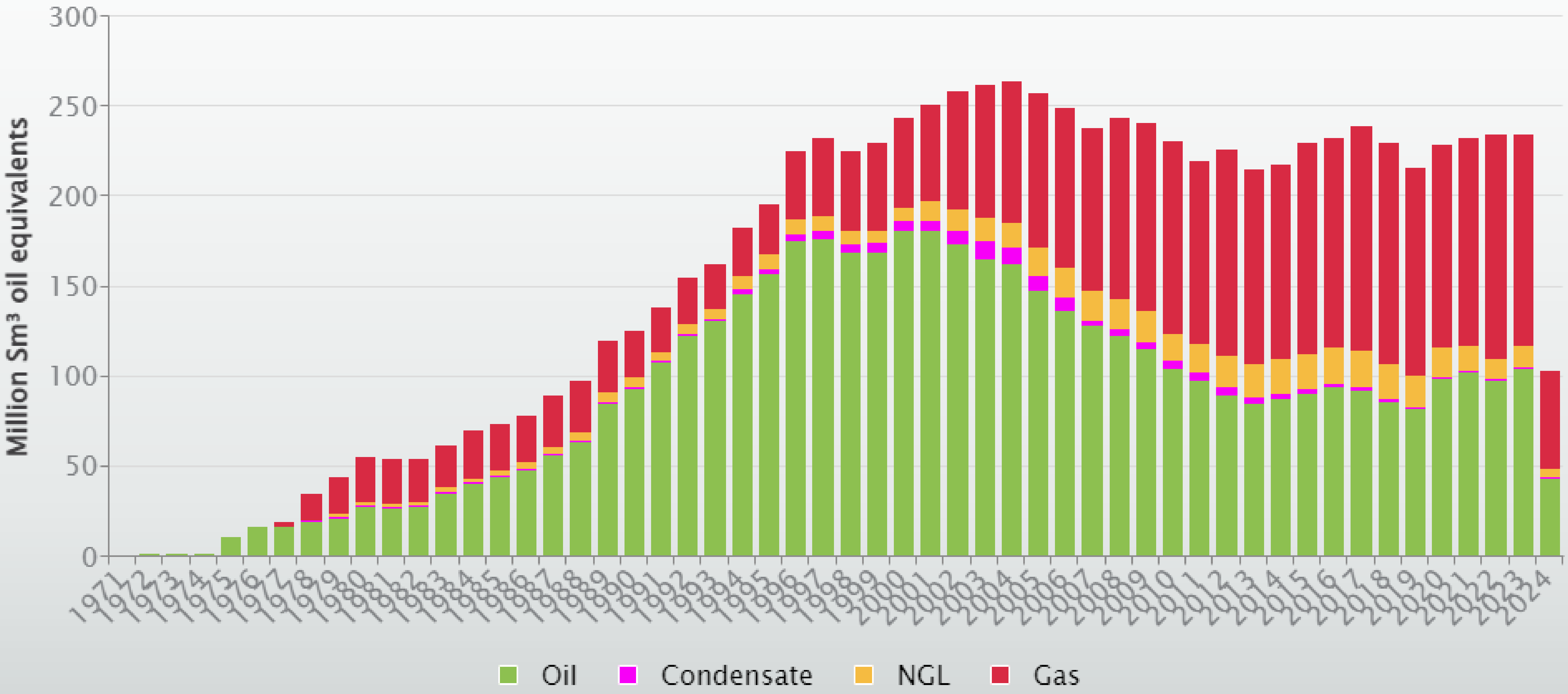
International Energy Agency (2023), World Energy Outlook 2023, IEA, Paris

Natural gas exports, 1980 to 2020

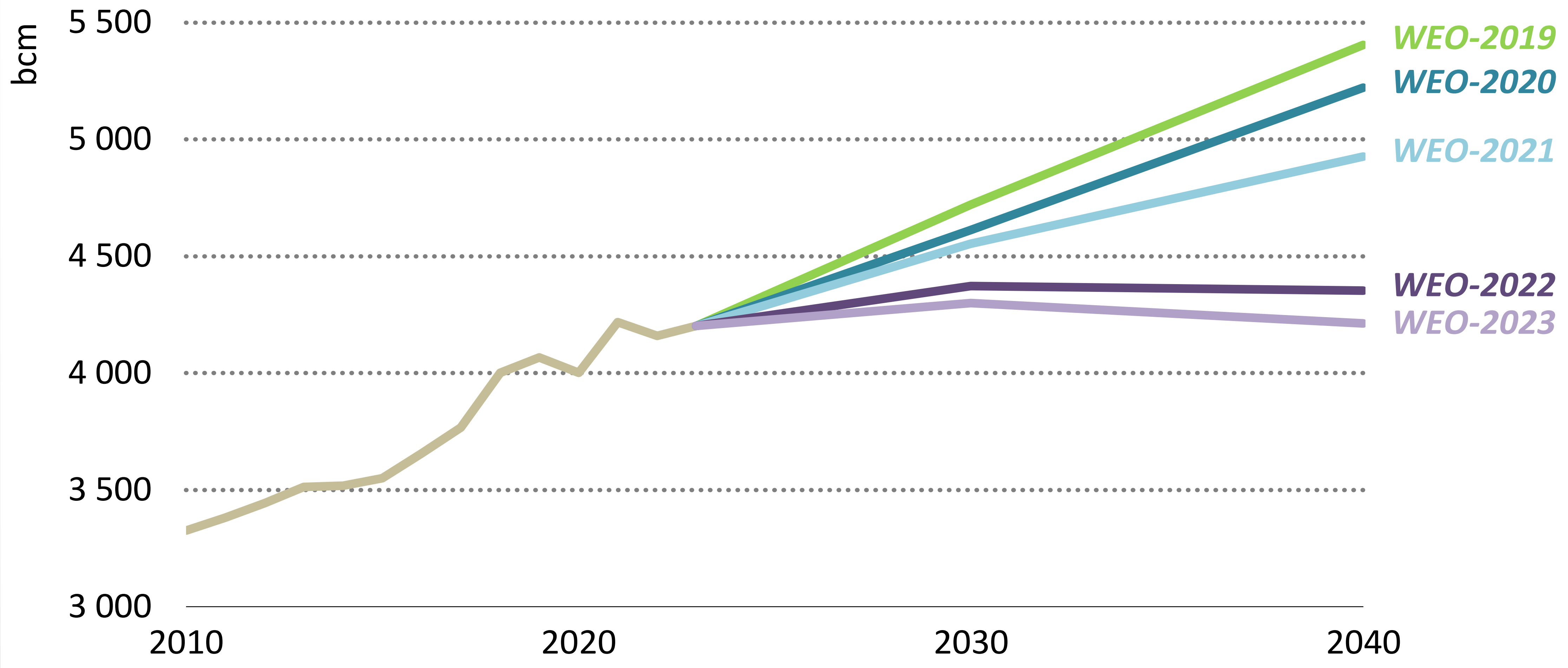
This includes all forms of dry natural gas, including liquified natural gas (LNG). Vented and flared gas are not included.



Annual production from fields in the Norwegian Sea



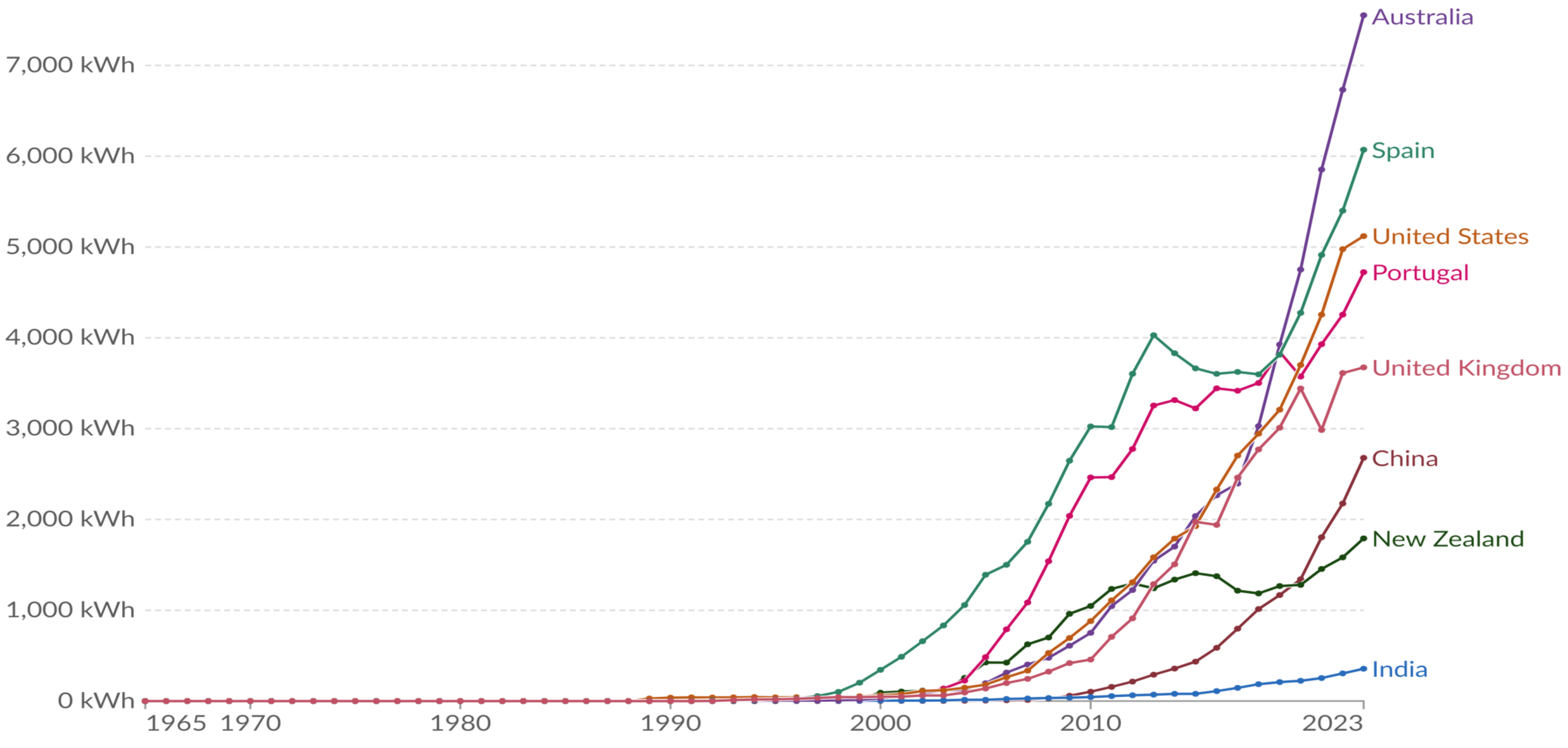
Natural gas demand projections in the STEPS to 2040 in five editions of the *World Energy Outlook*



International Energy Agency (2023), World Energy Outlook 2023, IEA, Paris

Per capita energy consumption from solar and wind, 1965 to 2023

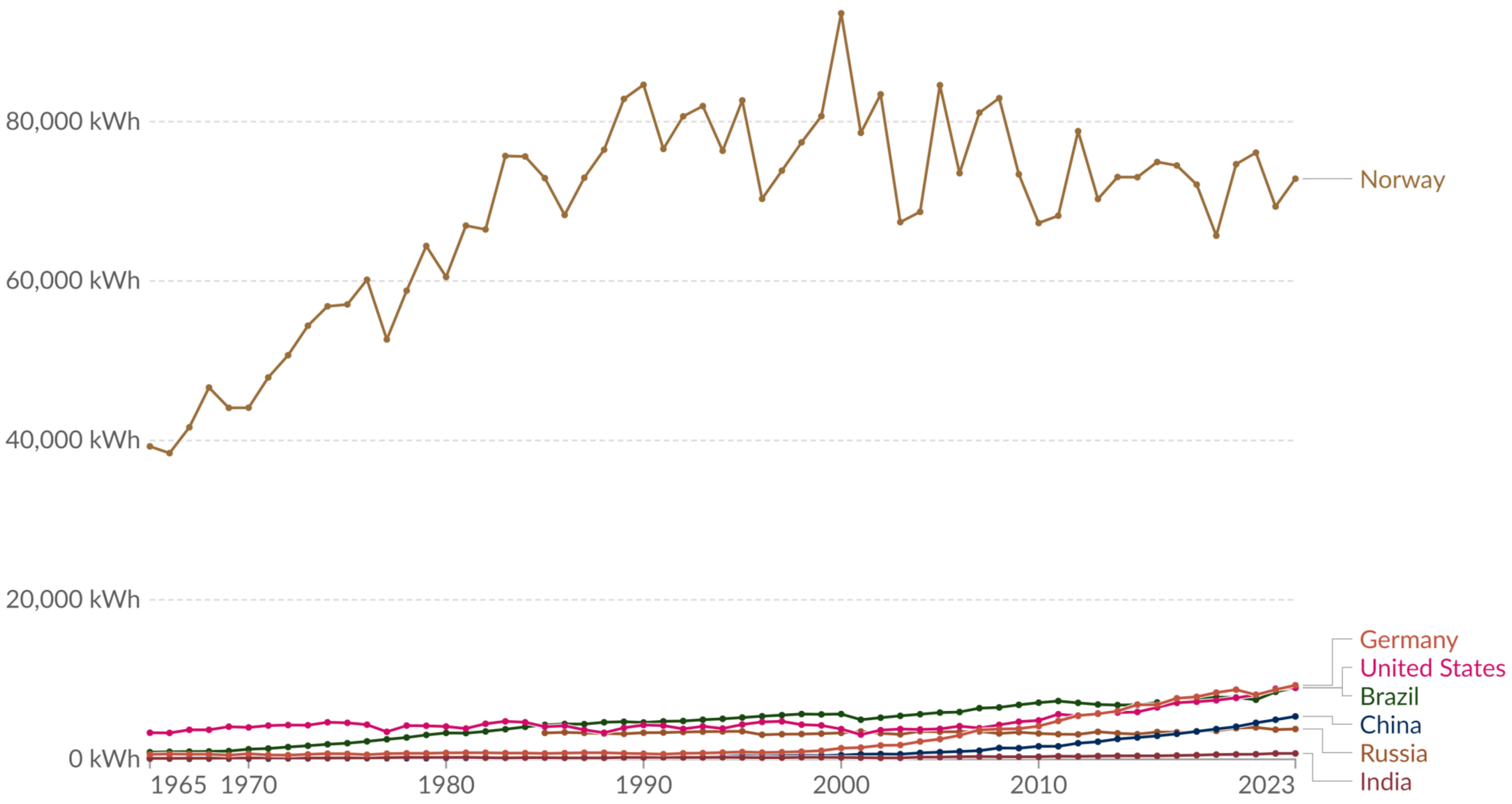
Measured in kilowatt-hours[1] of primary energy[2] per person, using the substitution method[3].



Data source: Energy Institute - Statistical Review of World Energy (2024); Population based on various sources (2023)

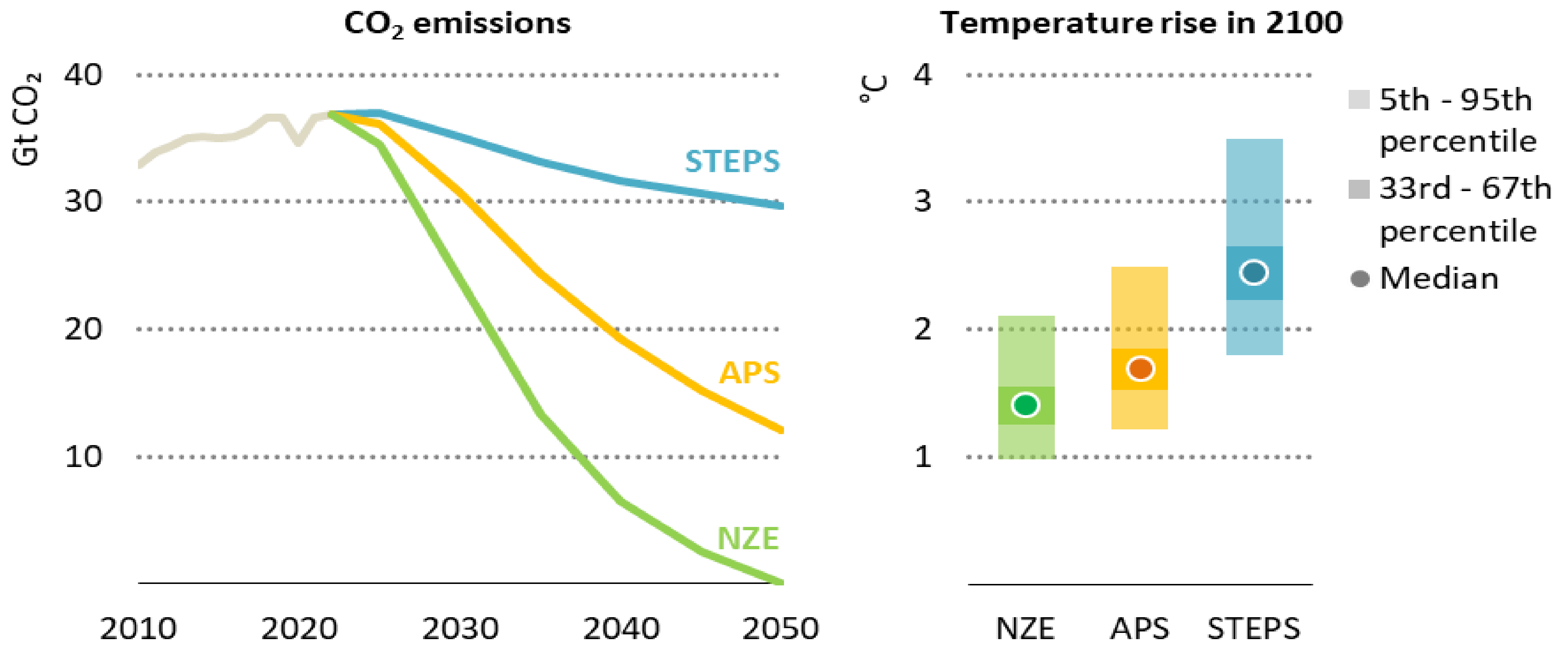
Per capita energy consumption from renewables, 1965 to 2023

Measured in kilowatt-hours[1] of primary energy[2] per person, using the substitution method[3].



Data source: Energy Institute - Statistical Review of World Energy (2024); Population based on various sources (2023)
Note: Renewables include hydropower, wind, solar, geothermal, wave and tidal, and bioenergy, but not traditional biofuels.

Global energy-related and industrial process CO2 emissions by scenario and temperature rise above pre-industrial levels in 2100



International Energy Agency (2023), World Energy Outlook 2023, IEA, Paris

Energy Transition Perspectives

Disruptive New CCUS Technologies and CO2 Storage Enable Petroleum as Future Low Carbon Energy Security

Prof. Arne Graue

Department of Physics and Technology, University of Bergen, Norway

Latin America CCUS Conference, Cartagena, Colombia, May 28-29th, 2025

Disruptive New CCUS Technologies Utilizing CO2 as a Commodity in Carbon Neutral Gas Production and Reduced Carbon Footprint Oil Production

Department of Physics and Technology, University of Bergen, Norway

Next Generation CO_2 Flooding

- Main challenges in CO_2 EOR:
  - Early CO_2 breakthrough and poor sweep efficiency
  - Up-scaling laboratory EOR to field performance

- US White Paper:
  - Mobility control in CO_2 EOR, USDOE/Advanced Resource International Inc.
  - Target: 137 Billion bbl

- US import of foreign oil may be reduced by 30%

- "Next generation CO_2 EOR technology" based on mobility control

- 68 billion barrels of oil: 1,35 billion bbl of oil every year for 50 years

- Similar results in the North Sea; pilot in the Snorre Field

- Economic at oil price of US$ 85 and CO_2 price of US$ 40/ton

- Need more CO2

- Carbon Capture Utilization and Storage (CCUS) a win-win situation

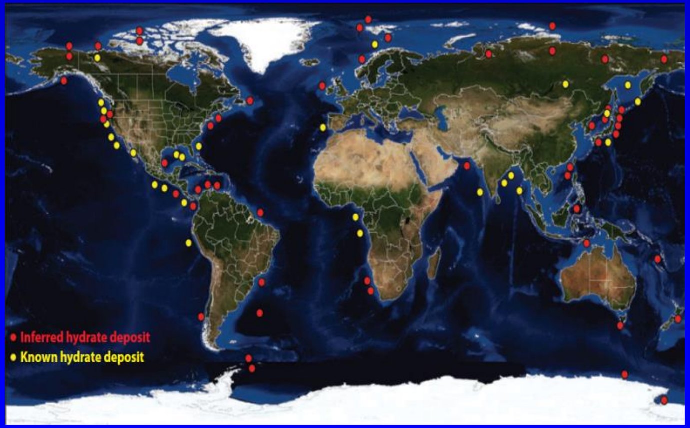
CO_2 Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

Arne Graue, Dept. of Physics & Technology, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway

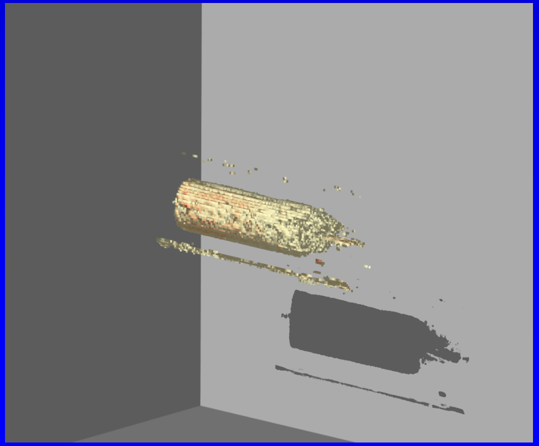
Energy bound in hydrates is more than all combined energy in conventional oil, gas and coal reserves world-wide

Simultaneous CO2 Storage in Gas Hydrates during Exploitation of Hydrate Energy:
- ***Carbon Neutral Gas Production***
- ***Net Zero CO2 Emissions when Utilizing Fossil Energy***

Methane hydrate reservoirs



***In-Situ* imaging (MRI) of hydrate formation**



Methane production by CO2 injection in field test in Alaska 2012

CO_2 EOR Enables CCUS: Integrated EOR (IEOR) for CO_2 Sequestration

CO_2 Foam EOR Mobility Control in Field Pilot in Texas

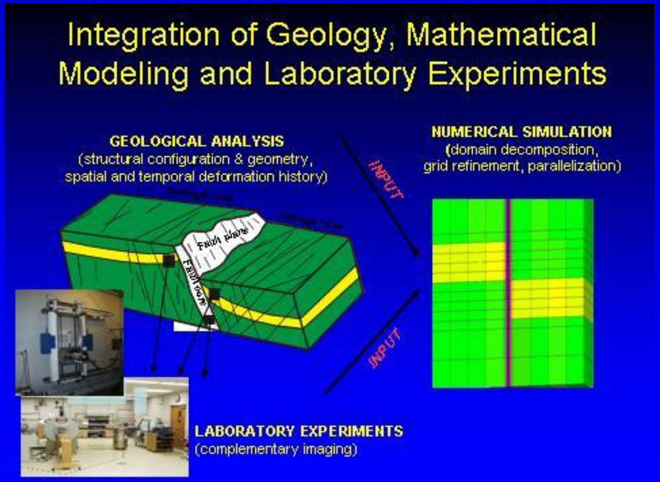
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

Coordinator: Arne Graue, Dept. of Physics, University of Bergen, NORWAY

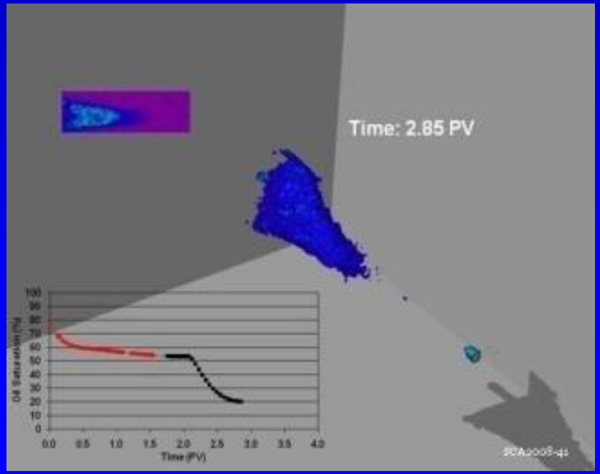
Funding: CLIMIT Program at the Research Council of Norway, Gassnova and 5 oil companies

Integrated EOR (IEOR) with CO2 Foam Mobility Control:

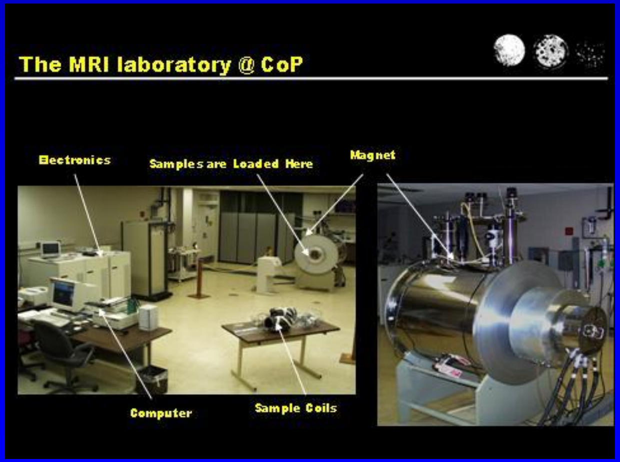
- Reduced Carbon Footprint in Oil Production
- 30% Increased Oil Production at More Sustainable Economy



Lab to pilot field test



MRI of CO_2 injection



Complementary NTI & MRI facilities

Summary

Using CO_2 as a commodity:

Business Cases for CO_2 Storage by CO_2 EOR:

- **Integrated EOR (IEOR) w/Foam:** ***Reduced Carbon Footprint in Oil Production***
- **Exploitation of Hydrate Energy:** ***Carbon Neutral Gas Production and Net Zero CO2 Emissions when Utilizing Fossil Energy***

Way Forward

New technologies ready for industrial scale implementation:

- **Onshore in Permian Basin, USA (80% CO_2EOR, EOR target 137Bbbl)**
- **Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil**