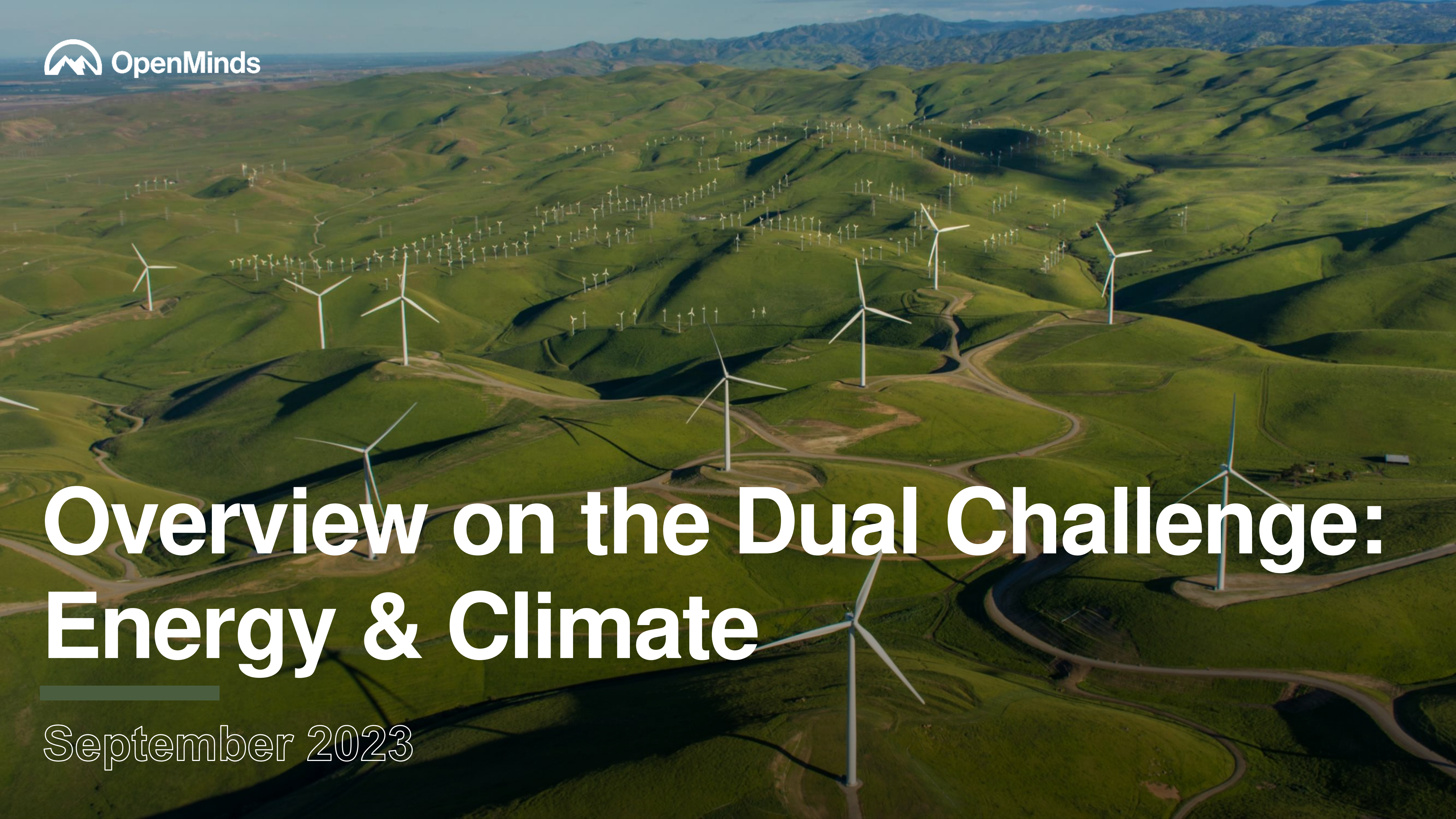


OpenMinds

Overview on the Dual Challenge: Energy & Climate

September 2023

An overview of OpenMinds and the Dual Challenge

The Dual Challenge

Affordable, reliable energy is the foundation upon which modern civilization rests. From the electricity used to light our homes to the fuels used in cars and planes to the energy needed to produce the fertilizer necessary to grow our food, energy is integral to everything we do. The massive expansion of primary energy supply since the nineteenth century has driven an unprecedented improvement in human longevity and prosperity. However, today, there is still considerable energy inequality: 2.4 billion people lack access to clean cooking fuels, and more than 700 million lack access to electricity. Future population growth will be overwhelmingly concentrated in these regions. The world needs more energy.

But our largest primary energy sources, fossil fuels, are also the largest sources of anthropogenic greenhouse gas emissions. Fossil fuels account for nearly 80% of our primary energy supply, and our reliance on them has not changed appreciably in 30 years. Rising greenhouse gas concentration in the atmosphere produced in large part by the combustion of fossil fuels is causing the planet to warm, and there is now widespread scientific evidence that adverse consequences to human prosperity and wellbeing will likely result if this warming trend continues.

The tension between energy supply and climate change presents a "Dual Challenge" for the 21st century. How do we affordably and reliably supply ever more energy while simultaneously reducing greenhouse gas emissions to limit future warming?

OpenMinds

OpenMinds is an association of business, academic, and political leaders from a range of backgrounds, geographies, and political affiliations.

The group was originally established by David Baldwin and Jeff Katz in 2018 to convene small, diverse groups of critical-thinking experts, with open minds, to discuss and debate in a non-partisan manner solutions to society's biggest challenges and opportunities.

We began work on the Dual Challenge in 2021. Our efforts in 2021 and 2022 culminated in the creation of a balanced, pragmatic definition of the challenge, supported by a detailed fact base.

This year, our focus is on solutions. We are seeking to create a realistic and actionable plan that optimizes for both energy and emissions, and we are collaborating with Bain & Company to develop that work.

OpenMinds' 2022–2023 Mission

We will convene a diverse team of climate and energy experts to create, debate, and refine in a non-partisan way the best combination of policies, practices, innovations, communications, and capital flows to expand energy access and by "203X" accelerate the reduction of anthropogenic greenhouse emissions without unduly limiting global economic growth and development

Our deliverables will be:

- (i) **DEFINITION:** A data set which supports a balanced and clear understanding of the global "Dual Energy & Climate Challenge".
- (ii) **SOLUTIONS:** An integrated set of recommendations drawing from the experience and knowledge of our experts for successfully addressing the "Dual Challenge", including proposed actions for both (a) medium term (2030), and (b) longer term (2050) success.
- (iii) **COMMUNICATIONS:** An array of communication tools and channels intended to reach and influence a broad audience towards strategic action.

A note on these materials

Focus of this deck

Click to access more information about solutions

The purpose of this document is to define the "Dual Challenge" of meeting the growing demand for energy while reducing greenhouse gas emissions with the aim of enhancing the wellbeing of humans everywhere. **Our intent is for this to be accessible to anyone**, even those with no prior knowledge of energy or climate change.

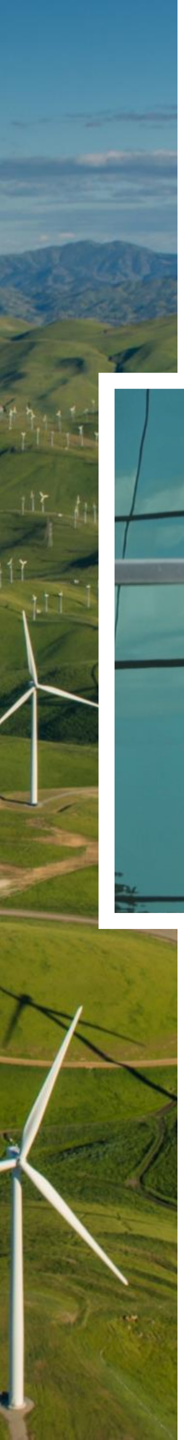
In preparing these materials, **we drew from a range of sources**, including the IPCC's Sixth Assessment Report, BP's Statistical Review of World Energy, the Global Carbon Project, and others.

Section 2 (Energy) and **Section 3 (Climate)** serve as building blocks for successive chapters. Each begins with first principles, establishes civilizational relevance, provides an overview of energy demand and emissions over a three-decade period, and offers thoughts on the future.

Section 4 (Reality Check) summarizes long term trends and demonstrates that emissions reductions will almost certainly need to be done in the context of rising energy demand, which is the core of the Dual Challenge.

Section 5 (Headwinds & Tailwinds) presents a non-exhaustive overview of the forces, both favorable and unfavorable, influencing progress toward resolving the Dual Challenge.

It will take a global, "all of us" effort to address the Dual Challenge. **We hope these materials convey the importance of attending to the physical realities of both energy and climate, alongside the world's economic and development needs, as we seek solutions.**



The Dual Challenge: An overview

Energy is fundamental to human well being and flourishing…

… but our primary energy sources, fossil fuels, are also the principal source of human greenhouse gas emissions, which **cause global warming**

The tension between energy supply and climate change presents the **Dual Challenge**

This is a **global** problem of enormous **scale and complexity**, and addressing it will require us to balance **competing priorities**

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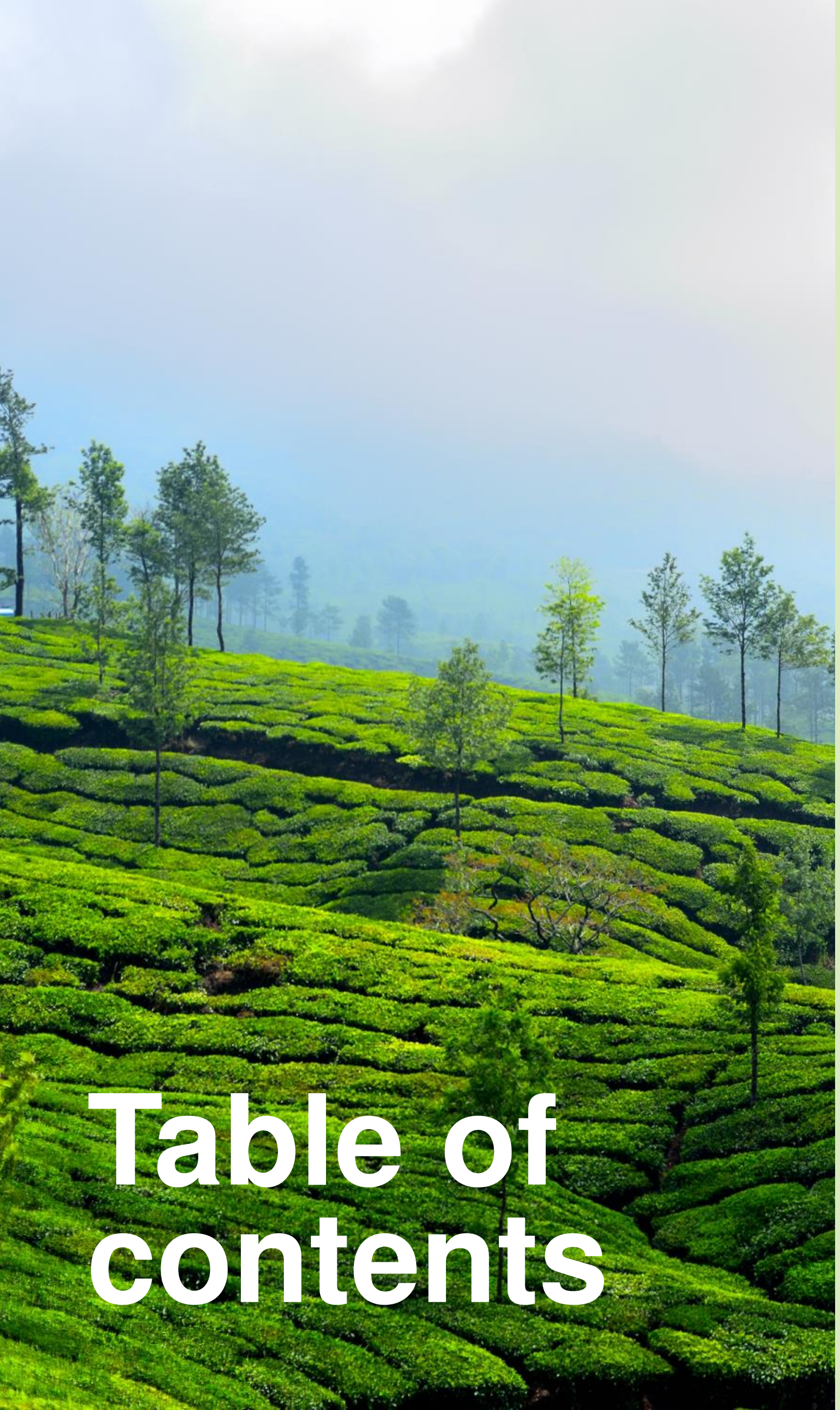

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03 Climate Change: Fundamentals and Possible Trajectories

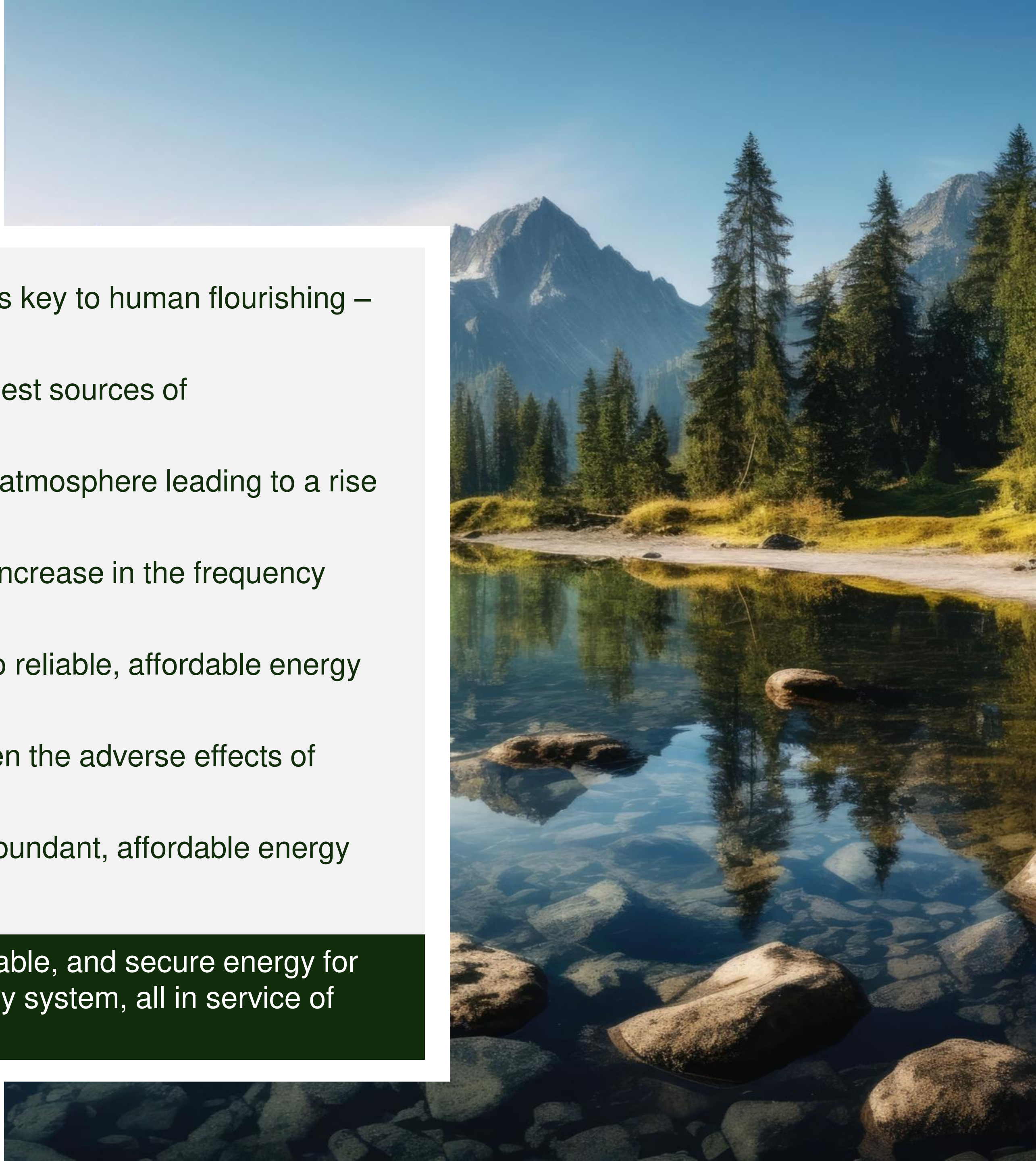
04 Reality Check: Where We Are Today

05 The Dual Challenge: Headwinds and Tailwinds

The Dual Challenge

- Affordable, reliable energy forms the bedrock of modern civilization is key to human flourishing – and the world needs more of it.
- But our largest primary energy sources, fossil fuels, are also the largest sources of anthropogenic greenhouse gas emissions.
- These greenhouse gas emissions have a heat-trapping effect in the atmosphere leading to a rise in the earth's average temperature over time.
- Warming presents risks over time, such as rising sea levels and an increase in the frequency and intensity of some forms of extreme weather.
- Solving solely for emissions and warming could jeopardize access to reliable, affordable energy in the developed and developing world.
- Conversely, solving for energy without considering climate will worsen the adverse effects of human-induced climate change in the future.
- Consequently, there is considerable tension between our need for abundant, affordable energy and the need to address the risks of climate change.

This tension presents the "**Dual Challenge**"—providing affordable, reliable, and secure energy for billions while simultaneously reducing the warming impact of our energy system, all in service of enhancing human wellbeing now and in the future.



Energy is fundamental to human flourishing

Survival

Quality of life

Physical human effort, unleveraged

Human productivity, multiplied

DRAFT

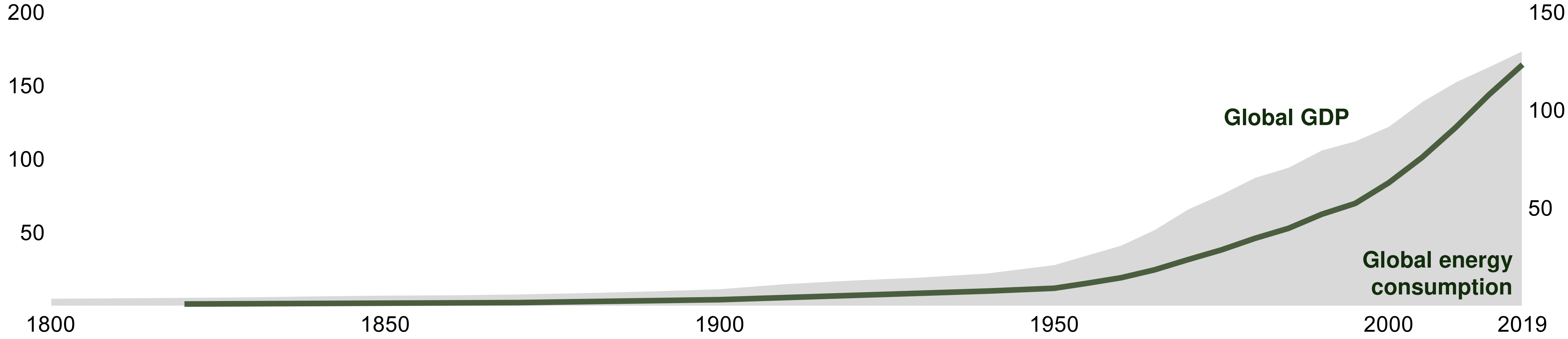
Energy has played a crucial role in economic and human development

Global energy consumption

PETAWATT-HOURS

Global GDP

TRILLIONS OF CONSTANT 2011 INTERNATIONAL USD, PPP ADJUSTED



World population

1.0B → 7.8B

Average life expectancy

29yrs. → 73yrs.

Source: Bain & Company analysis; BP Statistical Review of World Energy, 2021; World Bank & Maddison (2017); Vaclav Smil, *Energy Transitions: Global and National Perspectives* (2017); World Bank; Our World in Data

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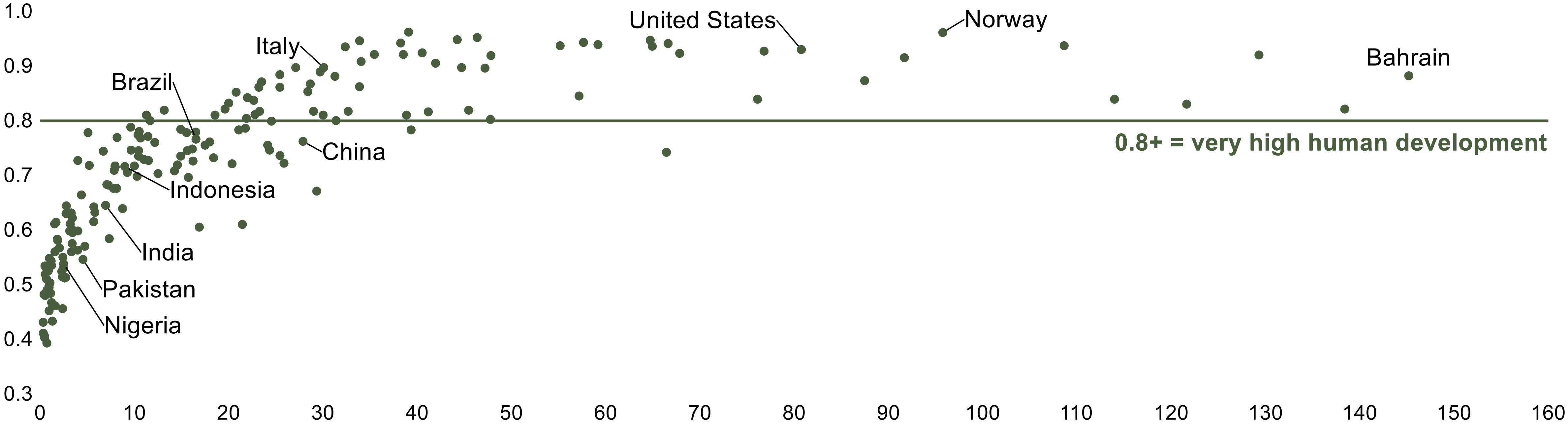
Energy underpins human well-being

Human development Index – 2019

The HDI is a summary measure of key dimensions of human development: a long and healthy life, a good education, and having a decent standard of living



Energy consumption per capita – 2019

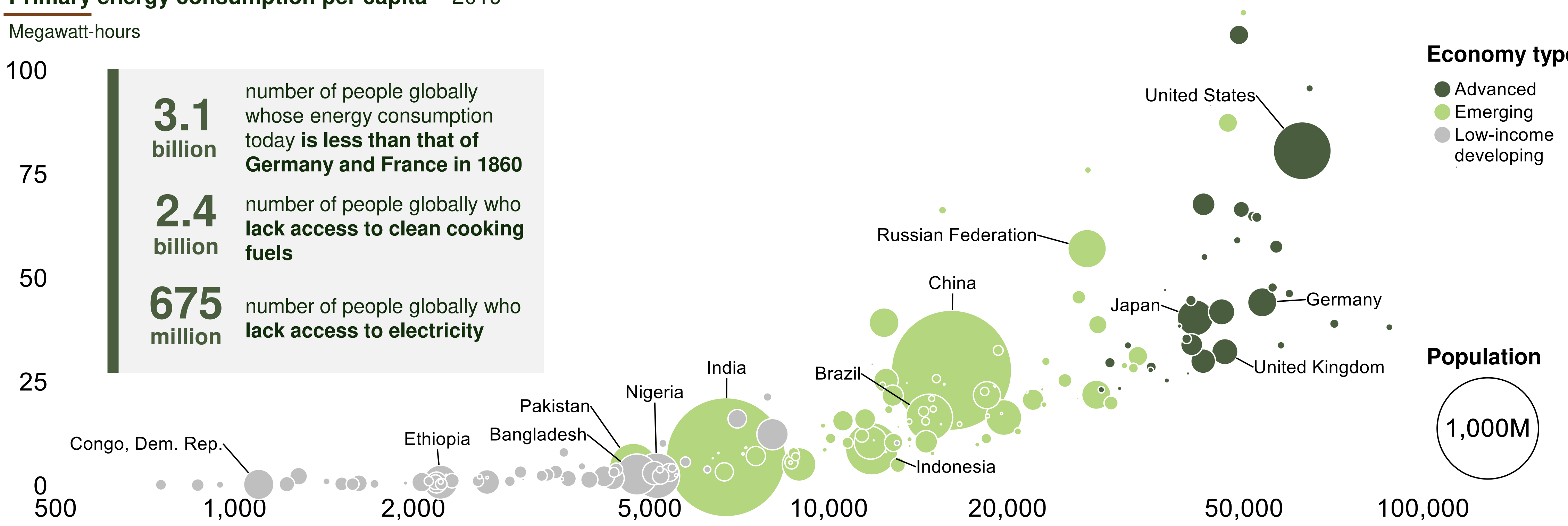
Measured in megawatt-hours

Source: Bain & Company analysis; Our World in Data; Center for Global Development; BP Statistical Review of World Energy, 2021; EIA

Energy consumption is highly correlated with economic progress—and there is still considerable inequality

Primary energy consumption per capita – 2019

Megawatt-hours



GDP per capita – 2019

Measured in 2017 International dollars, PPP-adjusted; logarithmic axis

Source: Bain & Company analysis; Our World in Data; World Bank; IMF; Global Carbon Project; Vaclav Smil, *How the World Really Works*

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Despite progress, the world needs more energy

Energy consumption per capita, 2019 *(shown as bars)*

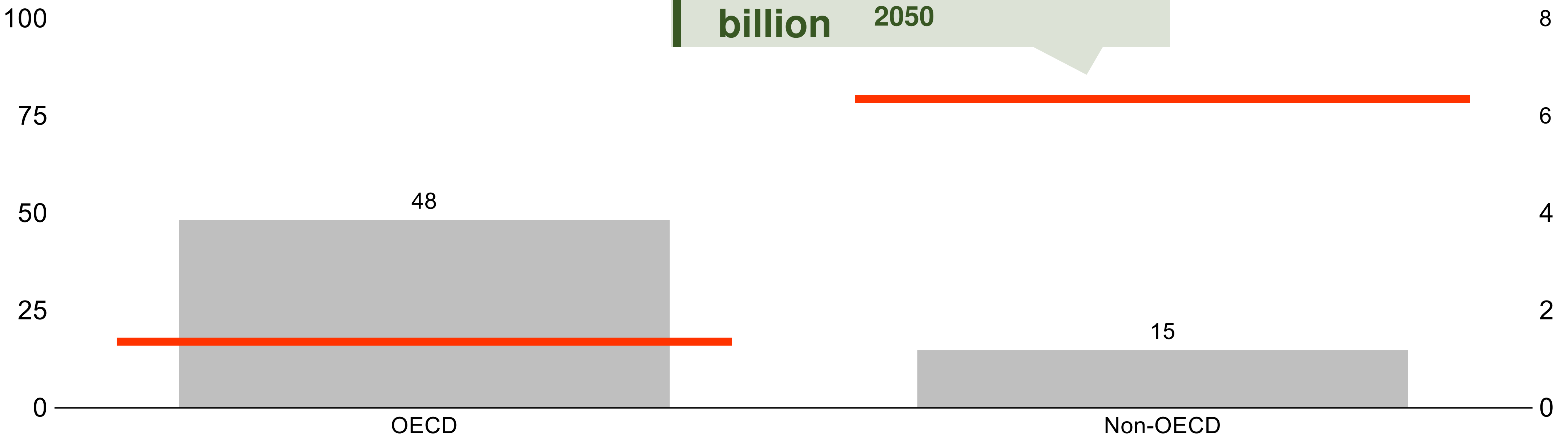
MEGAWATT-HOURS

1.7 billion

Expected population growth in non-OECD countries through 2050

Population, 2019 *(shown as red lines)*

BILLIONS



GDP per capita[1]	$45K	$11K

Note: (1) GDP per capita is adjusted for purchasing power parity and is measured in 2017 USD. Source: World Bank; BP Statistical Review of World Energy, 2022; Our World in Data

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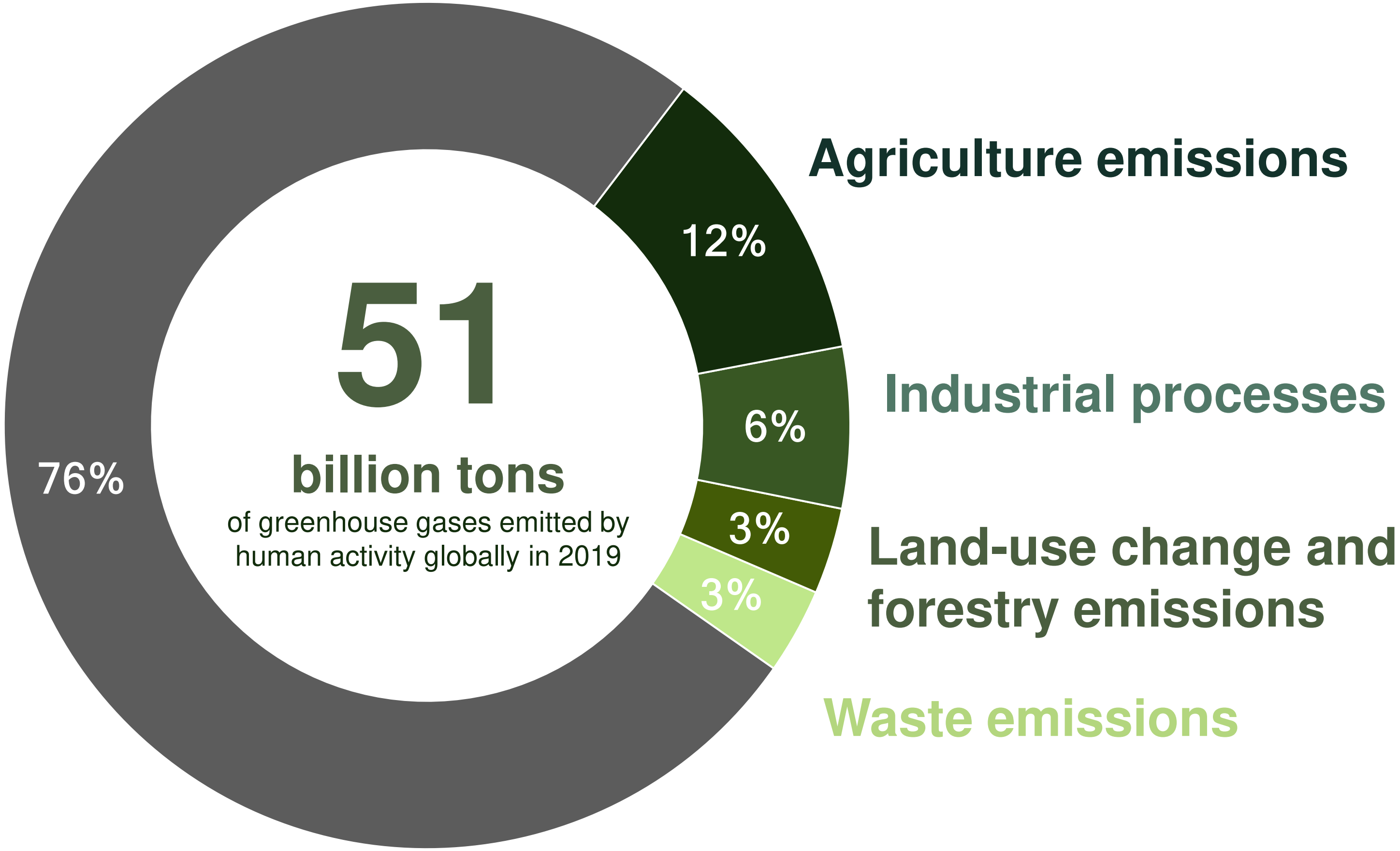
1

But conventional energy is the primary source of human emitted greenhouse gases

Energy emissions
Emissions from the production and combustion of fossil fuels for power generation, heat generation, manufacturing/construction, transportation, and other uses



Note: Emissions measured in tons of CO_2-equivalent and include carbon dioxide, methane, nitrous oxide, and f-gases
Source: Bain & Company analysis; Our World in Data; Climate Watch

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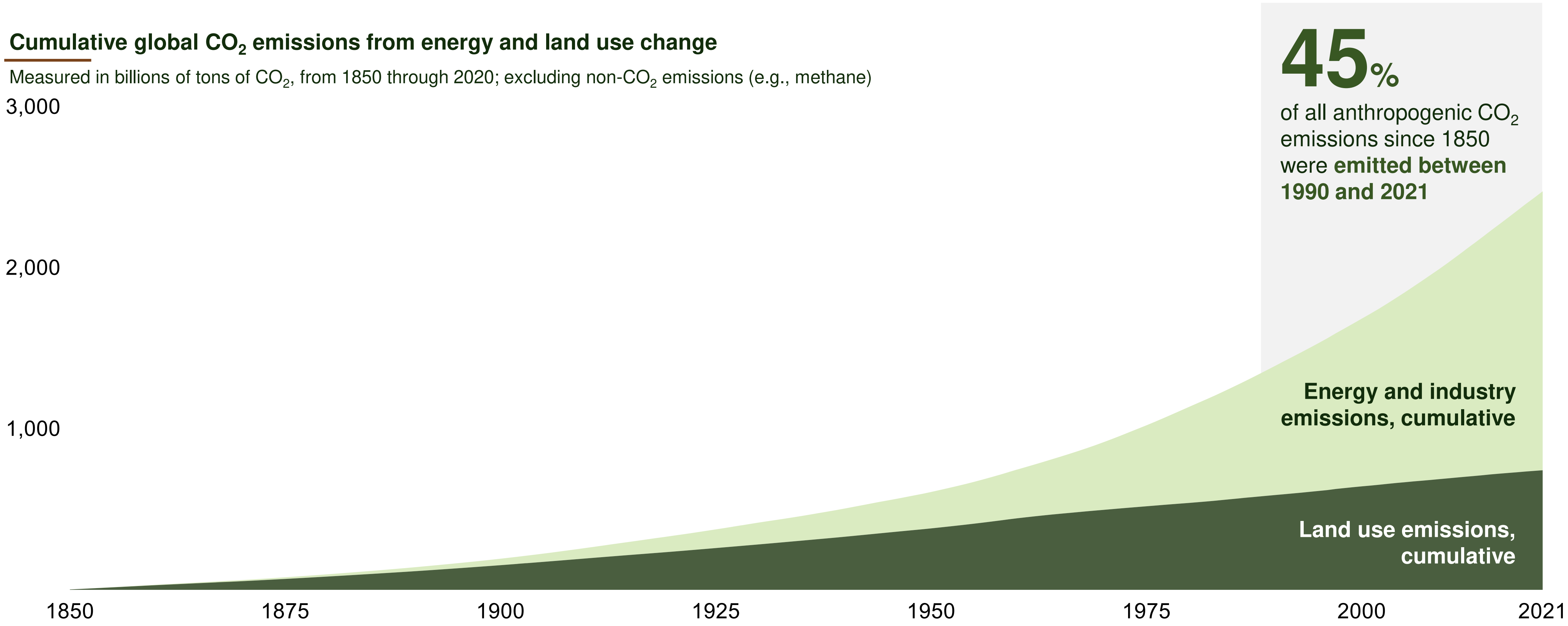
DRAFT

But the consumption of traditional sources of energy releases greenhouse gases like carbon dioxide (CO_2)

Cumulative global CO_2 emissions from energy and land use change

Measured in billions of tons of CO_2, from 1850 through 2020; excluding non-CO_2 emissions (e.g., methane)



Source: Bain & Company analysis; Global Carbon Project; Our World in Data

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CO_2 is not the only greenhouse gas, but it accounts for the majority of anthropogenic emissions

Carbon dioxide

Sources include fossil fuel (e.g., coal, oil, gas) combustion, cement production, steel production.

Nitrous oxide

Sources include agriculture (fertilizer), fossil fuel combustion, and industrial processes.

Methane

Sources include livestock, natural gas production, and landfills.

Fluorinated gases

Sources include electronics manufacturing, and aluminum production.

SHARE OF GLOBAL ANTHROPOGENIC EMISSIONS*

Note: * 2019 global emissions measured in tons of CO_2-equivalent
Source: EPA; Climate Watch; IPCC, Fourth Assessment Report (AR4)

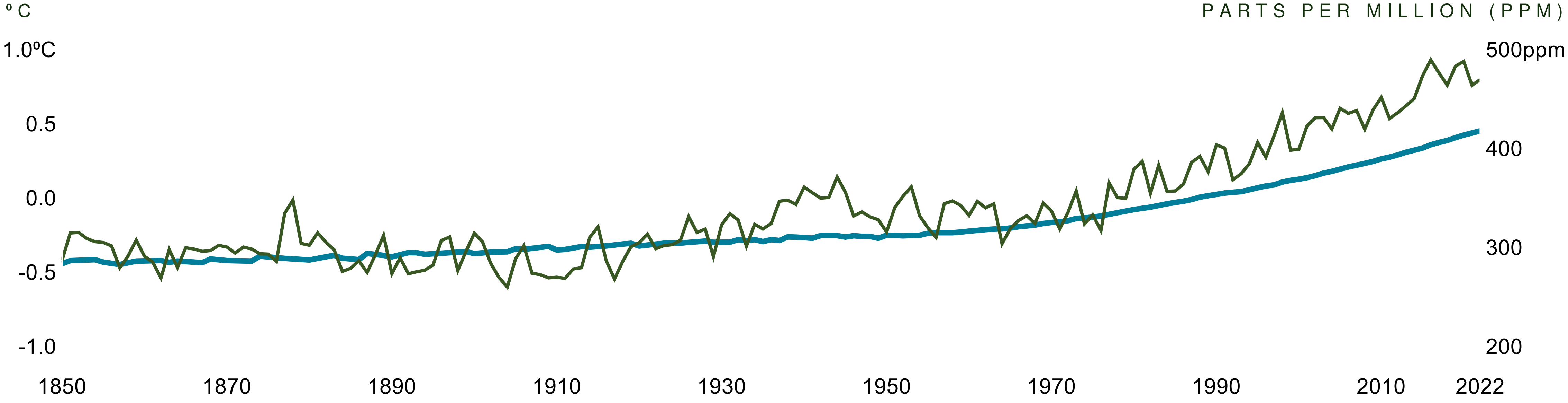
DRAFT

1

The cumulative effect of human emissions has caused the earth to warm 1.2°C since pre-industrial times

Average global temperature anomaly

Atmospheric CO_2 concentration



1.2ºC **Approximate warming since pre-industrial times**

Median global temperature anomaly

Atmospheric CO_2 Concentration

Note: The green line represents the median average temperature deviation, or anomaly, vs. the 1961-1990 baseline (average) value. Atmospheric CO_2 concentration reflects the annual average.
Source: Bain & Company analysis; Hadley Center; NOAA; IPCC, Sixth Assessment Report (AR6), *Climate Change 2021: The Physical Science Basis, Summary for Policymakers*, A.1.2 (2022); Our World in Data

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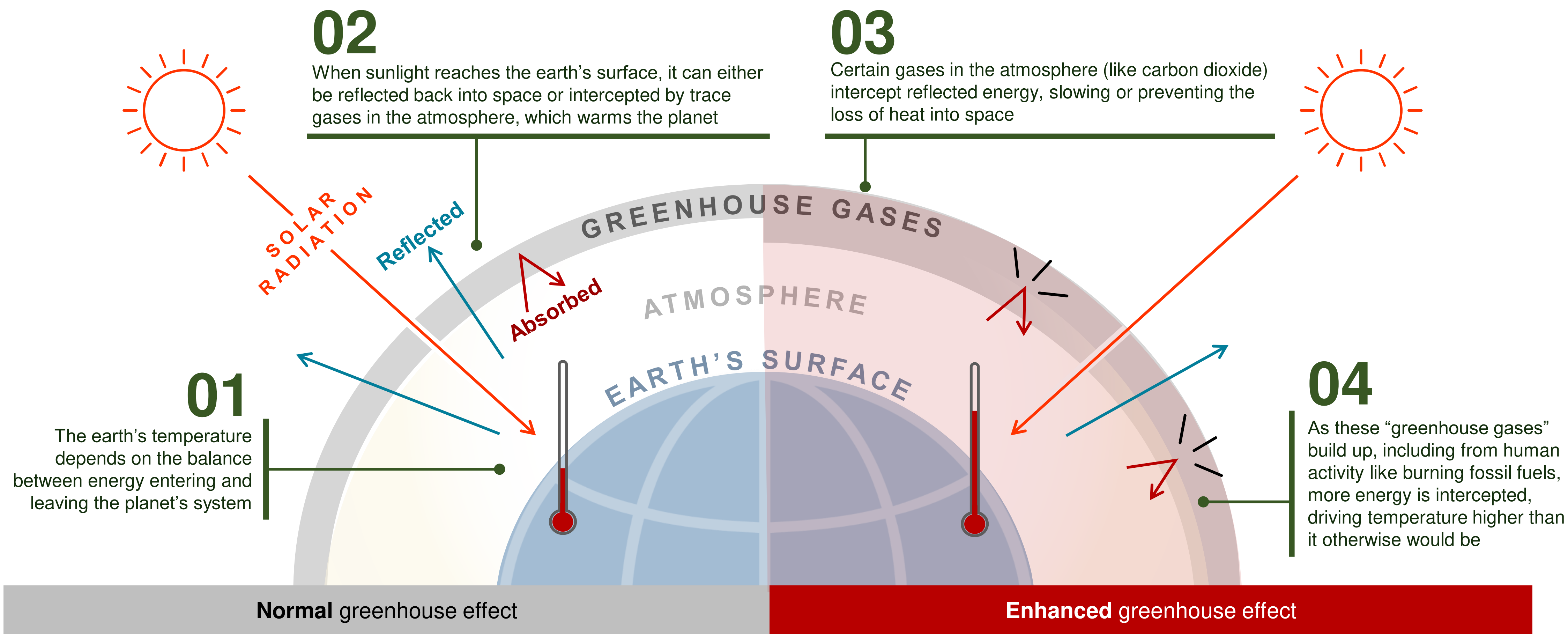
The greenhouse effect is the physical process that links anthropogenic GHG emissions to warming

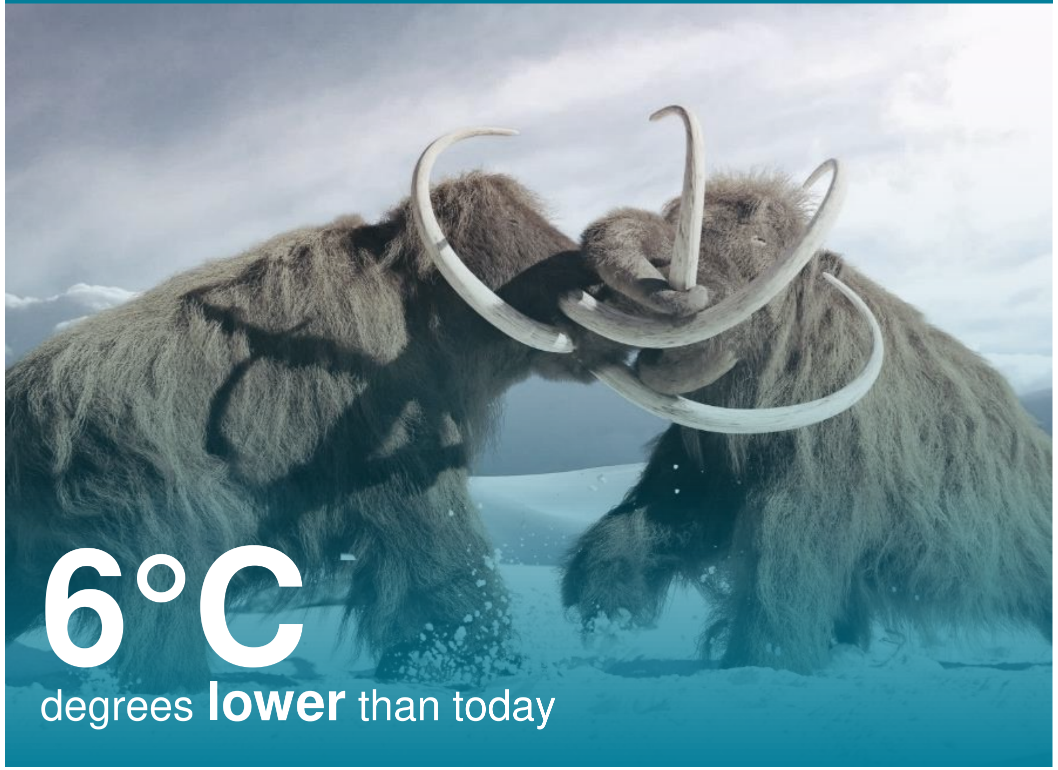


Source: EPA

And history suggests "a little is a lot" with respect to temperature changes

Last ice age

when ~25% of Earth's land area was covered in glaciers

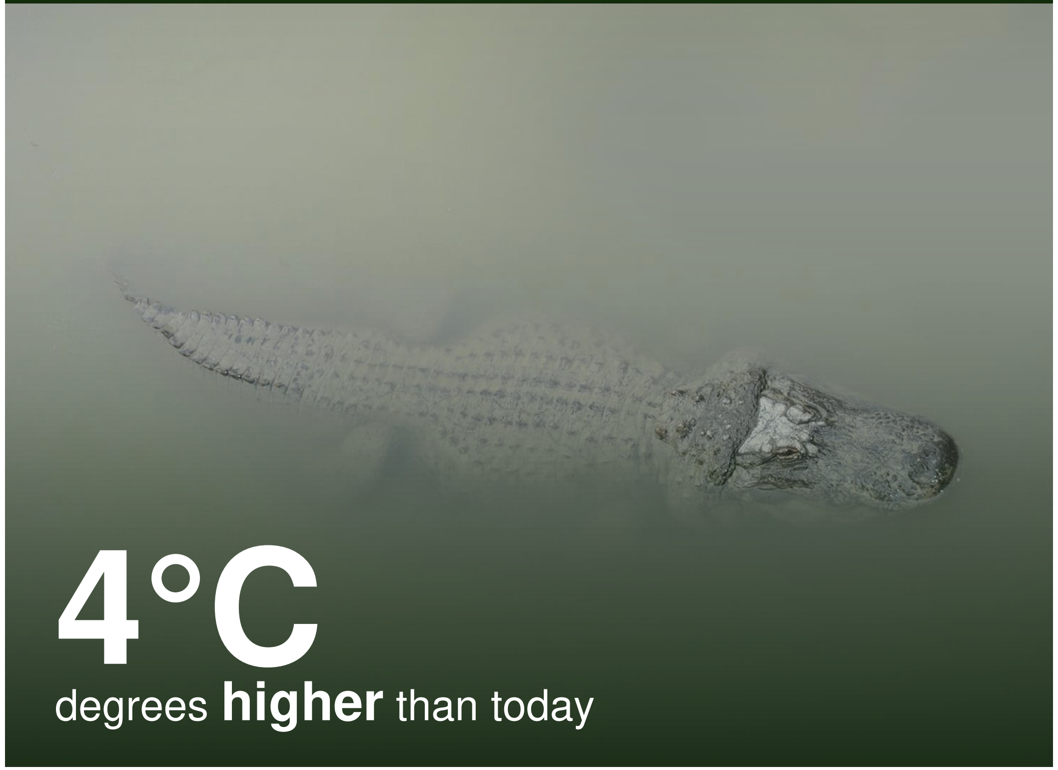


6°C

degrees **lower** than today

Age of the dinosaurs

when crocodiles could be found above the Arctic Circle



4°C

degrees **higher** than today

Source: Bill Gates, How to Avoid a Climate Disaster (2021); USGS

Warming has already produced adverse impacts

Observed impact on ecosystems

Changes in ecosystem structure

Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (**high confidence**)."

Species range shifts

Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (**high confidence**), as well as mass mortality events on land and in the ocean (**very high confidence**)."

Observed impact on human systems

Water scarcity and food production

Climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals (**high confidence**)."

Health and wellbeing

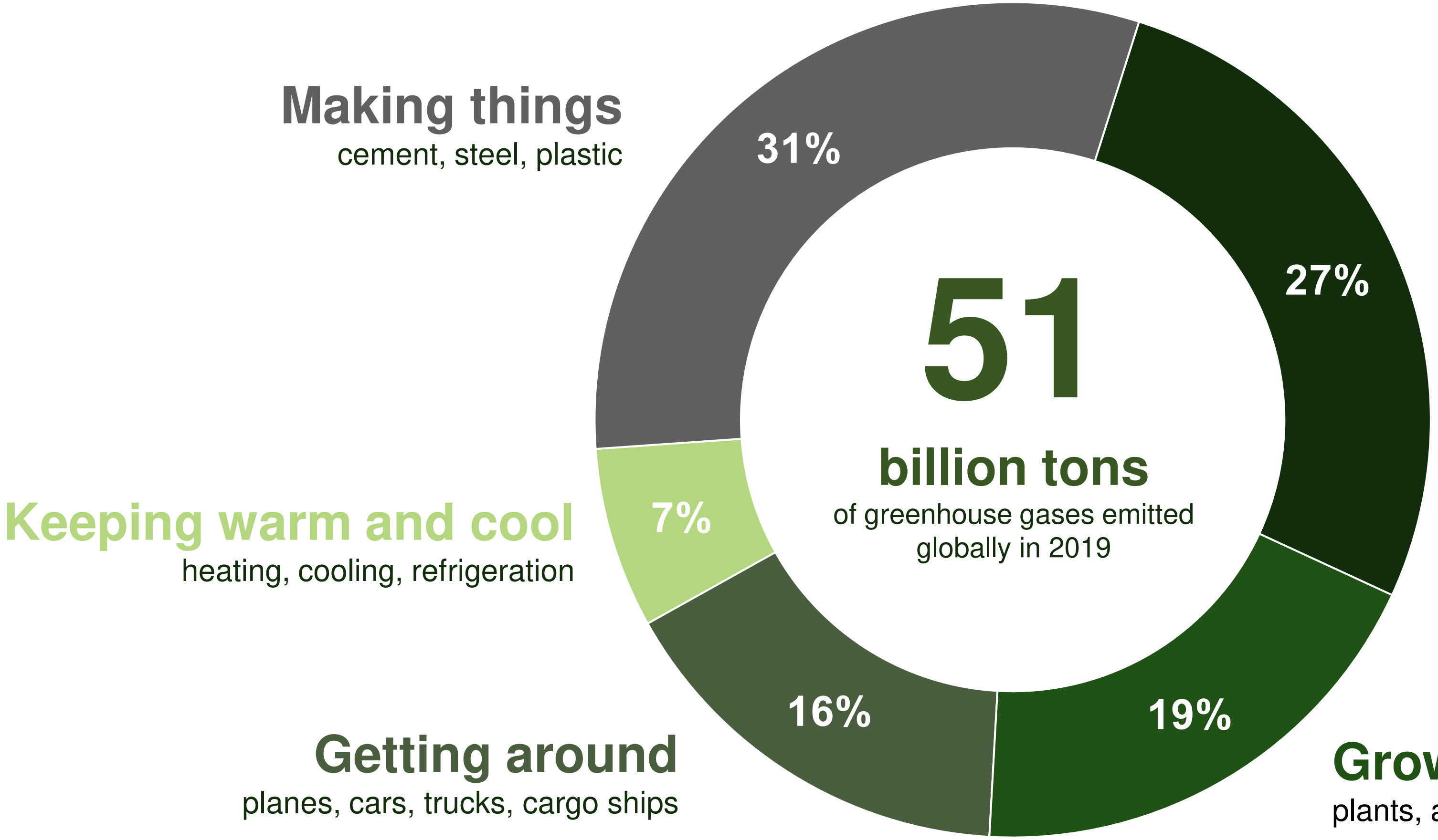
The occurrence of climate-related food-borne and water-borne diseases has increased (**very high confidence**). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (**high confidence**)."

Human displacement

Hazards resulting from the increasing intensity and frequency of extreme weather events…are **already causing an average of more than 20 million people** to leave their homes and move to other areas in their countries each year."

Source: IPCC, Sixth Assessment Report (AR6), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, Section B (2022); UNHCR

In 2019, a range of human activities resulted in the release of about 51 billion tons of greenhouse gases



76% share of total emissions accounted for by **fossil fuels (coal, oil, gas) combustion**

Note: Emissions measured in tons of CO_2-equivalent and include carbon dioxide, methane, nitrous oxide, and f-gases
Source: Bill Gates, *How to Avoid a Climate Disaster* (2021)

Nations outside of the OECD have driven all of global anthropogenic emissions growth since 1990

Gigatons of CO_2[1]	1990 Emissions	1990 % of total	2021 Emissions	2021 % of total	Share of 1990-2021 growth
United States	5.4	20%	5.1	12%	(2%)
EU – 27	3.7	13%	2.6	6%	(8%)
Other OECD	3.7	13%	4.6	11%	6%
Total OECD	**12.8**	**46%**	**12.3**	**30%**	**(4%)**
China	3.8	14%	11.8	29%	60%
India	0.8	3%	2.8	7%	15%
Other non-OECD	10.2	37%	14.2	34%	29%
Total non-OECD	**14.8**	**54%**	**28.7**	**70%**	**104%**
World	**27.6**	**100%**	**41.1**	**100%**	**100%**

Note: (1) Emissions are production-based and include emissions from energy and land-use change, measured in gigatons of CO_2
Source: Bain & Company analysis; Our World in Data; Global Carbon Project

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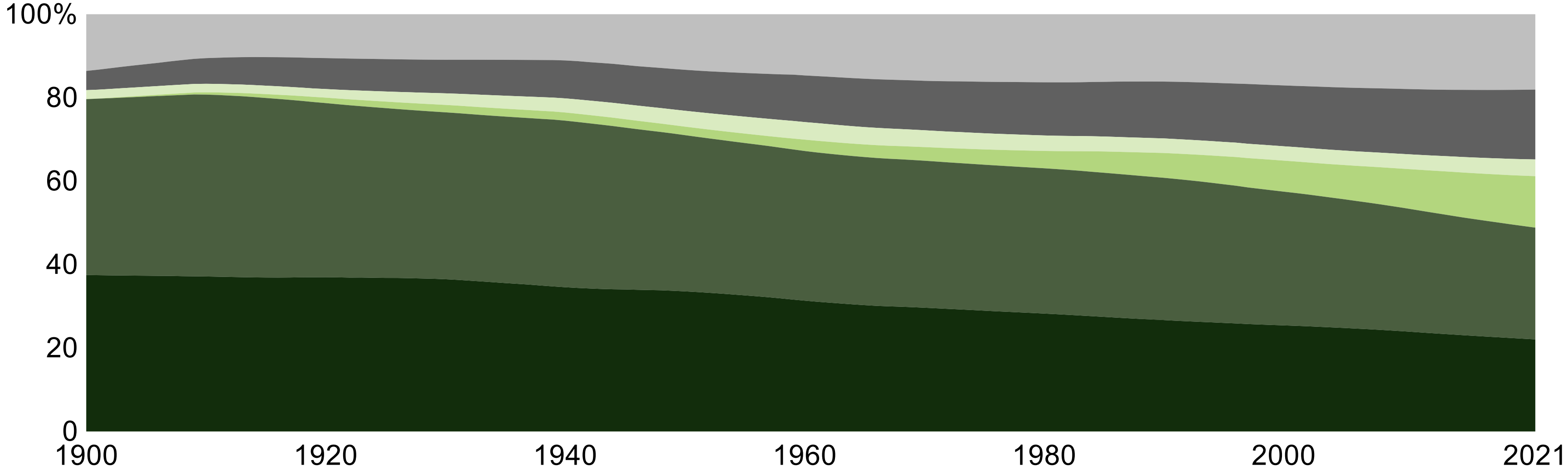
But on a cumulative basis, the US and Europe have contributed much more to increased atmospheric CO_2 concentration

Cumulative global CO_2 emissions from energy and land use change

cumulative production-based emissions of carbon dioxide [CO_2] since the first year of data available, measured in million tons. This is based on territorial emissions, which do not account for emissions embedded in traded goods. Excludes non-CO_2 emissions



Share of cumulative emissions

18%
18%
4%
13%
26%
21%

Cumulative global emissions ~193 ~747 ~2,475

Billions of tons since 1850

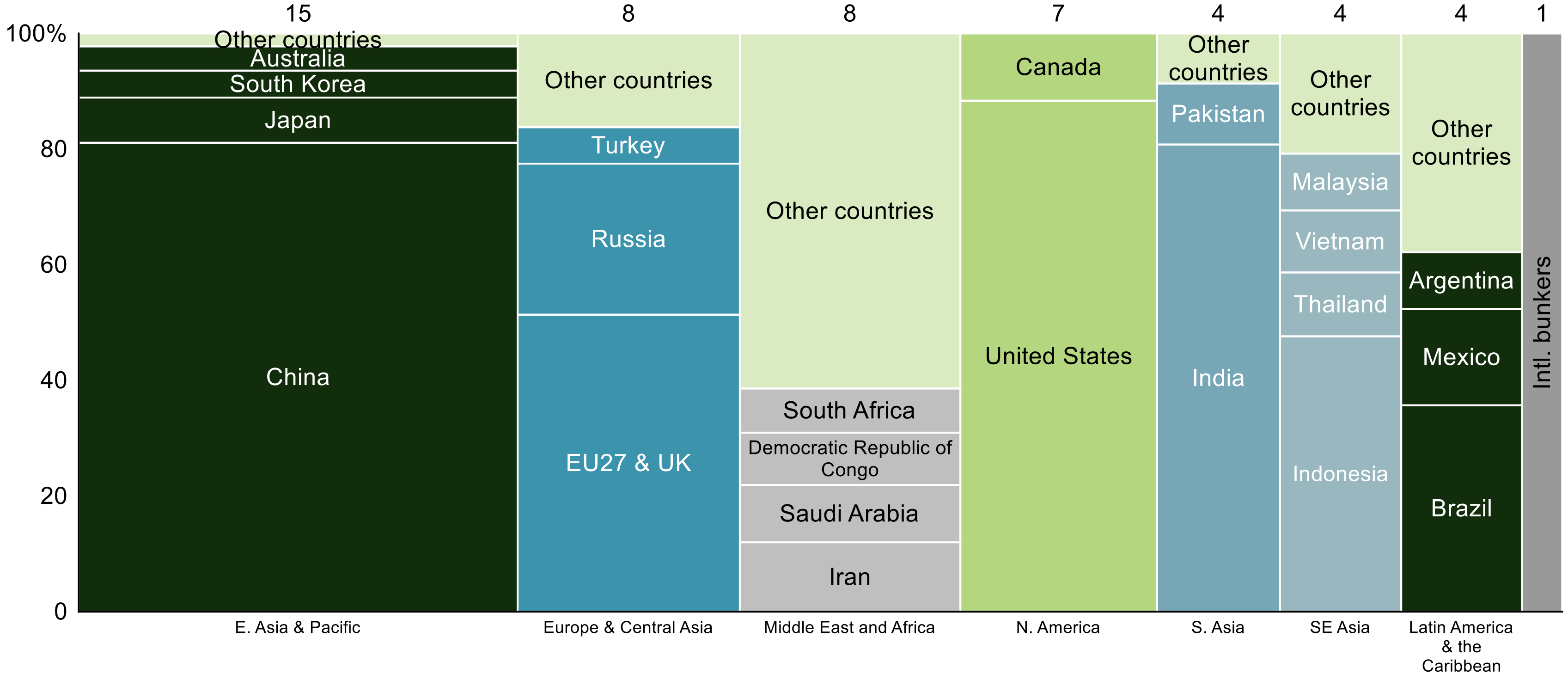
United States, Europe, Rest of the world, China, India, Rest of Asia

Note: Includes CO_2 emissions from fossil fuels and land use change
Source: Bain & Company analysis; Global Carbon Project; Our World In Data

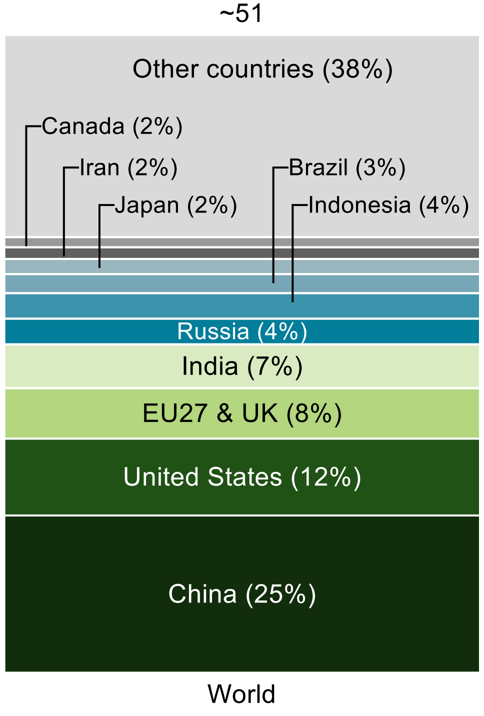
The top 10 emitting countries account for nearly two-thirds of global GHG emissions, China and the US alone nearly 40%

Greenhouse gas emissions by continent and country, 2019

(measured in billions of tons of CO_2-equivalent; includes non-CO_2 GHG emissions like methane)



Top 10 global emitters



Note: * Other countries include those with <400M tons of CO_2- equivalent emissions in 2018. Emissions from international aviation and shipping included in "other countries" in right-side chart.
Source: Bain & Company analysis; Climate Watch; Our World in Data

1

Continued global warming presents increasing risks over time

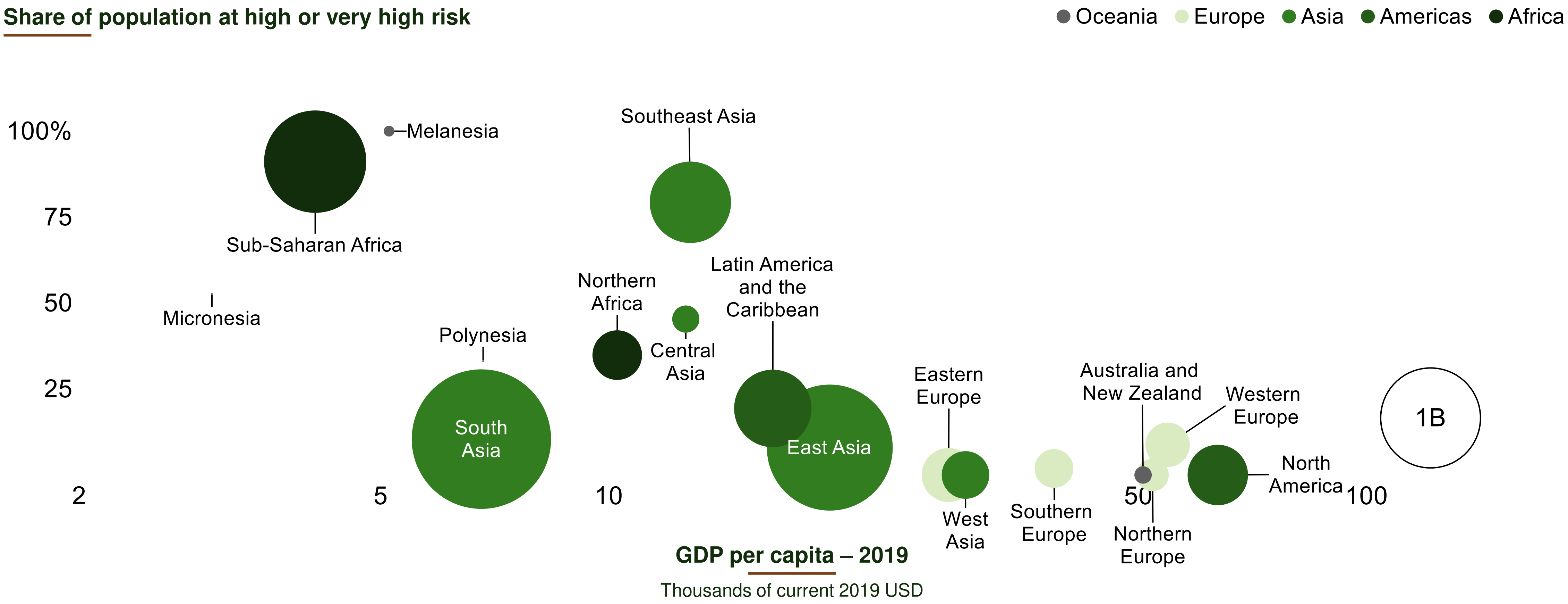
Rising sea levels

Hot temperature extremes

Extreme precipitation events

Source: IPCC, Sixth Assessment Report (AR6), Climate Change 2021: The Physical Science Basis, paragraphs A.1.7, B.5.3, A.3.1, B.2, B.2.2, A.3.2, and figure SPM.6 (2022)

Future risks aren't uniformly distributed, with Southeast Asia and sub-Saharan Africa disproportionately exposed



Notes: Share of population at risk based on the WorldRiskIndex, which assesses the risk of disaster as a result of natural hazards, incorporating exposure and vulnerability, and is used by the IPCC to gauge region- and country-level climate change risks; currency is adjusted for purchasing power parity; GDP per capita is shown on a logarithmic scale and is adjusted for purchasing power parity.
Sources: Bain & Company analysis; Our World in Data; IPCC, Sixth Assessment Report; World Risk Report 2021; World Bank

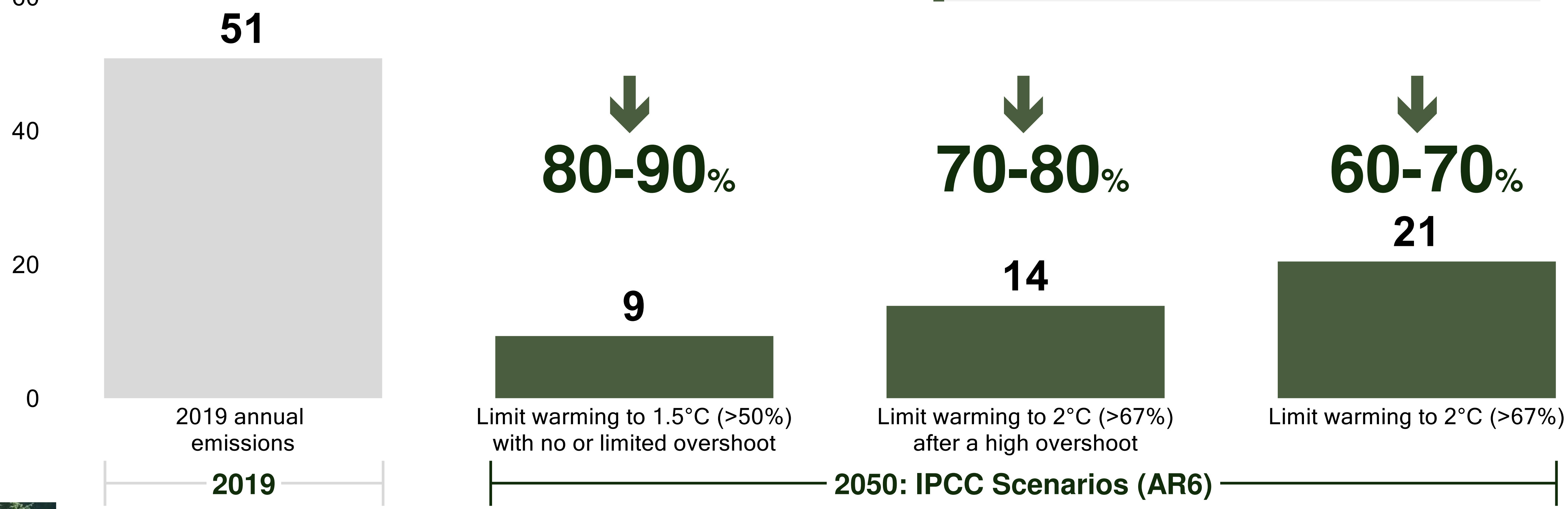
1

Limiting future warming will require substantial emissions reductions

-44% **Approximate change in GHG emissions**, 2050 vs. 2019, in a scenario in **which all announced national pledges & targets are met**, according to the Climate Action Tracker (Nov 2021), **not enough to limit warming to 2°C or less**

Global primary energy demand

PETAWATT-HOURS

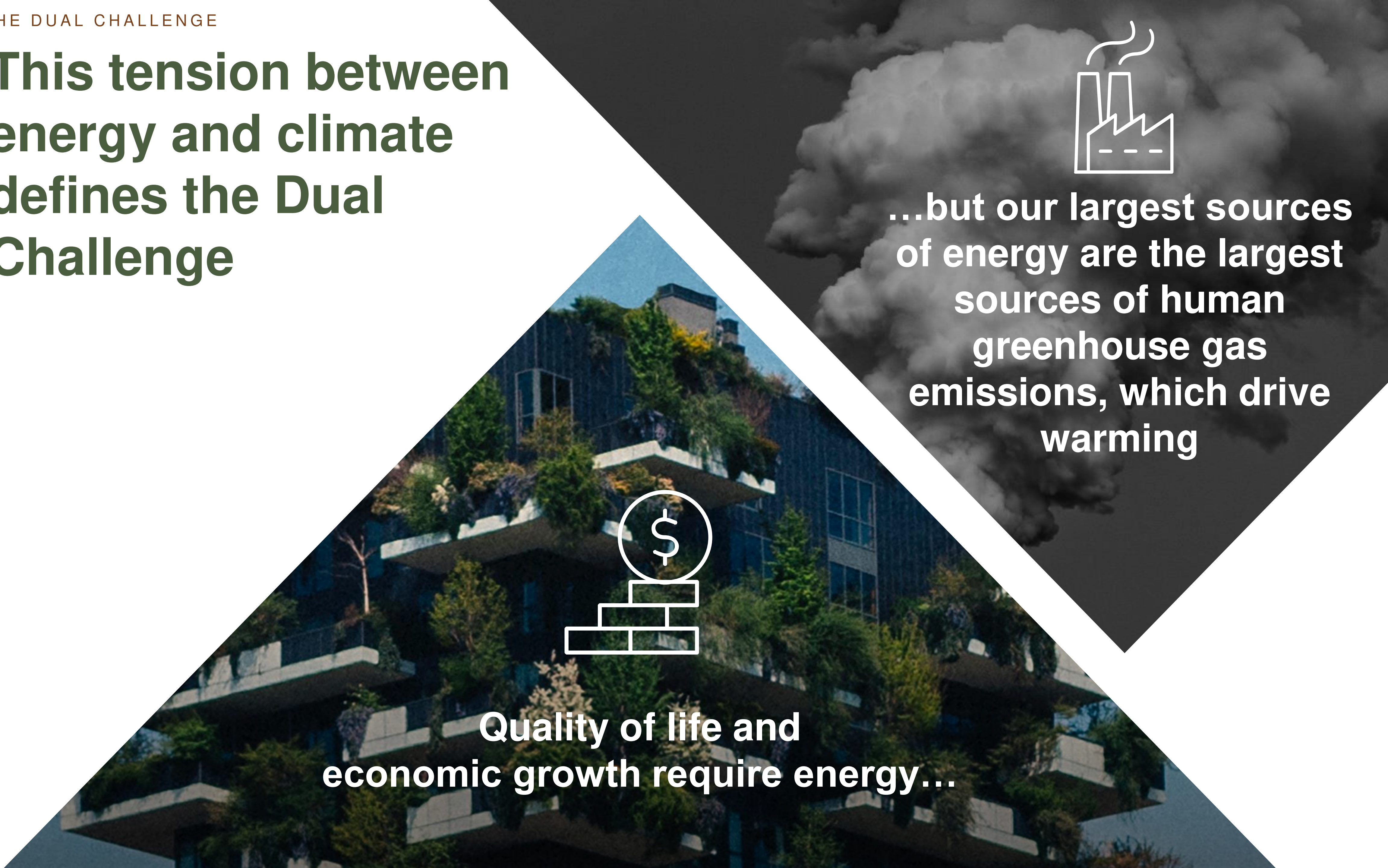


Note: “>50%” and “>67%” refer to probability of reaching scenario should emissions reduction targets be reached

Source: Bain & Company analysis; IPCC, Sixth Assessment Report (AR6), Climate Change 2022: *Mitigation of Climate Change – Summary for Policymakers*, Table SPM.1 (2022); Climate Action Tracker (updated Nov 2021)

1

This tension between energy and climate defines the Dual Challenge

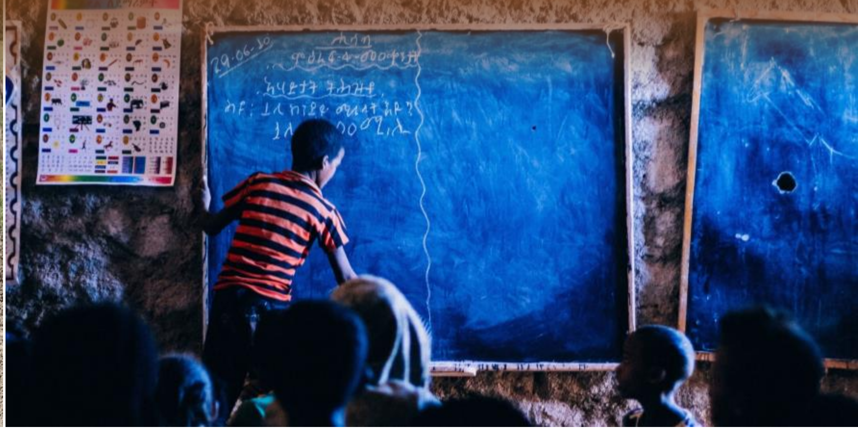


…but our largest sources of energy are the largest sources of human greenhouse gas emissions, which drive warming

Quality of life and economic growth require energy…

1 Solving solely for emissions and warming will be expensive and could jeopardize access to reliable, affordable energy

The developing world needs more energy to improve living standards, including food security



The developed world needs continued access to energy to support economic growth and living standards

▶ Energy access for everyone needs to be **reliable, affordable, and secure**

1 But solving solely for energy access enhances the risks of climate change

Extrapolating current trends, average temperature will **exceed Paris targets by 2050 and keep rising**



Extreme weather events are **likely to worsen as temperatures rise,** accelerating demand for action



Energy production must be **clean and sustainable**

1

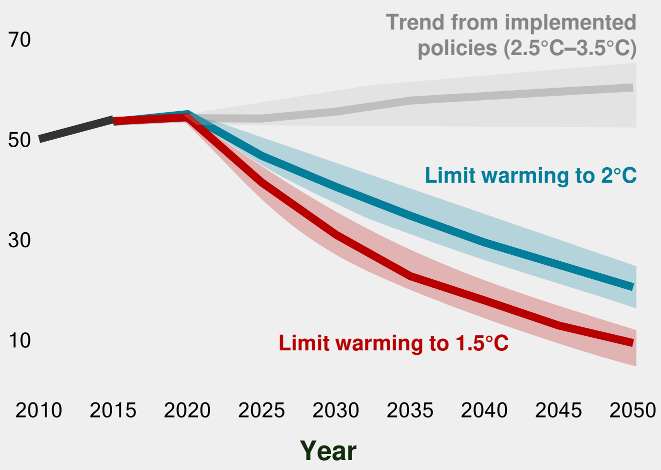
The Dual Challenge: Expand affordable, reliable, secure energy access and reduce emissions

Emissions

- To limit warming, greenhouse gas emissions will need to decline significantly in the coming years

Global annual greenhouse gas emissions

GIGATONS OF CO_2-EQUIVALENT

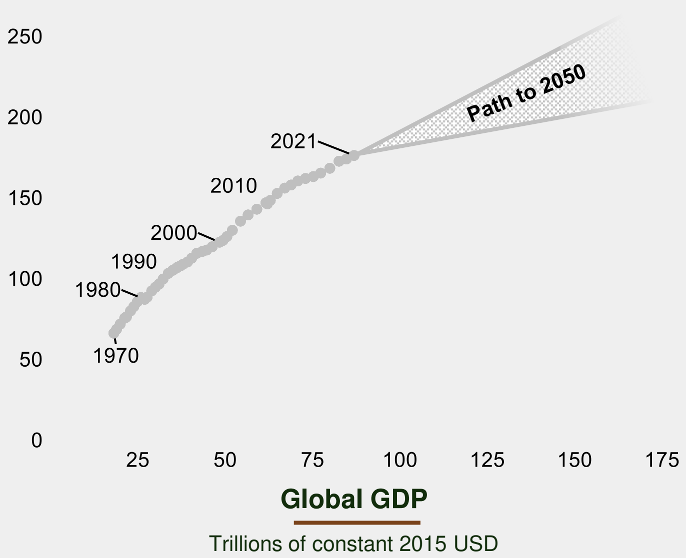


Energy

- At the same time, **global energy demand will continue to rise** as the population grows and developing economies advance

Global primary energy demand

PETAWATT-HOURS

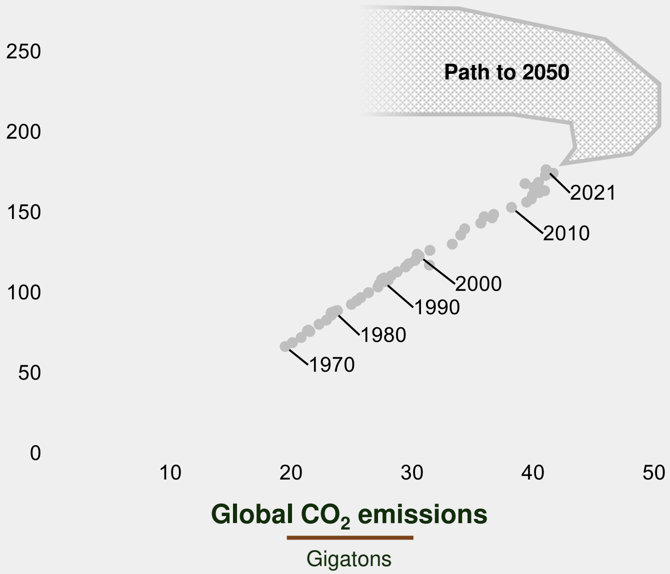


The Dual Challenge

- We must meet **growing demand for energy** while **reducing greenhouse gas emissions** to enhance wellbeing of all humans everywhere

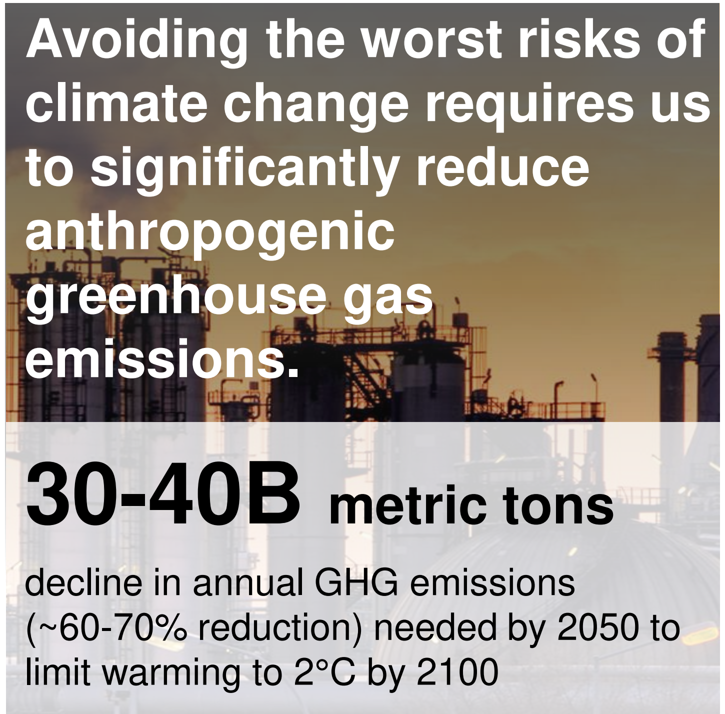
Global primary energy demand

PETAWATT-HOURS



Notes: Warming figures in left-side emissions chart are relative to the preindustrial period and reflect projected warming level by 2100 in each scenario; bold lines in emissions chart represent median estimate, and shaded regions reflect a range from the 25th to 75th percentile. Emissions in right-side chart reflect global CO_2 emissions inclusive of land use change and exclude non-CO_2 emissions like methane.
Sources: Bain & Company analysis; Our World in Data; IPCC, Sixth Assessment Report; World Bank; Global Carbon Project; BP Statistical Review of World Energy, 2022

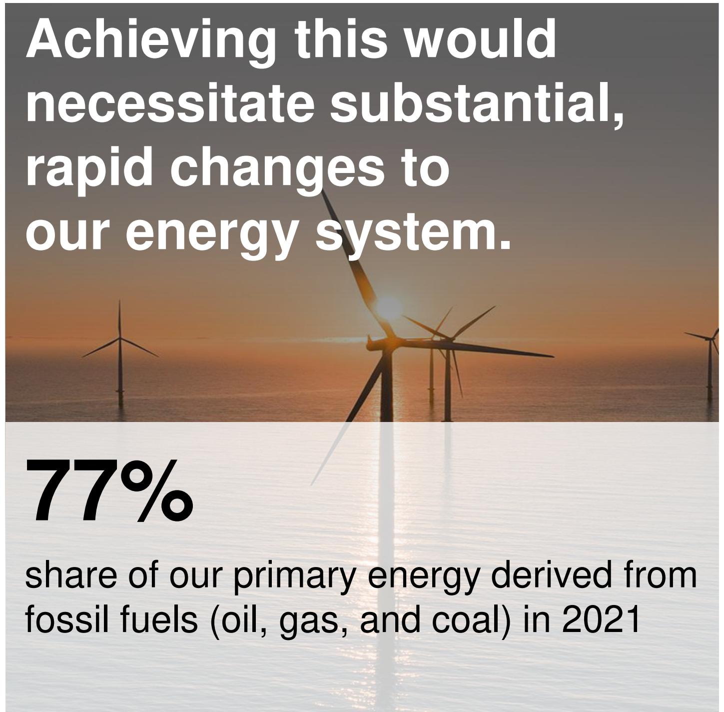
This is the world's most difficult problem



Avoiding the worst risks of climate change requires us to significantly reduce anthropogenic greenhouse gas emissions.

30-40B **metric tons**

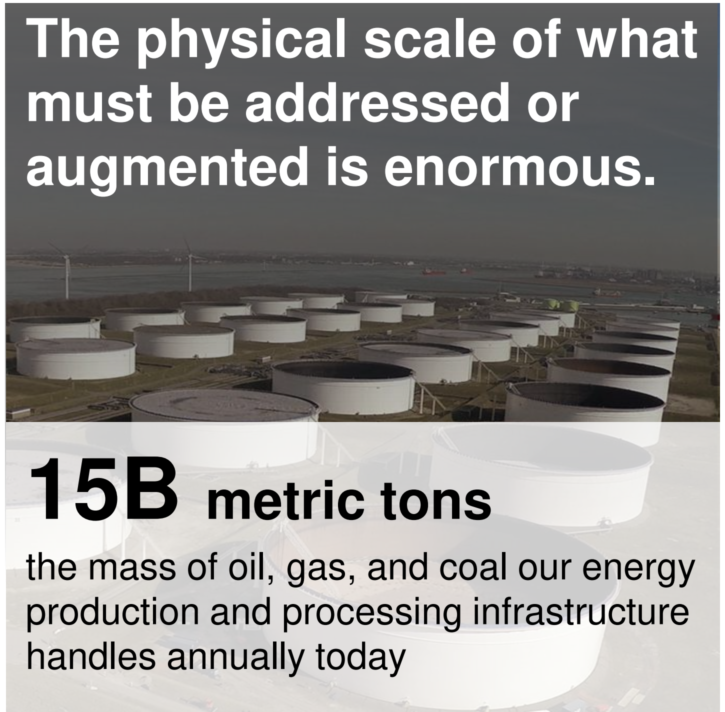
decline in annual GHG emissions (~60-70% reduction) needed by 2050 to limit warming to 2°C by 2100



Achieving this would necessitate substantial, rapid changes to our energy system.

77%

share of our primary energy derived from fossil fuels (oil, gas, and coal) in 2021



The physical scale of what must be addressed or augmented is enormous.

15B **metric tons**

the mass of oil, gas, and coal our energy production and processing infrastructure handles annually today

A significant global industrial mobilization is required if we hope to achieve our goals

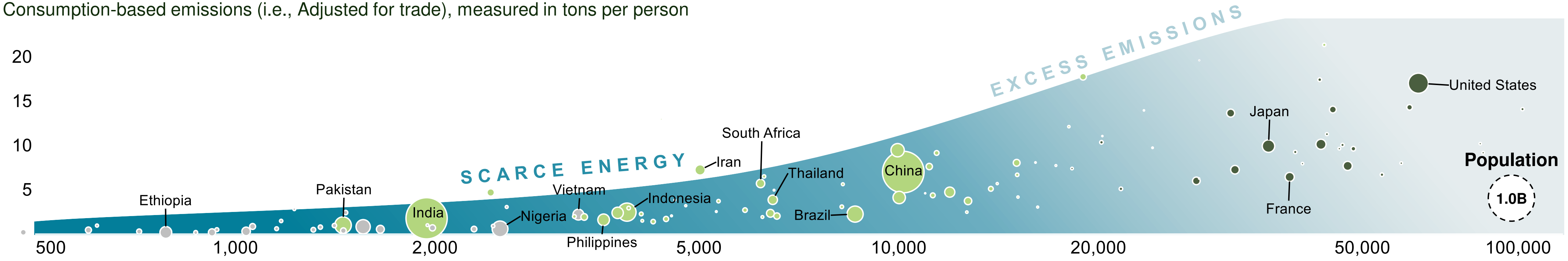
Source: IPCC; IEA; BP Statistical Review of World Energy, 2021

Solving it will require different measures for developed vs. developing countries

~3 billion people	~3.5 billion people	~1 billion people
Birth rate: ~25/1,000 people	Birth rate: ~15/1,000 people	Birth rate: ~11/1,000 people

CO_2 emissions per capita, 2019

Consumption-based emissions (i.e., Adjusted for trade), measured in tons per person



GDP per capita, 2019

Measured in constant 2015 USD; logarithmic axis

Low-income developing countries
How do we lift countries out of energy poverty in a low-carbon way without erecting barriers to economic development? (i.e., without following the previous trajectory of the Advanced countries)

Emerging countries
How do we support countries in industrialization and accessing low cost clean energy?

Advanced countries
How do we reduce emissions while maintaining high quality of life and growth?

Note: GDP is adjusted for purchasing power parity
Source: Bain & Company analysis; Max Roser, "The world's energy problem", Our World in Data; Switch On (2020); World Bank; Global Carbon Project; IMF; UN World Population Prospects 2019

1 Achieving “clean” without compromising “reliable, affordable, and secure” in our energy supply is the essence of it

Deliver energy globally…

We need to deliver affordable, reliable, secure energy for the entire world before 203X.

…while significantly reducing emissions…

We need to dramatically reduce emissions to mitigate the worst risks of climate change.

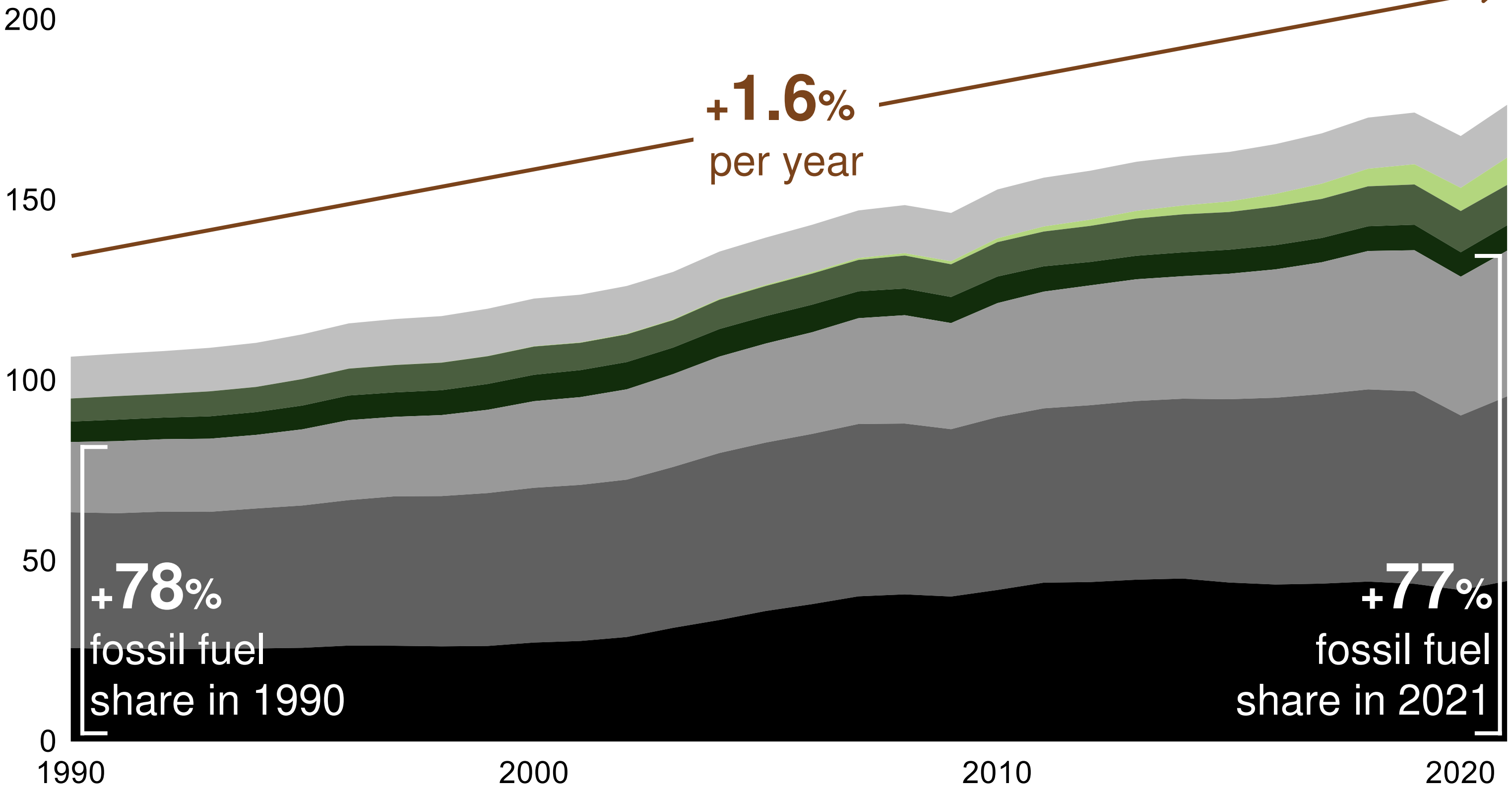
…to maximize human flourishing

The aim is to enhance the wellbeing of humans everywhere.

Our starting point: fossil fuels remain the world's chief source of energy

Global primary energy consumption by source

PETAWATT-HOURS



percent of total 1990	percent of total 2021	Share of 1990-2021 demand growth
11%	8%	4%
0%	4%	11%
6%	6%	7%
5%	4%	2%
18%	23%	30%
35%	29%	19%
24%	25%	27%

Coal | Oil | Gas | Nuclear | Hydro | Wind & Solar | Other*

Note: * Other includes traditional biomass, biofuels, and other renewables
Source: Bain & Company analysis; BP Statistical Review of World Energy, 2022; Vaclav Smil, *Energy Transitions: Global and National Perspectives* (2017); Our World in Data

DRAFT

1 The scale of what must be replaced or abated in our existing energy system is immense

15 billion

metric tons

Mass of fossil fuels (oil, gas, and coal) extracted each year, the energy equivalent of more than **230 million barrels of oil per day**, or about **1,500 kg of oil per year for every person on the planet.**[1]

4,400

gigawatts

Fossil fuel electrical generation capacity globally, which is responsible for **61% of world electricity production**—and about **one-quarter of global greenhouse gas emissions**.[3]

1.6 billion

internal combustion engines

Approximate number of **internal combustion engines** in use around the world in cars and trucks, **almost all of which run on petroleum products like gasoline and diesel**.[2]

6 billion

metric tons

Total mass of cement and steel produced globally. Production of these critical products **added more than 7 billion tons of CO_2 to the atmosphere** in 2019.[4]

Source: (1) EIA; IEA; BP; Vaclav Smil, *How the World Really Works.* (2) International Journal of Engine Research, *The future of the internal combustion engine vehicle.* (3) Ember. (4) Portland Cement Association; World Steel Association; IEA

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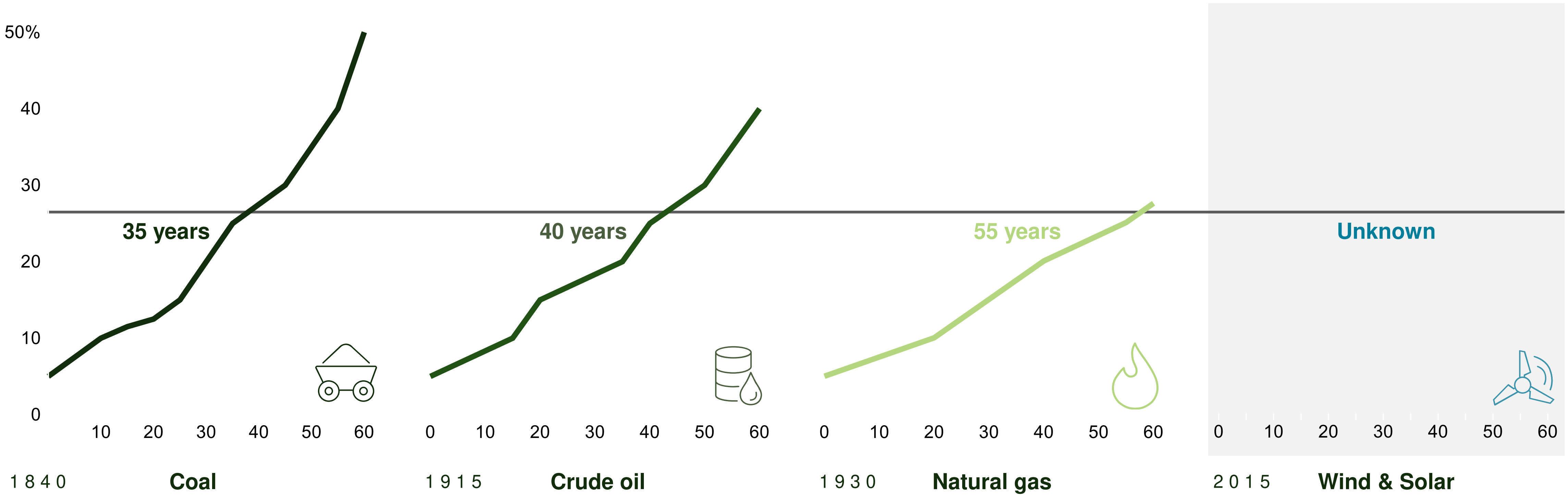
1

This will take time—history suggests that turning over even a quarter of the global energy system takes decades

Years until supplying 25% of global primary energy supply

SHARE OF GLOBAL PRIMARY ENERGY SUPPLY



Note: Based on time from 5% to 25% of global energy supply
Source: Vaclav Smil, *Energy Transitions: Global and National Perspectives* (2017)

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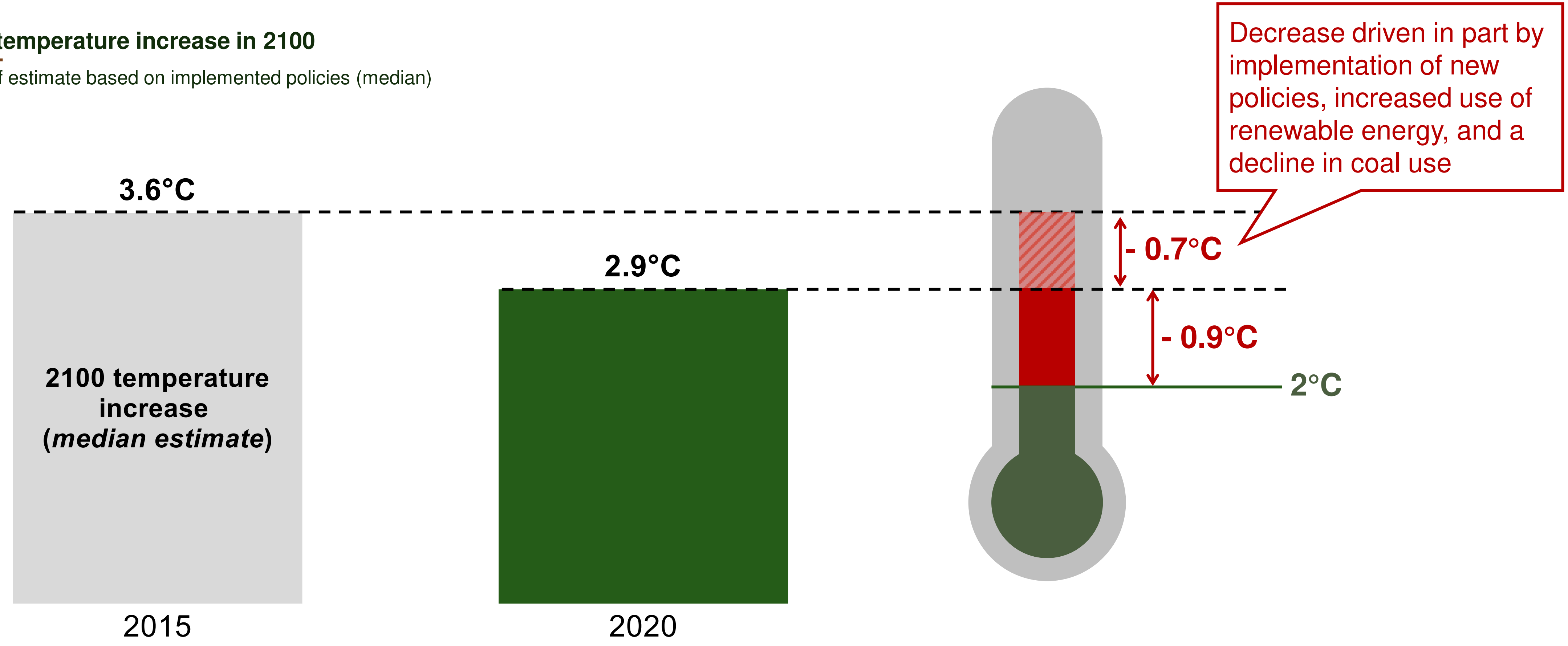
We have made progress on emissions—but still have work to do

Global temperature increase in 2100

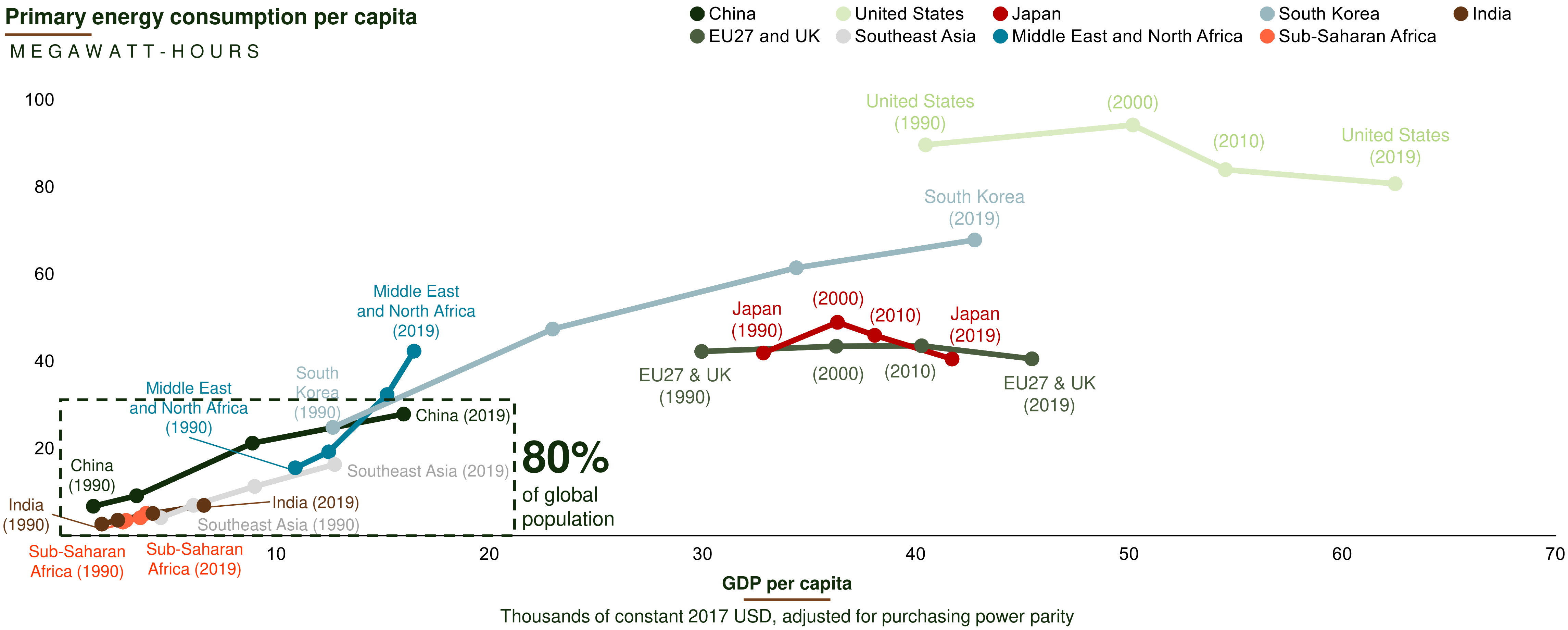
By year of estimate based on implemented policies (median)



Note: Temperature estimates reflect end-of-century warming above the pre-industrial average based on implemented policies
Source: Bain & Company analysis; Climate Action Tracker, "Paris Agreement turning point", December 2020

1

Most of the world is still climbing the energy ladder



Sources: Bain & Company analysis; Our World in Data; World Bank; BP Statistical Review of World Energy, 2022; EIA

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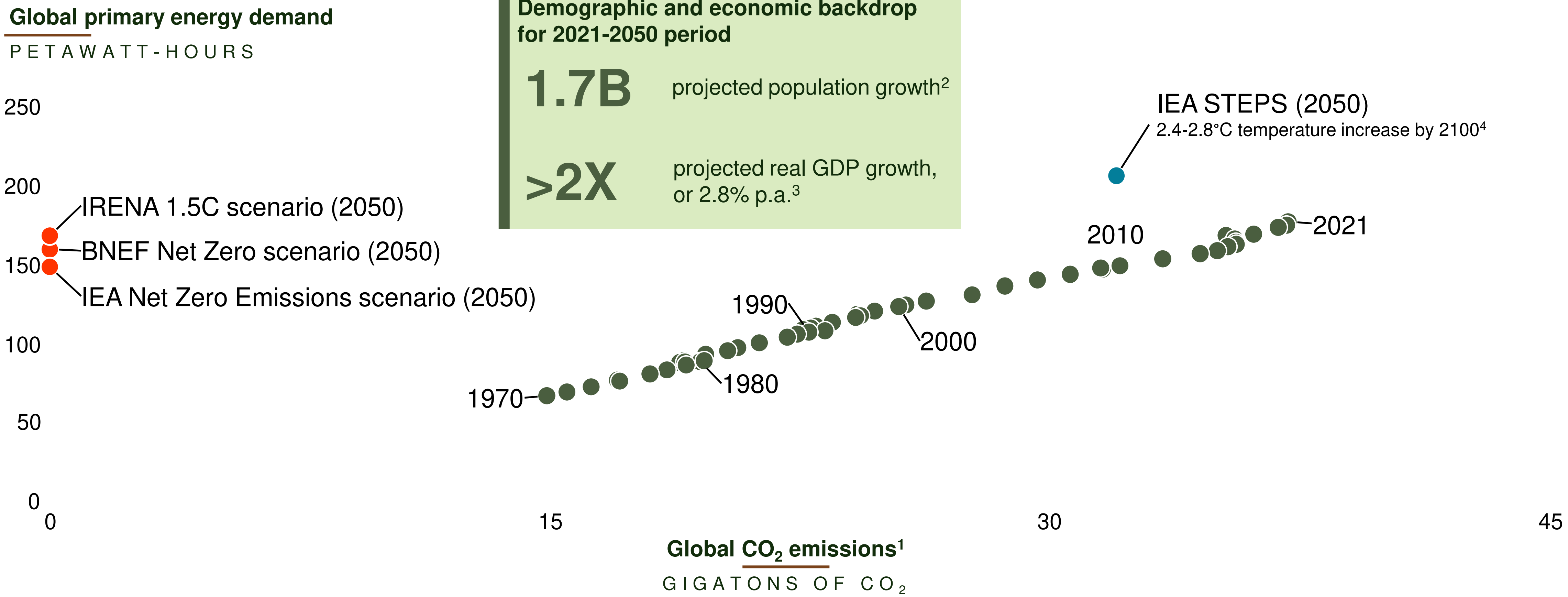
1

Achieving net zero emissions by 2050 amidst demographic and economic growth would require unprecedented change

Demographic and economic backdrop for 2021-2050 period

1.7B projected population growth[2]

>2X projected real GDP growth, or 2.8% p.a.[3]



Note: (1) CO_2 emissions exclude land use change and exclude non-CO_2 emissions like methane; (2) UN median fertility scenario; (3) GDP expressed in 2021 USD in purchasing power parity terms via IEA; (4) IEA STEPS scenario temperature estimate range reflects 33-67% confidence interval. Source: Bain & Company analysis; Our World in Data; IEA; BP Statistical Review of World Energy, 2022; BNEF; IRENA; Resources for the Future

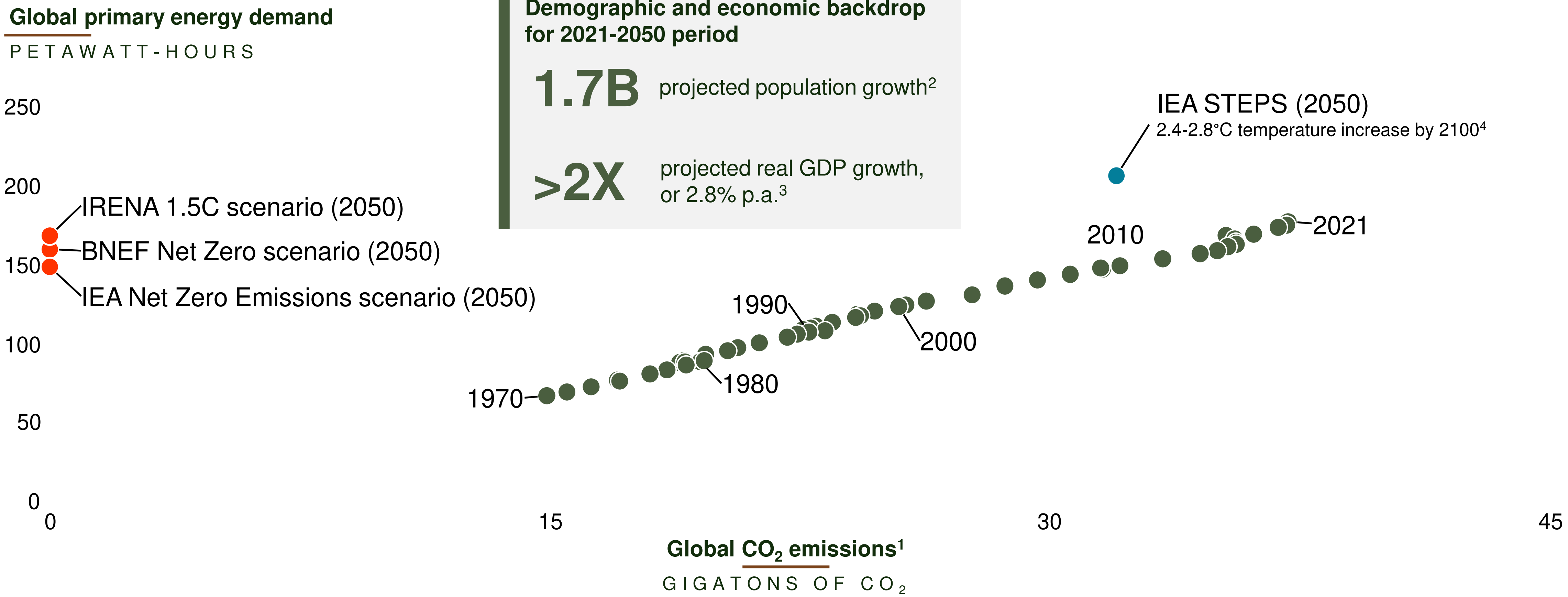
1

What will it take to bend the curve amidst expected demographic and economic growth?

Demographic and economic backdrop for 2021-2050 period

1.7B projected population growth[2]

>2X projected real GDP growth, or 2.8% p.a.[3]



Note: (1) CO_2 emissions exclude land use change and exclude non-CO_2 emissions like methane; (2) UN median fertility scenario; (3) GDP expressed in 2021 USD in purchasing power parity terms via IEA; (4) IEA STEPS scenario temperature estimate range reflects 33-67% confidence interval. Source: Bain & Company analysis; Our World in Data; IEA; BP Statistical Review of World Energy, 2022; BNEF; IRENA; Resources for the Future

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Confronting the Dual Challenge: Emerging Solutions

September 2023

Agenda

01 OpenMinds and the Dual Challenge: Executive Summary

02 **Energy: Uses, Sources, and Outlook**

03 Climate Change: Fundamentals and Possible Trajectories

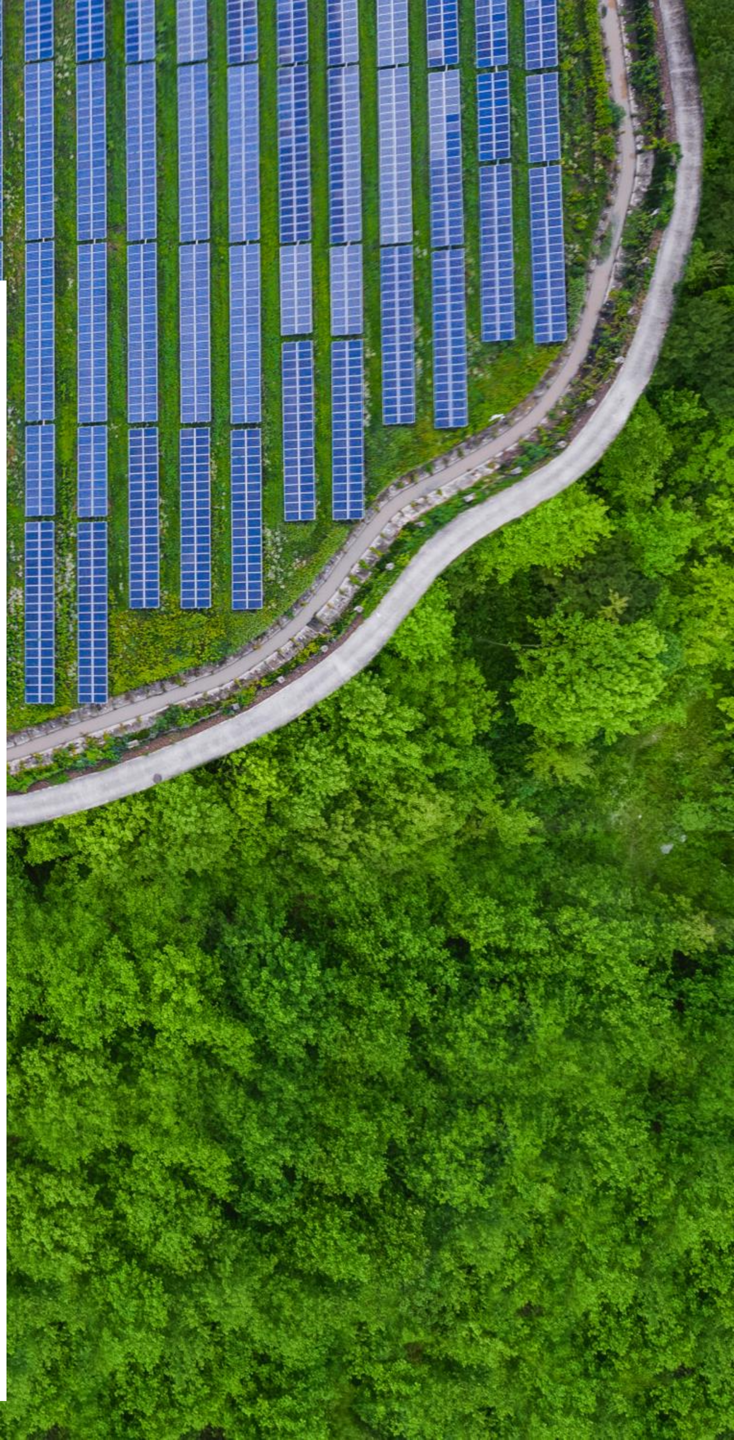
04 Reality Check: Where We Are Today

05 The Dual Challenge: Headwinds and Tailwinds

Energy:
Uses, Sources, and Outlook

- Affordable and reliable energy underpins modern civilization and enables longer, healthier lives
- Fossil fuels unlocked tremendous progress in global population, productivity, and GDP over the last century and today account for roughly 80% of the world's total energy supply
- Our dependence on fossil fuels has not changed materially in three decades (despite a slight shift to wind & solar, which make up 3% of the world's current energy supply), with total energy consumption growing about 60% since 1990
- While energy usage *per dollar of GDP* declined in most countries over the last 30 years, overall energy usage *per capita* grew as developing economies, particularly China, advanced
- Despite this growth, a meaningful share of the world still lacks access to sufficient energy, and future population growth will be concentrated in these low-energy regions
- It is a good thing for energy-driven quality of life to improve for these populations, but the energy supply must be both affordable and reliable to unlock those improvements
- Moreover, in a world of increased geopolitical tension (and perhaps deglobalization), energy security at the national level will rise in prominence—and will shape the energy transition differently in different regions

Primary energy demand will very likely continue rising into the future as GDP grows and living conditions improve, and affordability, reliability, and security of energy supply will be key concerns. To the extent this increasing demand is met by fossil fuels (unabated), greenhouse gas emissions will continue to grow as well.



2

In physical terms, energy is the capacity for doing work and can be measured in joules or watt-hours

en·er·gy

\ˈe-nər-jē\

in physics, **the capacity for doing work**, measured in joules

1

joule

Approximate amount of energy needed to lift a smartphone 15 inches, or 40 cm, off the table

6 x 10^{20}

joules

Total amount of energy used by the world in 2019

3,600

joules

Amount of energy in one watt-hour, a common measure of electricity usage

Source: Encyclopedia Brittanica; Oxford English Dictionary; BP Statistical Review of World Energy, 2021

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Energy enables virtually everything we do

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Daily activities and products have a range of energy needs

Keep a lightbulb on for one hour

100,000 joules

Use a gallon of gasoline

100 million joules

Grow a metric ton of wheat

10 billion joules

Power New York City for a day

100 trillion joules

Note: All values are order of magnitude estimates. Energy usage for lightbulb based on 40-Watt bulb; energy usage for gallon of gasoline based on EPA standard; energy usage for wheat includes human labor, fuel for agricultural machinery, fertilizer, chemicals, irrigation, and other operations; energy consumption for New York assumes 144 gigawatt-hours per day on average
Source: Department of Energy; Bill Gates, How to Avoid a Climate Disaster (2021); EPA; World Journal of Agricultural Sciences; IEA; New York Building Congress

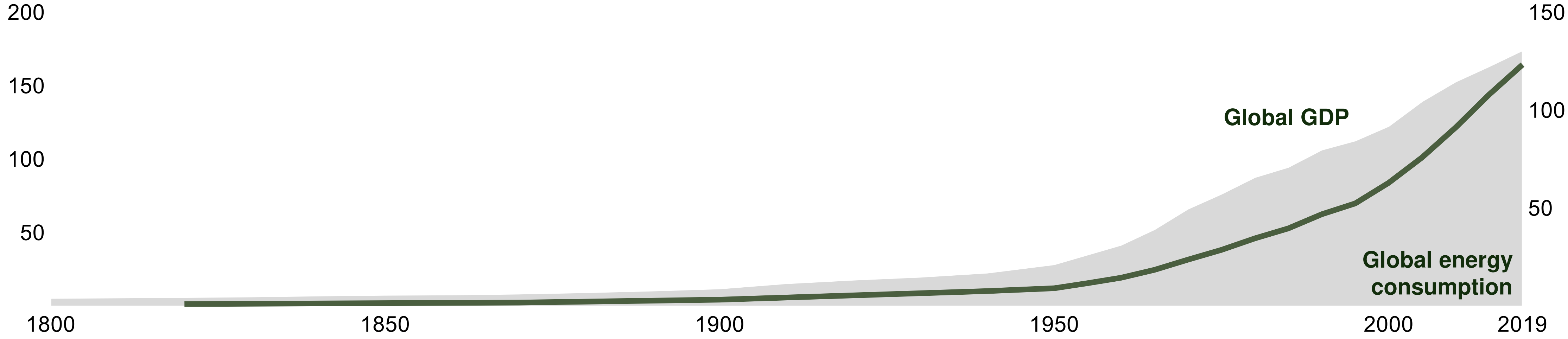
Energy has played a crucial role in economic and human development

Global energy consumption

PETAWATT-HOURS

Global GDP

TRILLIONS OF CONSTANT 2011 INTERNATIONAL USD, PPP ADJUSTED



World population

1.0B → 7.8B

Average life expectancy

29yrs. → 73yrs.

Source: Bain & Company analysis; BP Statistical Review of World Energy, 2021; World Bank & Maddison (2017); Vaclav Smil, *Energy Transitions: Global and National Perspectives* (2017); World Bank; Our World in Data

2

Energy consumption is highly correlated with economic progress—and there is still considerable inequality

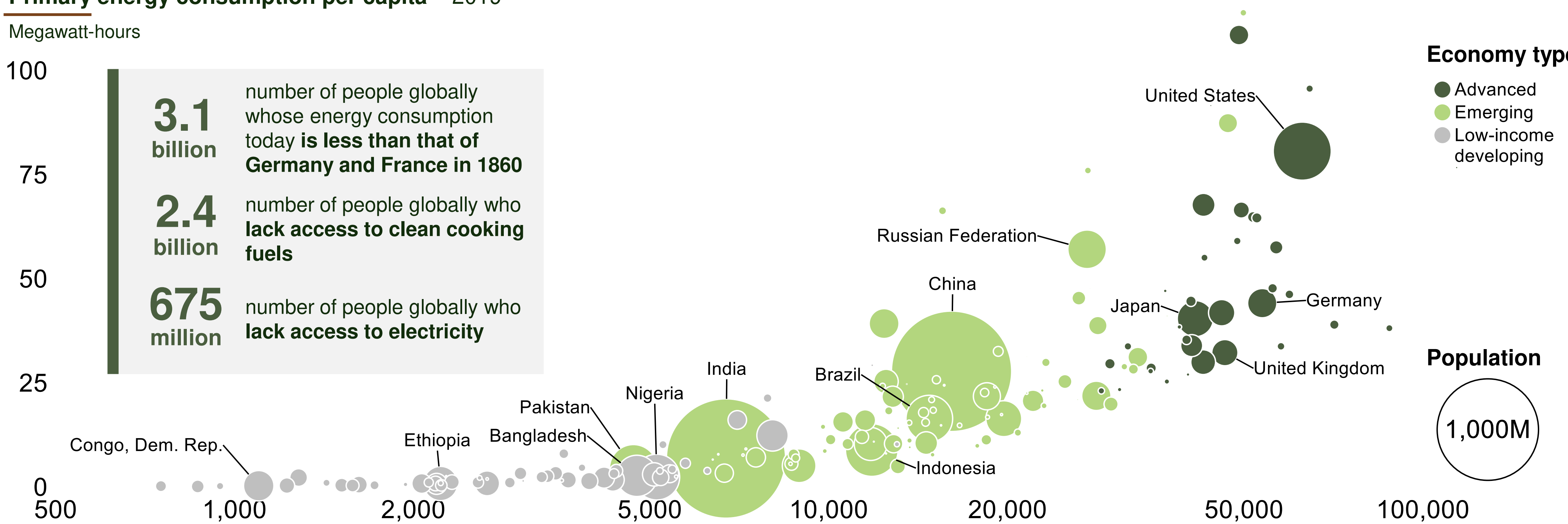
Primary energy consumption per capita – 2019

Megawatt-hours

3.1 billion number of people globally whose energy consumption today **is less than that of Germany and France in 1860**

2.4 billion number of people globally who **lack access to clean cooking fuels**

675 million number of people globally who **lack access to electricity**



GDP per capita – 2019

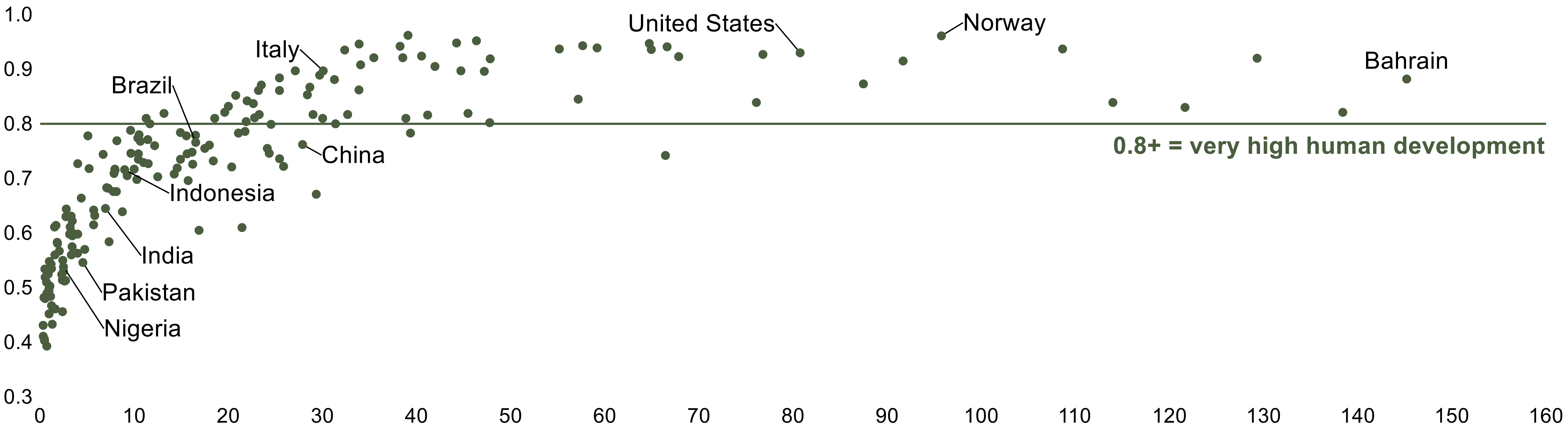
Measured in 2017 International dollars, PPP-adjusted; logarithmic axis

Source: Bain & Company analysis; Our World in Data; World Bank; IMF; Global Carbon Project; Vaclav Smil, *How the World Really Works*

Energy underpins human well-being

Human development Index – 2019

The HDI is a summary measure of key dimensions of human development: a long and healthy life, a good education, and having a decent standard of living



Energy consumption per capita – 2019

Measured in megawatt-hours

Source: Bain & Company analysis; Our World in Data; Center for Global Development; BP Statistical Review of World Energy, 2021; EIA

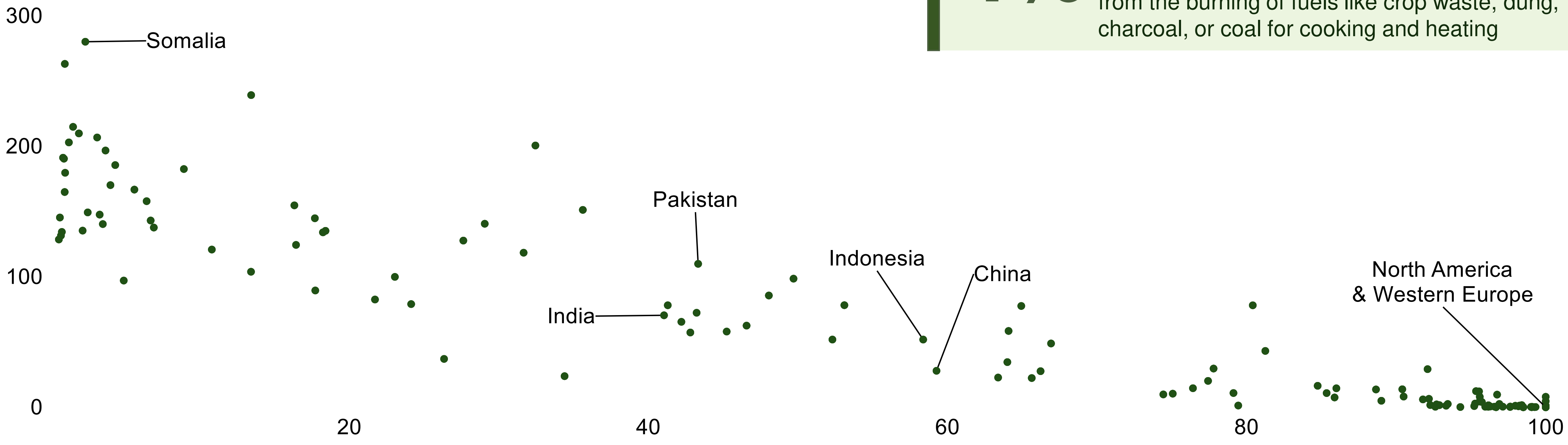
2

For example, those lacking modern energy access die at higher rates from indoor air pollution

4% **of global deaths are attributable to indoor air pollution** (2.3M total). These deaths result from health complications arising from the burning of fuels like crop waste, dung, charcoal, or coal for cooking and heating

Indoor air pollution death rate 2016

Measured per 100,000 individuals



Share of population with access to clean fuels for cooking, 2016

Measured in percentage

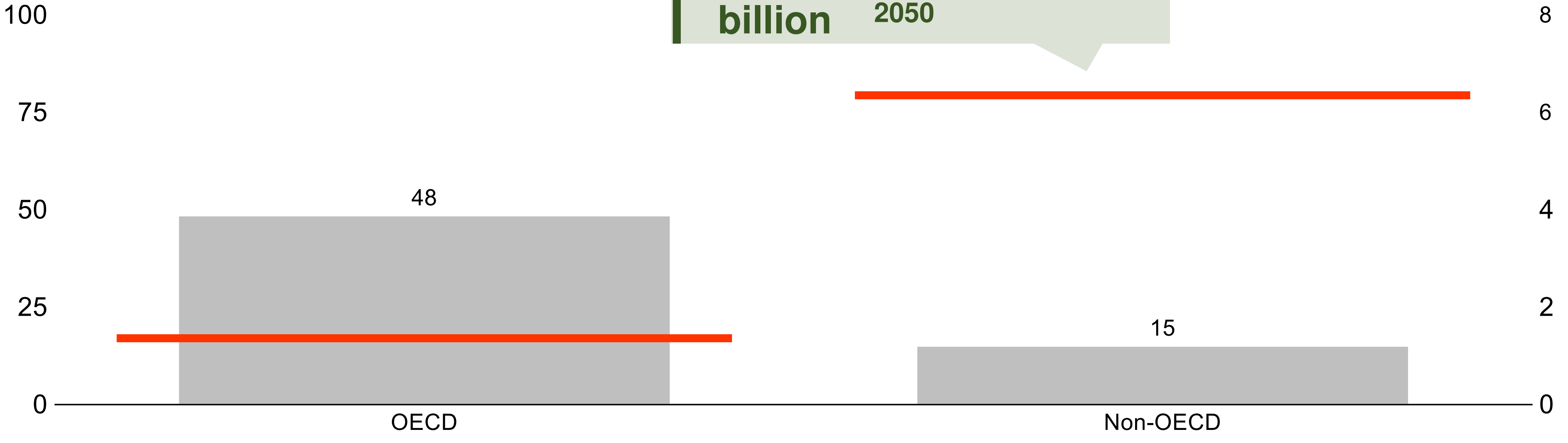
Source: Bain & Company analysis; Our World in Data; IHME, Global Burden of Disease; World Bank

Despite progress, the world needs more energy

1.7 billion — **Expected population growth in non-OECD countries through 2050**

Energy consumption per capita, 2019 *(shown as bars)*
MEGAWATT-HOURS

Population, 2019 *(shown as red lines)*
BILLIONS



	OECD	Non-OECD
GDP per capita[1]	$45K	$11K

Note: (1) GDP per capita is adjusted for purchasing power parity and is measured in 2017 USD. Source: World Bank; BP Statistical Review of World Energy, 2022; Our World in Data

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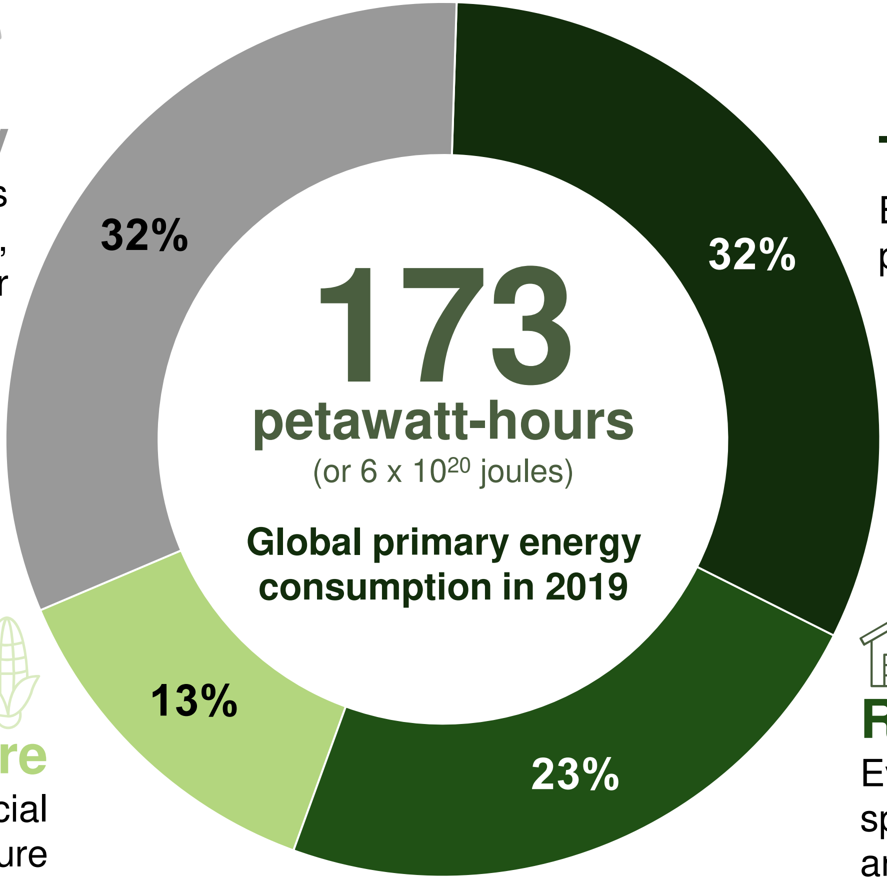
Primary energy demand is about 173 petawatt-hours per year, or the equivalent of 300 million barrels of oil per day

Industry
Energy needed to manufacture materials and goods like cement, steel, plastic, and paper



Transport
Energy needed to operate cars, trucks, planes, trains, and boats

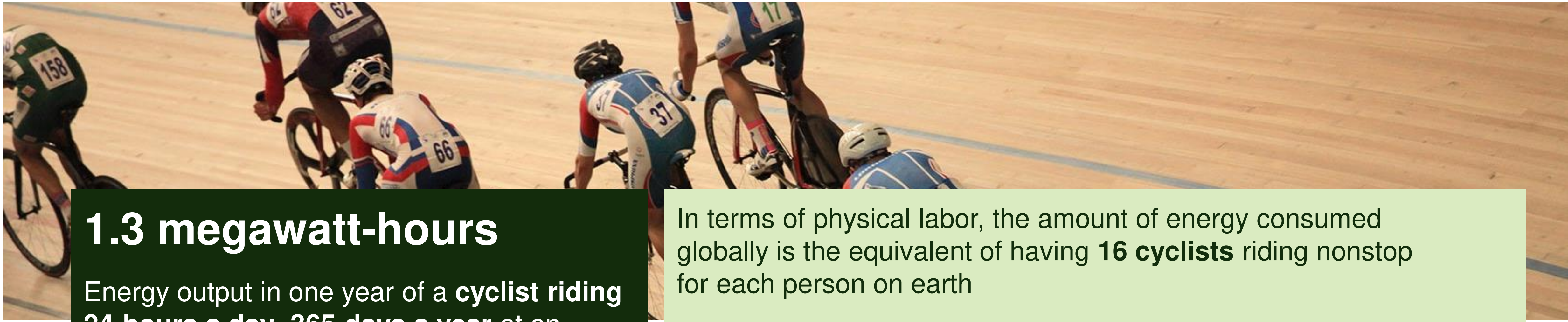
19% share of total final energy consumed **by electricity generation**

Commerce and agriculture
Energy needed to power commercial buildings and agriculture

Residential
Everyday energy needs at home like space heating, water heating, appliances, and lighting

Note: Usage mix is based on IEA estimates (net energy content and excludes energy lost to produce water vapor during combustion); total usage, including losses, based on EIA and XOM
Source: Bain & Company analysis; Our World in Data; IEA, Total Final Consumption (TFC) by Sector, 2019; BP Statistical Review of World Energy, 2021; ExxonMobil 2021 Outlook for Energy

In terms of physical labor, the amount of energy consumed globally per capita is enormous

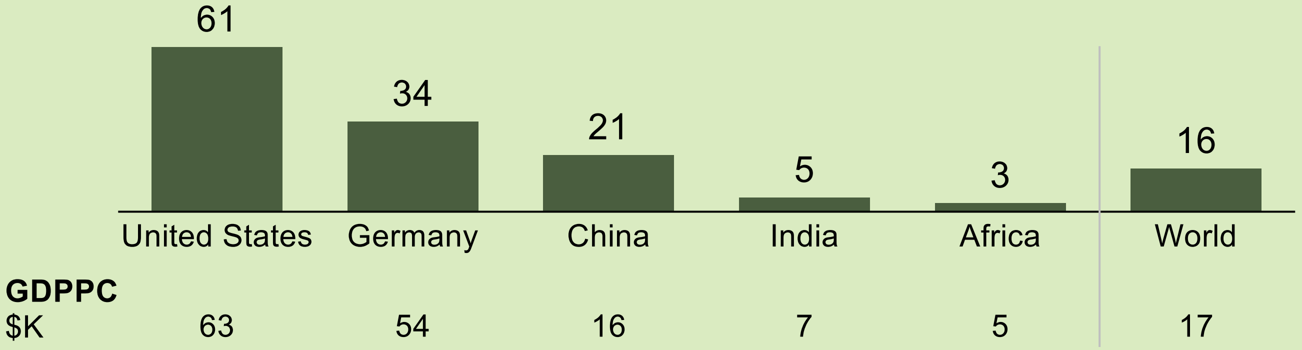


1.3 megawatt-hours

Energy output in one year of a **cyclist riding 24-hours a day**, **365-days a year** at an average power output of 150 watts

(Tour de France riders average 230-250 watts and can sustain a maximum of about 350-400 watts for one hour)

In terms of physical labor, the amount of energy consumed globally is the equivalent of having **16 cyclists** riding nonstop for each person on earth



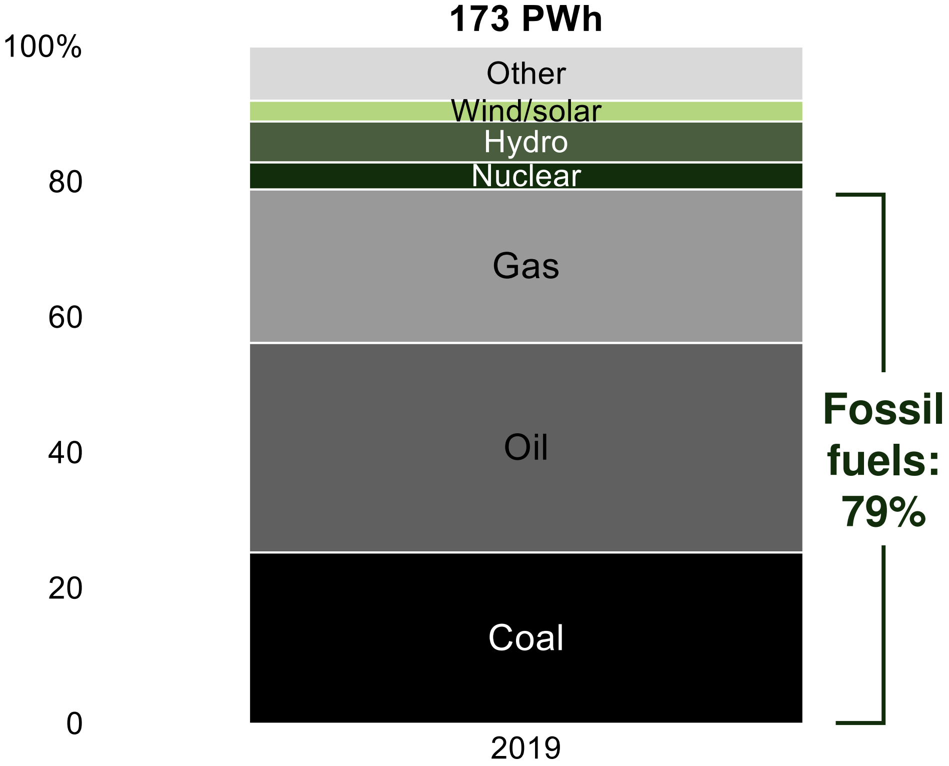
Note: * GDP measured in thousands of real PPP-adjusted 2017 USD
Source: Bain & Company analysis; Our World in Data; World Bank; BP Statistical Review of World Energy, 2021

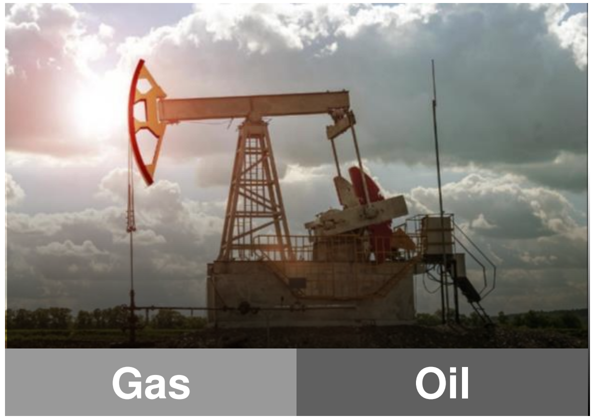
2

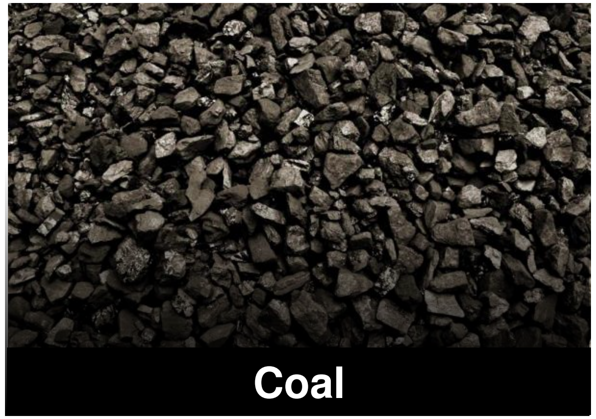
Almost 80% of primary energy supplied globally derives from fossil fuels (i.e., coal, oil, and gas)

Global primary energy demand by source 2019

PETAWATT-HOURS







Note: “Other” includes traditional biomass (i.e., burning wood), other renewables, and biofuels
Source: Bain & Company analysis; Our World in Data; IEA; Vaclav Smil, Energy Transitions: Global and National Perspectives (2017); BP Statistical Review of World Energy, 2021

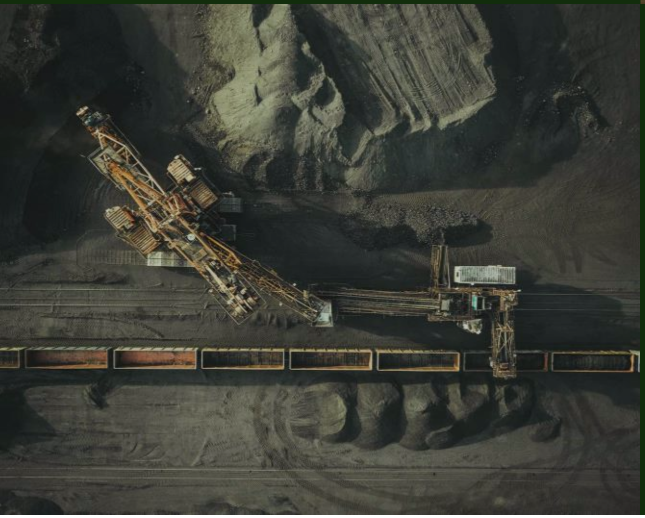
2 The fossil fuel infrastructure that provides most of our energy is enormous in its scale and was built over a 150+ year period

15 billion
metric tons

Mass of fossil fuels (oil, gas, and coal) extracted each year, the energy equivalent of more than **230 million barrels of oil per day**, or about **1,500 kg of oil per year for every person on the planet.**[1]

$813
billion

Global fossil fuel infrastructure capital investment **in a single year** (2021), inclusive of up-, mid-, and downstream oil & gas, coal supply, and fossil fuel power generation.[3]



1.2 million
kilometers

Combined length of oil & gas pipelines globally, **enough to circle the earth 29 times.**[2]

1846

The year the world's first giant oilfield opened in Baku, Azerbaijan, **marking the beginning of the modern oil era.**[4] Oil & gas infrastructure has been continuously developed since then.

Source: (1) Vaclav Smil, How the World Really Works; IEA; EIA; BP; World Bank; (2) Global Energy Monitor; (3) IEA, World Energy Investment 2021;; (4) Vaclav Smil, Energy Transitions: Global and National Perspectives (2017)

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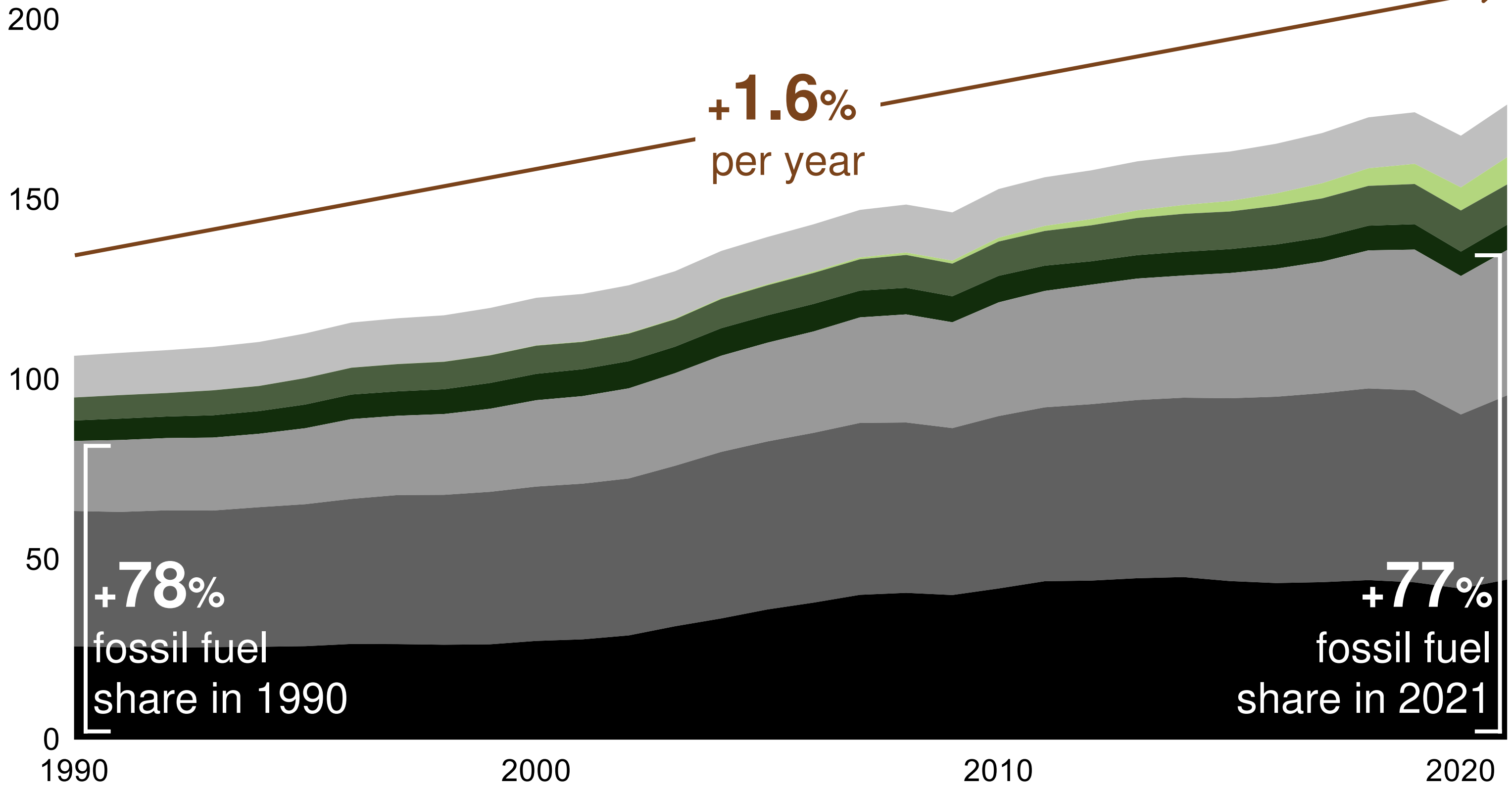
2 Energy demand has grown steadily over time, and today, fossil fuels remain the world's chief source of energy

Global primary energy consumption by source

PETAWATT-HOURS



	percent of total 1990	percent of total 2021	Share of 1990-2021 demand growth
Other*	11%	8%	4%
Wind & Solar	0%	4%	11%
Hydro	6%	6%	7%
Nuclear	5%	4%	2%
Gas	18%	23%	30%
Oil	35%	29%	19%
Coal	24%	25%	27%

Note: * Other includes traditional biomass, biofuels, and other renewables
Source: Bain & Company analysis; BP Statistical Review of World Energy, 2022; Vaclav Smil, *Energy Transitions: Global and National Perspectives* (2017); Our World in Data

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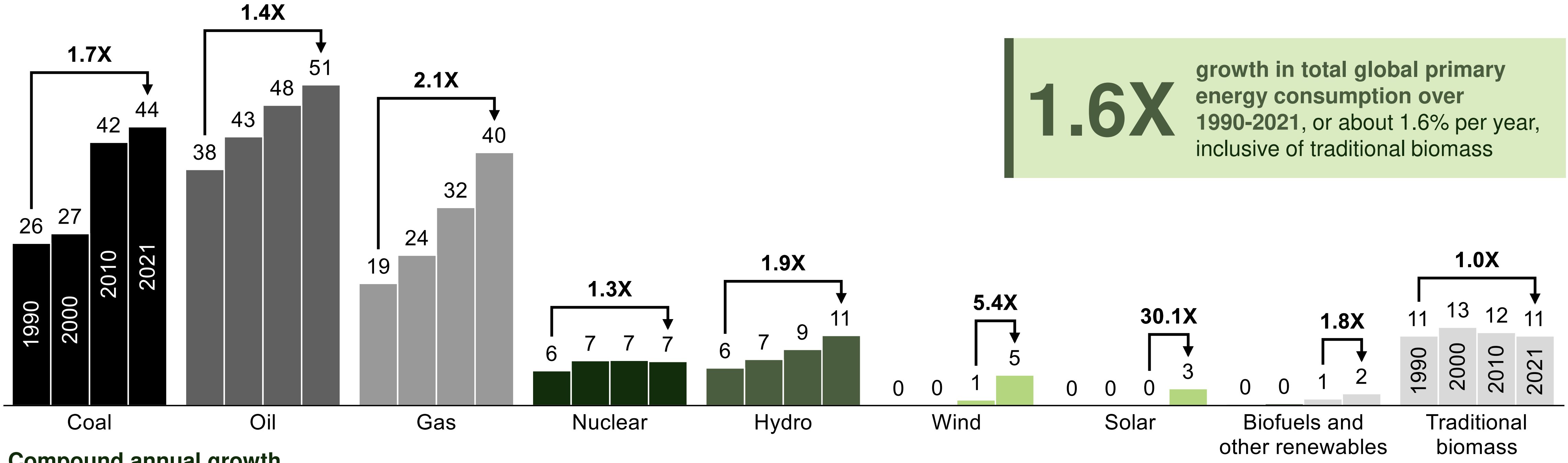
2

The amount of energy supplied by every source, excluding traditional biomass, grew over the last three decades

Global primary energy consumption by source

PETAWATT-HOURS



1.6X growth in total global primary energy consumption over 1990-2021, or about 1.6% per year, inclusive of traditional biomass

Compound annual growth

1990-2021

Coal	Oil	Gas	Nuclear	Hydro	Wind	Solar	Biofuels and other renewables	Traditional biomass
1.8%	1.0%	2.4%	0.7%	1.8%	21.8%	28.5%	7.2%	0.0%

Source: Bain & Company analysis; Vaclav Smil, Energy Transitions: Global and National Perspectives (2017); BP Statistical Review of World Energy, 2021; Our World in Data

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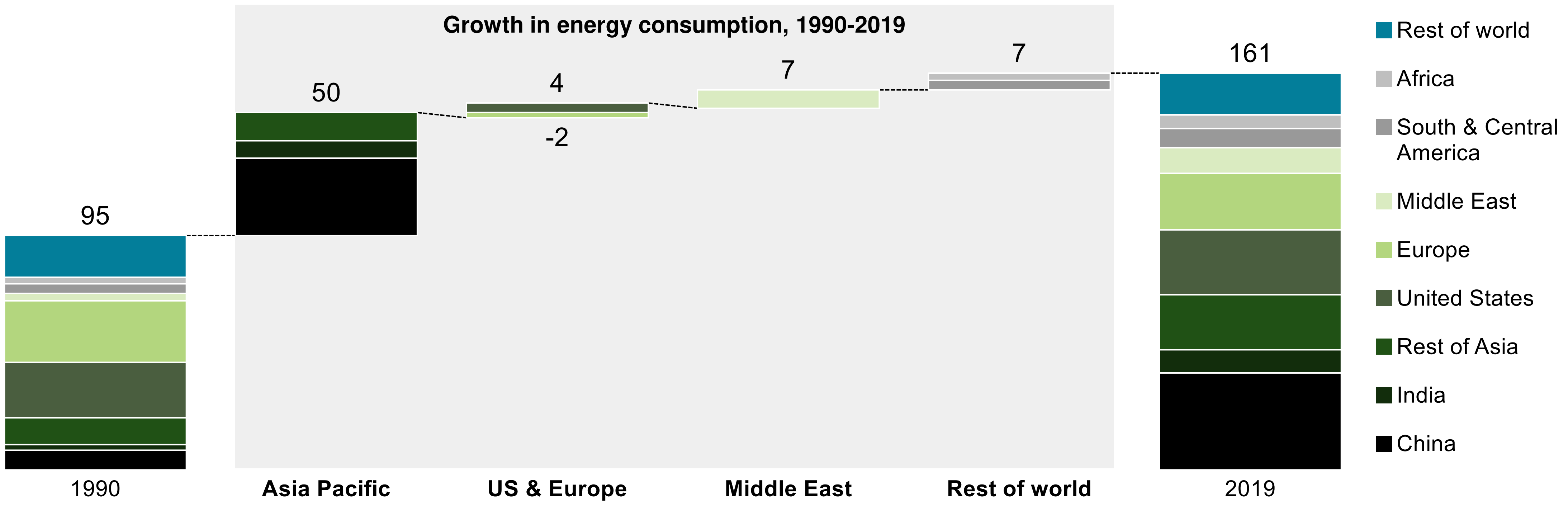
The Asia-Pacific region drove 75% of energy demand growth over 1990-2019, with China alone accounting for nearly half

Global primary energy consumption by country/region

Measured in petawatt-hours; excludes traditional biomass



Note: Chart excludes traditional biomass (~10,000 TWh in 2019)
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021

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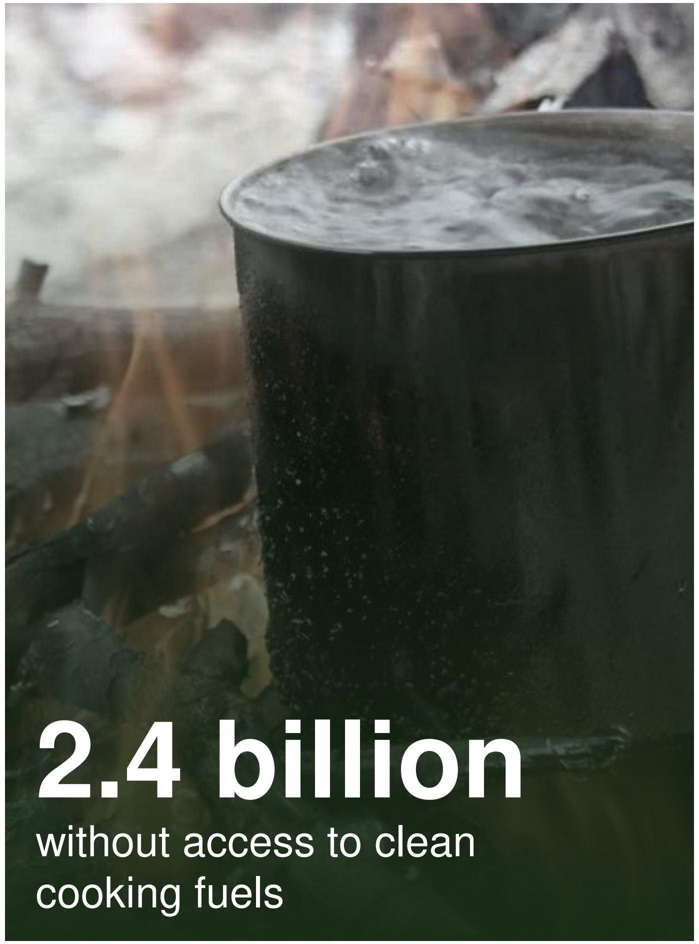
Despite this growth, a material share of the world still lacks access to electricity and clean cooking fuels



2.4 billion
without access to clean cooking fuels

675 million
without access to electricity

Share without electricity access in…

0% High-income countries

6% Middle-income countries

59% Low-income countries

Source: World Bank; IEA

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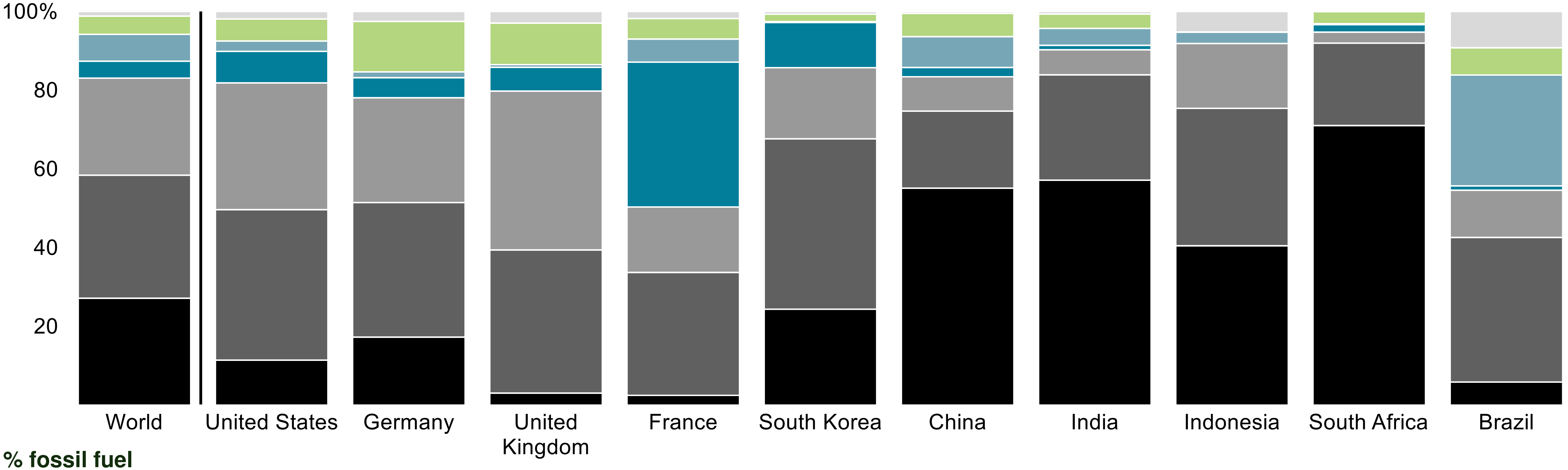
2

The mix of energy sources varies widely by country, based on local resource availability, government policy, and economic needs

Primary energy consumption by source – 2021

Measured in terawatt hours; excludes traditional biomass



% fossil fuel

World	United States	Germany	United Kingdom	France	South Korea	China	India	Indonesia	South Africa	Brazil
83%	82%	78%	80%	50%	86%	83%	90%	92%	95%	55%

Note: Excludes traditional biomass. "Other" includes other renewables and biofuels
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021

2

And energy prices for end consumers also show cross-country variability

2019 energy prices	USA	Germany	UK	France	South Korea	China	India	Indonesia	South Africa	Brazil
Residential electricity (USD per kWh)	0.13	0.33	0.24	0.20	0.10	0.08	0.07	0.08	0.10	0.20
Gasoline* (USD per 10 liters)	7.9	16.1	15.9	16.8	15.3	11.0	10.3	9.1	11.4	12.1
Automotive diesel (USD per 10 liters)	8.1	14.5	16.8	16.1	11.5	10.1	10.2	7.3	11.5	10.0

Note: * Premium unleaded petrol
Source: Euromonitor

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2 Population, GDP, and efficiency are important drivers of energy demand

Energy demand measured in joules or watt-hours = **Population** number of people globally × **Energy consumption per person** measured in joules or watt-hours per person

Energy consumption per person is made up of:

- **Income**: goods and services (GDP) per person, measured in dollars. Important considerations: consumer preferences, productivity, policy
- **Energy intensity**: measured in joules per dollar of income. Important considerations: sources, technology, regulation

173 trillion (2019 global consumption, measured in kilowatt-hours) = **7.7 billion** (2019 global population) × **17,000** (2019 GDP per capita, 2017 international-$) × **1.3** (2019 energy intensity, measured in kilowatt-hours x dollar of GDP)

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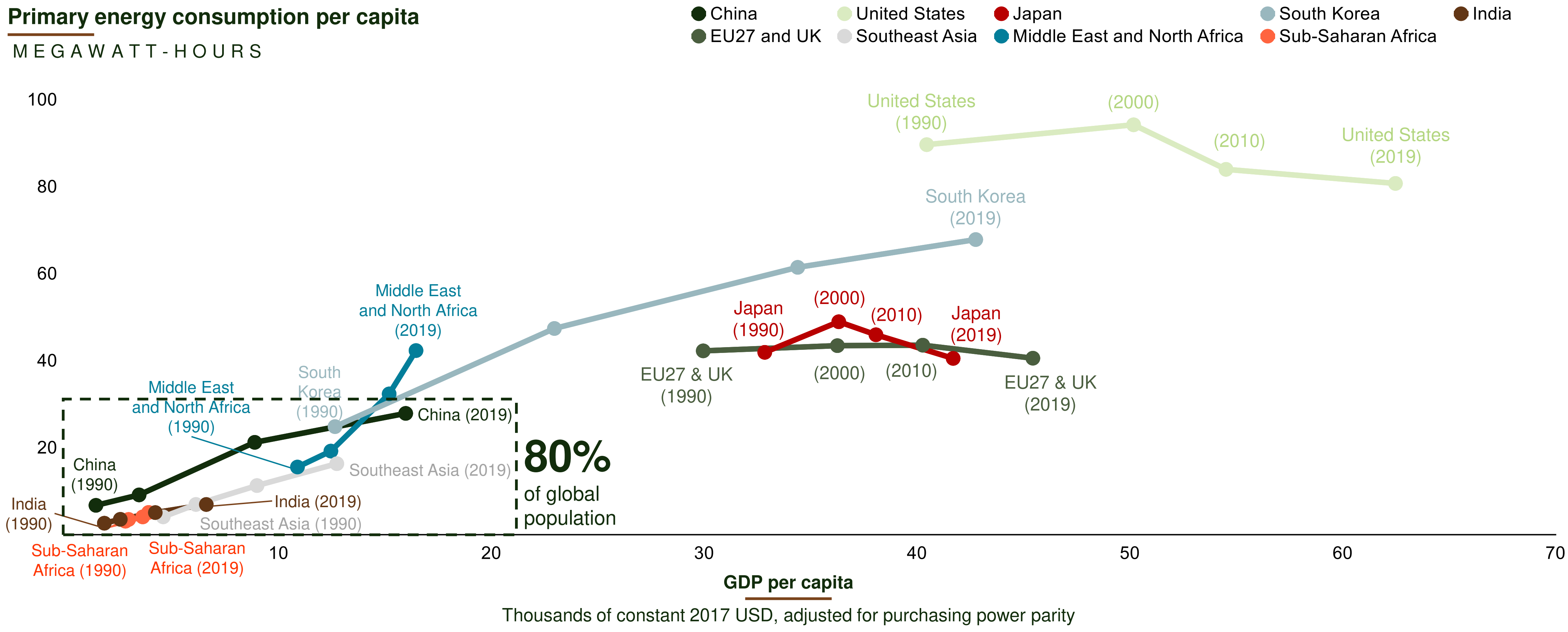
For developing economies, economic output and energy consumption grow together

Primary energy consumption per capita

MEGAWATT-HOURS

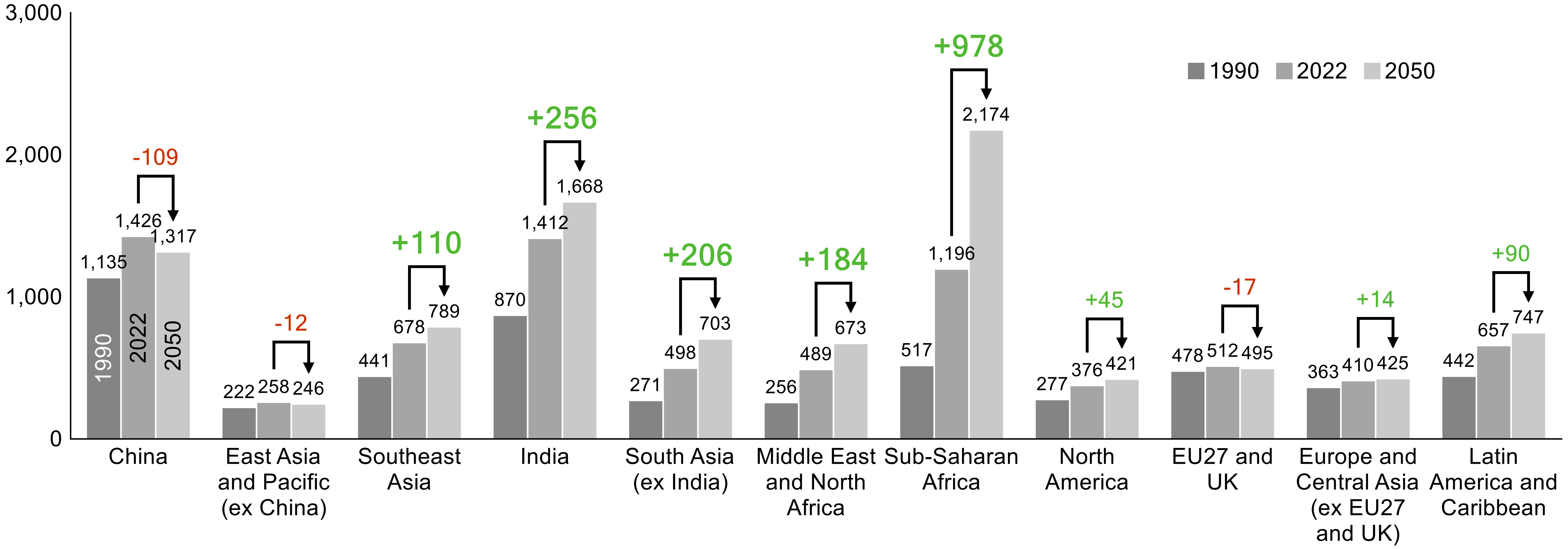


Sources: Bain & Company analysis; Our World in Data; World Bank; BP Statistical Review of World Energy, 2022; EIA

Developing countries, particularly in Asia and Africa, will drive population growth over the next decades

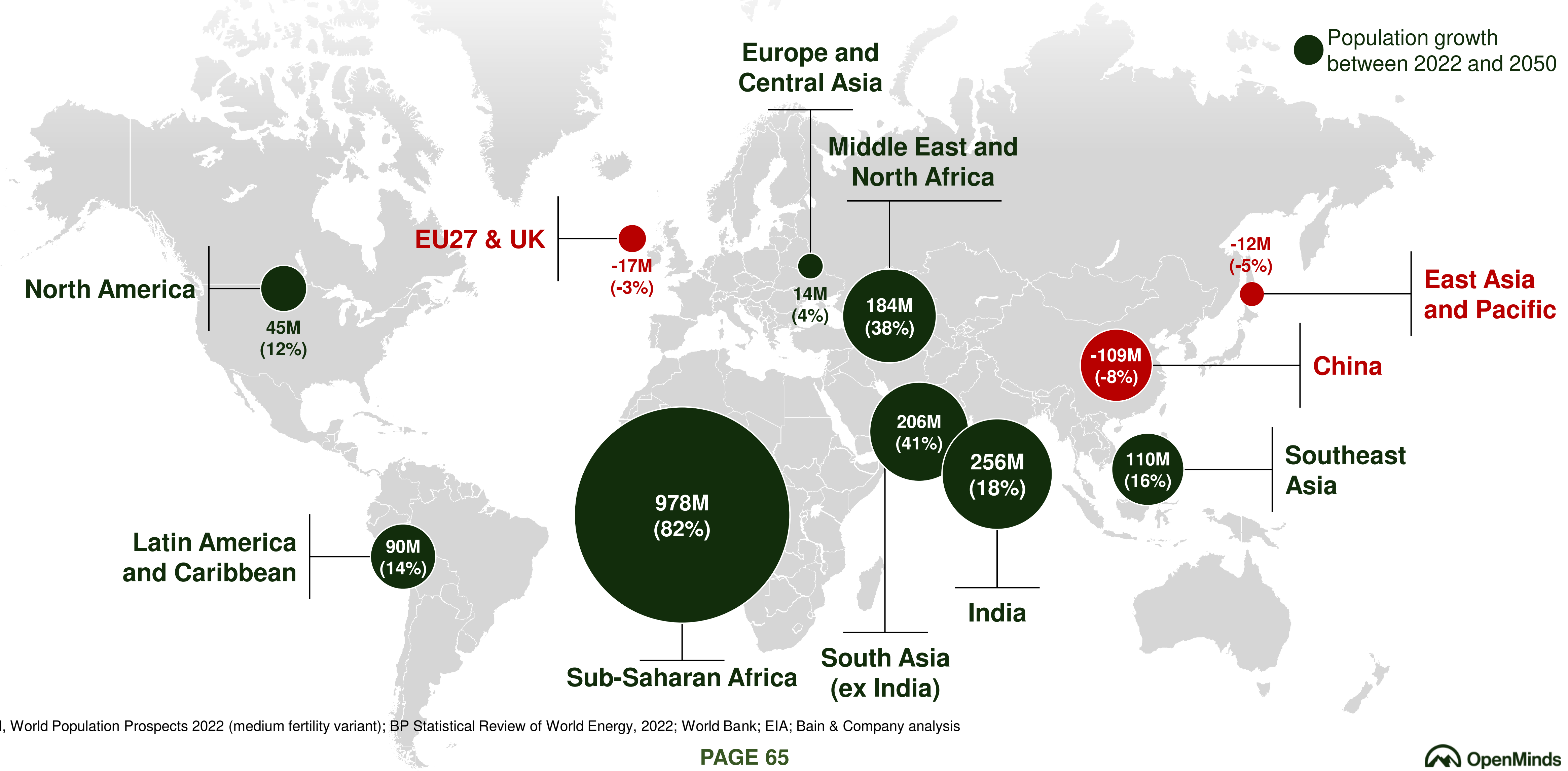
Global population

MILLIONS



Source: UN, World Population Prospects 2022 (medium fertility variant); BP Statistical Review of World Energy, 2022; World Bank; EIA; Bain & Company analysis

2 Population growth will be overwhelmingly concentrated in regions of lower energy consumption today



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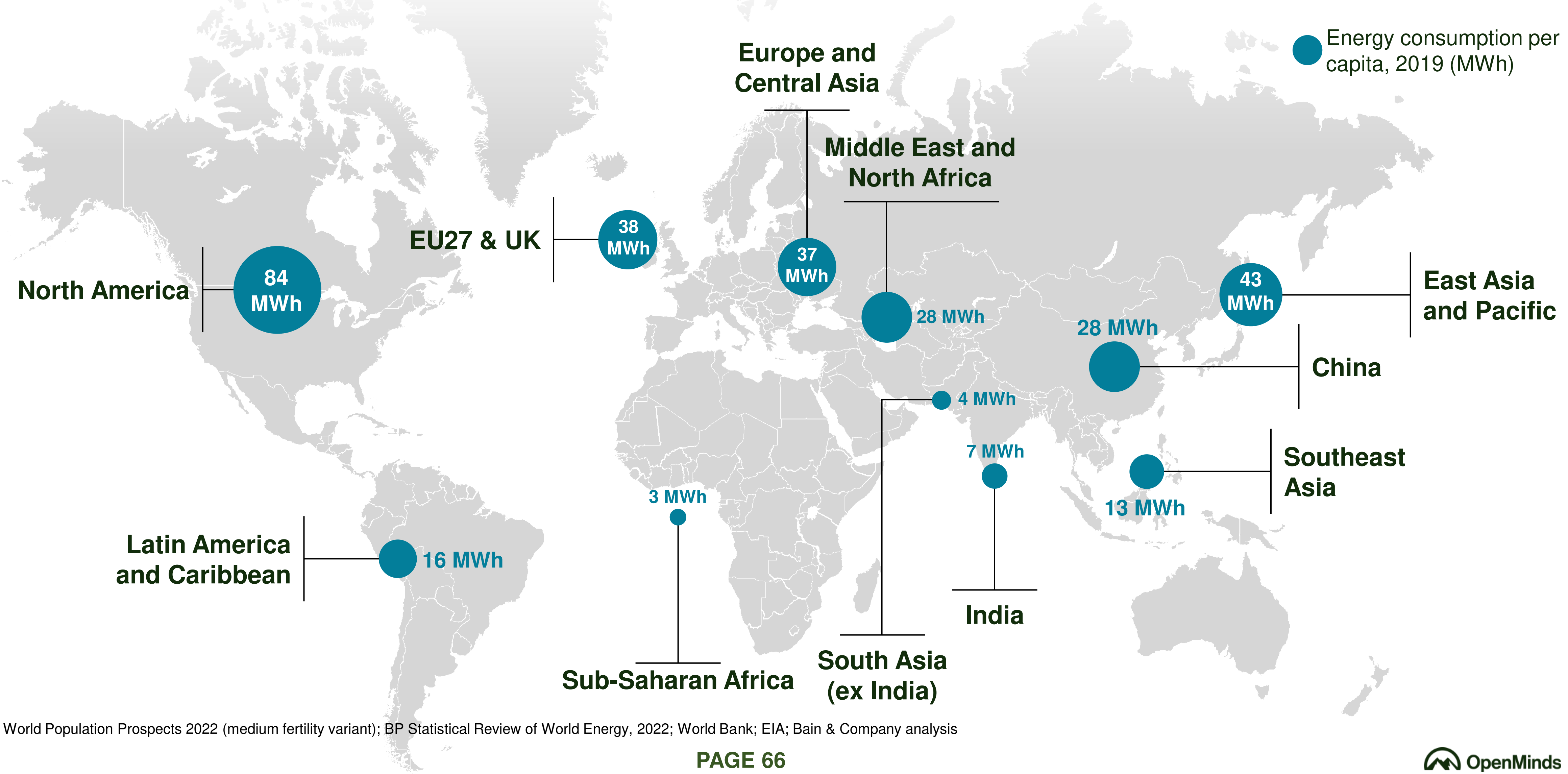


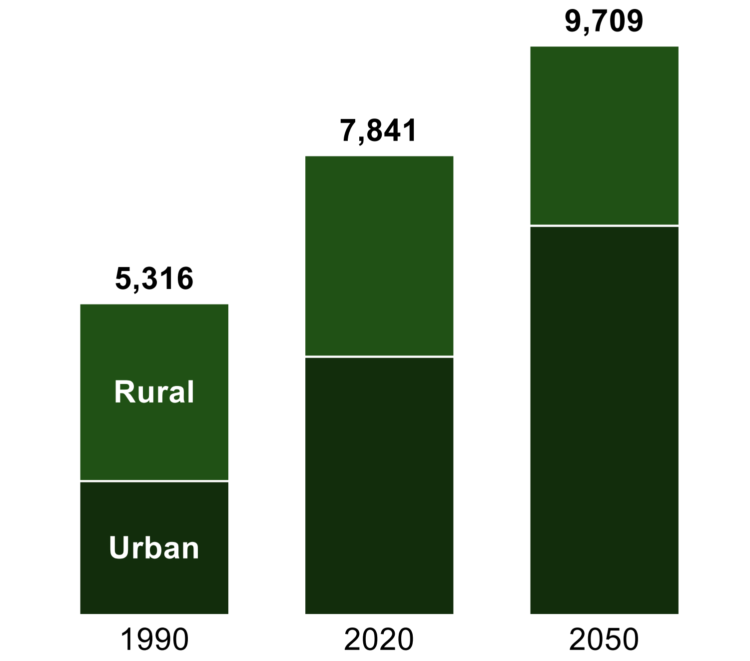
Source: UN, World Population Prospects 2022 (medium fertility variant); BP Statistical Review of World Energy, 2022; World Bank; EIA; Bain & Company analysis

Moreover, urban areas will grow by 2.2 billion, including significant growth in Africa and Asia, through 2050

The world will increasingly urbanize over the next 30 years

Global population

MILLIONS



% Urban

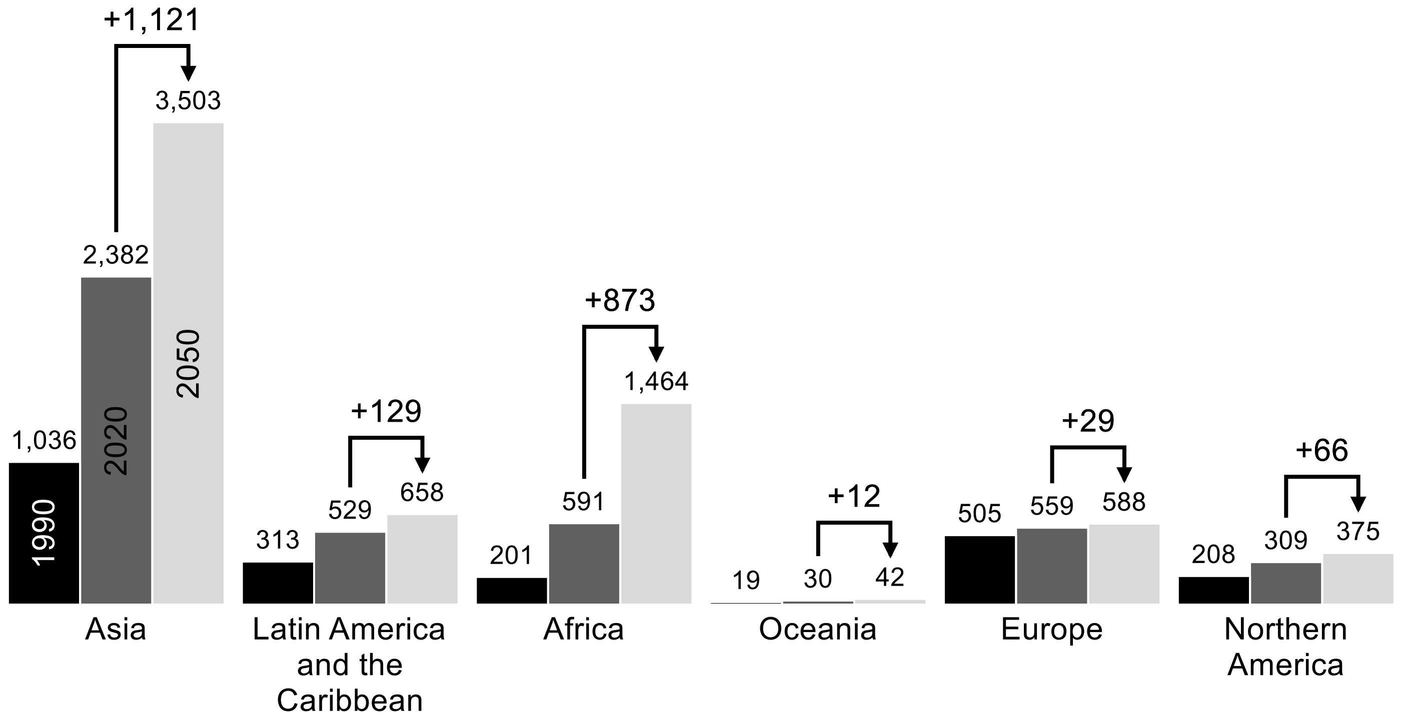
1990	2020	2050
43%	56%	68%

Source: UN World Urbanization Prospects (2018)

Urban population growth will be most pronounced in Africa and Asia

Urban population by region

MILLIONS



Global GDP is expected to more than double by 2050, driven mostly by non-OECD regions

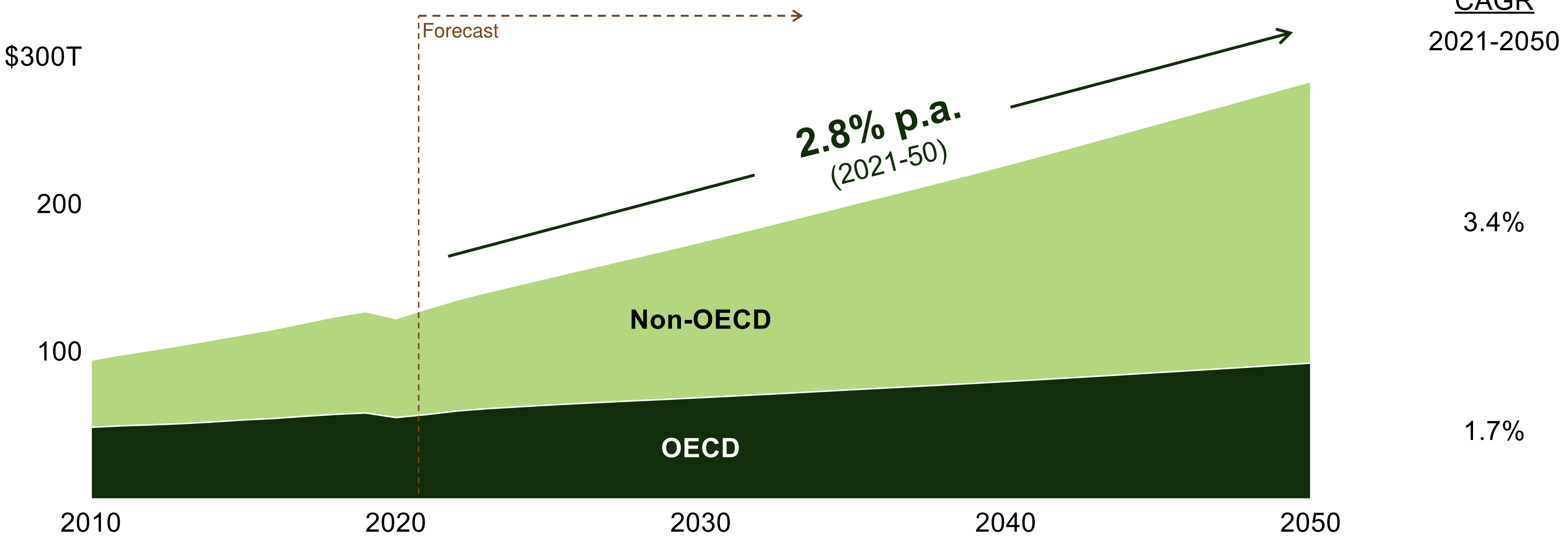
ENERGY DEMAND DRIVER

Income

goods and services (GDP) purchasing power parity, measured in dollars

GDP purchasing power parity, historical and forecast

PPP, TRILLIONS OF 2015 USD



Source: U.S. Energy Information Administration, International Energy Outlook 2021 (IEO2021), reference case

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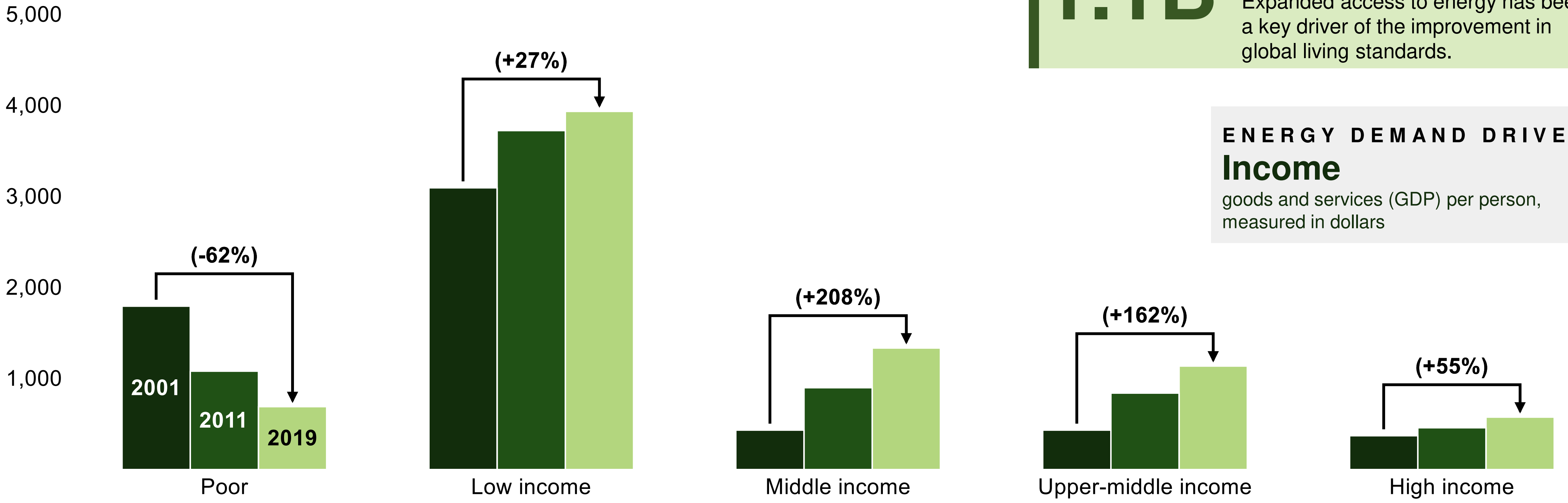
2

GDP growth is a good thing—more than one billion have been lifted out of poverty in the last 20 years

Global population by income tier 2001 - 2019

MILLIONS OF PEOPLE



1.1B **decline in number of people considered poor since 2001 (from 29% to 9% of the global population).** Expanded access to energy has been a key driver of the improvement in global living standards.

ENERGY DEMAND DRIVER

Income

goods and services (GDP) per person, measured in dollars

Note: 1. Note: Income buckets defined as follows, Poor: <$2/day, Low income: $2.01-$10/day, Middle income: $10.01-$20/day, Upper-middle income: $20.01-$50/day, High income: >$50/day. Figures expressed in 2011 purchasing power parities in 2011 prices

Source: Bain & Company analysis; Pew Research Center; World Bank

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2

We have become more efficient over time: energy used per dollar of GDP has declined around the world

ENERGY DEMAND DRIVER

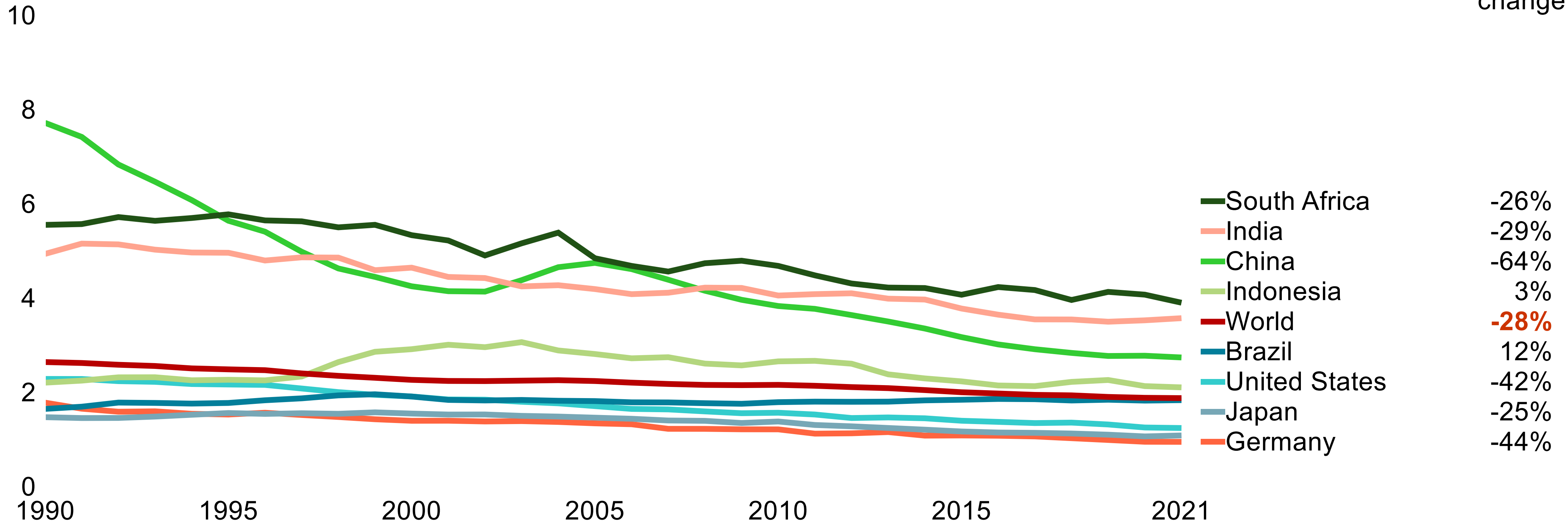
Energy intensity

measured in joules per dollar of income

Energy intensity per dollar

Consumption-based energy consumption, measured in kWh/$, or kilowatt-hours divided by GDP, measured in 2017 international-$

1990-2019 change



Note: GDP measured in 2017 international-$, which adjusts for inflation and cross-country price differences
Source: Bain & Company analysis; EXIOBASE database, aggregated by Our World in Data

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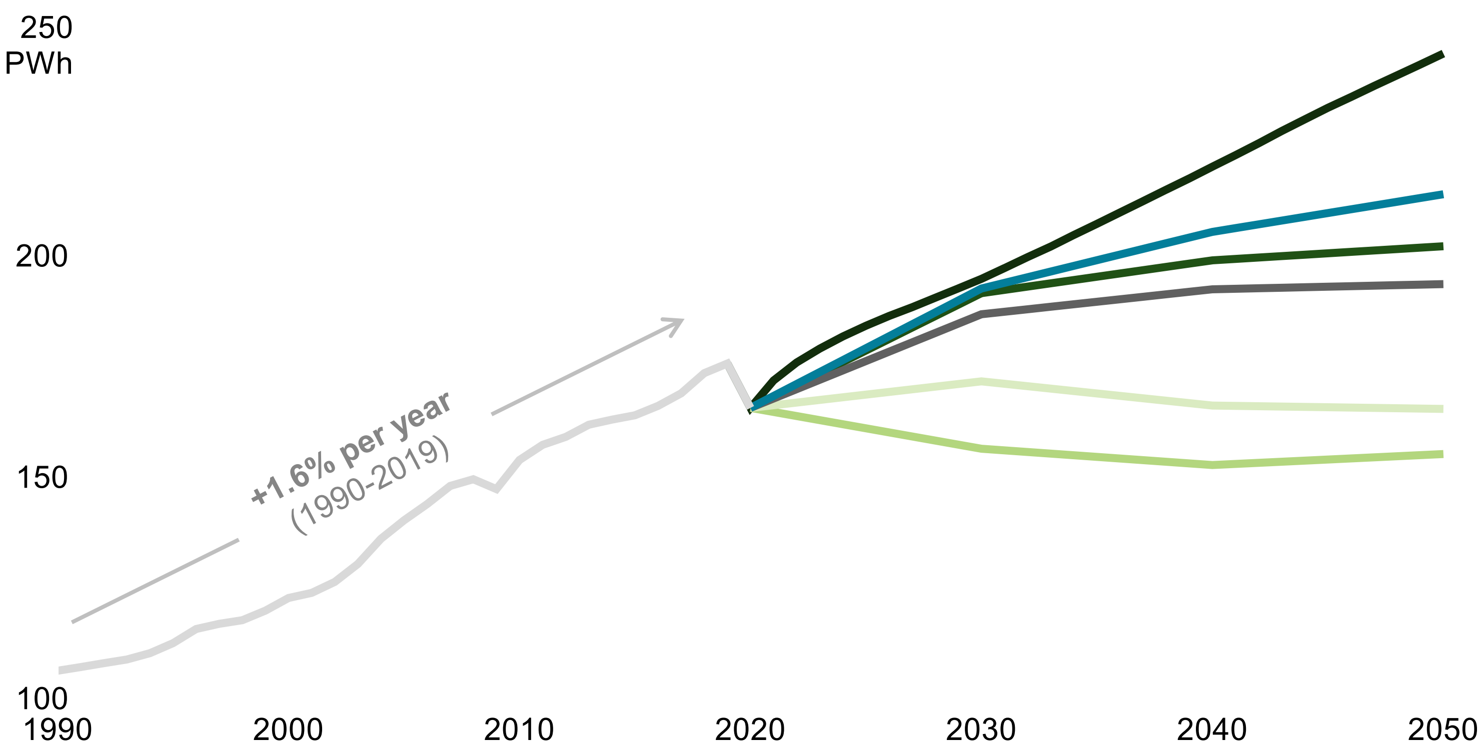
2

All things considered, energy demand will almost certainly continue to grow for the foreseeable future

Global primary energy demand

PETAWATT-HOURS



Scenario	Growth per year 2019-2050
Scenarios without significant policy or tech shifts	
EIA: International Energy Outlook 2021	1.1%
IEA: Stated Policies Scenario (STEPS)	0.6%
ExxonMobil: 2021 Outlook for Energy (XOM)	0.4%
IEA: Announced Pledges Scenario (APS)	0.3%
Scenarios with significant policy and tech shifts	
IEA: Sustainable Dev. Scenario (SDS)	(0.2%)
IEA: Net Zero Emissions by 2050 (NZE)	(0.4%)

IEA's **Stated Policies Scenario** and **Announced Pledges Scenario**, along with **ExxonMobil's Outlook for Energy** and **EIA's International Energy Outlook**, conclude that **energy demand will continue growing absent significant policy changes or technology innovation** that drive material improvement in energy intensity

Source: Bain & Company analysis; BP Statistical Review of World Energy, 2021; ExxonMobil 2021 Outlook for Energy; International Energy Agency (2021), World Energy Outlook 2021, IEA, license: Creative Commons Attribution CC BY-NC-SA 3.0 IGO; EIA International Energy Outlook 2021

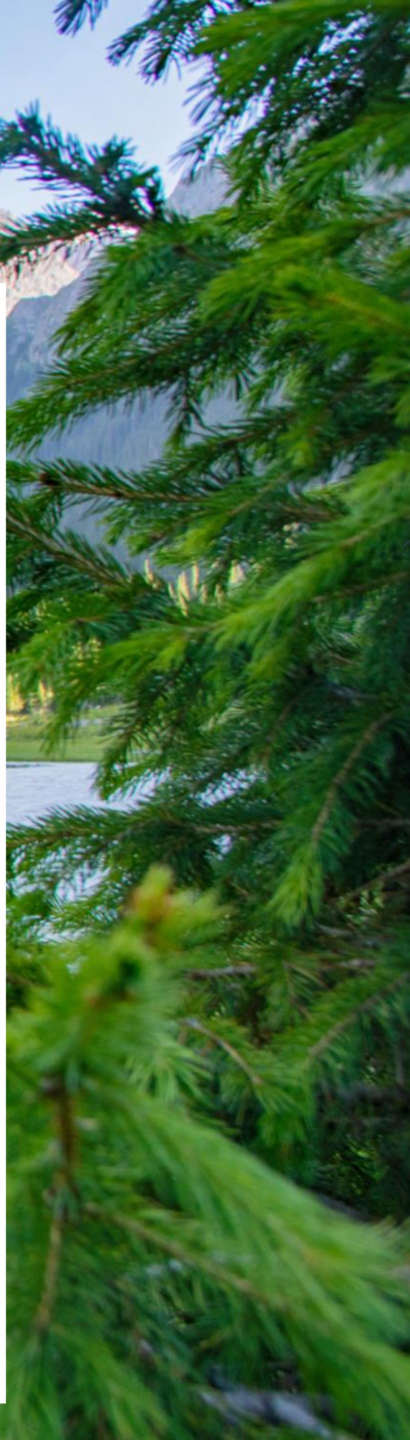
SECTION RECAP

Energy: Uses, Sources, and Outlook

- Modern civilization and quality of life depend on affordable & reliable energy supply
- Fossil fuels have historically been that supply, enabling tremendous economic and standard of living improvements over the last century
- Today, fossil fuels account for about 80% of total global energy supply
- That share has not changed meaningfully over the last 30 years, during which time total supply grew by 60%
- Despite consistent global growth in overall and per capita energy use, much of the world lacks access to sufficient energy
- Future population growth will be concentrated in these low-energy regions
- Delivering affordable, reliable energy will be key to enabling the development of these countries
- Energy security is becoming more important with increased geopolitical tension
- Total energy demand will continue rising; affordability, reliability, and security of supply will remain essential

Agenda

Climate Change: Fundamentals and Possible Trajectories



- The Earth's climate, including average surface temperature, changes over time for a variety of reasons; fluctuations in the quantity, or concentration, of greenhouse gases (GHGs) in the atmosphere is one of those reasons
- Since 1850, human activity, including land use and fossil fuel combustion, has resulted in the release of more than two trillion cumulative tons of greenhouse gases, mostly carbon dioxide (CO_2), into the atmosphere
- The planet's natural CO_2 sinks have been unable to keep up with the volume of human emissions; consequently, the atmospheric concentration of CO_2 has increased by about 50% versus pre-industrial times
- Rising CO_2 (and other GHG) concentration, caused by human activity, has been a key driver of an observed increase in average global surface temperature
- Warming has already produced adverse human and ecosystem impacts, and further warming will amplify risks such as accelerated sea level rise and increased frequency and severity of certain types of extreme weather
- The largest anthropogenic source of emissions is the production and combustion of fossil fuels for transportation, electricity generation, and heating; such fuels are the source of 80% of the world's primary energy
- As their economies grew and became more energy-intensive, Asia has quickly emerged as the leading GHG emitter globally, but the US and Europe together emitted significantly more than any other region during the last century

To limit warming and mitigate the worst risks of climate change, anthropogenic greenhouse gas emissions will need to decline significantly, and ideally reach zero, within a few decades—this can only be accomplished as an "all of us" global effort

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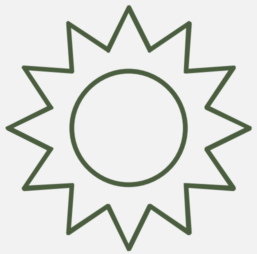
"Climate" refers to long-term average weather patterns

Weather
Short-term (day-to-day or hour-to-hour) atmospheric conditions

Tuesday
August 2, 2022



93°F

Wednesday
August 3, 2022

91°F

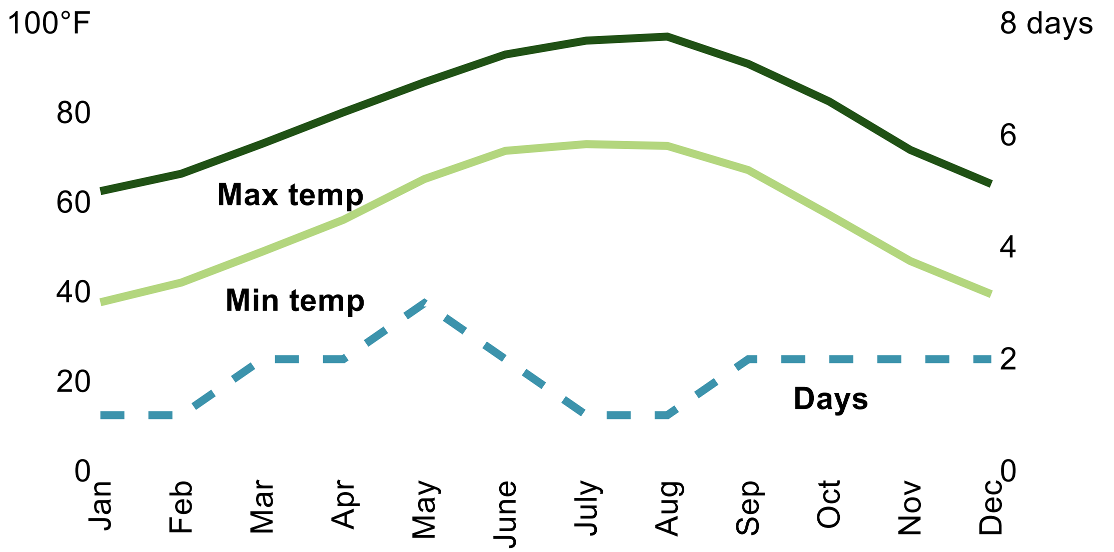
Thursday
August 4, 2022

89°F

Climate
Long-term (multi-year or multi-decadal) average weather patterns

30-year average: Daily temperatures in Austin, TX
(1991-2020)

30-year average: Number of days with ≥0.5 in. precipitation in Austin, TX
(1991-2020)



Note: Temperature and precipitation data reflective of Austin, Texas over 1991-2020; data from Austin Bergstrom weather station
Source: NOAA, USGS, NASA

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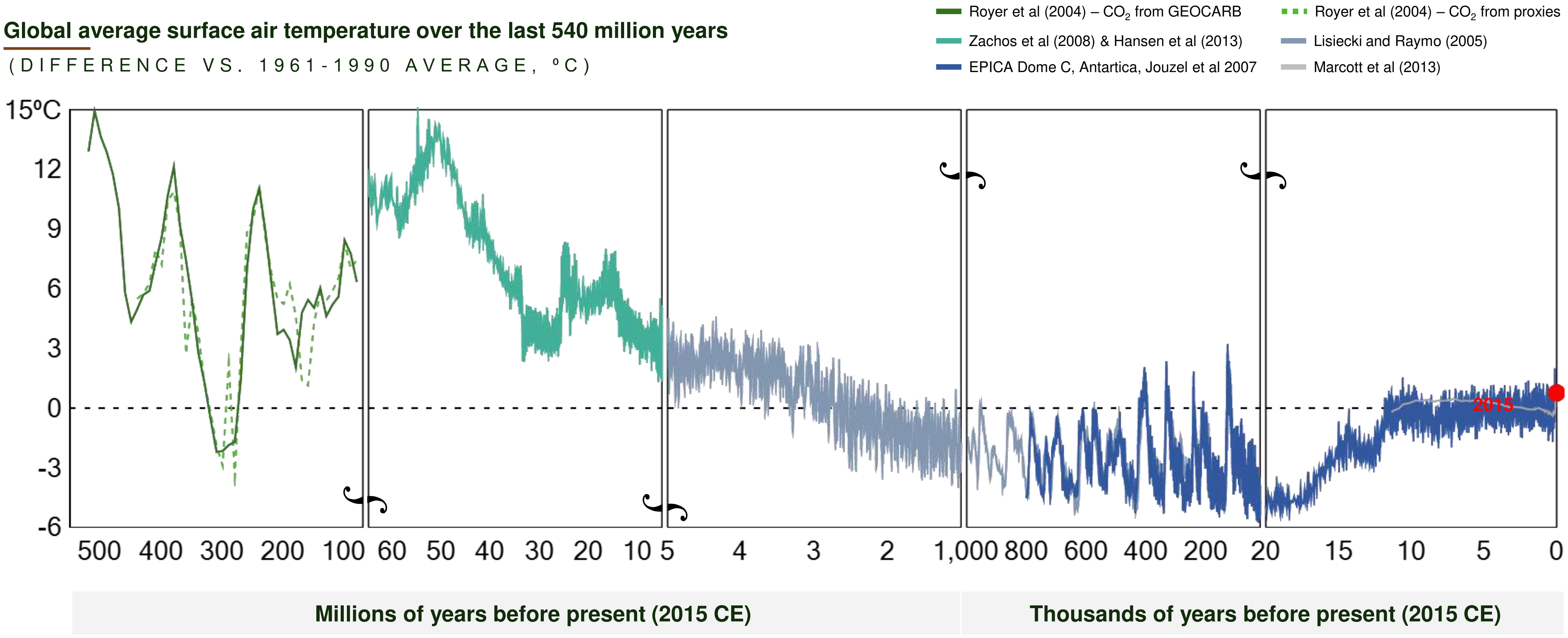
The Earth's climate, including average surface temperature, changes over time

Global average surface air temperature over the last 540 million years

(DIFFERENCE VS. 1961-1990 AVERAGE, ºC)



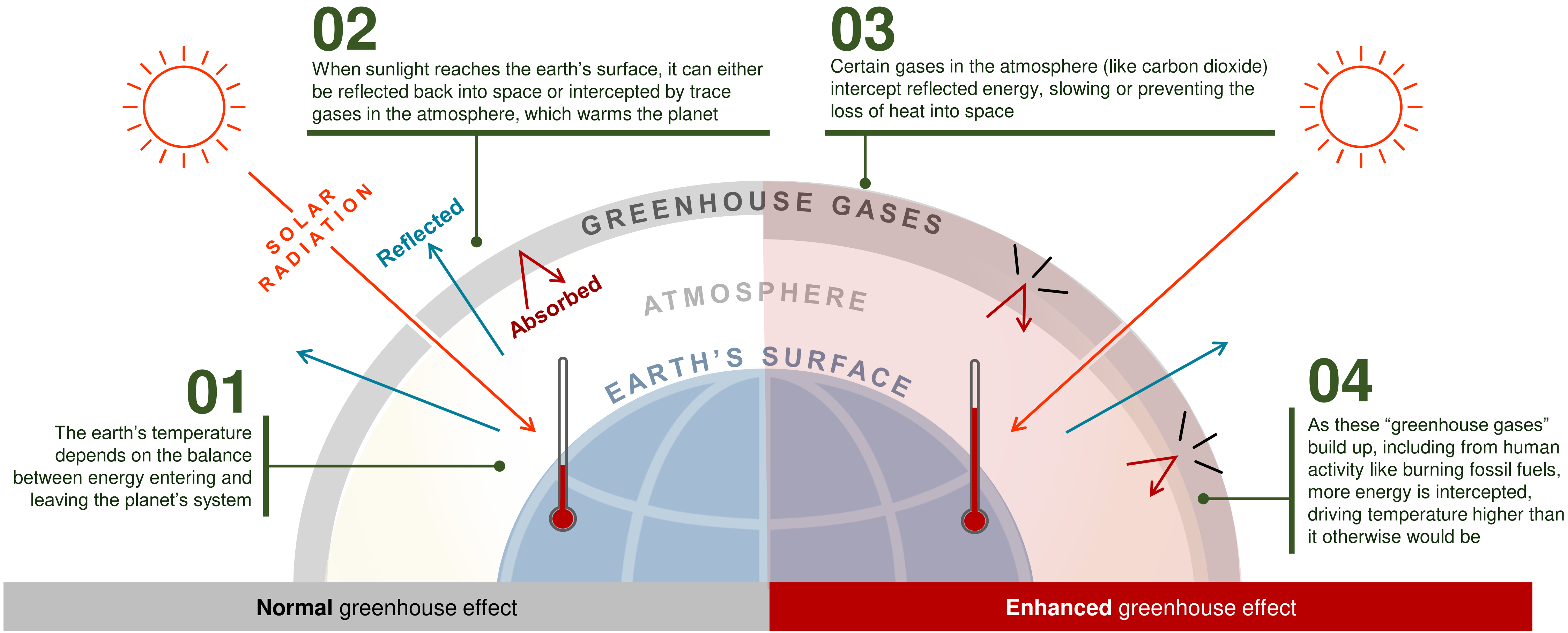
Source: Royer et al (2004); Zachos et al (2008); Hansen et al (2013); Lisiecki and Raymo (2005); EPICA Dome C, Antartica; NGRIP, Greenland; Marcott et al (2013); data compiled by Glen Fergus

Climate fluctuates for a variety of reasons, including changes in the atmospheric concentration of greenhouse gases

Factor	Description
Variation in solar output	The energy output of the sun is not constant, and changes in its irradiance affect climate
Changes in the Earth's orbit around the sun	The Earth's eccentricity, axial tilt, and precession change over time, and these changes influence climatic patterns, including periods of glaciation
Changes in the Earth's reflectivity	The Earth's albedo, or reflectivity, affects how much sunlight the planet absorbs. This effect can act as a feedback to other processes
Quantity of greenhouse gases in the atmosphere	Certain gases like water vapor and CO_2 impede the flow of infrared heat (solar radiation) from the Earth's surface into space, thereby warming the planet. This is the "greenhouse effect"
Changes in ocean currents	Ocean currents carry heat around the earth. Changes in circulation and heat content affect climate
Volcanic eruptions	Gas and particles thrown into the atmosphere during volcanic eruptions may warm or cool the Earth's surface

Source: British Geological Survey; EPA

The quantity of greenhouse gases (GHGs) in the atmosphere influences climate via the greenhouse effect



Source: EPA

3

Certain human activities result in the release of several types of greenhouse gases, mostly carbon dioxide (CO_2)

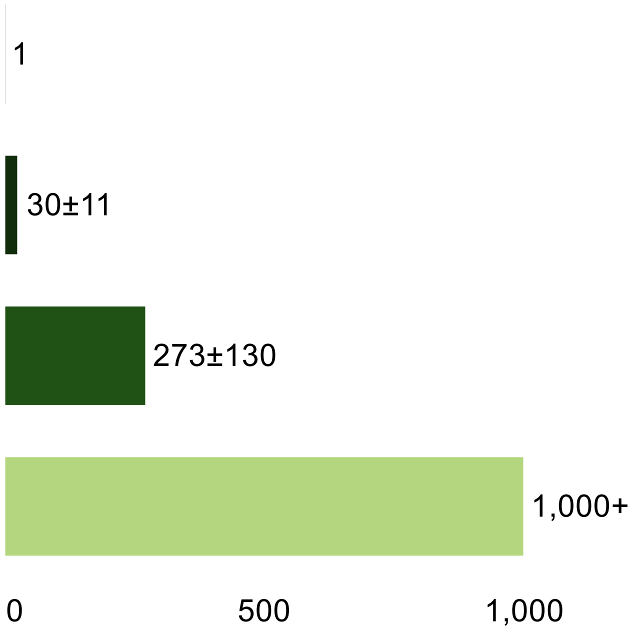
Typical sources

(non-exhaustive)

Gas	Typical sources
Carbon dioxide (CO_2)	Fossil fuel combustion, cement production, steel production
Methane (CH_4)	Natural gas production, livestock, landfills
Nitrous oxide (N_2O)	Agricultural soil management (fertilizer application) and fuel combustion
Fluorinated gases	Industrial processes such as electronics manufacturing and aluminum production

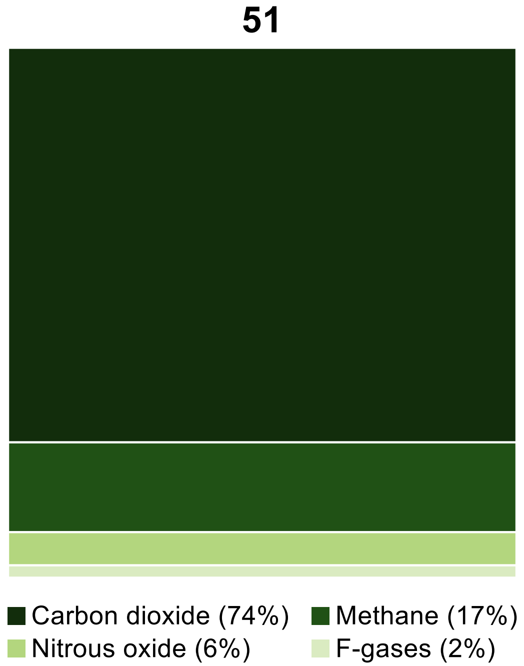
Global warming potential

(GWP, which measures how much a gas would warm the earth in a 100-year period compared to one ton of CO_2)



Human GHG emissions

(measured in billions of tons of CO_2-equivalent, i.e., adjusted for GWP factor)



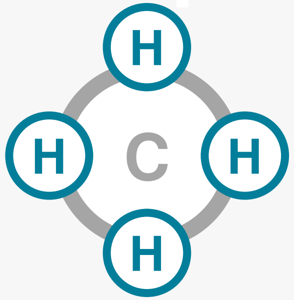
Note: Global Warming Potential uncertainties expressed as 5-95% confidence interval based on IPCC AR6. Source: Bain & Company analysis; EPA; IPCC, Sixth Assessment Report (AR6), Working Group I, Chapter 7, Table 7.15; IPCC, Fifth Assessment Report (AR5), Working Group I, Box 6.1, Figure 1; Daniel A. Vallero, *Air Pollution Calculations* (2019), 8.3.2; Climate Watch. Additional detail can be found in the appendix

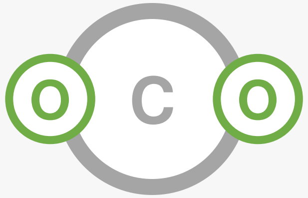
For example, CO_2 is a product of fossil fuel combustion, as is a significant quantity of energy in the form of heat

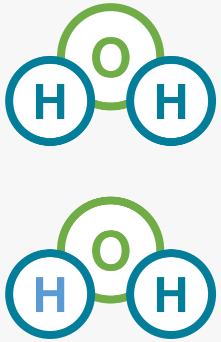
Natural gas example

Natural gas, or methane, is commonly used in homes for space heating, water heating, and/or cooking and in power plants for producing electricity. When combusted, it produces CO_2 and water, along with a significant quantity of energy in the form of heat

1 mol of **natural gas**	+	2 mols of **oxygen**	=	1 mol of **carbon dioxide**	+	2 mols of **water**	+	890,400 joules of **energy**
(CH_4 or methane, usually extracted from below the earth's surface)		(O_2, found in the atmosphere)		(CO_2, a greenhouse gas)		(H_2O)		(released as heat)





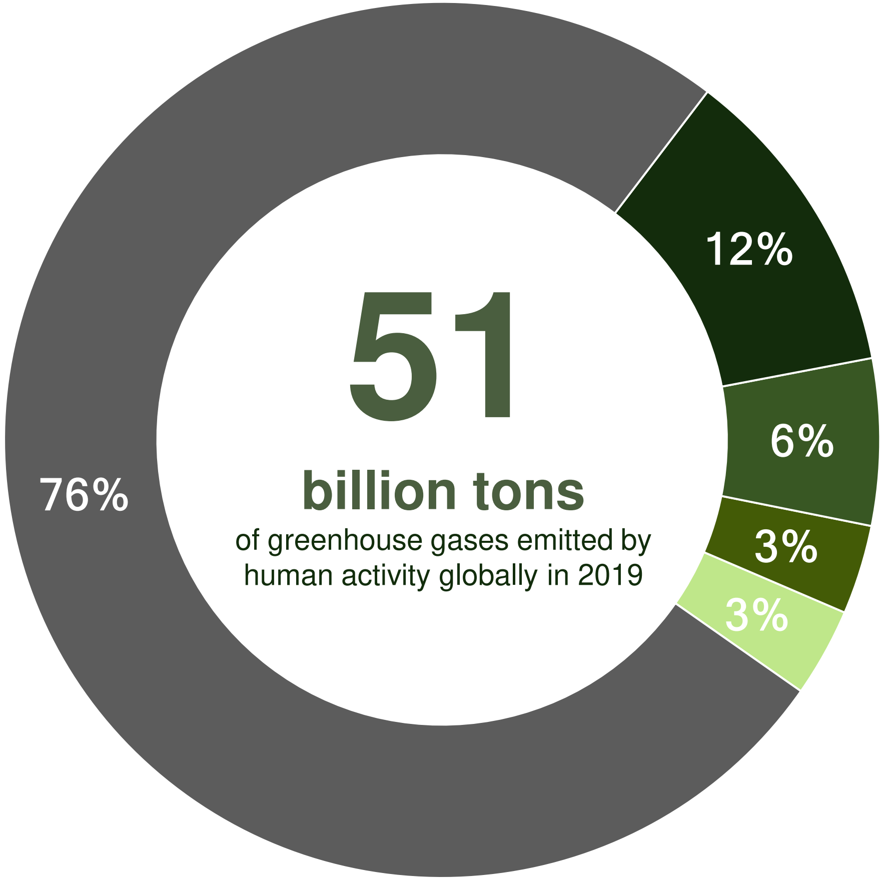


2.8 kg of CO_2 are produced for every 1 kg of methane gas combusted.
With gasoline, the ratio is about 3.2 to 1.

Note: 1 mol = 6 x 10^{23} molecules. 1 mol of water weighs about 18 grams

Altogether, the combustion of fossil fuels accounts for more than three-quarters of total anthropogenic GHG emissions

Energy emissions
Emissions from the production and combustion of fossil fuels for power generation, heat generation, manufacturing/construction, transportation, and other uses



Agriculture emissions
Emissions from livestock gas (enteric fermentation) and manure, rice cultivation, fertilizer application, and other sources

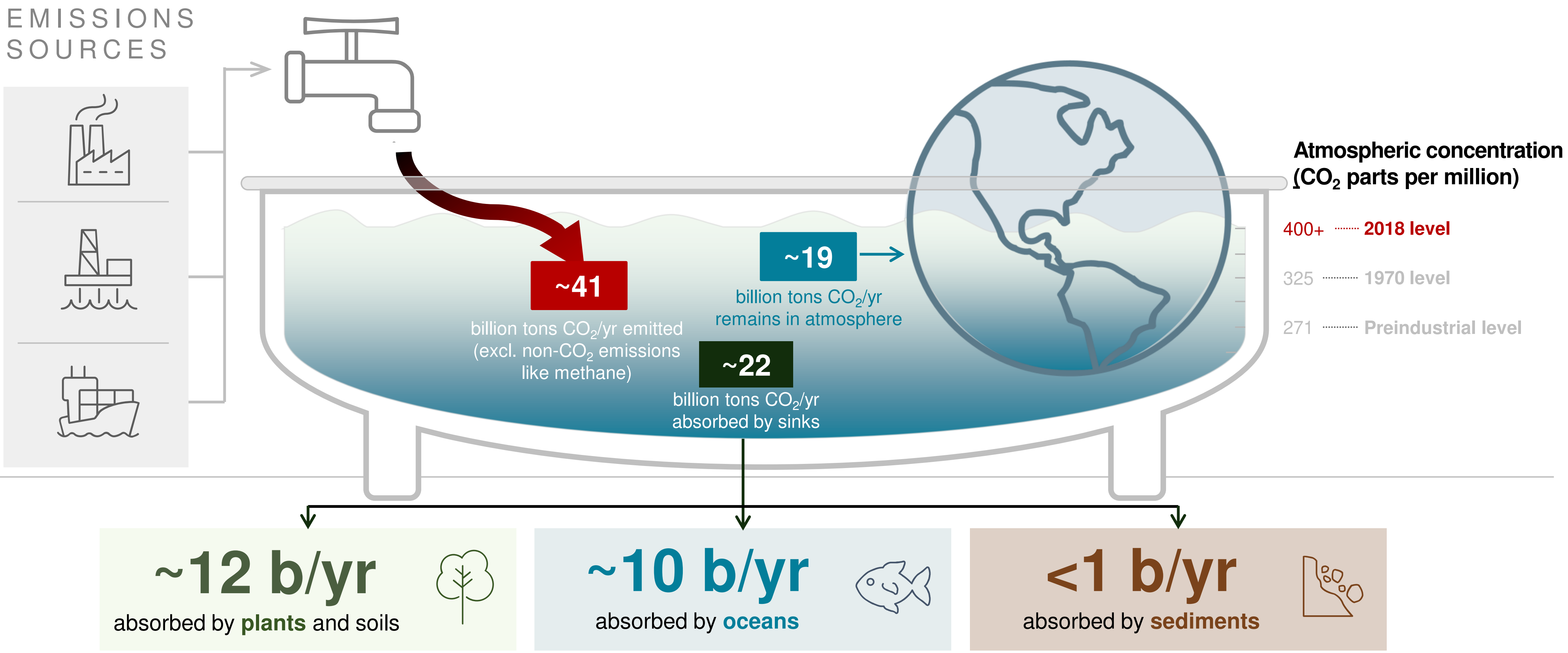
Industrial processes
By-product emissions from cement and chemical manufacturing and other industrial processes

Land-use change and forestry emissions
Emissions from changes in forest and other woody biomass stocks, forest and grassland conversion, and other LUCF sources

Waste emissions
Emissions from waste management like solid waste disposal on land and wastewater handling

Note: Emissions measured in tons of CO_2-equivalent and include carbon dioxide, methane, nitrous oxide, and f-gases
Source: Bain & Company analysis; Our World in Data; Climate Watch

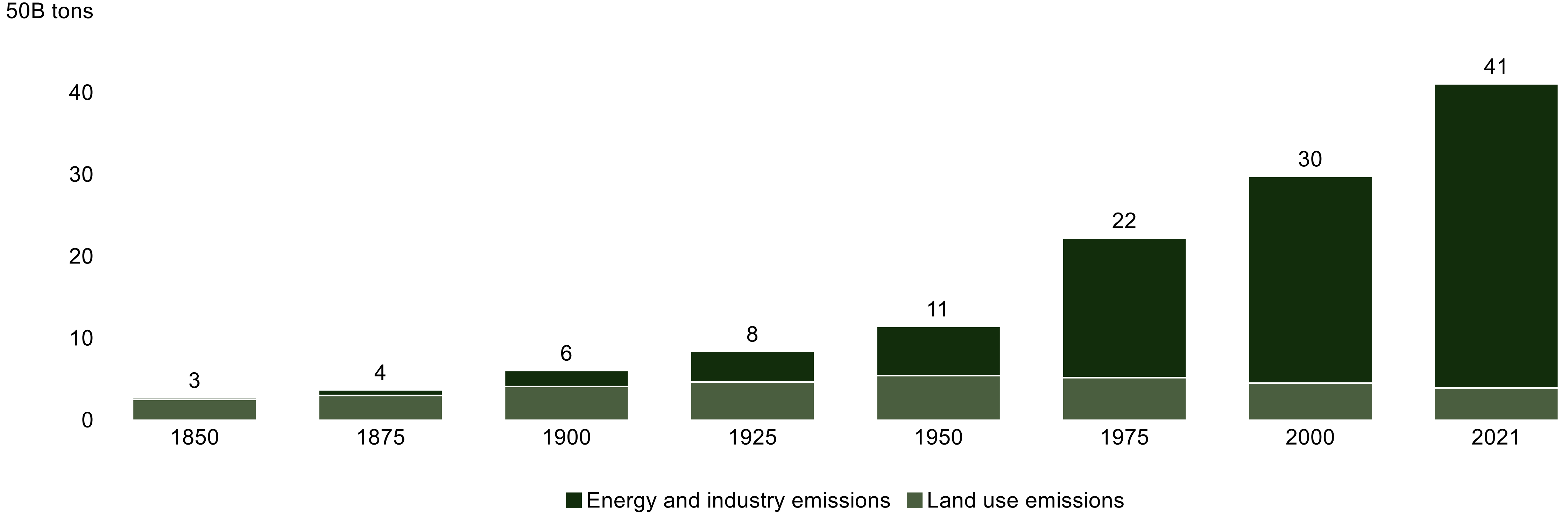
When considering the climate impact of anthropogenic GHG emissions, it is helpful to think of the atmosphere as a bathtub



Anthropogenic CO_2 emissions, the “faucet”, have doubled since 1975

Annual global CO_2 emissions from energy and land use change

(MEASURED IN BILLIONS OF TONS OF CO_2; EXCLUDES NON-CO_2 GHGS)



Source: Bain & Company analysis; Global Carbon Project; Our World in Data

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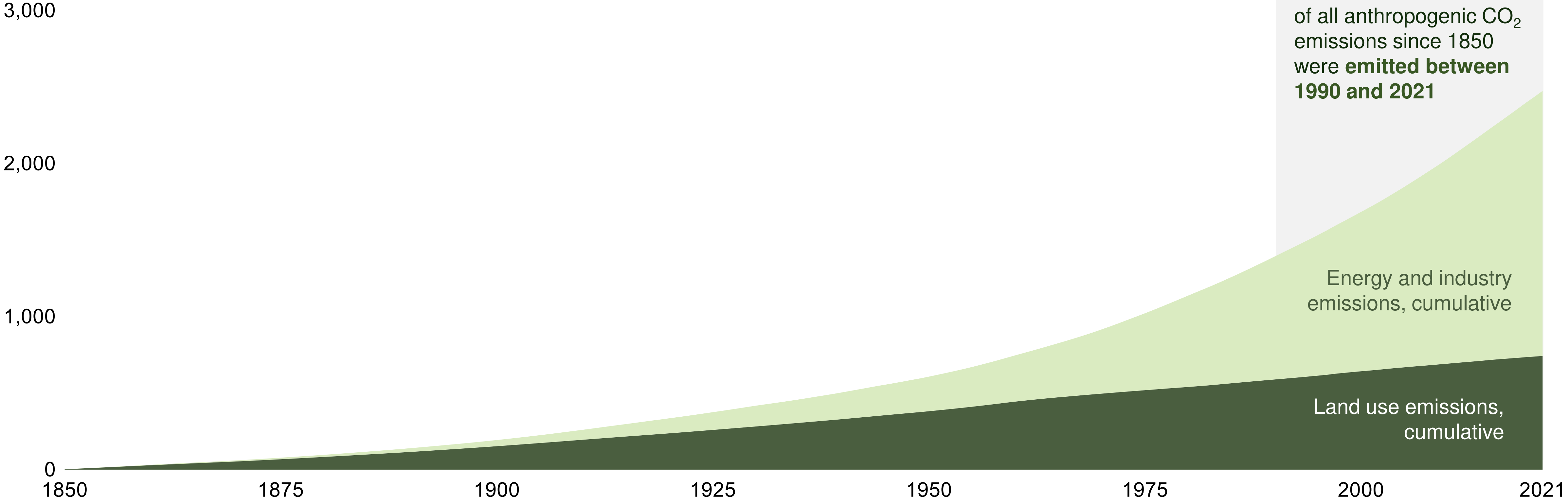
Since 1850, human activity has caused the release of more than two-trillion cumulative tons of CO_2

Cumulative global CO_2 emissions from energy and land use change

Measured in billions of tons of CO_2, from 1850 through 2020; excluding non-CO_2 emissions (e.g., methane)

45%

of all anthropogenic CO_2 emissions since 1850 were **emitted between 1990 and 2021**



Source: Global Carbon Project; Our World in Data

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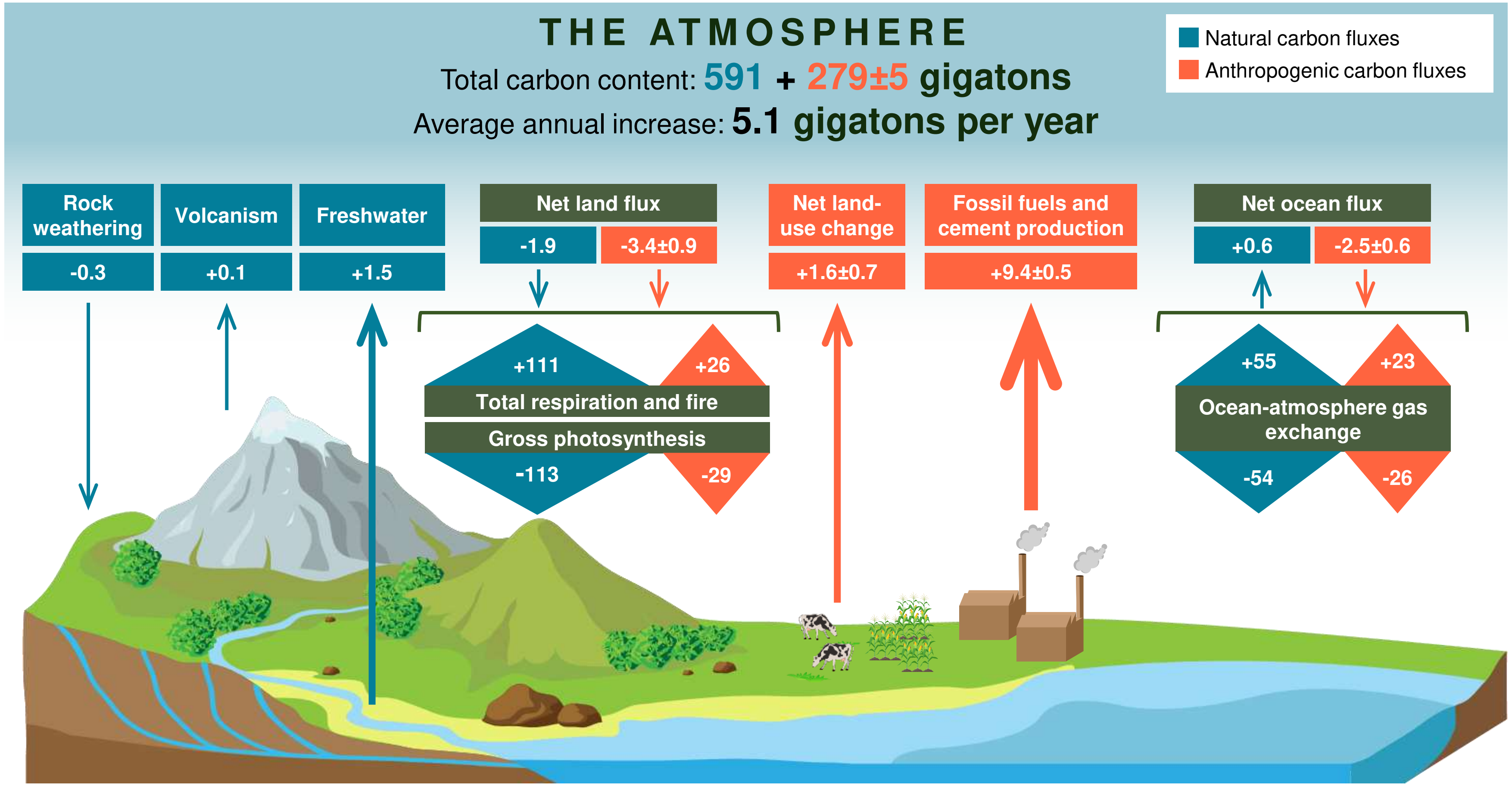
The Earth's natural carbon system affects the quantity of anthropogenically emitted carbon that remains in atmosphere



All figures are in gigatons of carbon (not CO_2) **per year** except total atmospheric content

Natural carbon fluxes (blue arrows) represent annual carbon fluxes associated with the natural carbon cycle, estimated for the time prior to the industrial era (pre-1750)

Anthropogenic carbon fluxes (yellow arrows) are averaged over the period 2010-2019

Total atmospheric content reflects the total stock of carbon in the atmosphere today (denoted as the sum of the pre-industrial stock and the anthropogenic change since 1750)

Of about 11 gigatons of anthropogenically emitted carbon per year, **roughly 55% is absorbed by the land and ocean**

Source: Bain & Company analysis; IPCC, Sixth Assessment Report (AR6), Working Group I, Chapter 5, Global Carbon and Other Biogeochemical Cycles and Feedbacks (2022)

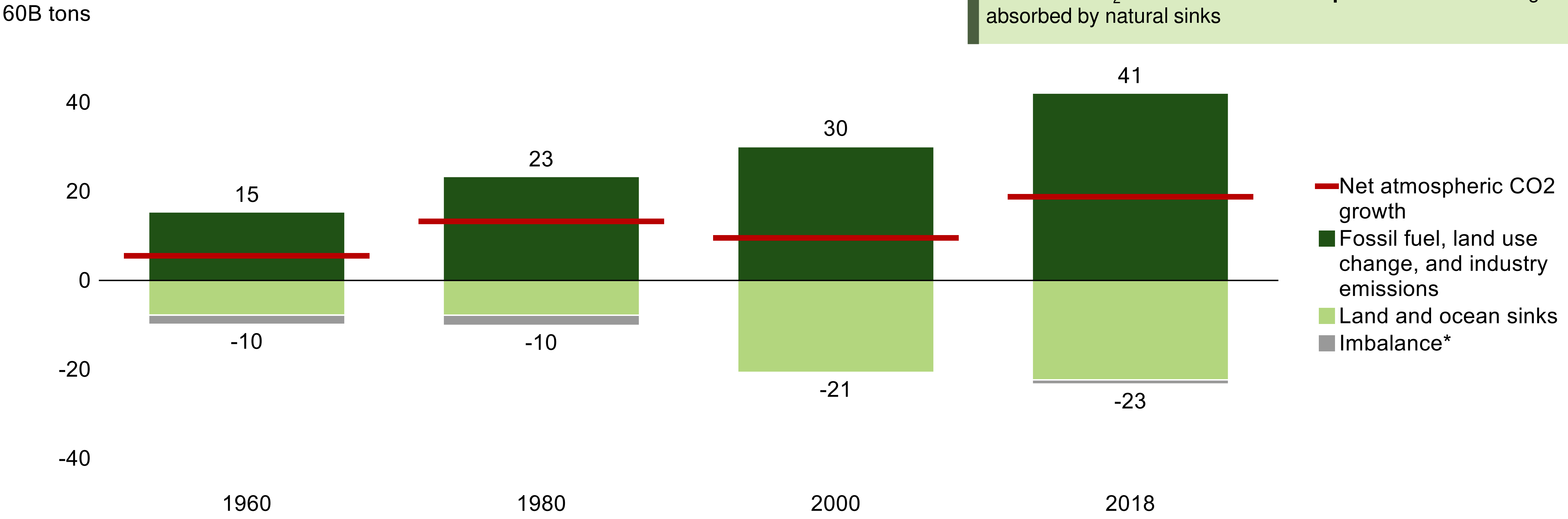
The Earth's natural carbon sinks, the "drain", have been unable to keep up with the pace of anthropogenic emissions

Global annual CO_2 sources and sinks

(MEASURED IN BILLIONS OF TONS OF CO_2)

45% or 20B tons

of emitted CO_2 **remains in the atmosphere** instead of being absorbed by natural sinks



Note: * The "imbalance" is the sum of emissions minus sinks; it is a measure of our imperfect data and understanding of the contemporary carbon cycle.
Source: Bain & Company analysis; Global Carbon Project

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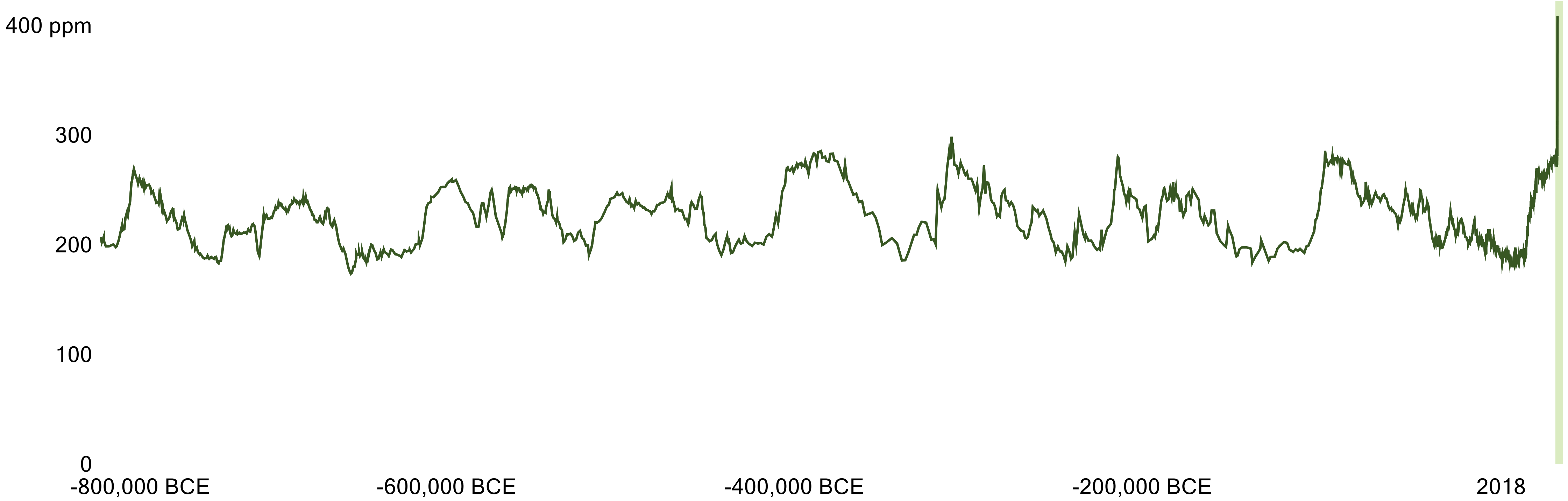
As a result, the atmospheric concentration of CO_2, the “fill level”, has risen rapidly over the past century

Atmospheric CO_2 concentration

(GLOBAL AVERAGE LONG-TERM ATMOSPHERIC CONCENTRATION OF CO_2, MEASURED IN PARTS PER MILLION [PPM]. LONG-TERM TRENDS IN CO_2 CONCENTRATIONS CAN BE MEASURED AT HIGH-RESOLUTION USING PRESERVED AIR SAMPLES FROM ICE CORES)



Source: NOAA

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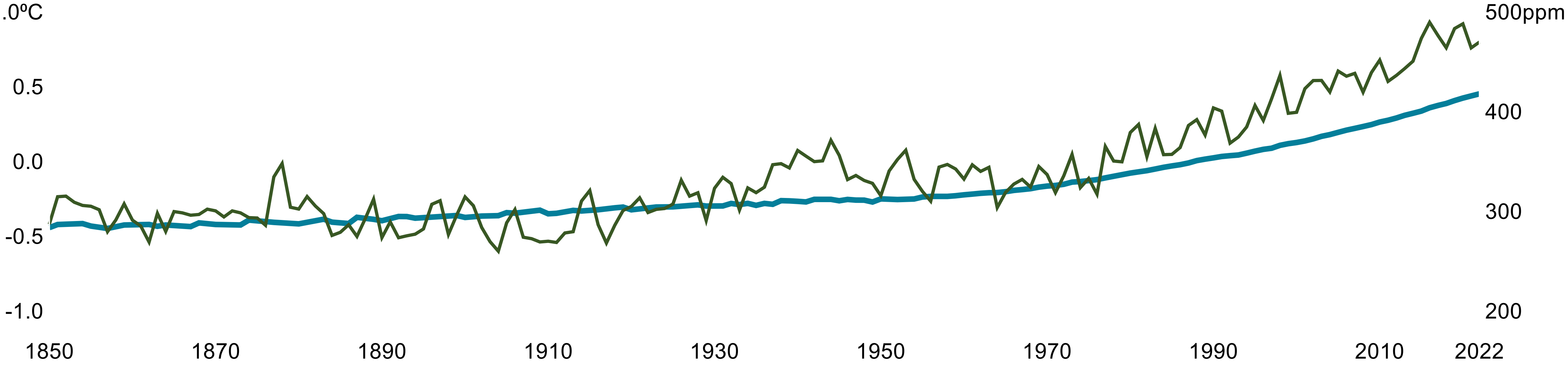
Due to the greenhouse effect, increased atmospheric CO_2 concentration has caused a rise in global temperature

Average global temperature anomaly

ºC

Atmospheric CO_2 concentration

PARTS PER MILLION (PPM)



1.2ºC Approximate warming since pre-industrial times

Median global temperature anomaly

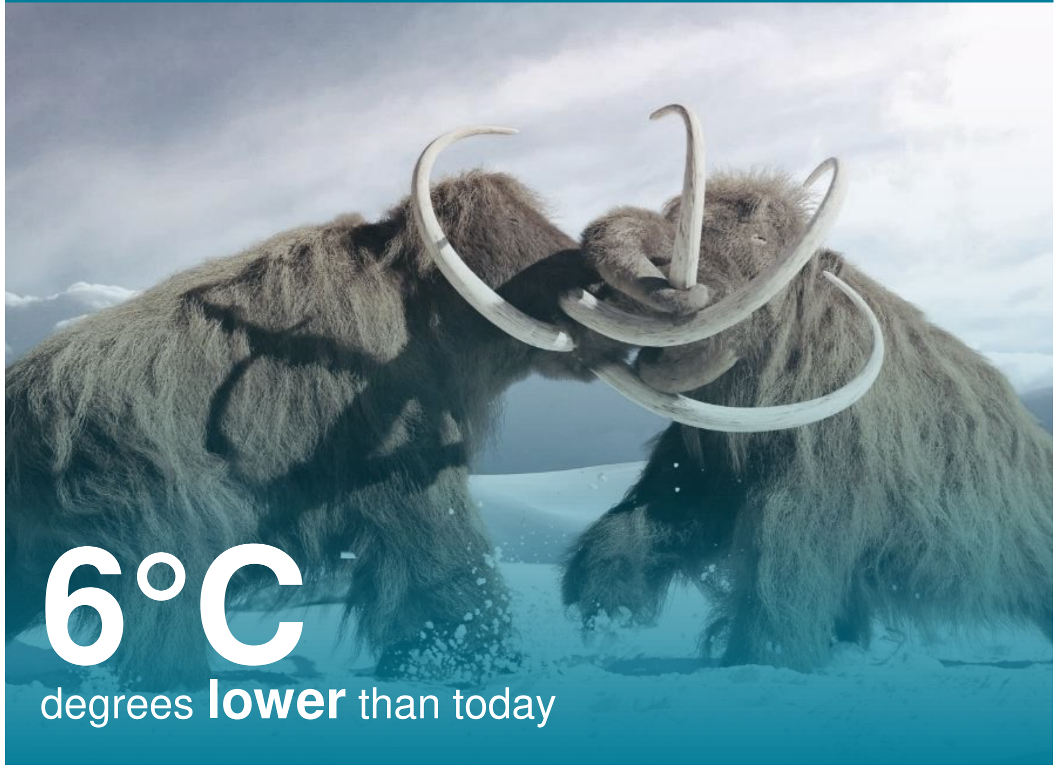
Atmospheric CO_2 Concentration

Note: The green line represents the median average temperature deviation, or anomaly, vs. the 1961-1990 baseline (average) value. Atmospheric CO_2 concentration reflects the annual average.
Source: Bain & Company analysis; Hadley Center; NOAA; IPCC, Sixth Assessment Report (AR6), *Climate Change 2021: The Physical Science Basis, Summary for Policymakers*, A.1.2 (2022); Our World in Data

In climate, “a little is a lot” with respect to temperature changes

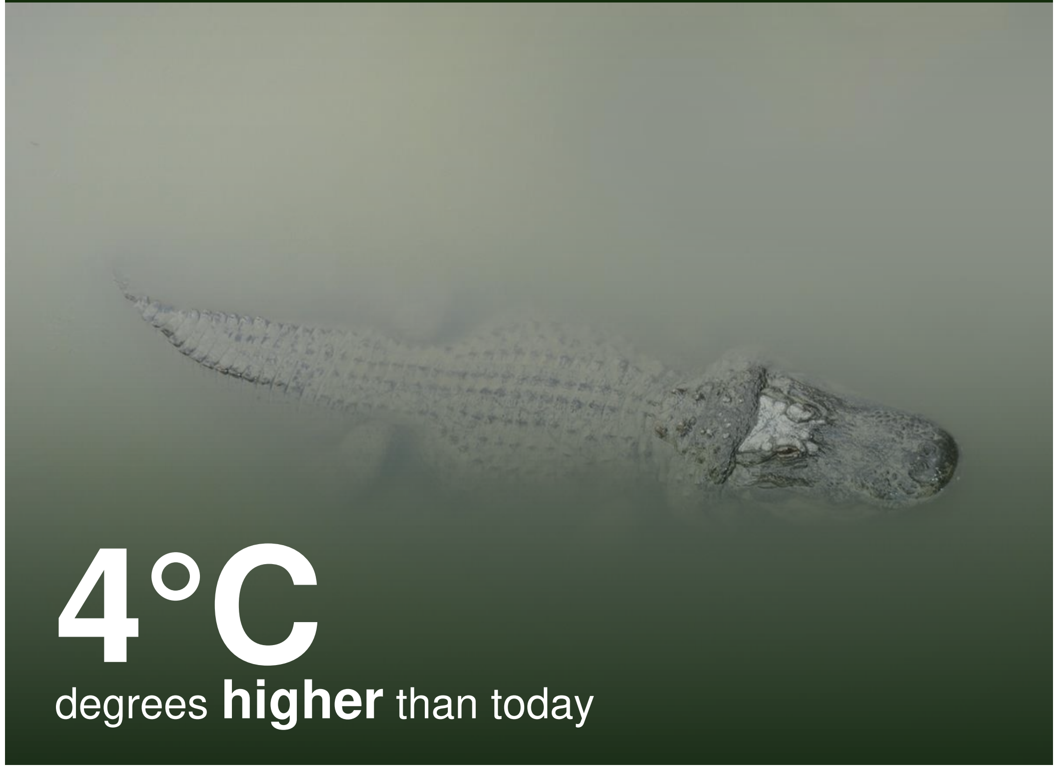
Last ice age

when ~25% of Earth’s land area was covered in glaciers



Age of the dinosaurs

when crocodiles could be found above the Arctic Circle



Source: Bill Gates, How to Avoid a Climate Disaster (2021); USGS

Warming has already produced adverse impacts

Observed impact on ecosystems

Changes in ecosystem structure

Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (**high confidence**)."

Species range shifts

Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (**high confidence**), as well as mass mortality events on land and in the ocean (**very high confidence**)."

Observed impact on human systems

Water scarcity and food production

Climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals (**high confidence**)"

Health and wellbeing

The occurrence of climate-related food-borne and water-borne diseases has increased (**very high confidence**). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (**high confidence**)."

Human displacement

Hazards resulting from the increasing intensity and frequency of extreme weather events…are **already causing an average of more than 20 million people** to leave their homes and move to other areas in their countries each year."

IPCC, AR6

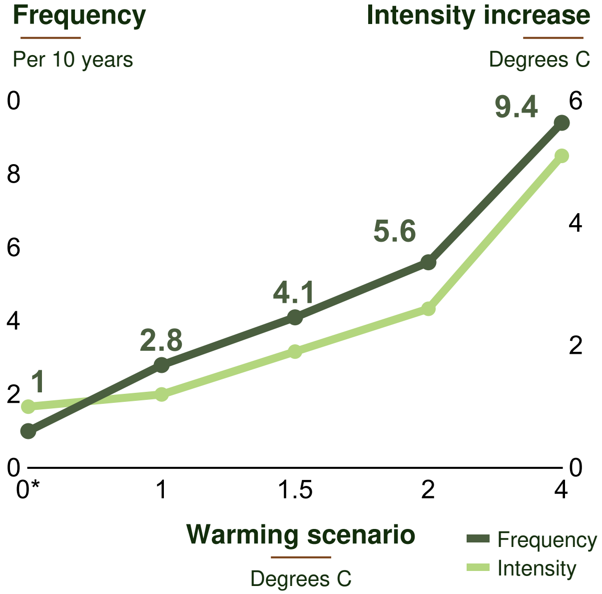
UNHCR

Source: IPCC, Sixth Assessment Report (AR6), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, Section B (2022); UNHCR. Additional detail on IPCC confidence levels can be found in the appendix

IPCC: Warming will very likely lead to a higher frequency, and intensity, of extreme weather events

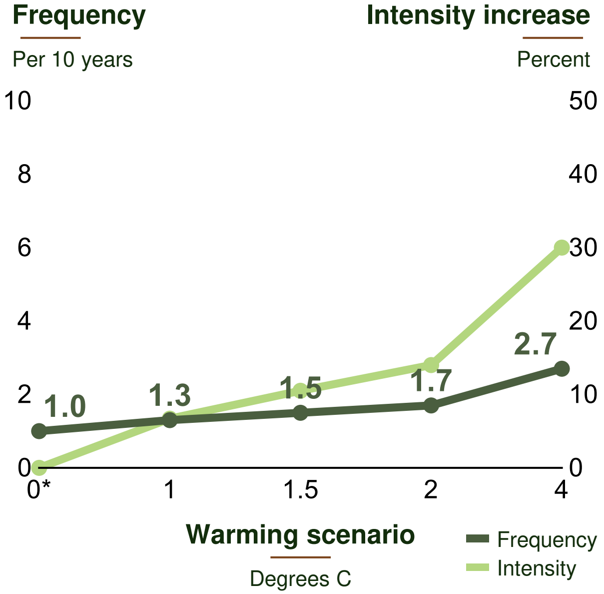
Extreme heat events

Frequency and increase in intensity of extreme temperature event that occurred once in ten years on average in a climate w/out human influence



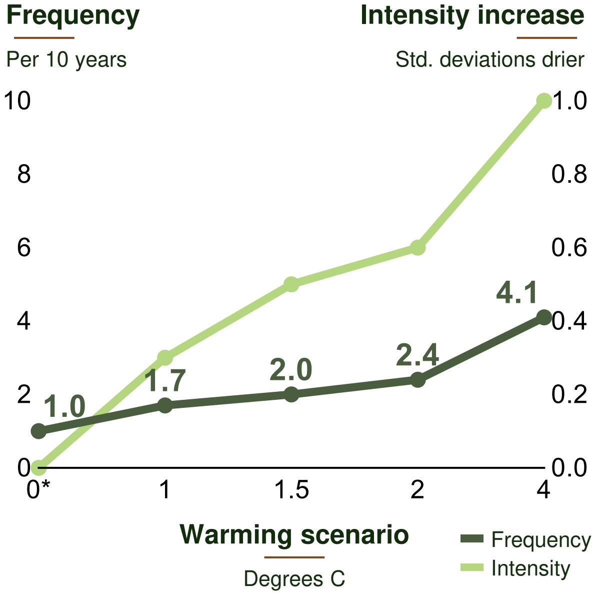
Heavy one-day precipitation events

Frequency and increase in intensity of heavy one day precipitation event that occurred once in ten years on average in a climate w/out human influence



Severe agricultural and ecological drought event

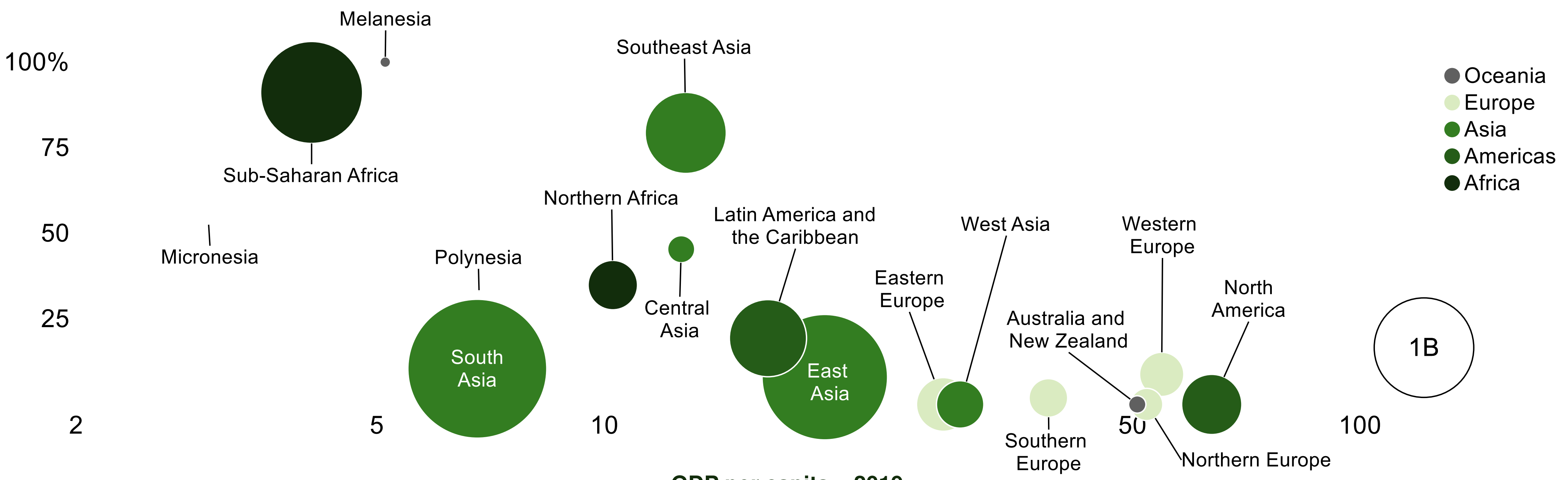
Frequency and increase in intensity of an agricultural & ecological drought event that occurred once in ten years on average across drying regions in a climate w/out human influence



Note: (*) 0 is based on 1850-1900 – all changes are relative to 1850-1900, representing a climate without human influence
Source: IPCC, Sixth Assessment Report (AR6), *The Physical Science Basis – Summary for Policymakers* (2021), Section B.2

Future risks aren't uniformly distributed, with Southeast Asia and sub-Saharan Africa disproportionately exposed

Share of population at high or very high risk



GDP per capita – 2019

Thousands of current 2019 USD

Notes: Share of population at risk based on the WorldRiskIndex, which assesses the risk of disaster as a result of natural hazards, incorporating exposure and vulnerability, and is used by the IPCC to gauge region- and country-level climate change risks; currency is adjusted for purchasing power parity; GDP per capita is shown on a logarithmic scale and is adjusted for purchasing power parity.
Sources: IPCC, Sixth Assessment Report; World Risk Report 2021; World Bank; Bain analysis

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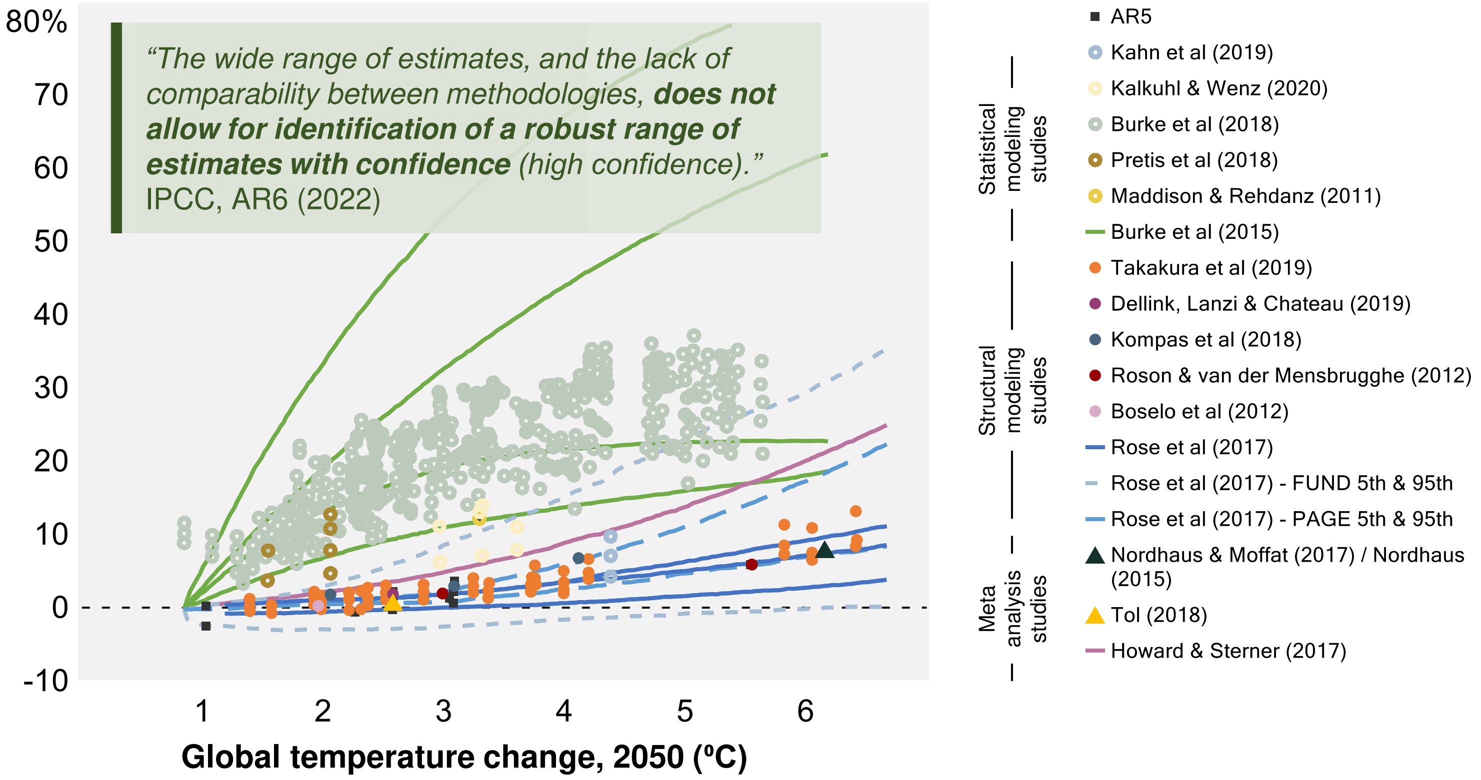
The overall economic cost of continued warming is difficult to estimate but could be substantial

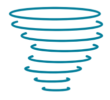
Percent loss in global GDP by 2050

(global GDP losses from rising temperatures, relative to a world without climate change (0ºC))

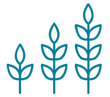


Drivers of adverse GDP impact

(non-exhaustive)



Property / infrastructure damage and disruptions to trade flows from sea level rise and more, and more intense, extreme weather events



Reduced working capacity and lower productivity from labor / land due to heat stress and extreme changes in rainfall

Adverse impacts on human health from heat, weather events and climate-related food- and water-borne diseases

Source: IPCC, Sixth Assessment Report (AR6), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, 16-111 (2022)

OpenMinds

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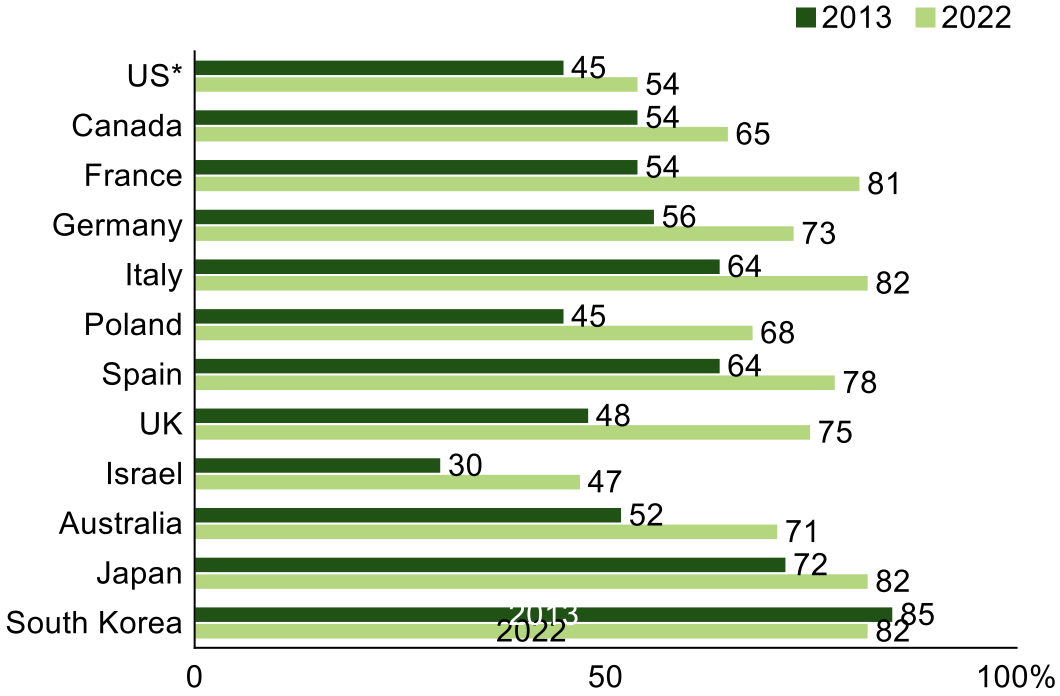
The public is increasingly aware of the risks of climate change—and acting on those concerns

Concern about climate change is significant, and increasing, in advanced economies

Percentage of who say global climate change is a major threat to their country



These concerns are factoring into reproductive decisions

26% Share of **childless adults** in the US **cite climate change as a "major" or "minor" reason** they don't have children

"

…this movement to not have children owing to fears over climate change is growing and impacting fertility rates quicker than any preceding trend in the field of fertility decline…

MORGAN STANLEY, DEMOGRAPHICS: GRADUALLY, THEN SUDDENLY (JULY 2021)

"

Basically, **there's a scientific consensus that the lives of children are going to be very difficult**. And it does lead, I think, young people to have a legitimate question: **Is it okay to still have children**?

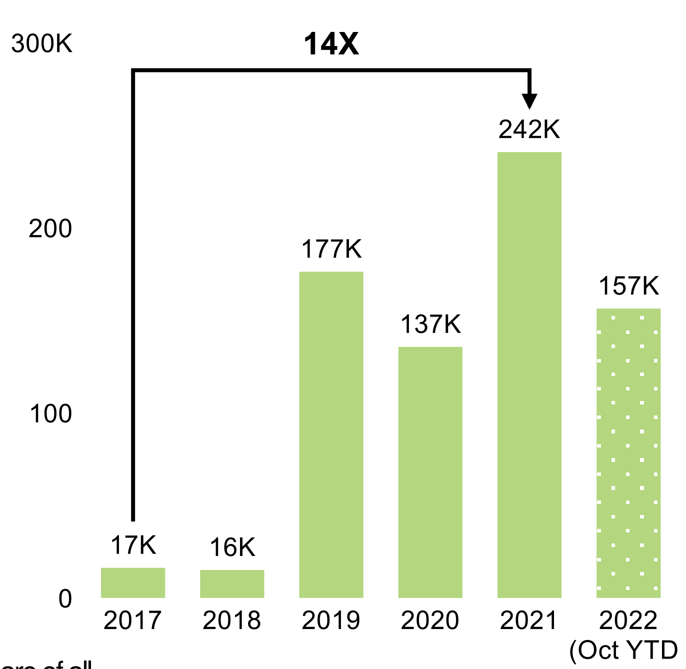
REP. ALEXANDRIA OCASIO-CORTEZ, INSTAGRAM LIVE VIDEO (2019)

Note: * US data in left hand chart reflects 2012 and 2022
Source: Bain & Company analysis; Pew Research Center, *Climate Change Remains Top Global Threat Across 19-Country Survey* (2022); Morgan Stanley, *Demographics: Gradually, Then Suddenly* (July 2021); Morning Consult, *1 in 4 Childless Adults Say Climate Change Has Factored Into Their Reproductive Decisions* (Sep 2020)

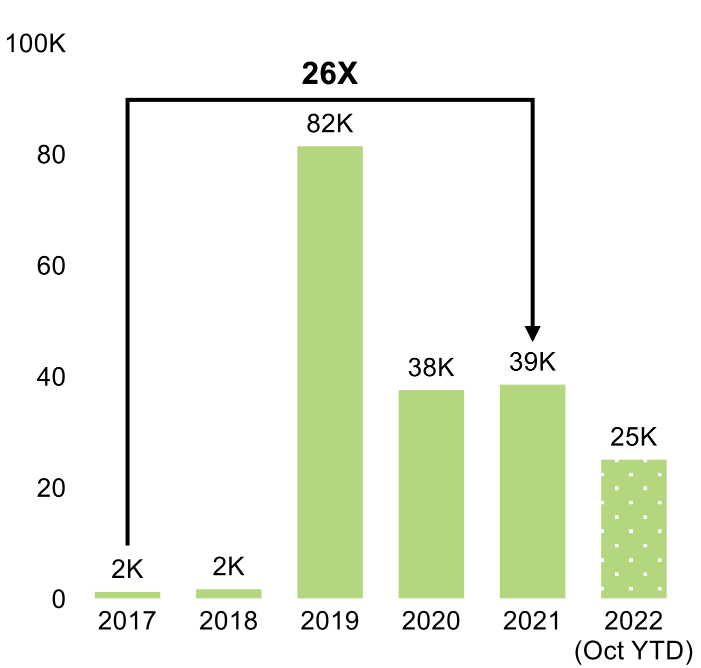
The tone news outlets use to describe climate change has become more urgent

Number of mentions of search term in global online news (thousands of articles)

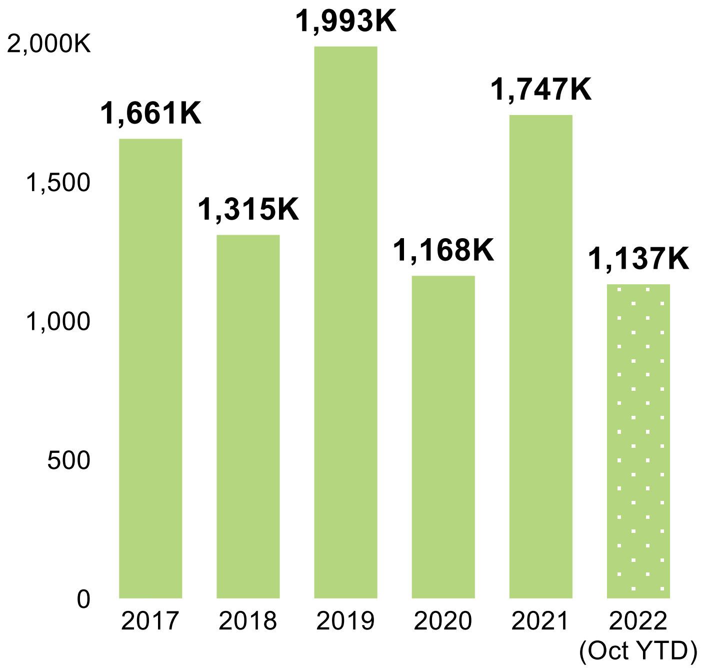
Climate crisis



Climate emergency



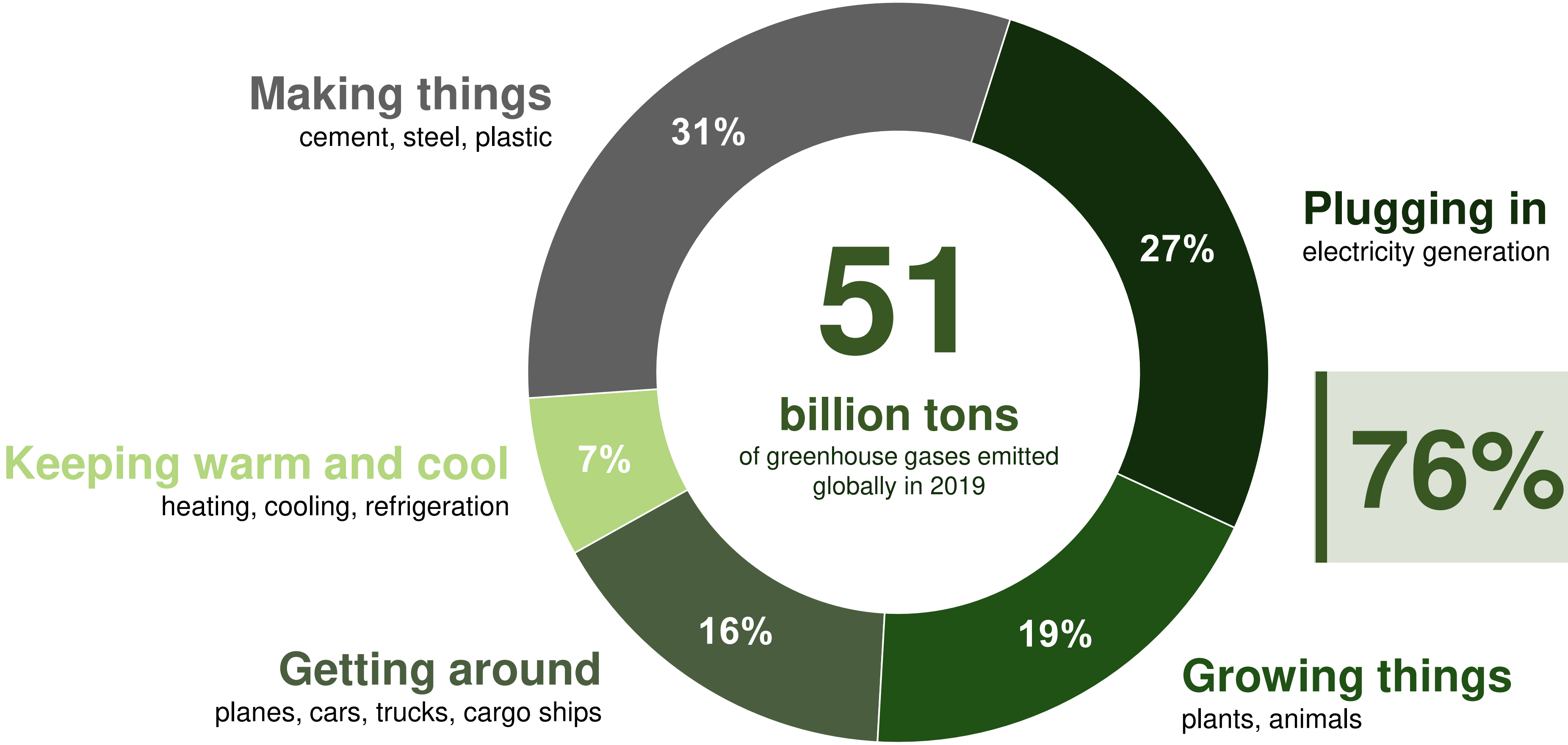
Climate change



	2017	2018	2019	2020	2021	2022
Share of all monitored articles (Climate crisis)	0.01%	0.01%	0.10%	0.10%	0.20%	0.19%
(Climate emergency)	0.00%	0.00%	0.05%	0.03%	0.03%	0.03%
(Climate change)	0.73%	0.68%	1.17%	0.85%	1.45%	1.34%

Source: Bain & Company analysis; GDELT Online News Summary

In 2019, a range of human activities resulted in the release of about 51 billion tons of greenhouse gases



76% share of total emissions accounted for by **fossil fuels (coal, oil, gas) combustion**

Note: Emissions measured in tons of CO_2-equivalent and include carbon dioxide, methane, nitrous oxide, and f-gases
Source: Bill Gates, *How to Avoid a Climate Disaster* (2021)

3

Even one gigaton is enormous in scale

1 gigaton

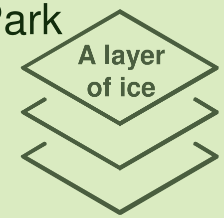
(or 1 billion metric tons)

2.2
trillion pounds

10,000
fully loaded US aircraft carriers

400,000
Olympic-sized swimming pools

~1,100ft
(or 100+ stories) **deep** covering Central Park



Source: NASA, NOAA

OpenMinds

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Products we rely on everyday are significant sources of greenhouse gas emissions





Materials	**Steel**	**Cement**	**Plastic**	**Beef**	**Gasoline**
Annual global production (metric tons)	1.9 billion	4.3 billion	4.3 billion	59 m	billion
✖					
Emissions intensity (tons of CO_2-e emitted	1.8	0.9	1.3	100	3.1
=					
Total annual CO_2-e emissions globally (metric tons)	**~3.4 billion**	**~3.9 billion**	**~0.5 billion**	**~5.9 billion**	**~3.4 billion**

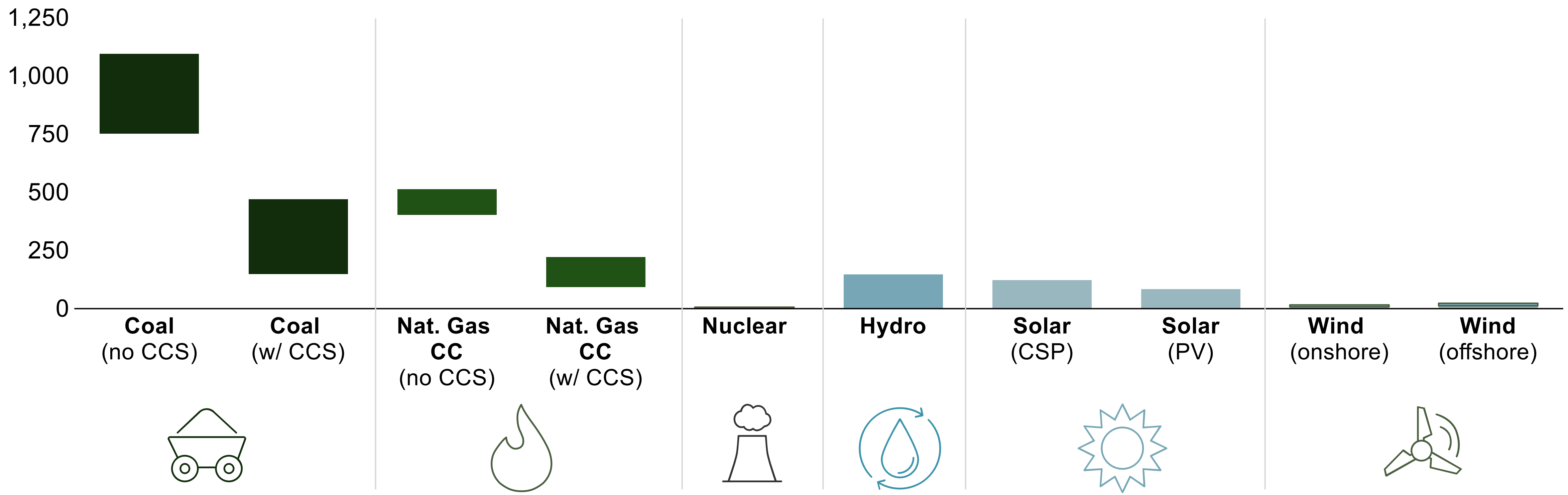
Consuming 20 gallons (75 L) of gasoline produces about **400 lbs (181 kg) of CO_2**

Note: Global production values are directional; gasoline intensity is based on burning a gallon of gasoline
Source: Bain & Company analysis; EIA; NIH; USDA; Bill Gates, How to Avoid a Climate Disaster (2021); Poore & Nemecek (2018); Portland Cement Association; UN Environment Programme

In electricity generation, greenhouse gas emission intensity varies widely by generation source

Lifecycle greenhouse gas emissions

(measured in g of CO_2 - equivalent per kWh)

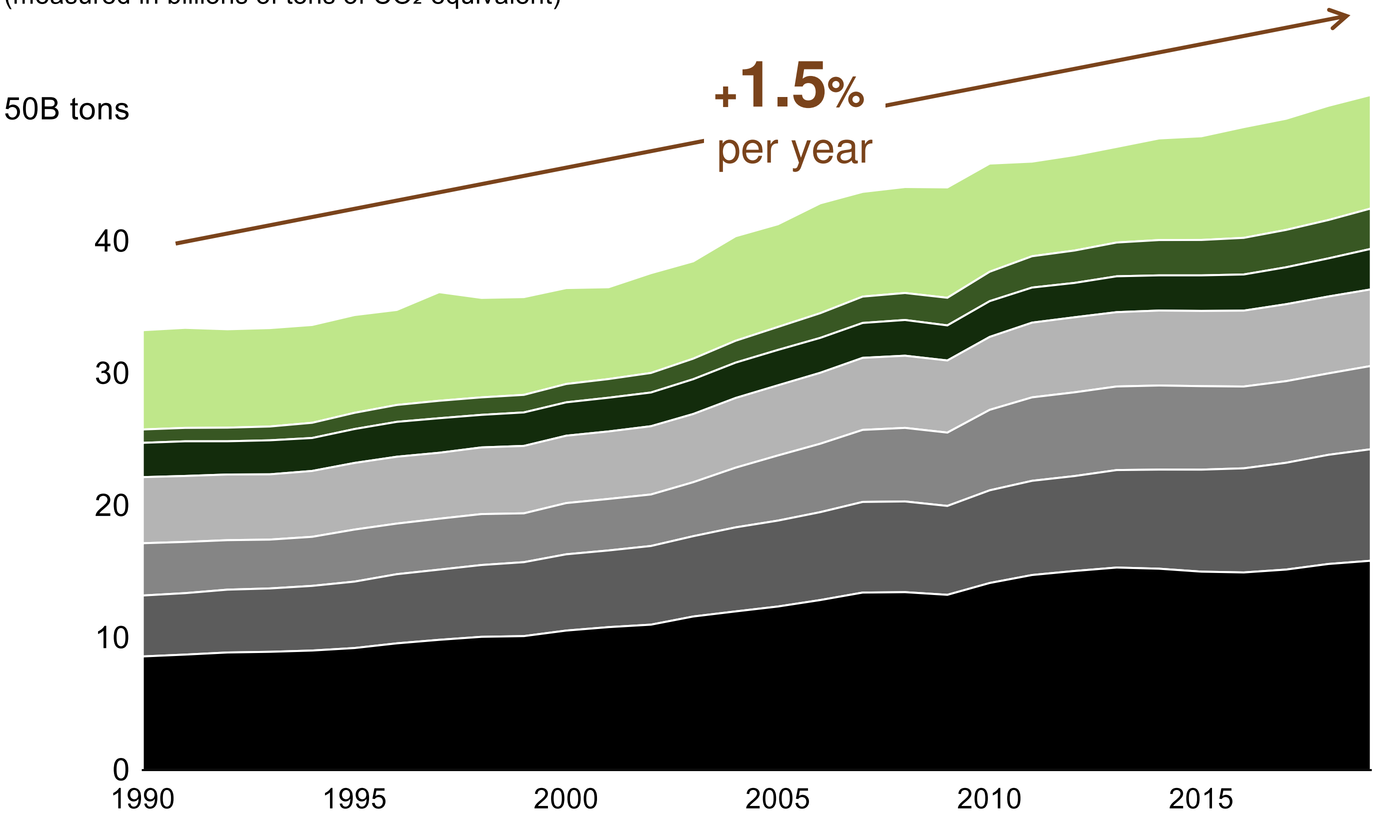


Note: CCS = Carbon Capture & Storage, CC = Combined Cycle, CSP = Concentrating Solar-Thermal Power, PV = Photovoltaic
Source: UN Economic Commission for Europe, Life Cycle Assessment of Electricity Generation Options (2021)

Anthropogenic GHG emissions have grown steadily and are 50% higher today than they were in 1990

Annual global greenhouse gas emissions by sector

(measured in billions of tons of CO_2-equivalent)



	% of total 1990	% of total 2019	1990-2019 change
Other sources*	23%	17%	1.1X
Industry	3%	6%	3.0X
Buildings	8%	6%	1.2X
Agriculture	15%	11%	1.2X
Manufacturing & construction	12%	12%	1.6X
Transport	14%	17%	1.8X
Electricity and heat	26%	31%	1.8X
	100%	100%	1.5X

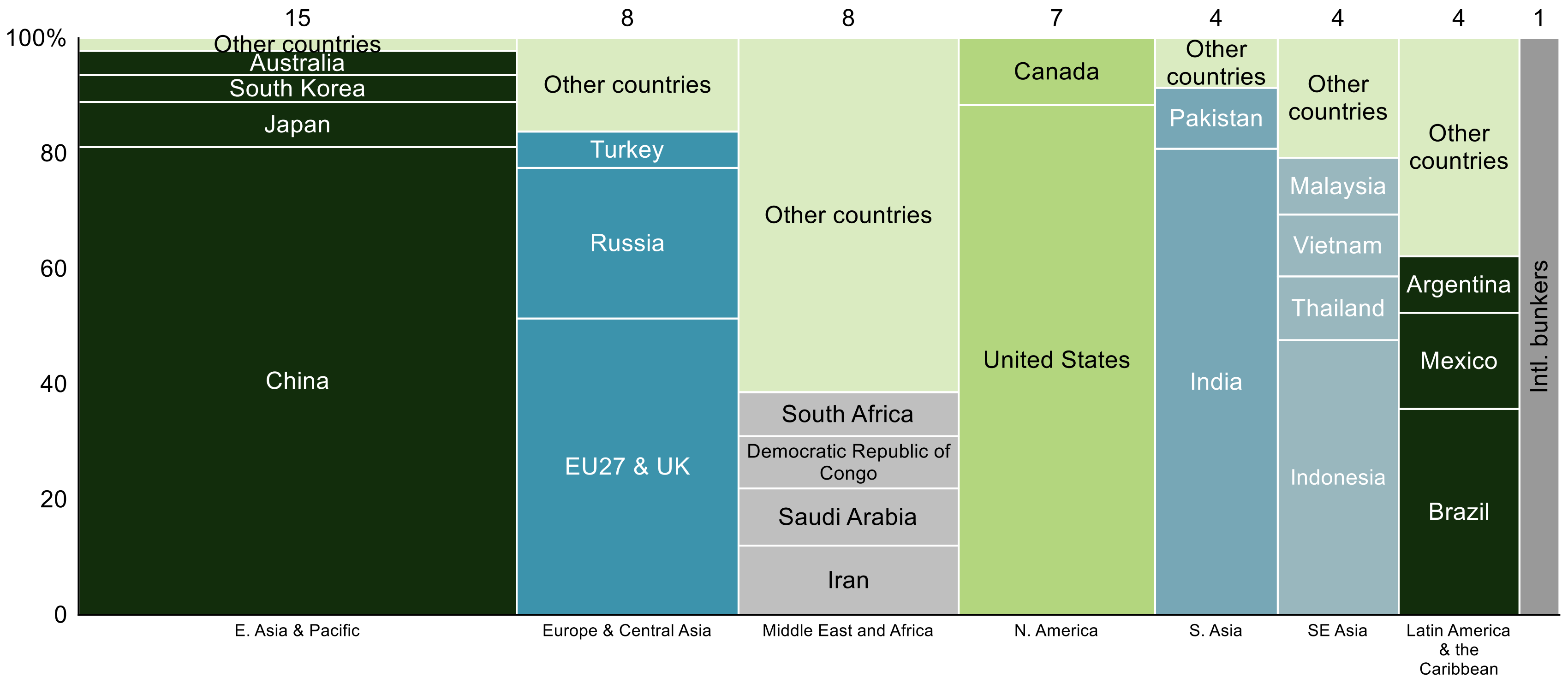
Note: * Other includes aviation / shipping, land-use change and forestry, waste, fugitive emissions, and other fuel combustion. Emissions source mix differs vs. prior pages due to categorization differences. For example, “Industry” and “Manufacturing & construction” are broken out separately here, versus included together in “Making things”. Source: Climate Watch

3

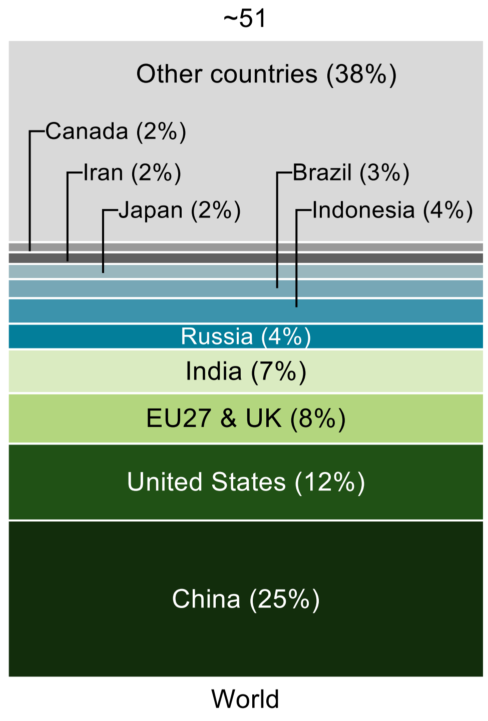
The top 10 emitting countries account for nearly two-thirds of global GHG emissions, China and the US alone nearly 40%

Greenhouse gas emissions by continent and country, 2019

(measured in billions of tons of CO_2-equivalent; includes non-CO_2 GHG emissions like methane)



Top 10 global emitters

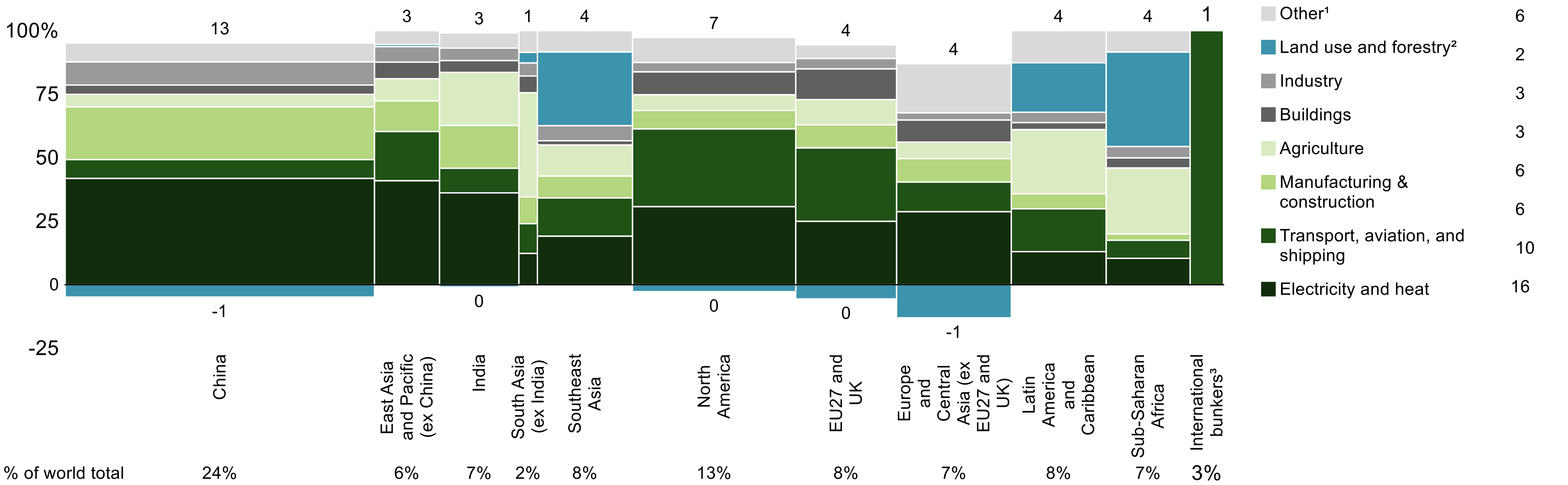


Note: * Other countries include those with <400M tons of CO_2-equivalent emissions in 2018. Emissions from international aviation and shipping included in "other countries" in right-side chart.
Source: Bain & Company analysis; Climate Watch; Our World in Data

Emissions sources vary materially from country to country

Greenhouse gas emissions by sector, 2019

(measured in billions of tons of CO_2-equivalent; includes non-CO_2 GHG emissions like methane)



Note: (1) "Other" includes waste, fugitive emissions, and other fuel combustion. (2) Land use and forestry emissions reflect the emission (via deforestation, conversion of other natural ecosystems to agriculture, etc.) or sequestration (via reforestation, afforestation, wetland restoration, grassland restoration, etc.) of carbon through human activities. (3) International bunkers comprises emissions associated with international aviation and marine transportation.
Source: Bain & Company analysis; Climate Watch; Our World in Data; IPCC, Sixth Assessment Report (AR6), Working Group III, Chapter 7

3

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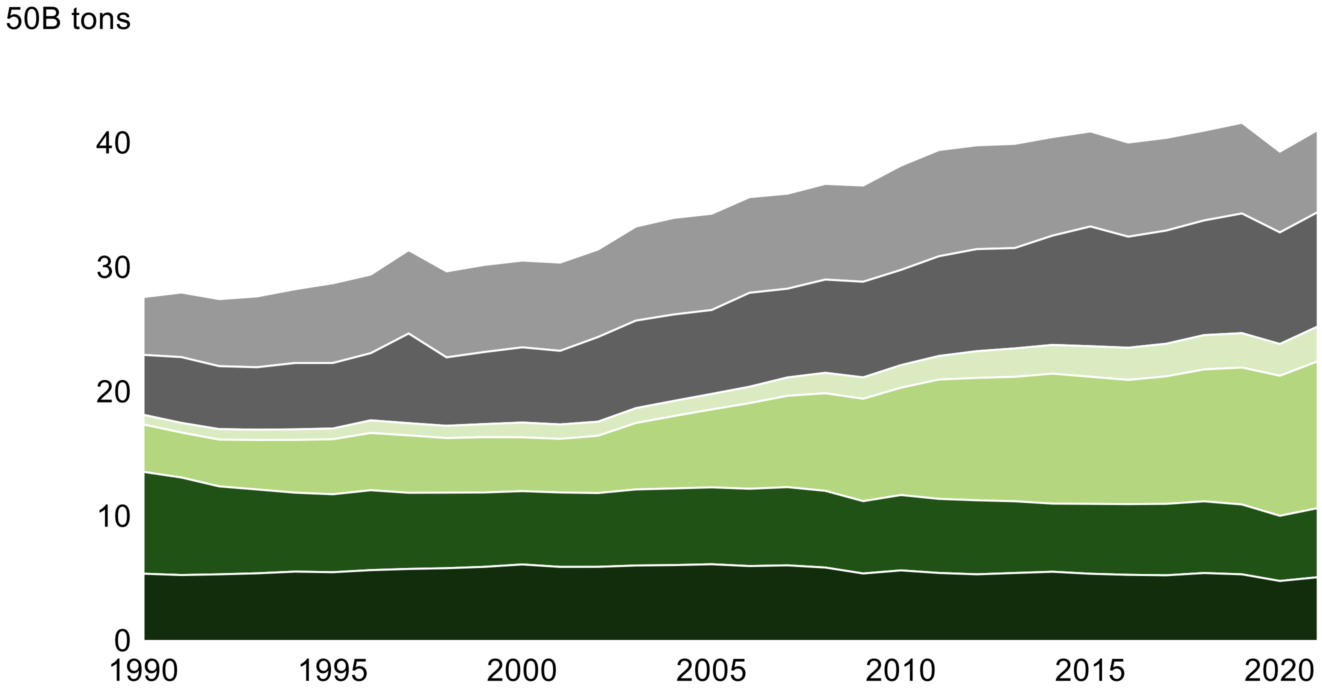
Asia accounts for nearly 60% of anthropogenic CO_2 emissions today

Annual CO_2 emissions by country or region

(PRODUCTION-BASED EMISSIONS OF CARBON DIOXIDE [CO_2], MEASURED IN MILLION TONS. THIS IS BASED ON TERRITORIAL EMISSIONS, WHICH DO NOT ACCOUNT FOR EMISSIONS EMBEDDED IN TRADED GOODS. EXCLUDES NON-CO_2 EMISSIONS)



	Percentage of total 1990	Percentage of total 2019	1990-2019 change
Rest of world	17%	18%	1.6X
Asia (excl. China and India)	17%	23%	2.0X
India	3%	7%	3.6X
China	14%	26%	2.9X
Europe	30%	13%	0.7X
United States	20%	13%	1.0X
	100%	100%	1.5X

Note: Includes CO_2 emissions from fossil fuels and land use change
Source: Bain & Company analysis; Global Carbon Project; Our World In Data

OpenMinds

Since 1990, non-OECD countries have driven all global anthropogenic CO_2 emissions growth

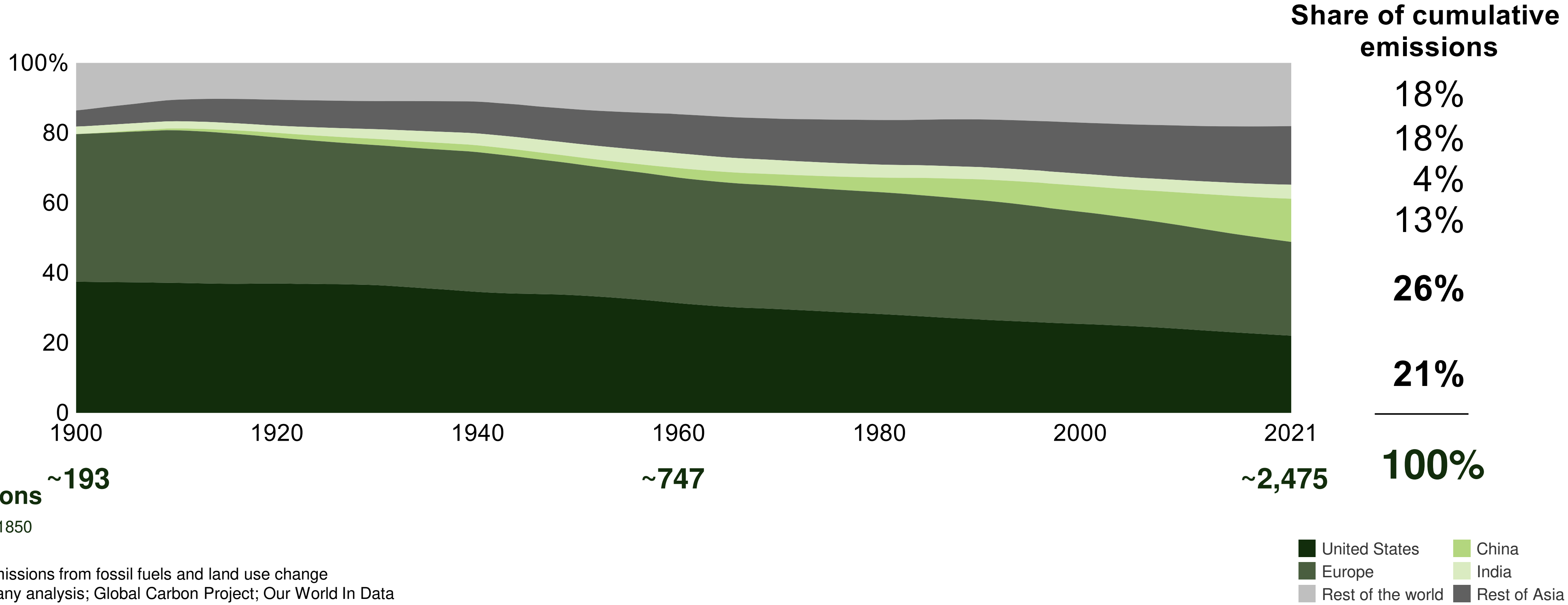
Gigatons of CO_2[1]	1990 Emissions	1990 % of total	2021 Emissions	2021 % of total	Share of 1990-2021 growth
United States	5.4	20%	5.1	12%	(2%)
European Union (27)	3.7	13%	2.6	6%	(8%)
Other OECD	3.7	13%	4.6	11%	6%
Total OECD	**12.8**	**46%**	**12.3**	**30%**	**(4%)**
China	3.8	14%	11.8	29%	60%
India	0.8	3%	2.8	7%	15%
Other non-OECD	10.2	37%	14.2	34%	29%
Total non-OECD	**14.8**	**54%**	**28.7**	**70%**	**104%**
World	**27.6**	**100%**	**41.1**	**100%**	**100%**

Note: (1) Emissions are production-based and include emissions from energy and land-use change, measured in gigatons of CO_2
Source: Global Carbon Project

But on a cumulative basis, the US and Europe have contributed much more to increased atmospheric CO_2 concentration

Cumulative CO_2 emissions by country or region

Acumulative production-based emissions of carbon dioxide [CO_2] since the first year of data available, measured in million tons. This is based on territorial emissions, which do not account for emissions embedded in traded goods. Excludes non-CO_2 emissions



Note: Includes CO_2 emissions from fossil fuels and land use change
Source: Bain & Company analysis; Global Carbon Project; Our World In Data

OpenMinds

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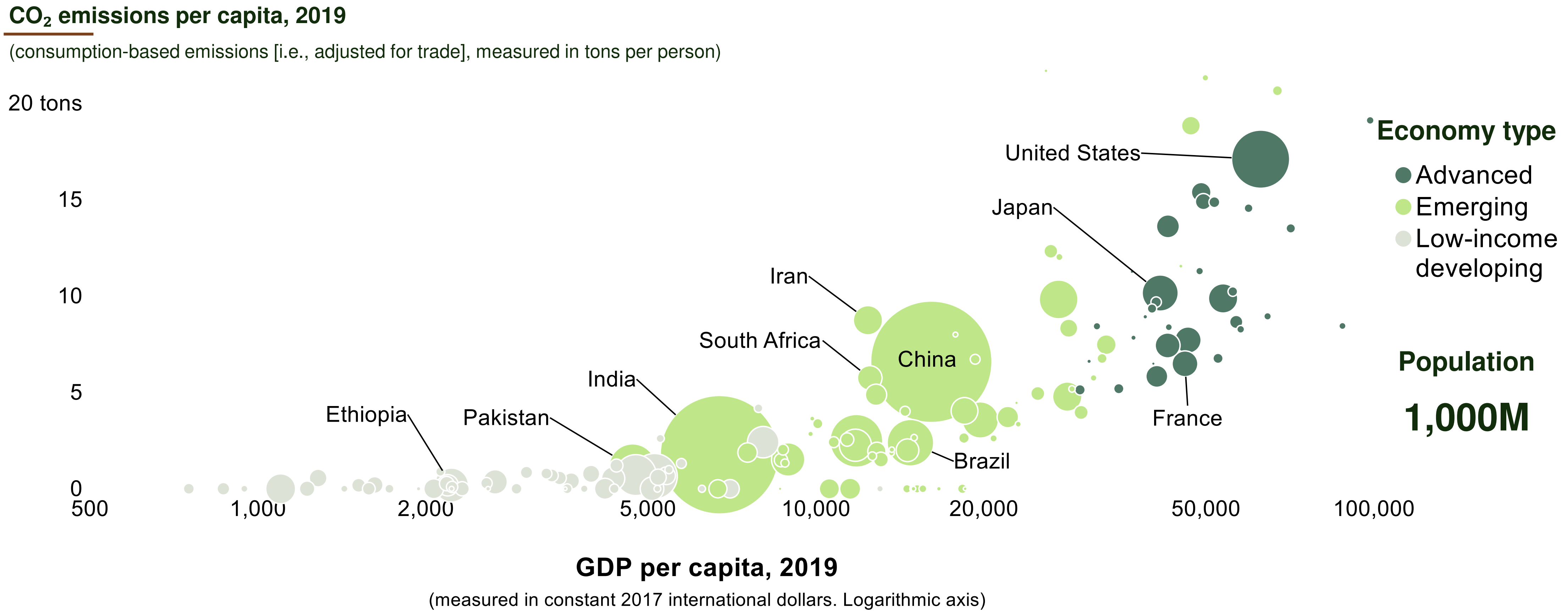
Similarly, energy consumption is highly correlated with economic progress—and there is still considerable inequality



Source: Bain & Company analysis; World Bank; IMF; Global Carbon Project; Our World In Data

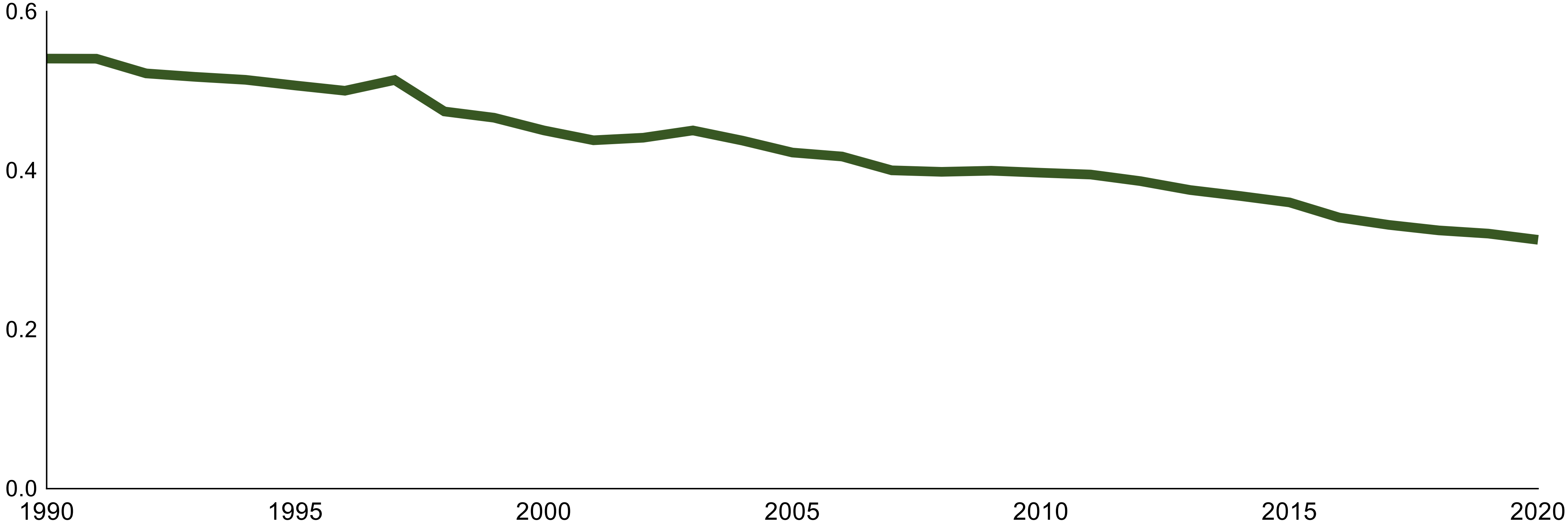
OpenMinds

But the emissions intensity of GDP has fallen significantly

41% **decline in CO_2 emissions per dollar of GDP over 1990-2019**. Drivers include **coal-to-gas switching** and **increased energy efficiency** in power generation and industrial processes, and today, in over 30 countries including the US, **economies are growing while emissions fall**

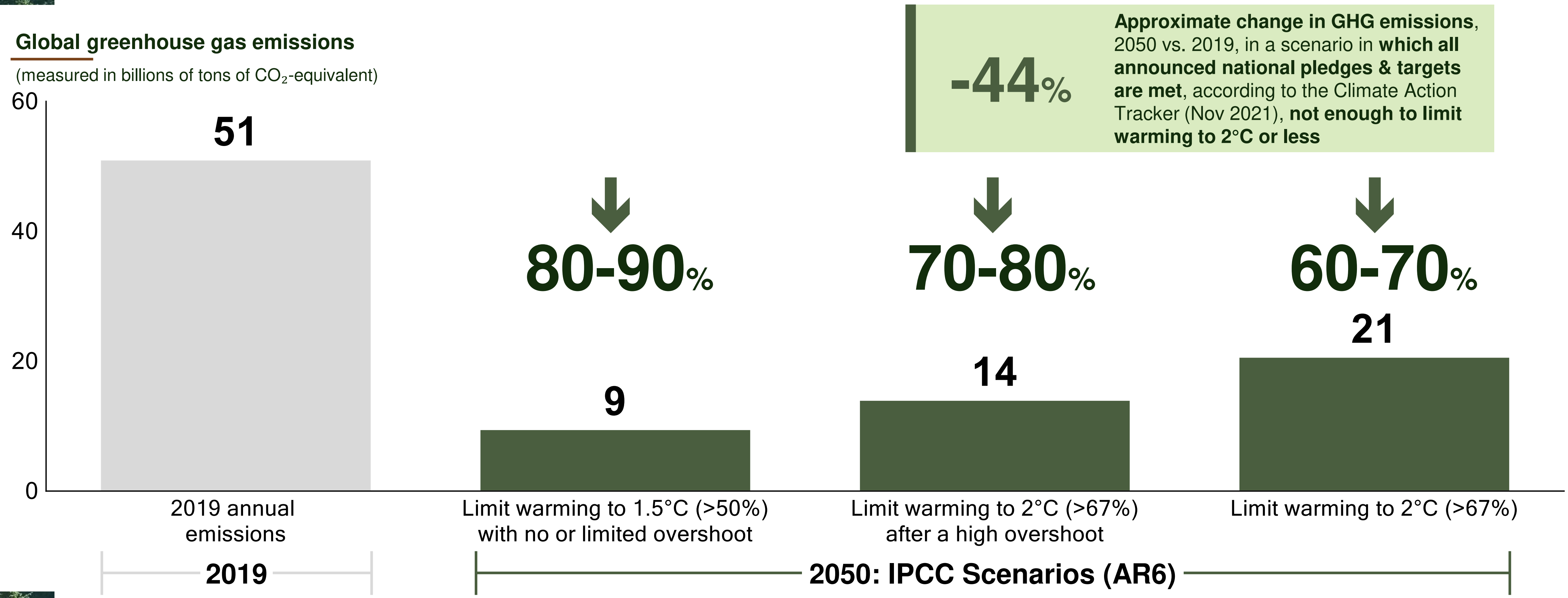
Global emissions intensity of GDP

(measured in tons of CO_2 per thousand 2015 PPP-adjusted USD; excludes non-CO2 GHG emissions like methane)



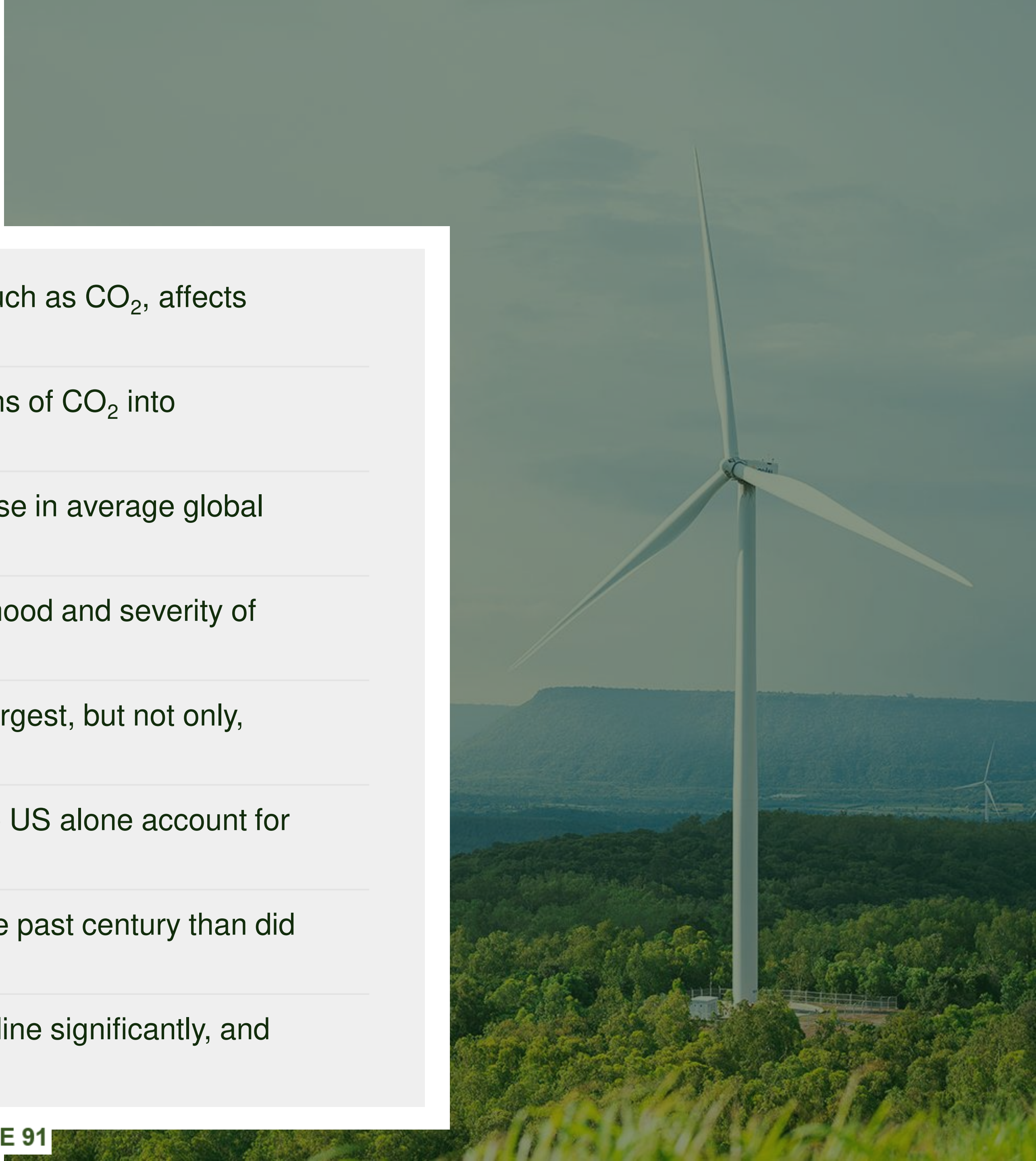
Note: Includes CO_2 emissions from fossil fuels and land use change
Source: Bain & Company analysis; Our World in Data; Global Carbon Project; Maddison Project Database 2020; Climate Action Tracker; The Breakthrough Institute

To limit warming, greenhouse gas emissions will need to decline significantly in the coming years



Note: ">50%" and ">67%" refer to probability of reaching scenario should emissions reduction targets be reached | Source: Bain & Company analysis; IPCC, Sixth Assessment Report (AR6), Climate Change 2022: Mitigation of Climate Change – Summary for Policymakers, Table SPM.1 (2022); Climate Action Tracker (updated Nov 2021); Our World in Data

Climate Change: Fundamentals and Possible Trajectories



- The atmospheric concentration of greenhouse gases (GHGs), such as CO_2, affects the earth's climate
- Human activity has led to the release of more than two trillion tons of CO_2 into the atmosphere since 1850
- This release has been an important driver of an observed increase in average global surface temperature vs. pre-industrial times
- Warming contributes to rising sea levels and increases the likelihood and severity of certain types of extreme weather
- The combustion of fossil fuels (for a variety of end uses) is the largest, but not only, source of emissions
- Today, Asia is the largest greenhouse gas emitter; China and the US alone account for almost 40% of the global total
- But the US and Europe cumulatively emitted much more over the past century than did any other region
- To mitigate the risk of climate change, GHG emissions must decline significantly, and ideally reach net zero, within a few decades

Agenda

01 OpenMinds and the Dual Challenge: Executive Summary

02 Energy: Uses, Sources, and Outlook

03 Climate Change: Fundamentals and Possible Trajectories

04 Reality Check: Where We Are Today

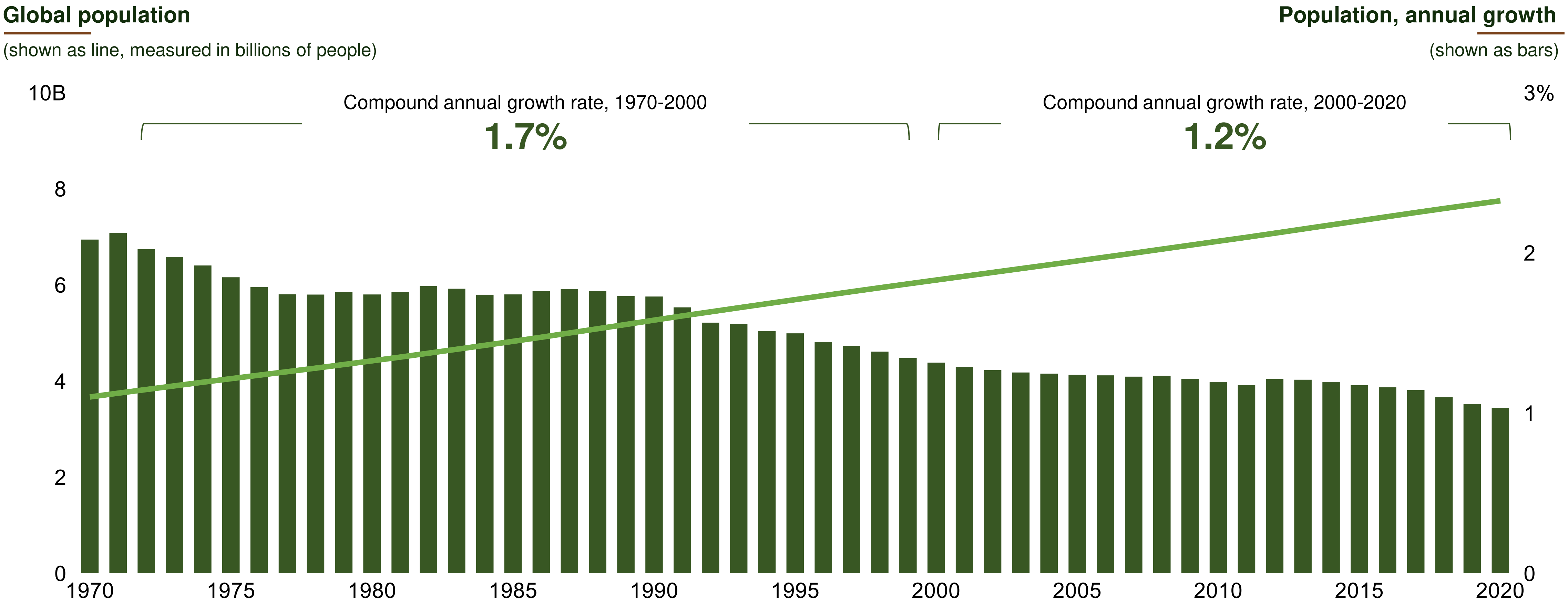
05 The Dual Challenge: Headwinds and Tailwinds

Reality Check: Where We Are Today

- Over the last half-century (since 1970), global population doubled, and overall GDP nearly quintupled
- As GDP per capita increased, so did energy consumption per capita (offset somewhat by efficiency gains)
- Altogether, driven by population and income, and somewhat offset by efficiency gains, total energy consumption tripled in the last 50 years
- To meet that tripling, the global energy supply mix changed only slightly, and today, we remain heavily reliant on fossil fuels
- Emissions increased alongside energy supply, doubling since 1970, and we have yet to "bend the curve"
- There is still considerable economic and energy inequality around the world today
- Emerging economies will need significantly more energy over the next decades to support development

The bottom line: We must meet the growing demand for energy while reducing greenhouse gas emissions, with the aim of enhancing the wellbeing of humans everywhere.

Since 1970, the global population doubled in size

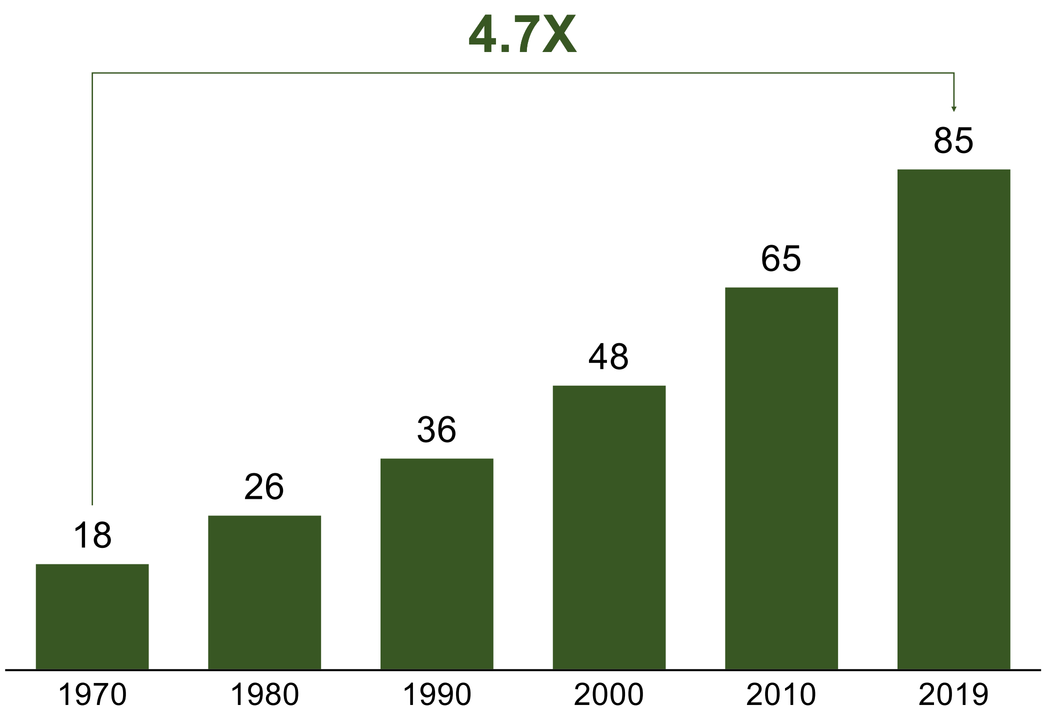


Source: Bain & Company analysis; Our World in Data; World Bank

During that time, global GDP nearly quintupled, and GDP per capita more than doubled

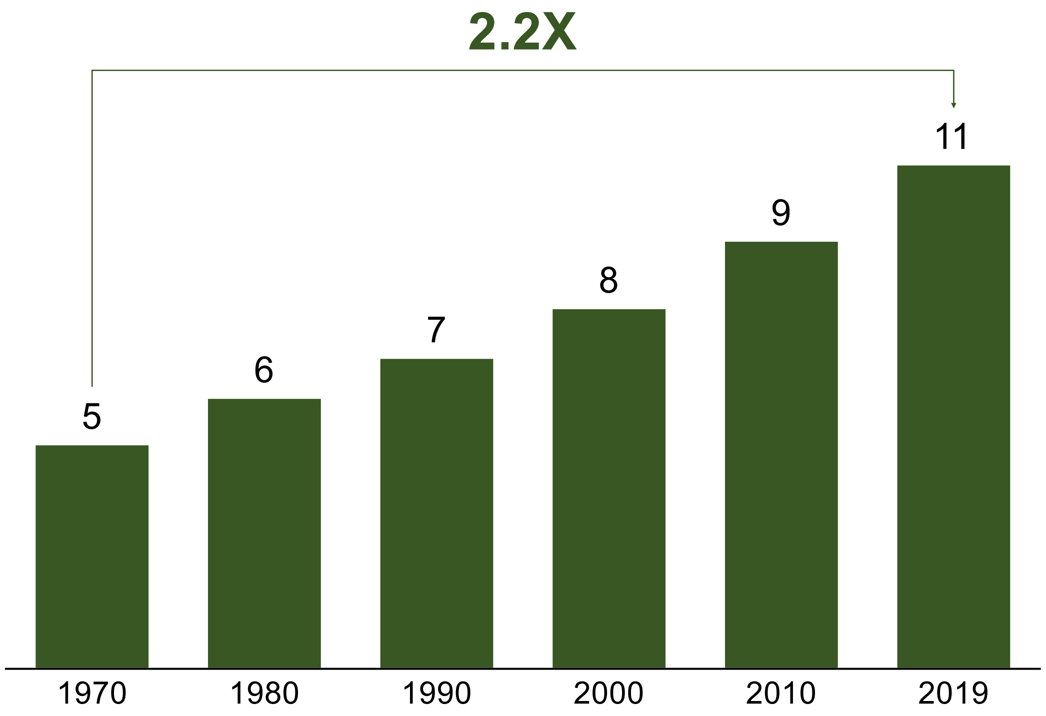
Global GDP

(trillions of constant 2015 US$)



Global GDP per capita

(trillions of constant 2015 US$ per person)

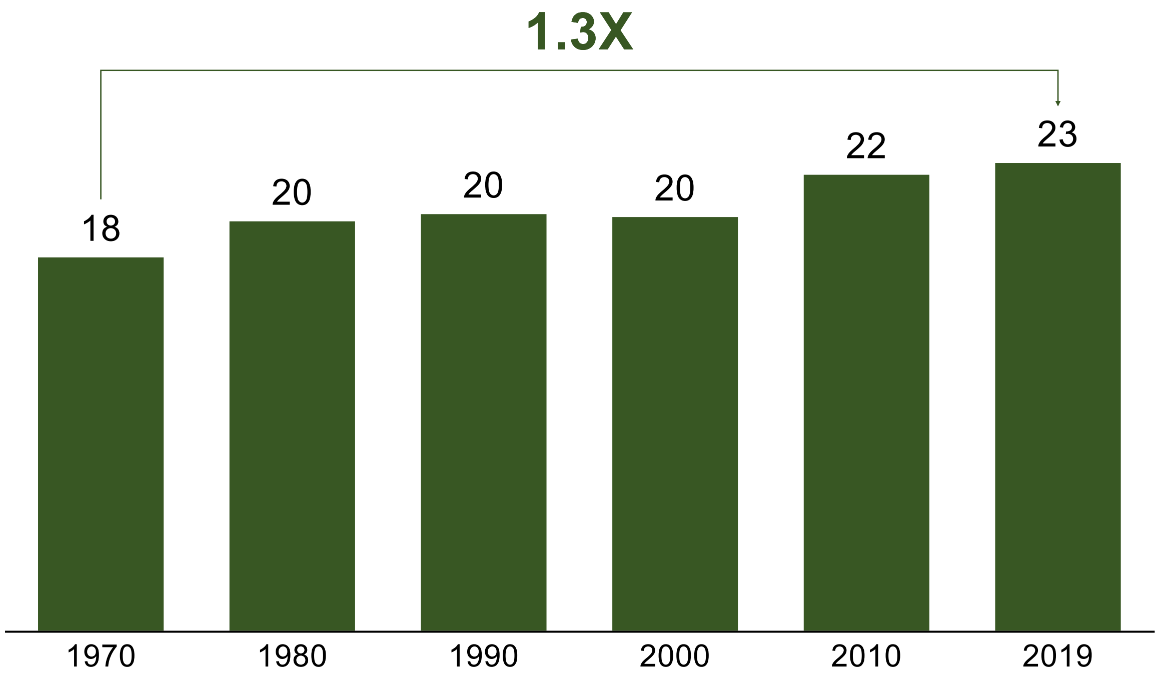


Note: Data are in constant 2015 prices, expressed in U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2015 official exchange rates.
Source: Bain & Company analysis; Our World in Data; World Bank

As GDP per capita increased, so did energy consumption, offset somewhat by efficiency gains

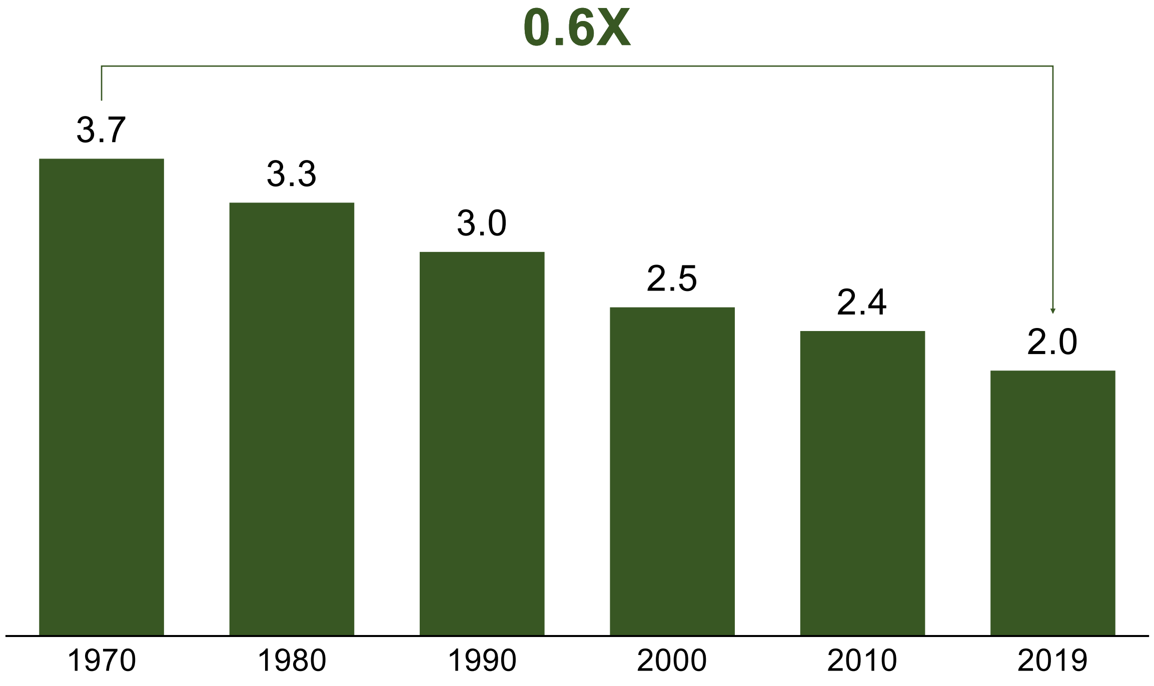
Global primary energy consumption per capita

(megawatt-hours per person per year)



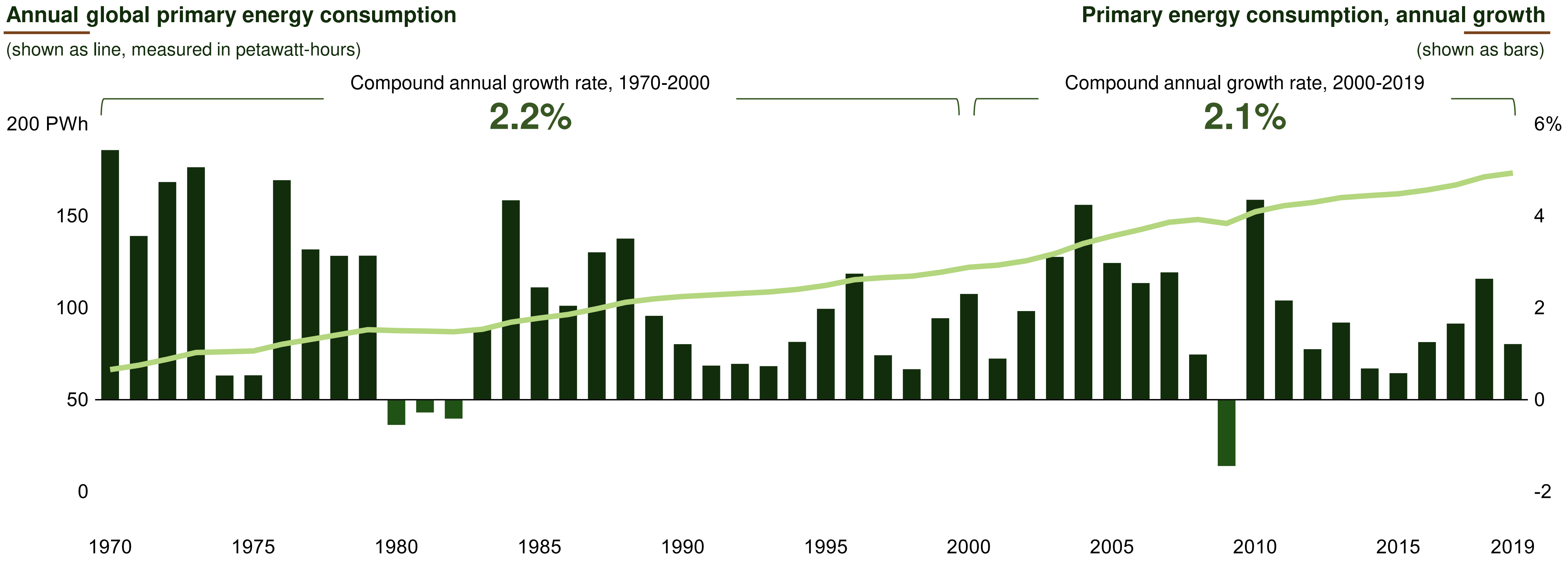
Global primary energy intensity

(kilowatt-hours per dollar of GDP in constant 2015 US$)



Note: Data are in constant 2015 prices, expressed in U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2015 official exchange rates.
Source: Bain & Company analysis; Our World in Data; World Bank; BP Statistical Review of World Energy, 2021

Altogether, annual global energy consumption nearly tripled in the last 50 years

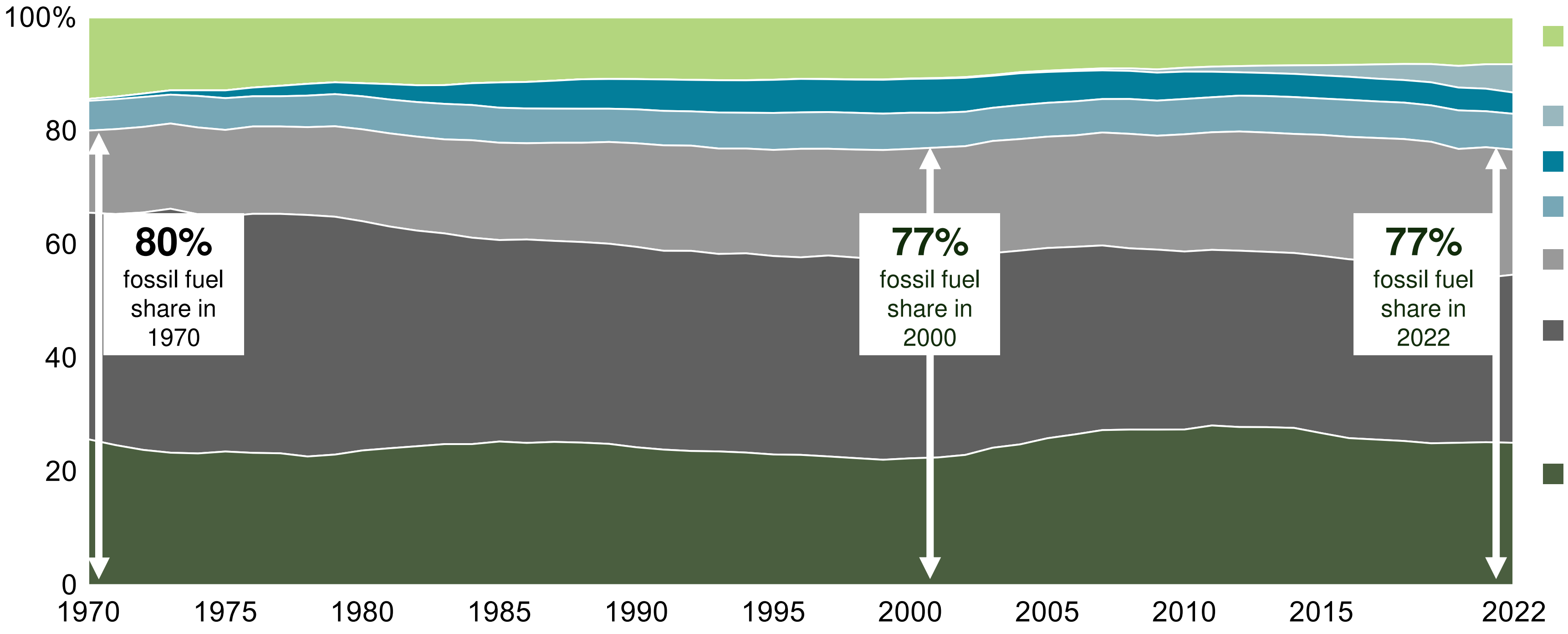


Note: Primary energy includes both commercially-traded fuels, including modern renewables used to generate electricity, and traditional biomass (~10k TWh in 2019)
Source: BP Statistical Review of World Energy, 2021

The global energy mix changed only modestly to meet the tripling in energy consumption

Global primary energy consumption by source, 1970-2022

(measured in petawatt-hours)



Share of total

	1970	2022
Other	14%	8%
Wind/solar	0%	5%
Nuclear	0%	4%
Hydro	5%	6%
Gas	14%	22%
Oil	40%	30%
Coal	26%	25%

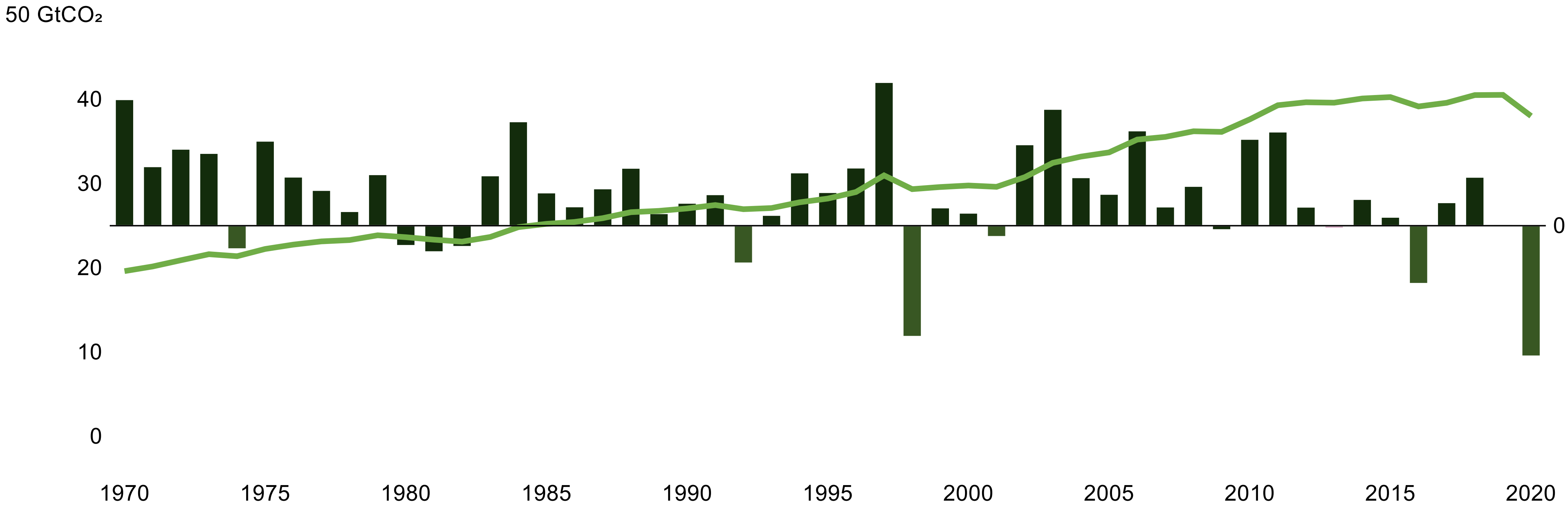
Note: "Other" includes other renewables, biofuels, and traditional biomass

Source: Bain & Company analysis; Our World in Data; Vaclav Smil, Energy Transitions: Global and National Perspectives (2017); BP Statistical Review of World Energy, 2021

Annual CO_2 emissions also steadily increased over the last five decades, roughly doubling

Annual global CO_2 emissions from industry and land use change
(shown as line, measured in billions of tons of CO_2)

CO_2 emissions, annual growth
(shown as bars)



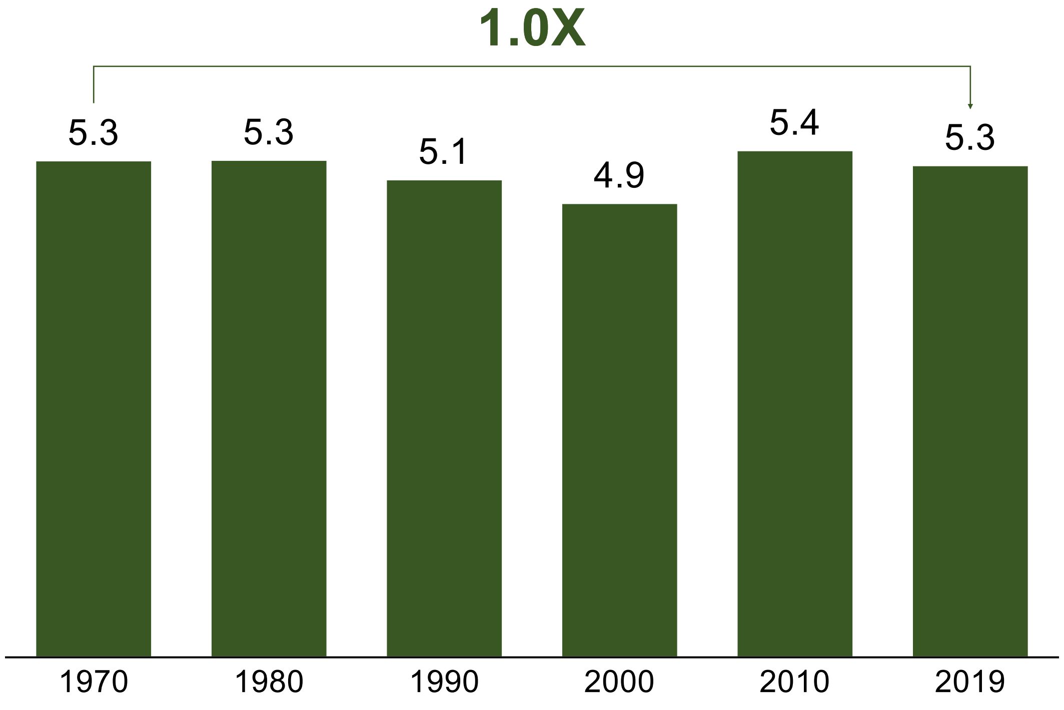
Note: Includes CO_2 emissions from land use change and the burning of fossil fuels for energy and cement production; excludes non-CO_2 greenhouse gases, including methane
Source: Bain & Company analysis; Our World in Data; Global Carbon Project

OpenMinds

Emissions per capita is about the same as it was in 1970, while emissions intensity halved

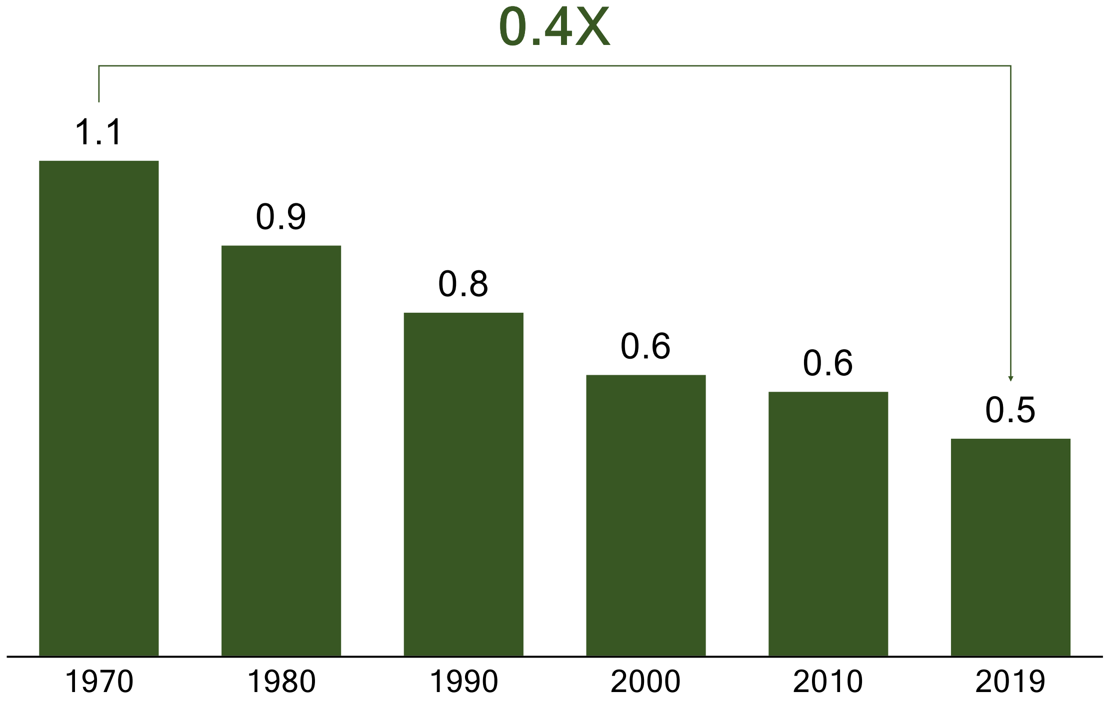
Global CO_2 emissions per capita

(tons of CO_2 per person per year)



Global CO_2 emissions intensity

kg of CO_2 per dollar of GDP in constant 2015 US$)



Note: Data are in constant 2015 prices, expressed in U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2015 official exchange rates.
Source: Bain & Company analysis; Our World in Data; World Bank

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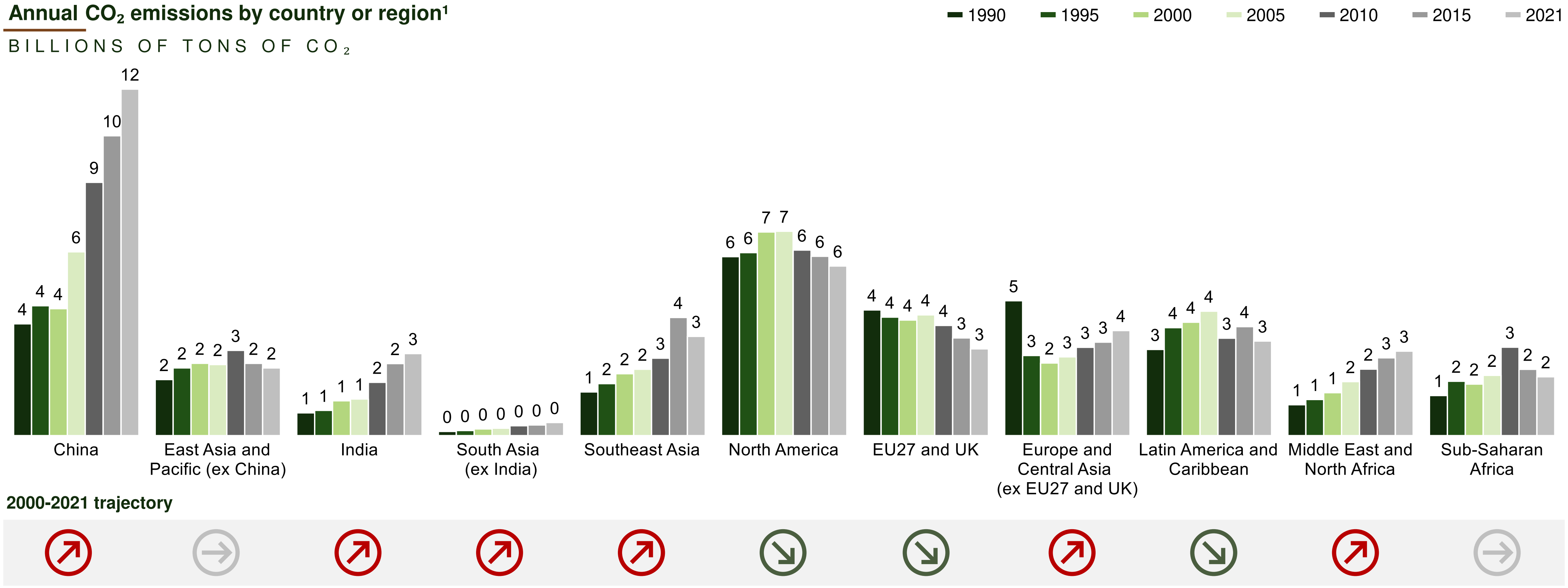
CO_2 emissions growth was concentrated in China and the developing world over the last 30 years

Annual CO_2 emissions by country or region[1]

BILLIONS OF TONS OF CO_2



Note: (1) Emissions are production-based and include emissions from energy and land-use change
Source: Bain & Company analysis; Our World in Data; Global Carbon Project

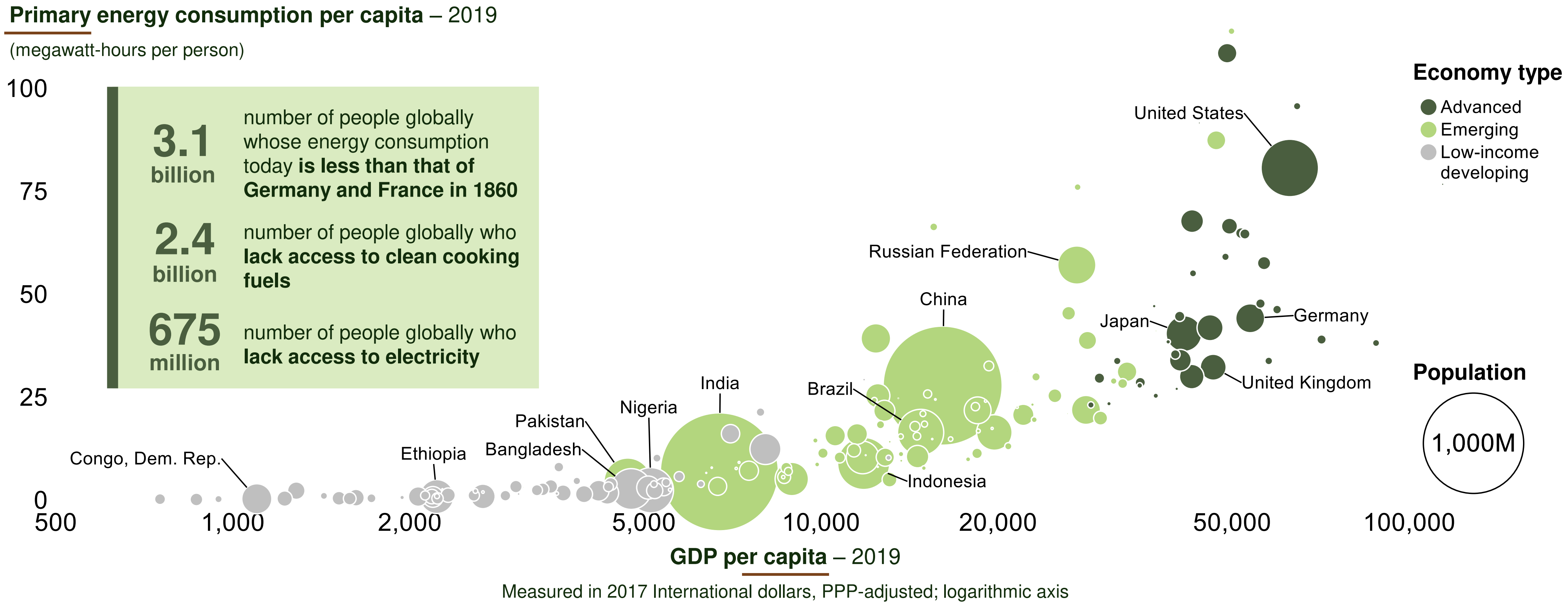
OpenMinds

Today, there is still considerable economic and energy inequality

3.1 billion number of people globally whose energy consumption today **is less than that of Germany and France in 1860**

2.4 billion number of people globally who **lack access to clean cooking fuels**

675 million number of people globally who **lack access to electricity**



Source: Bain & Company analysis; Our World in Data; World Bank; IMF; Global Carbon Project; Vaclav Smil, How the World Really Works

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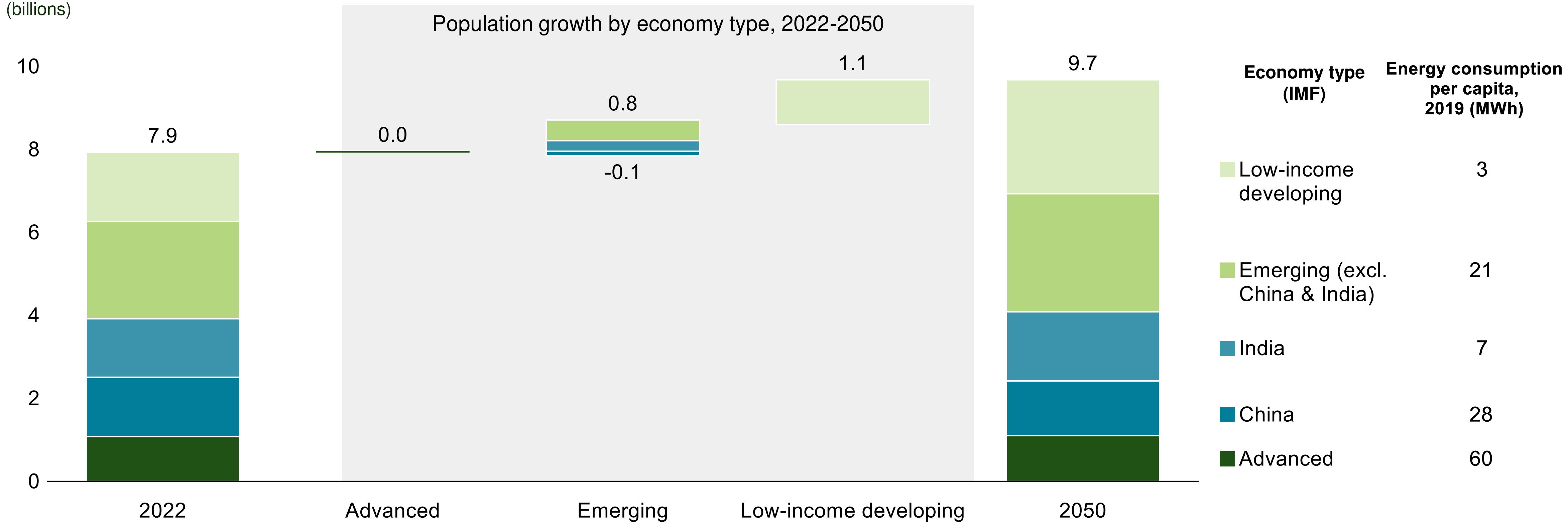
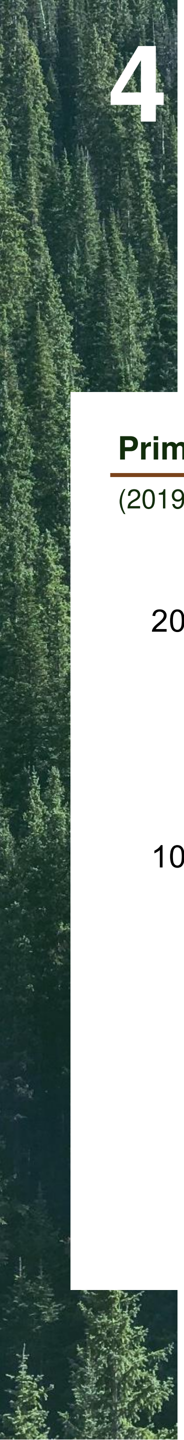
And future population growth will be concentrated in the least developed, lowest energy consumption regions

Global population by economy type, 2022-2050



Note: See appendix for country to economy type mapping
Source: Bain & Company analysis; Our World in Data; UN Population Division; BP Statistical Review of World Energy, 2021; IMF

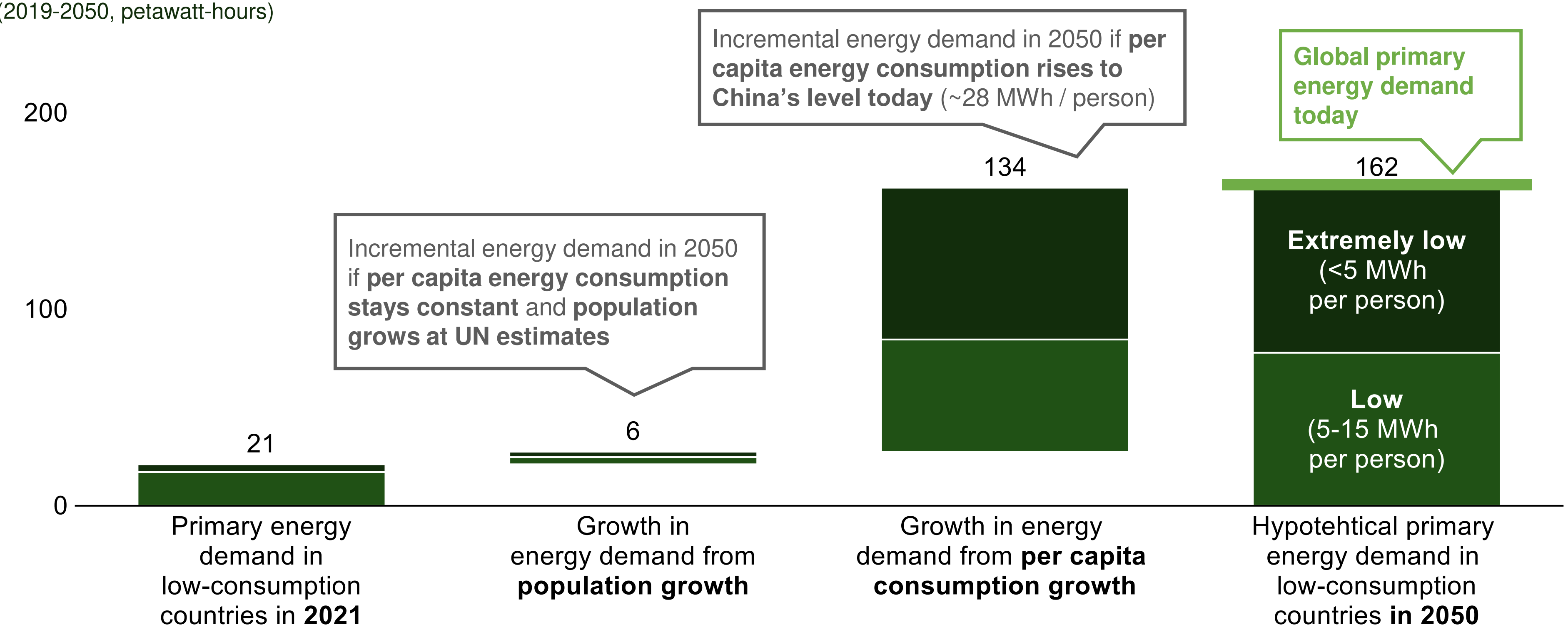
OpenMinds



An entire world's worth of future energy demand could come from countries still suffering from energy poverty

Primary energy demand in countries that consume <15 MWh per capita today

(2019-2050, petawatt-hours)



	Population (billions)		Primary energy per capita (MWh)
	2021	2050	2021
Extremely low (<5 MWh per person)	1.8	3.0	2.2
Low (5-15 MWh per person)	2.3	2.8	7.5

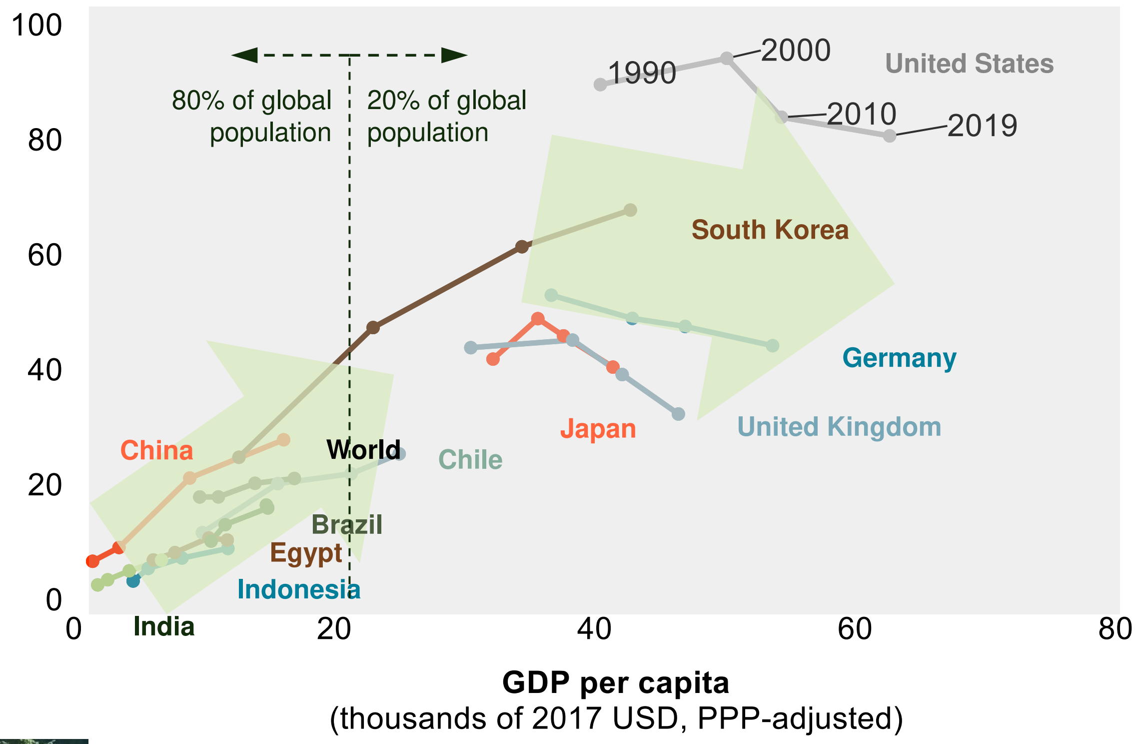
Source: Bain & Company analysis; Our World in Data; UN Population Division (medium estimates); BP Statistical Review of World Energy, 2021; IMF

OpenMinds

So far, only advanced economies have decoupled economic growth from energy consumption and emissions

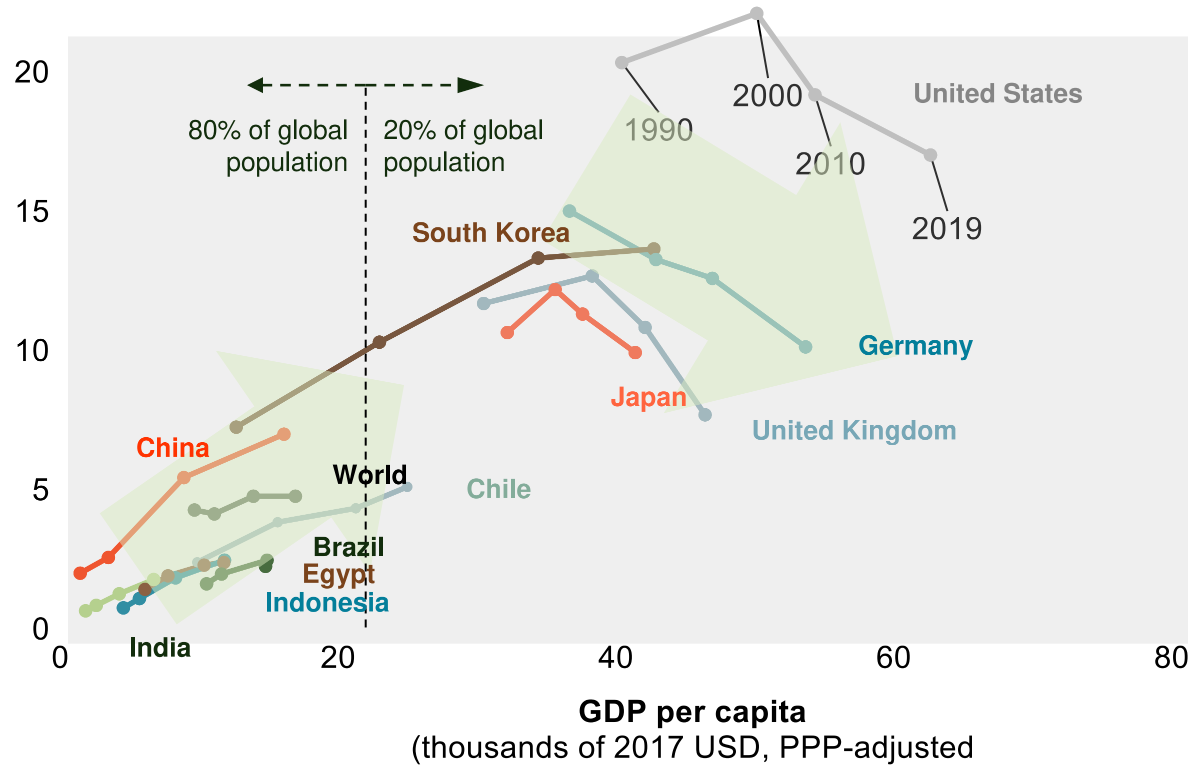
Primary energy consumption per capita

(MWh. Only 1990, 2000, 2010, and 2019 plotted for each country)



CO_2 emissions per capita

(Tons of CO_2*. Only 1990, 2000, 2010, and 2019 plotted for each country)



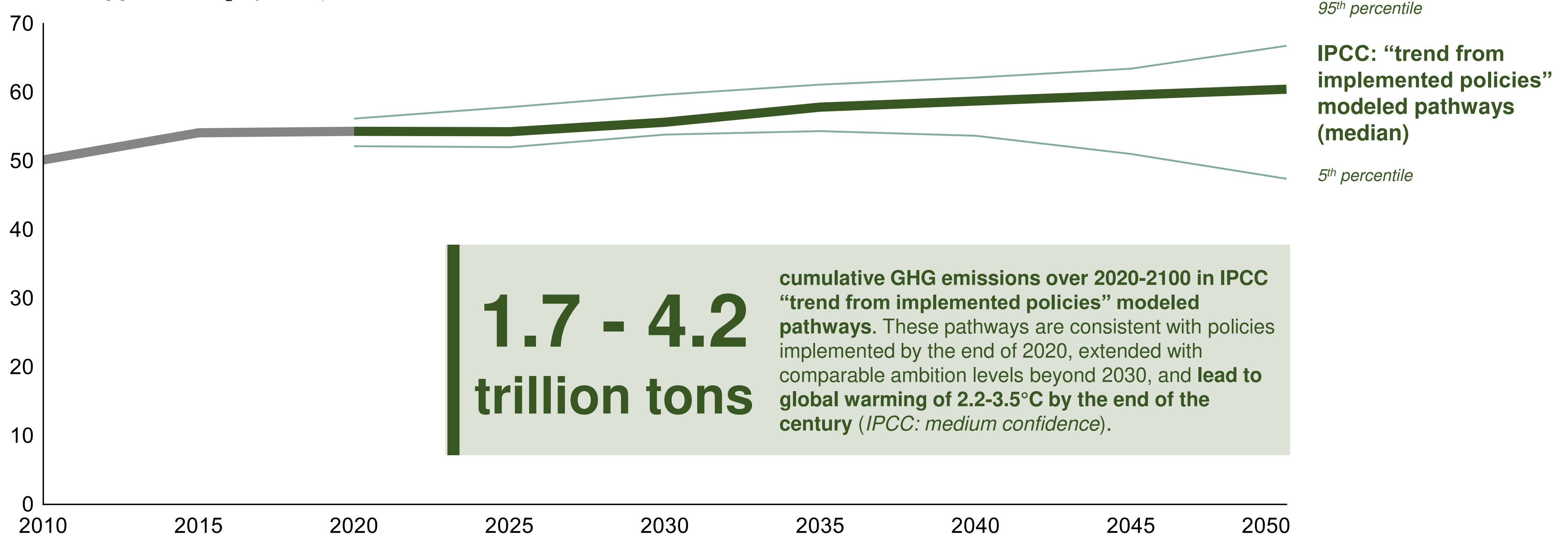
Note: * CO_2 emissions are consumption based (i.e., adjusted for trade) and do not include non-CO_2 emissions like methane

Source: Bain & Company analysis; Our World in Data; World Bank; Global Carbon Project; BP Statistical Review of World Energy, 2021

If we do not change how we deliver or consume energy, GHG emissions, and likely temperature, will continue rising

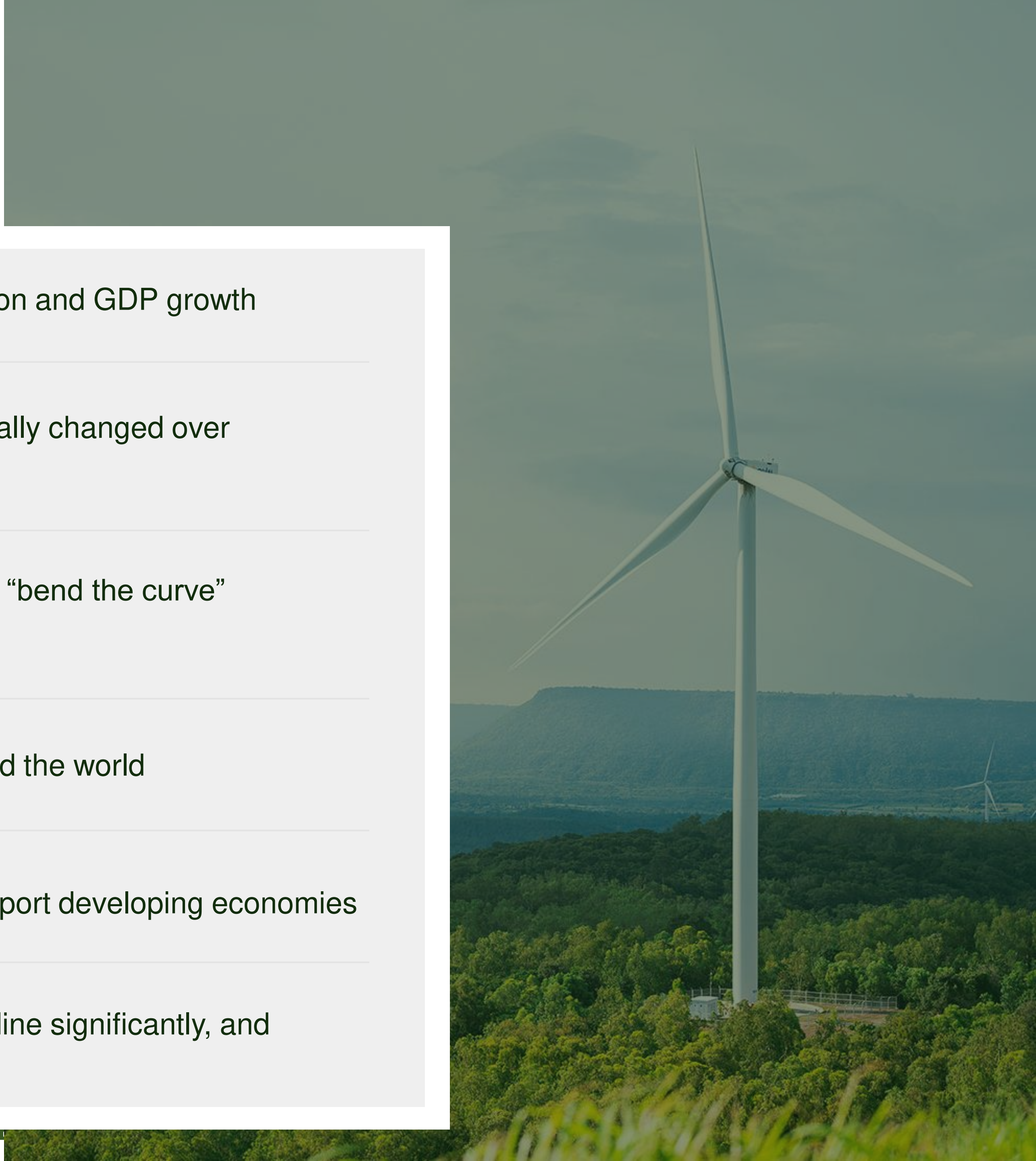
Global annual greenhouse gas (GHG) emissions

(measured in gigatons of CO_2-equivalent)



Note: Warming projections are relative to pre-industrial period and reflect warming by 2100 | Source: Bain & Company analysis; Our World in Data; IPCC, Sixth Assessment Report (AR6), Climate Change 2022: Impacts, Adaptation and Vulnerability, Summary for Policymakers, Figure SPM.4, Table SPM.1, Paragraph C.1.3 (2022)

Reality Check: Where We Are Today



- Energy demand tripled over the last 50 years, driven by population and GDP growth
- Our dependence on fossil fuels remains high and has not materially changed over the last decades
- CO_2 emissions accompanied energy growth, and we have yet to “bend the curve” on global emissions
- There is still considerable economic and energy inequality around the world
- The world will need significantly more energy in the future to support developing economies
- To mitigate the risk of climate change, GHG emissions must decline significantly, and ideally reach net zero, within a few decades

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03 Climate Change: Fundamentals and Possible Trajectories

04 Reality Check: Where We Are Today

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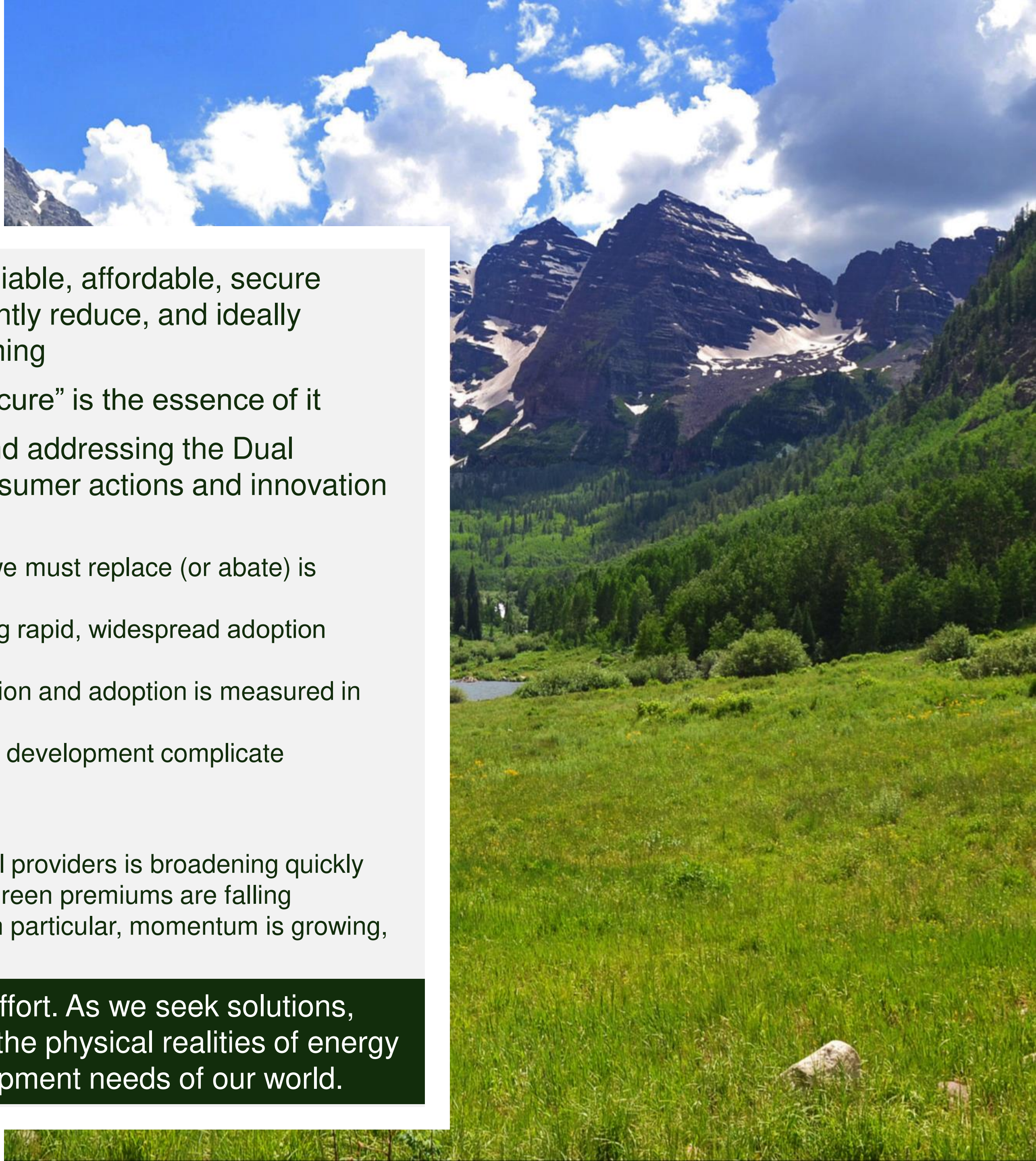
The Dual Challenge: Headwinds and Tailwinds

- The Dual Challenge: we must (1) deliver an increasing amount of reliable, affordable, secure energy to enable improvement in human wellbeing, and (2) significantly reduce, and ideally eliminate, emissions to mitigate environmental risks caused by warming
- Achieving “clean” without compromising “reliable, affordable, and secure” is the essence of it
- The momentum case based on current trends will not be enough, and addressing the Dual Challenge will require a mix of policy, technology, corporate and consumer actions and innovation
- But we face considerable obstacles in all these areas
  - Our dependence on fossil fuels runs deep, and the scale, and cost, of what we must replace (or abate) is enormous
  - Many currently available clean solutions come with “green premiums”, making rapid, widespread adoption financially challenging
  - Technological step-changes are needed, and the pace of technology maturation and adoption is measured in decades
  - Global cooperation is required, but competing priorities and different levels of development complicate coordination
- However, there are signs of progress—and clear tailwinds
  - Commitment to solve the problem among companies, employees, and capital providers is broadening quickly
  - Certain technologies, notably wind and solar, are scaling rapidly; for others, green premiums are falling
  - The governments of major emitters have made net zero pledges; in the US in particular, momentum is growing, as evidenced by the Inflation Reduction Act

Solving the Dual Challenge will be difficult, and it will require a global effort. As we seek solutions, we need visionary, pragmatic, system-oriented thinking that considers the physical realities of energy and climate alongside national priorities, and the economic and development needs of our world.



OpenMind's objective is making progress toward solving the Dual Challenge by 203X

Deliver energy globally…

We need to deliver affordable, reliable, secure energy for the entire world before 203X.

…while significantly reducing emissions…

We need to dramatically reduce emissions to mitigate the worst risks of climate change.

…to maximize human flourishing

The aim is to enhance the wellbeing of humans everywhere.

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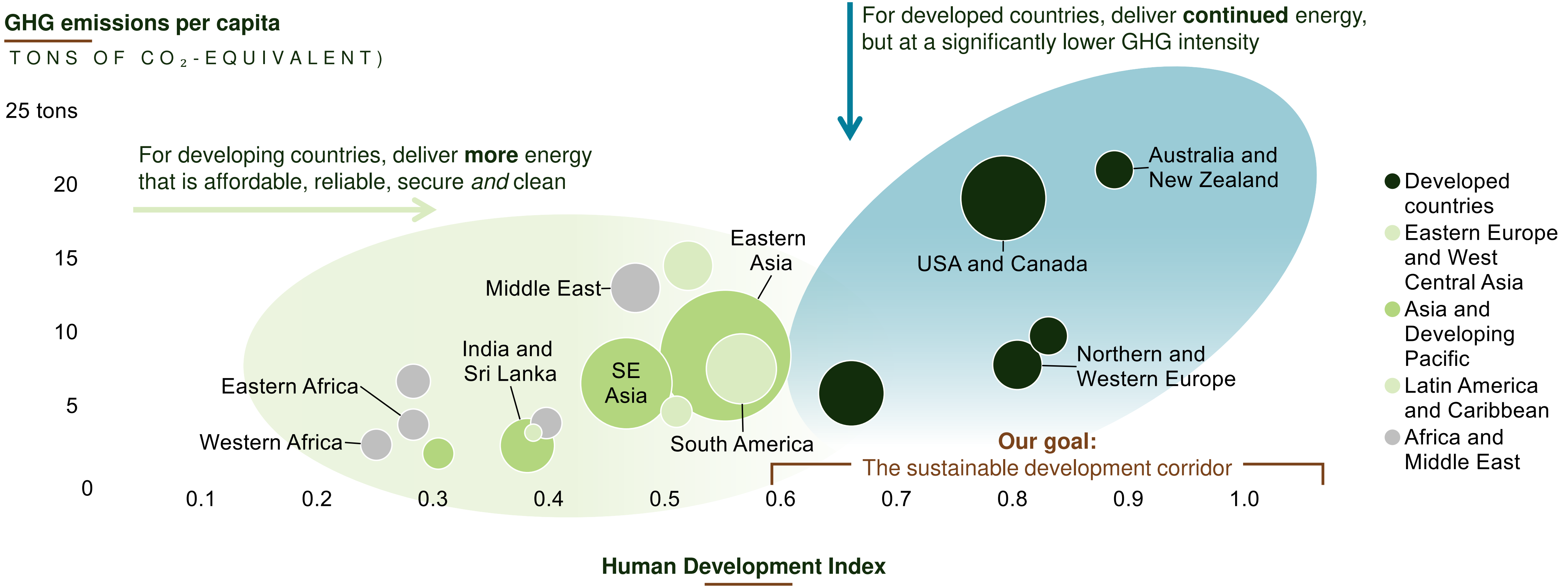
Achieving this will require different measures for developed vs. developing countries



HDI is a summary measure of key dimensions of human development: a long and healthy life, a good education, and having a decent standard of living

Note: Size of bubble represents population

Source: Bain & Company analysis; Our World in Data; IPCC, Sixth Assessment Report (AR6), Mitigation of Climate Change (2022)

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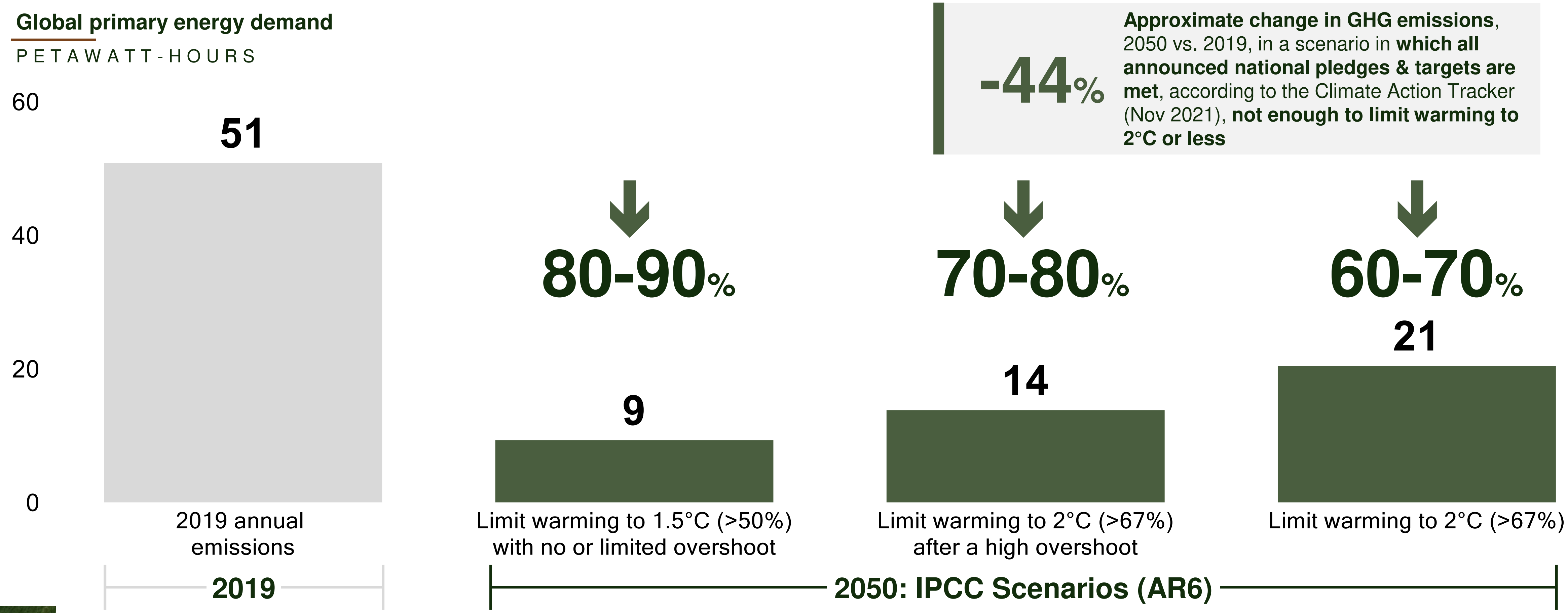
Overall, we must reduce greenhouse gas emissions significantly to limit the impact of warming



Note: “>50%” and “>67%” refer to probability of reaching scenario should emissions reduction targets be reached | Source: Bain & Company analysis; Our World in Data; IPCC, Sixth Assessment Report (AR6), Climate Change 2022: Mitigation of Climate Change – Summary for Policymakers, Table SPM.1 (2022); Climate Action Tracker (updated Nov 2021)

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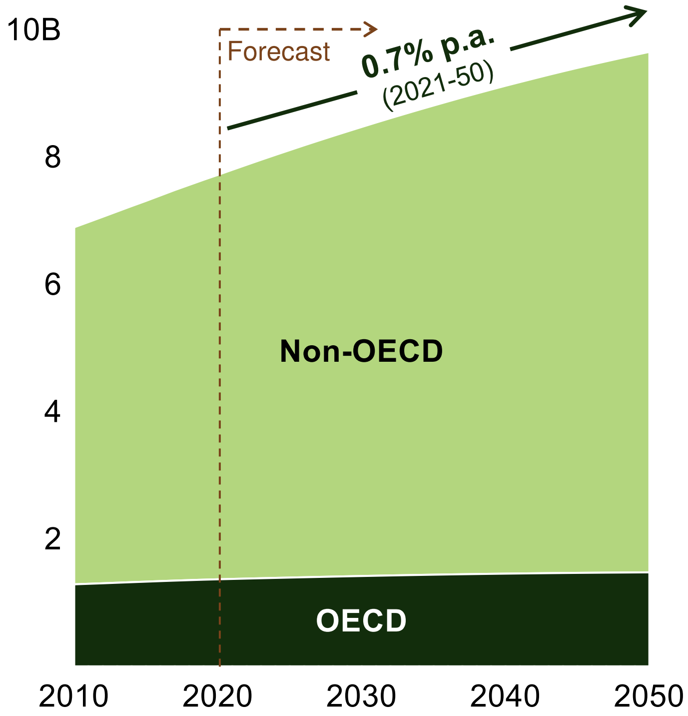
Emissions cuts will need to happen in parallel with rising energy demand driven by demographics and development

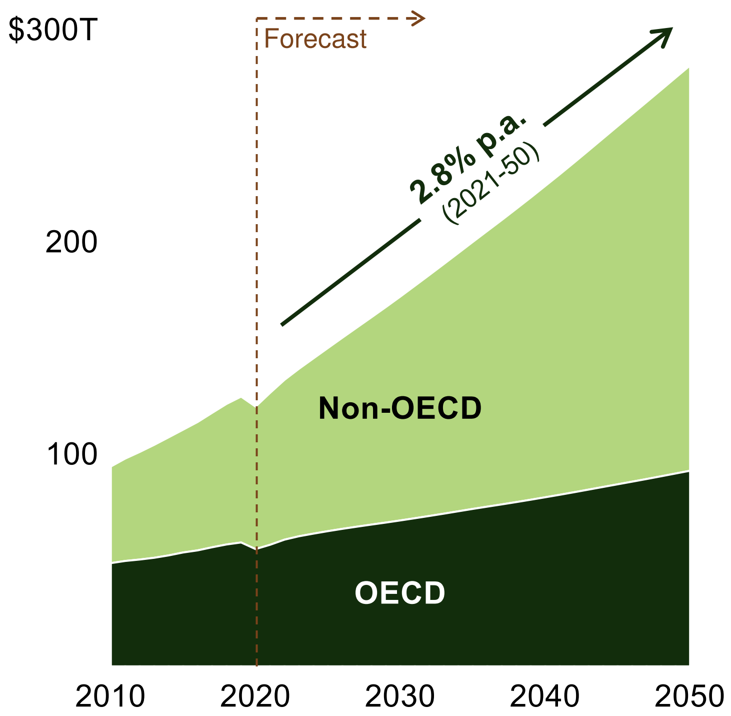
Global population

BILLIONS



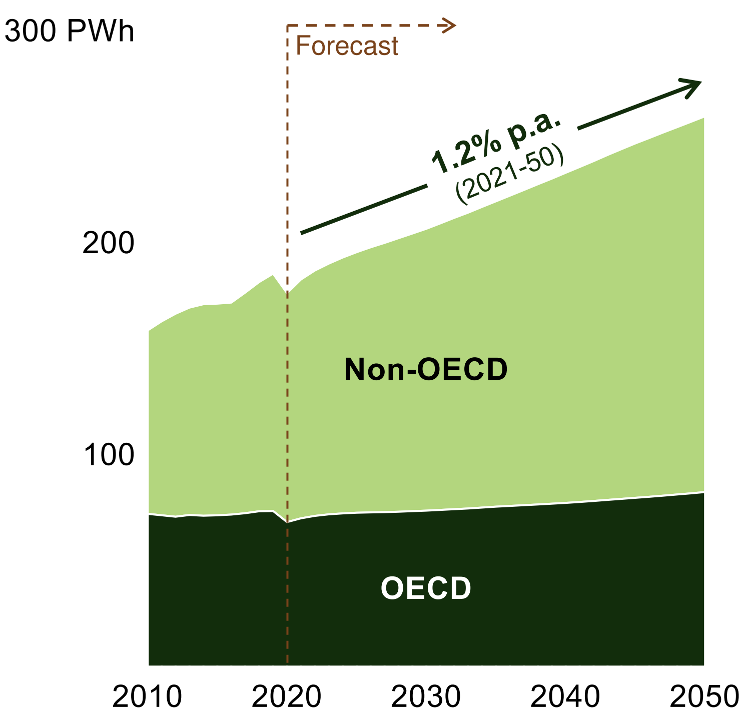
Global GDP

PPP, TRILLIONS OF 2015 USD



Global energy consumption

PETAWATT-HOURS



Source: Bain & Company analysis; Our World in Data; U.S. Energy Information Administration, International Energy Outlook 2021 (IEO2021), reference case

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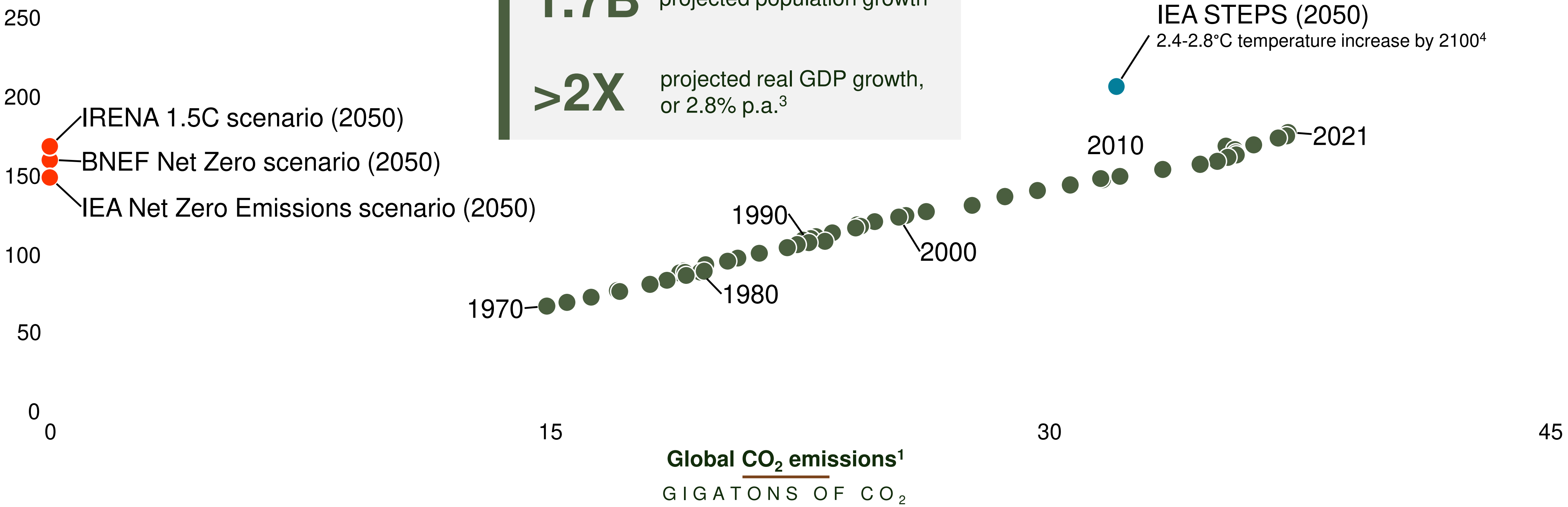
Achieving net zero emissions by 2050 amidst demographic and economic growth would require unprecedented change

Demographic and economic backdrop for 2021-2050 period

1.7B projected population growth[2]

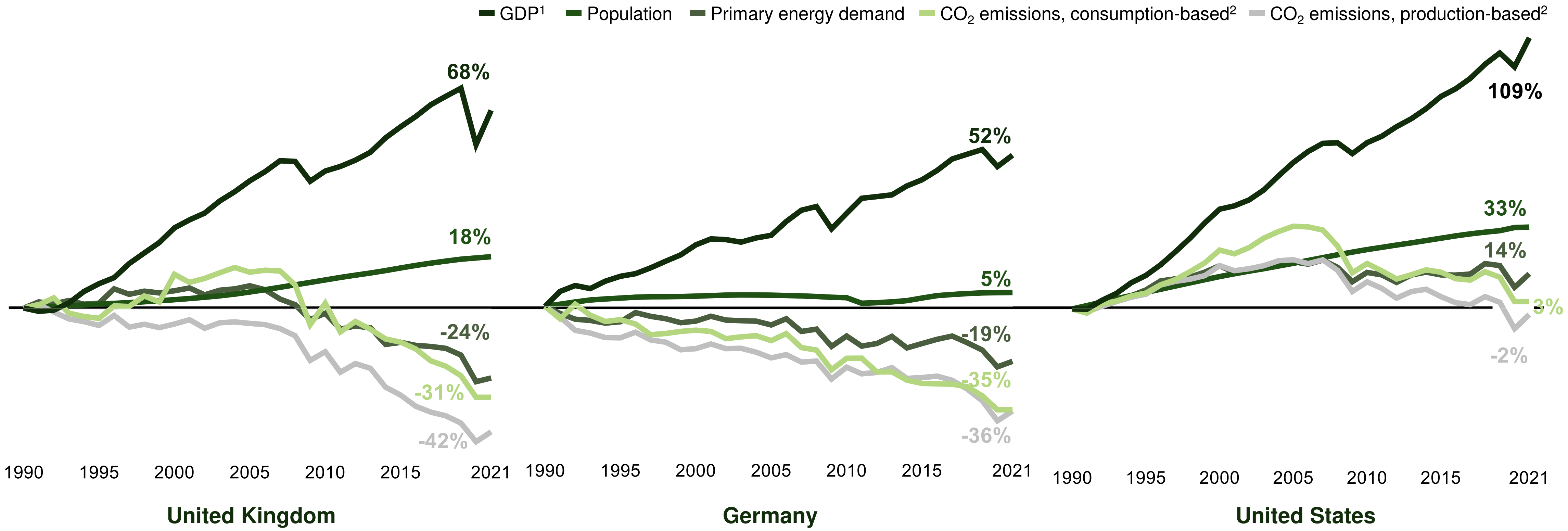
>2X projected real GDP growth, or 2.8% p.a.[3]



Note: (1) CO_2 emissions exclude land use change and exclude non-CO_2 emissions like methane; (2) UN median fertility scenario; (3) GDP expressed in 2021 USD in purchasing power parity terms via IEA; (4) IEA STEPS scenario temperature estimate range reflects 33-67% confidence interval. Source: IEA; BP Statistical Review of World Energy, 2022; BNEF; IRENA; Resources for the Future

But the experience of some advanced economies suggests we *can* decouple economic and emissions growth

Change in GDP, CO_2 emissions, and population, 1990-2021 for select countries



Note: (1) GDP is measured in real 2015 US dollars; (2) consumption-based emissions are adjusted for trade (i.e., production emissions minus emissions embedded in exports plus emissions embedded in imports), and neither consumption-based nor production-based include emissions from land use change

Source: Bain & Company analysis; Our World in Data; World Bank; Global Carbon Project; BP Statistical Review of World Energy, 2021

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To realize our aim, we will need action in three areas

Markets

Financial structures, corporate / institutional investment postures, and consumer preferences that favor low- or zero-emissions solutions

Technology

Scientific breakthroughs across a range of low-carbon solutions

Policy

Smart rules and regulations that encourage the development and adoption of low- or zero-emissions tech

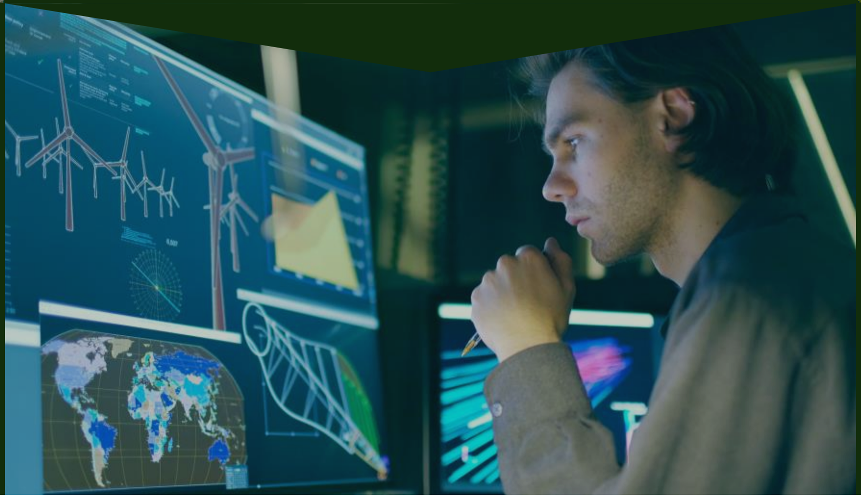
Source: Bill Gates, *How to Avoid a Climate Disaster* (2021)

But we face challenges in all three

Technology

Decarbonization will require some new and un-scaled technologies…

…And new technologies will present new complications



Markets

Fossil fuels are deeply embedded in modern civilization…

…And "Green Premiums" remain high

Policy

Global consensus and coordination are necessary…

…But countries at different stages of development have competing priorities

Fossil fuels are deeply embedded in modern civilization, with a production and distribution system built over 150 years

The material “pillars” of civilization depend heavily on fossil fuels and are significant emissions sources

Materials	Cement	Steel	Plastic	Ammonia
Product volume in metric tons	4.3 billion tons	1.9 billion tons	400 million tons	180 million tons
Emissions CO_2e in metric tons	3.9 billion tons	3.4 billion tons	520 million tons	500 million tons
Civilizational significance	Central ingredient in concrete, the material upon which modern infrastructure, including cities, bridges, roads, dams, hospitals, and runways, is built	Most widely used metal, valued for its abundance and physical properties. Found in everything from cooking equipment and cars, to bridges and buildings, to wind turbines and pipelines	Lightweight, durable, and easily moldable. Plastics are ubiquitous, and are particularly important in healthcare	Crucial ingredient in fertilizer. Without it, we could not feed nearly half the world
Fossil fuel dependence	Heating in cement production depends on fossil fuels (e.g., coal dust, heavy fuel oil)	About two-thirds of the world’s steel production depends on coal for purifying iron and heating	Crude oil and natural gas are used as feedstocks in the vast majority of plastics production	Natural gas (methane) is critical to synthesis, both as a feedstock and as the source of energy needed to provide high temperature and pressure

Source: Vaclav Smil, How the World Really Works; Columbia Climate School; Institute for Industrial Productivity; EIA

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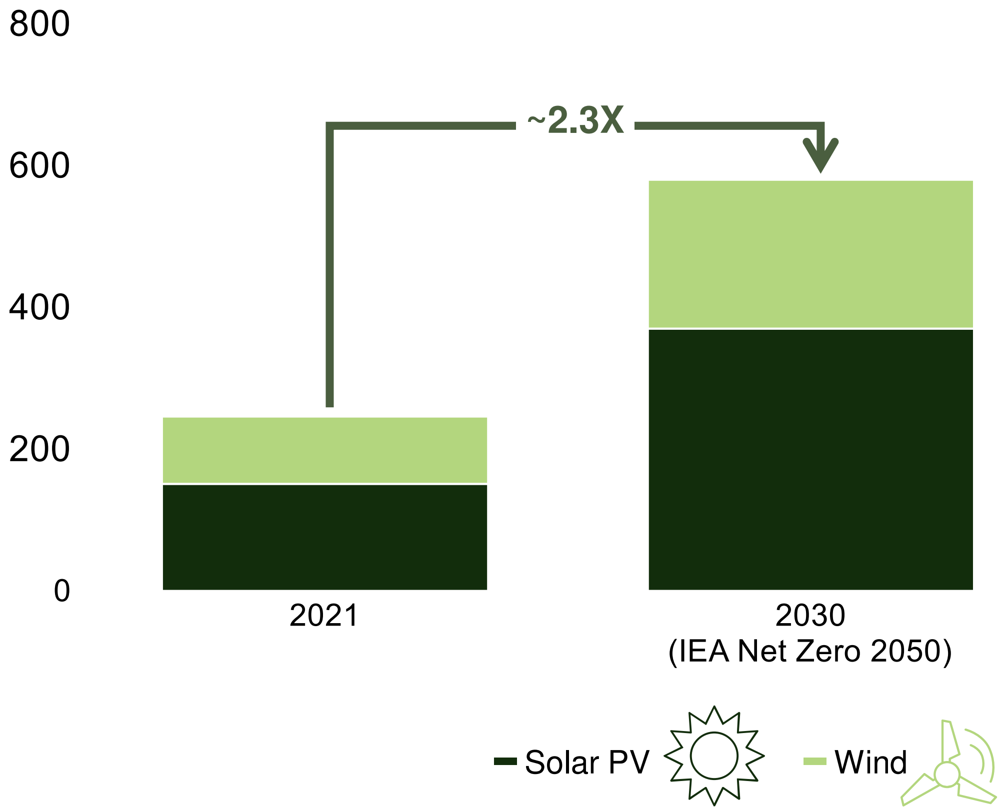
Achieving net zero by 2050 would require an unprecedented ramp-up in the deployment of clean solutions…

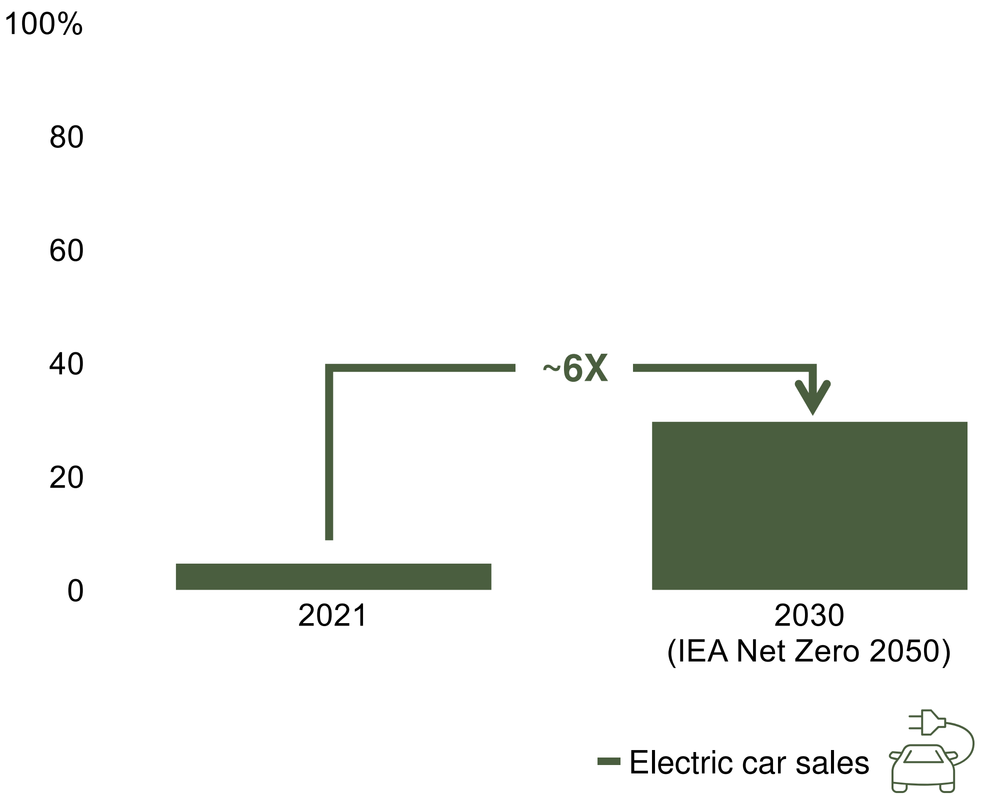
Annual global wind and solar PV capacity additions

GW OF CAPACITY



Annual global electric vehicle sales share

PERCENTAGE OF TOTAL CAR SALES



Markets

Source: IEA (2022), World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

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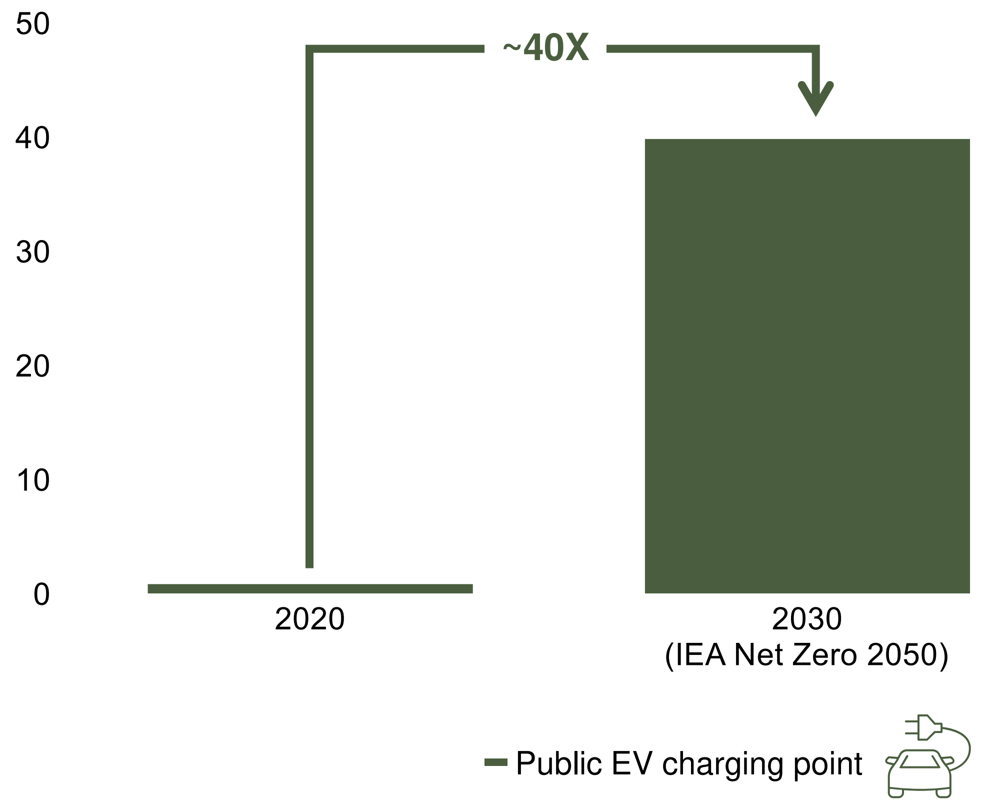
…As well as an immense expansion of critical infrastructure that enables those solutions

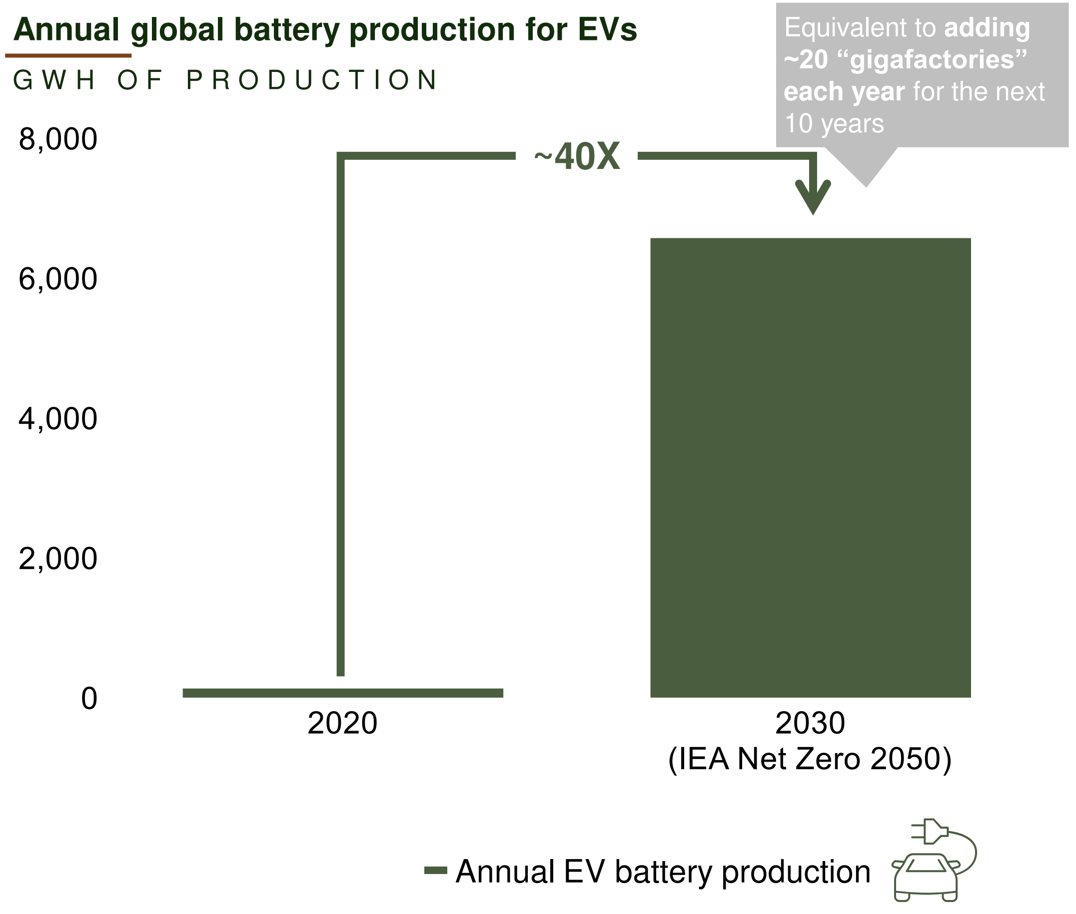
Global number of public charging points for EVs

MILLIONS OF PUBLIC CHARGING POINTS



Annual global battery production for EVs

GWH OF PRODUCTION



Markets

Source: IEA (2022), Net Zero by 2050 – A Roadmap for the Global Energy Sector – Summary for Policy Makers, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

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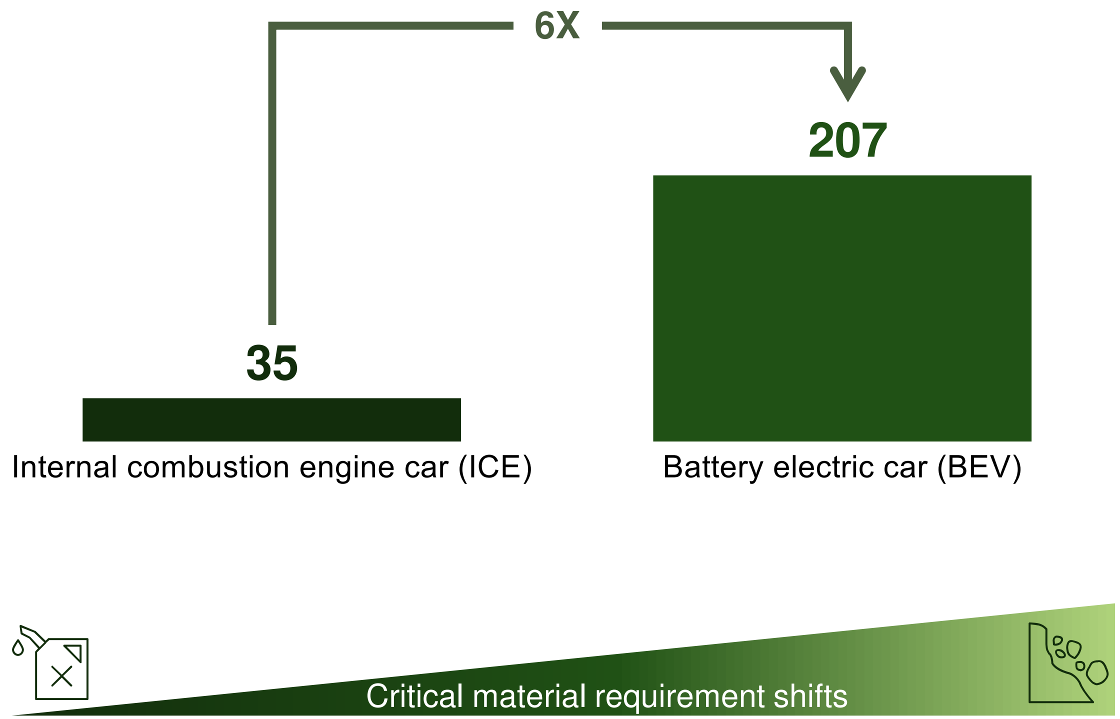
Continued progress requires a significant industrial effort

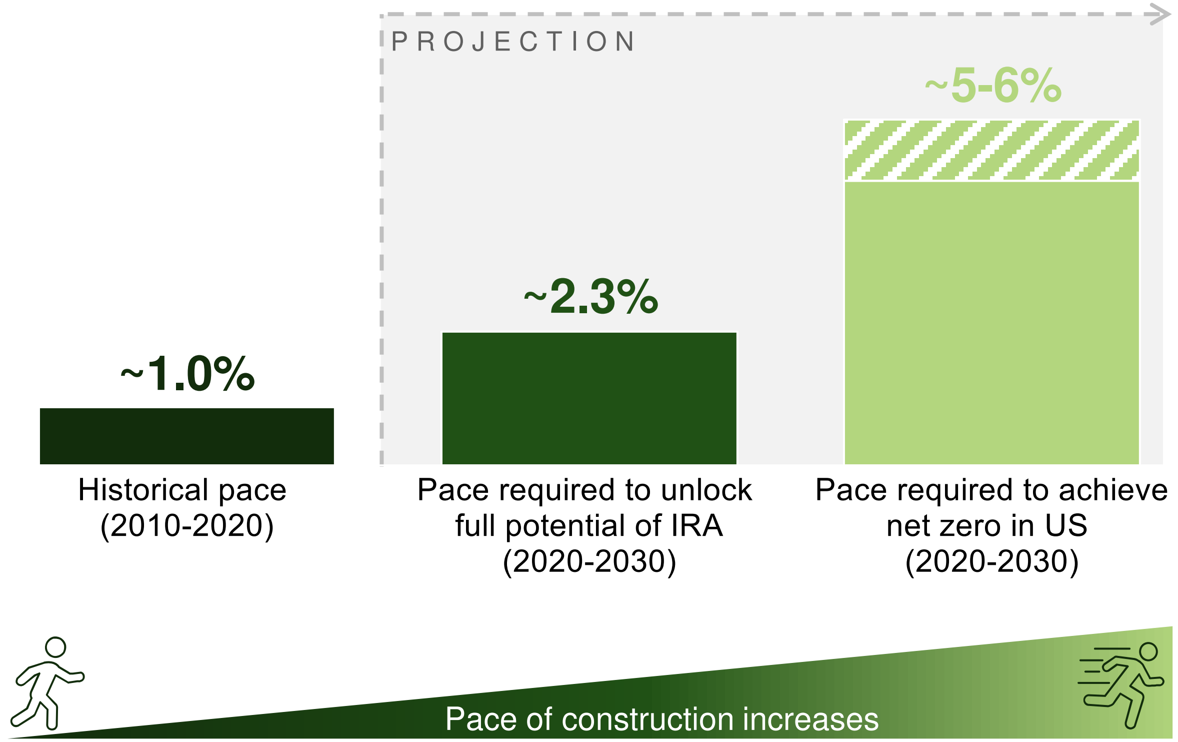
Our energy system will move from “fuel intensive” to “mineral intensive”

Critical mineral intensity (kg per vehicle)



In the US, we will need to expand transmission capacity rapidly, more than double the historical pace

US high-voltage transmission capacity growth per annum, 2020-2030

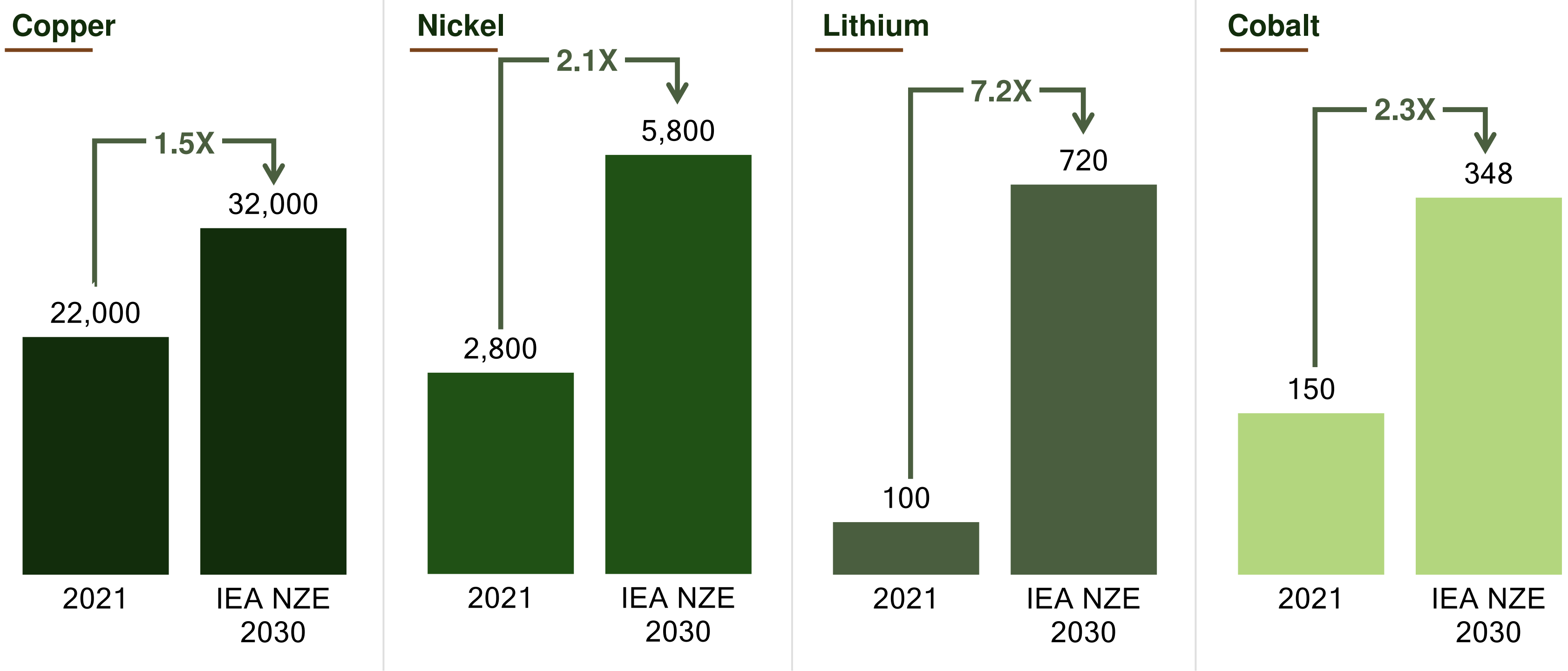


Note: Critical minerals include copper, platinum, rare earths, graphite, cobalt, manganese, nickel, lithium, and others. Transmission capacity growth measured using GW-miles.
Source: IEA, Energy Technology Perspectives 2023, Figure 1.9; Princeton, Net Zero America; Princeton, Electricity Transmission is Key to Unlock the Full Potential of the Inflation Reduction Act

The attendant ramp-up in mineral extraction would be enormous

Annual global production of select minerals

THOUSANDS OF METRIC TONS PER YEAR
2030 forecasts are shown based on IEA NZE scenarios

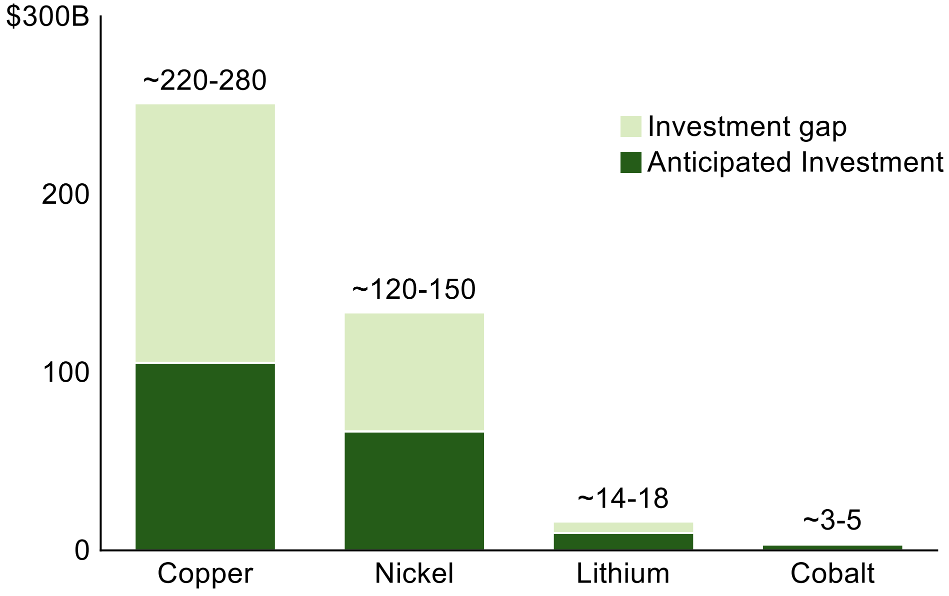


Source: IEA (2023), Energy Technology Perspective 2023, Figure 3.7, License: CC BY 4.0

For example, almost 200 new mines would be required to support critical mineral demand by 2030

We are underinvesting in mines relative to what is required to achieve 2030 climate goals

Funding required to meet mineral demand over 2022-2030 in IEA NZE (billions of USD)



- To achieve 2030 climate goals under the IEA NZE scenario, **we need ~180 new mines:**
  - ~30 Cobalt mines
  - ~70 lithium and nickel mines
  - ~80 copper mines (~250 copper mines exist today)
- **~$360-450B investment required**, and there is a projected **investment gap of ~$200-250B**

17 years **Average amount of time to open a new mine,** this includes exploration, feasibility, development and construction *(excludes ramp-up time)*

Note: IEA NZE = IEA Net Zero Emissions scenario
Source: IEA (2023), Energy Technology Perspective 2023, Figure 3.8, License: CC BY 4.0

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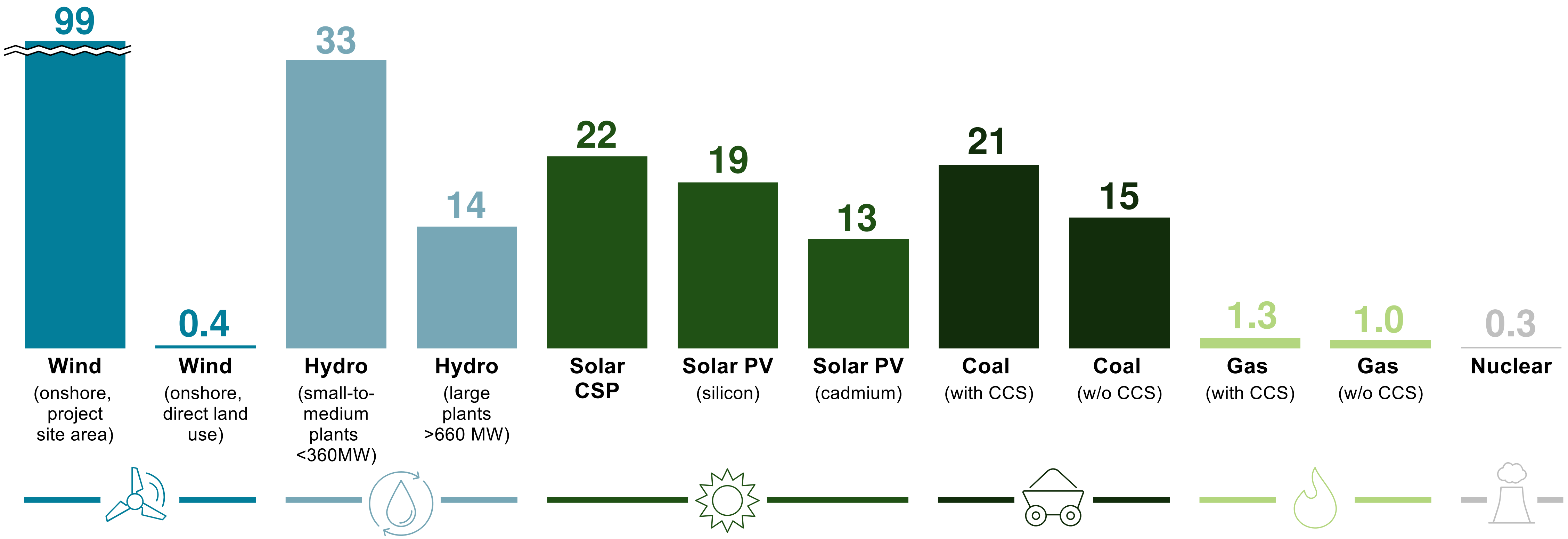
As we consider decarbonizing electricity generation, land use could be a major constraint

Land use per unit of produced electricity

SQUARE METERS PER MEGAWATT-HOUR; MEDIAN VALUE



Note: Land use includes both direct use of land by the facility and indirect use of land for the mining of materials used in construction, fuel inputs, decommissioning, and waste management; CCS = Carbon Capture and Storage.
Source: Our World in Data; UNECE, Integrated Life-cycle Assessment of Electricity Sources (2021); Lovering et al., Land-use intensity of electricity production and tomorrow's energy landscape (2022)

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In the US, full decarbonization by 2050 would require massive shifts in energy infrastructure

Fully decarbonizing the US by 2050, absent major technological breakthroughs, would entail…

Dramatically expanding the supply of wind and solar to achieve 100% renewable electricity

13X
more solar & wind

Capacity of wind (10X) and solar (20X) must expand significantly. Pace of deployment would be 2-3X that of the one-year US record over the next two decades, and it would approach the one-year world record by 2050

590,000
sq. km of land

Total area spanned by onshore wind and solar farms, an area roughly equal to the combined size of IL, IN, OH, KY, TN, MA, CT, and RI

3X
more high voltage transmission capacity

Electricity transmission expands to about 700K GW-km, a 200%+ increase from 2020

Building an enormous carbon capture and sequestration system

1-1.7 billion
tons of CO_2 sequestered per year by 2050

A massive carbon capture and storage (CCS) system is required to capture emissions from hard-to-abate sources like cement production and natural gas reforming

1.3-2.4X
size of CCS system relative to current US crude oil production

On a volume basis, the system would handle 1.3-2.4X the volume of current US crude oil production and would necessitate ~110,000 km of new CO_2 pipeline infrastructure

Note: Figures shown are for NZA's E+ "High Electrification" scenario
Source: Princeton University, Net Zero America; Vaclav Smil, How the World Really Works

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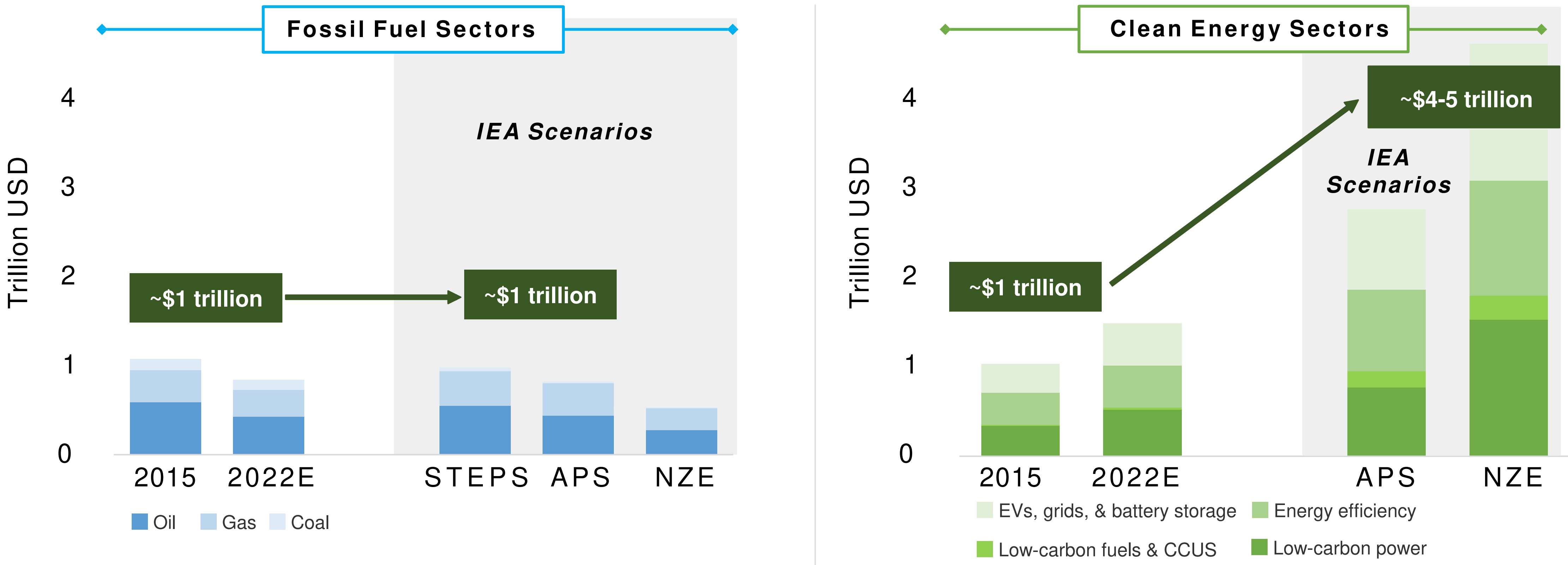
2050 would require the world to more than triple its investment in clean energy

Annual global energy investment needs from 2023-2030 in different IEA scenarios



Markets

Note: STEPS = Stated Policy Scenario; APS = Announced Pledges Scenario, the spending required to meet all country and regional climate pledges on time and in full. NZE = Net Zero Emissions by 2050 Scenario, the spending required to get the global energy sector to net zero by mid-century.
Source: IEA (2023), World Energy Investment 2023, IEA, Paris https://www.iea.org/reports/world-energy-investment-2023, License: CC BY 4.0

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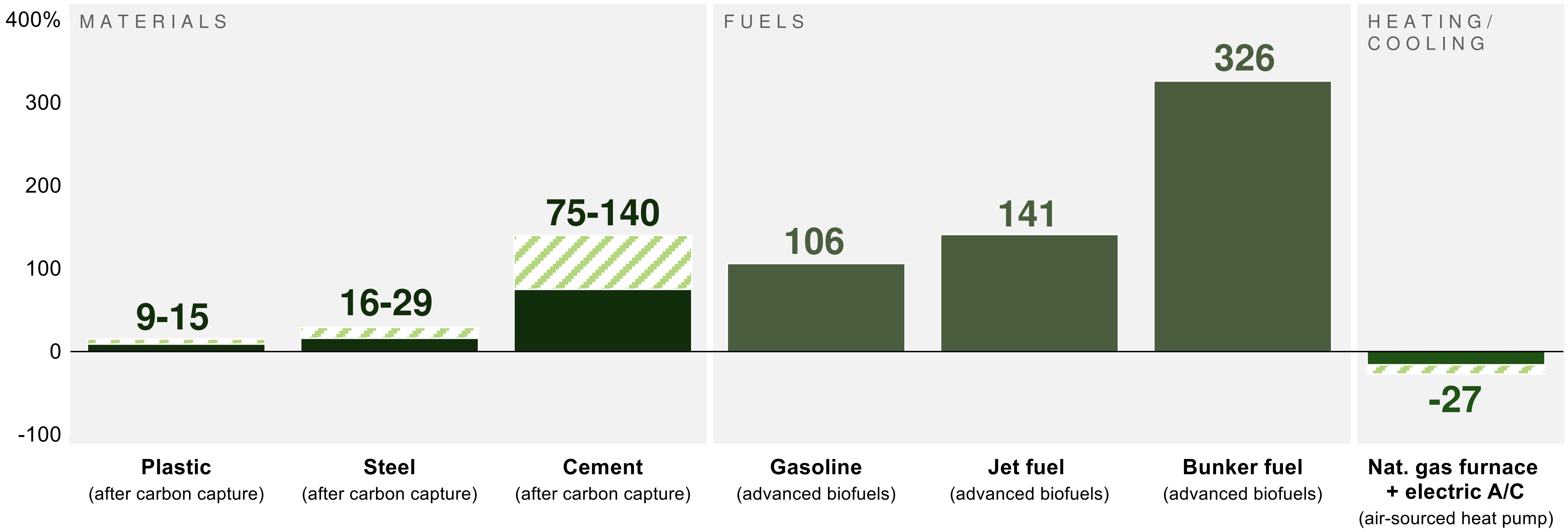
Today, “green premiums” hamper the adoption of low- or zero-emissions solutions

Incremental price of zero / low carbon substitute

PERCENTAGE ABOVE EXISTING SOLUTION COST



Source: Bill Gates, How to Avoid a Climate Disaster (2021)

Markets

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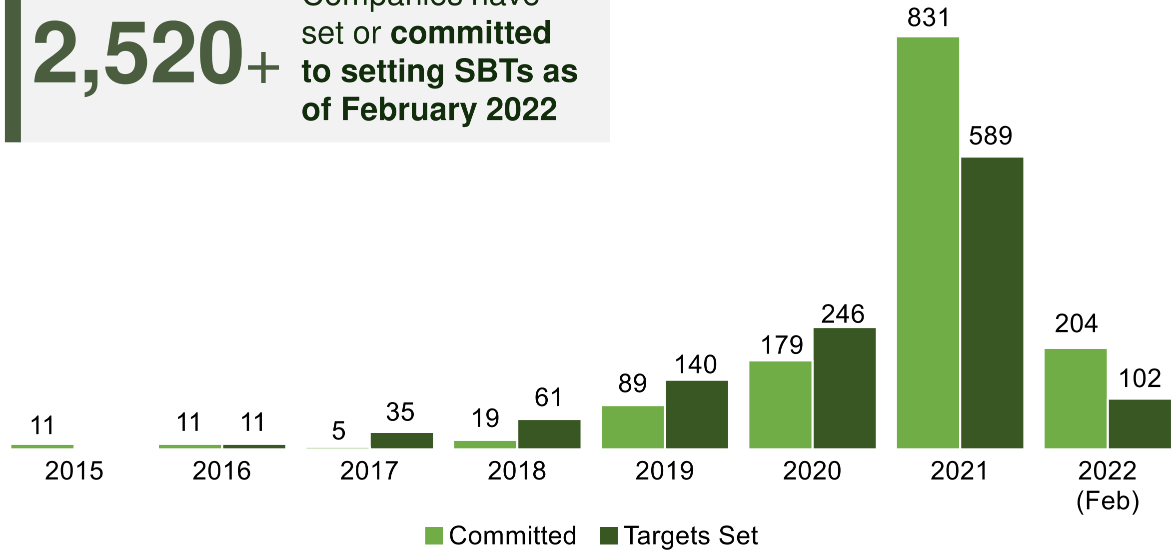
Despite these challenges, sustainability is becoming more important for companies, investors, and employees

Companies are committing to reducing emissions

More and more companies in the US and elsewhere, ranging from Microsoft to Air France to CEMEX, are setting “science-based targets” as they work to reduce emissions

Annual verifications and commitments (2015-YTD2022)

2,520+ Companies have set or **committed to setting SBTs as of February 2022**



Wider stakeholders are prioritizing ESG

In private equity, limited partners (LPs) are making ESG a priority, and employees around the world believe sustainability should be a top priority for companies

Note: Companies work with the Science Based Targets initiative (SBTi) to set targets that provide a clearly defined pathway to reduce GHG emissions
Source: Science Based Targets initiative; Refinitiv; INSEAD

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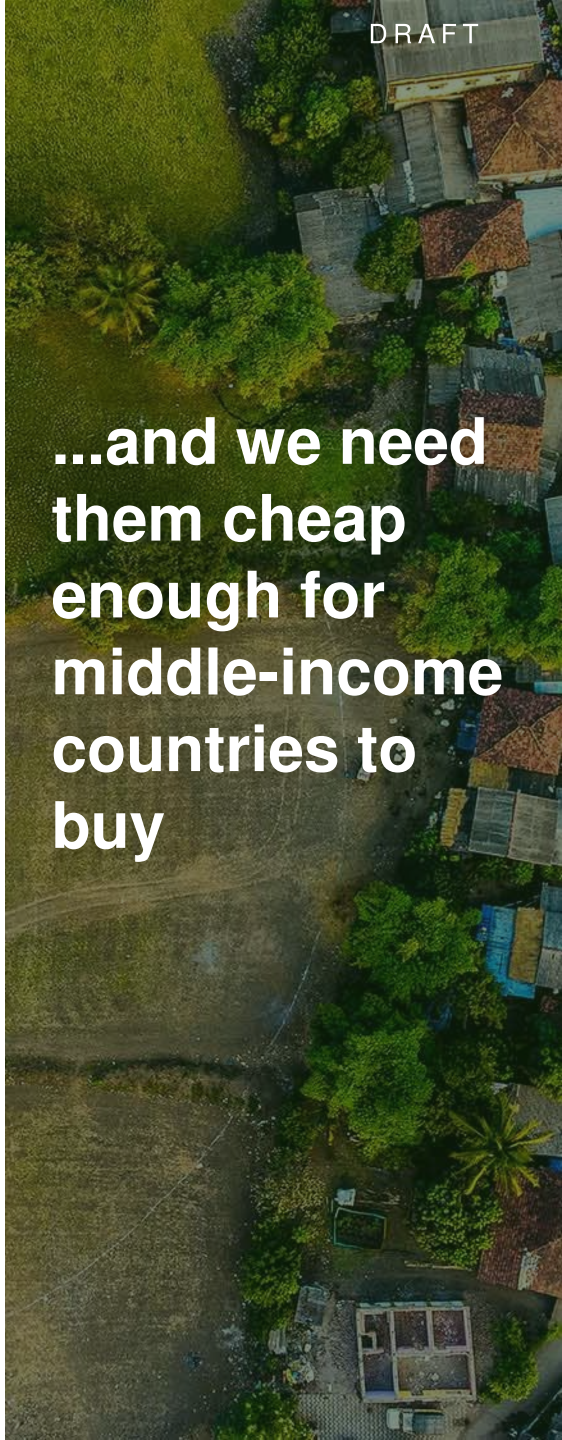
Technologically, we likely need a multitude of breakthroughs to deeply decarbonize

- Zero-carbon plastics
- Zero-carbon cement
- Zero-carbon fertilizer
- Zero-carbon steel
- Carbon capture (direct air capture and point capture)
- Next-generation nuclear fission
- Nuclear fusion

- Nuclear fusion
- Pumped hydro
- Geothermal energy
- Grid-scale electricity storage that can last a full season
- Hydrogen produced without emitting carbon
- Underground electricity transmission

- Plant- and cell-based meat and dairy
- Zero-carbon alternatives to palm oil
- Drought- and flood-tolerant food crops
- Advanced biofuels
- Electrofuels
- Thermal storage
- Coolants that don’t contain F-gases



Source: Bill Gates, How to Avoid a Climate Disaster (2021)

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Technology

Technical progress typically proceeds slowly, Moore's Law an exception

46% p.a.

Moore's Law:
rate that the number of transistors in a dense integrated circuit increases (i.e., doubling about every two years)

vs.

2% p.a.
increase in **corn yields** since 1950

1.7% p.a.
decrease in **energy intensity** to produce a **ton of steel** since 1950

1.5-2% p.a.
increase in efficiency of converting **thermal power to electricity** during the 20th century

2.5% p.a.
improvement in **U.S. car gas mileage** from 1973 to 2014

2.5-3% p.a.
increase in **light efficacy** (lumens per watt), 1881-2014

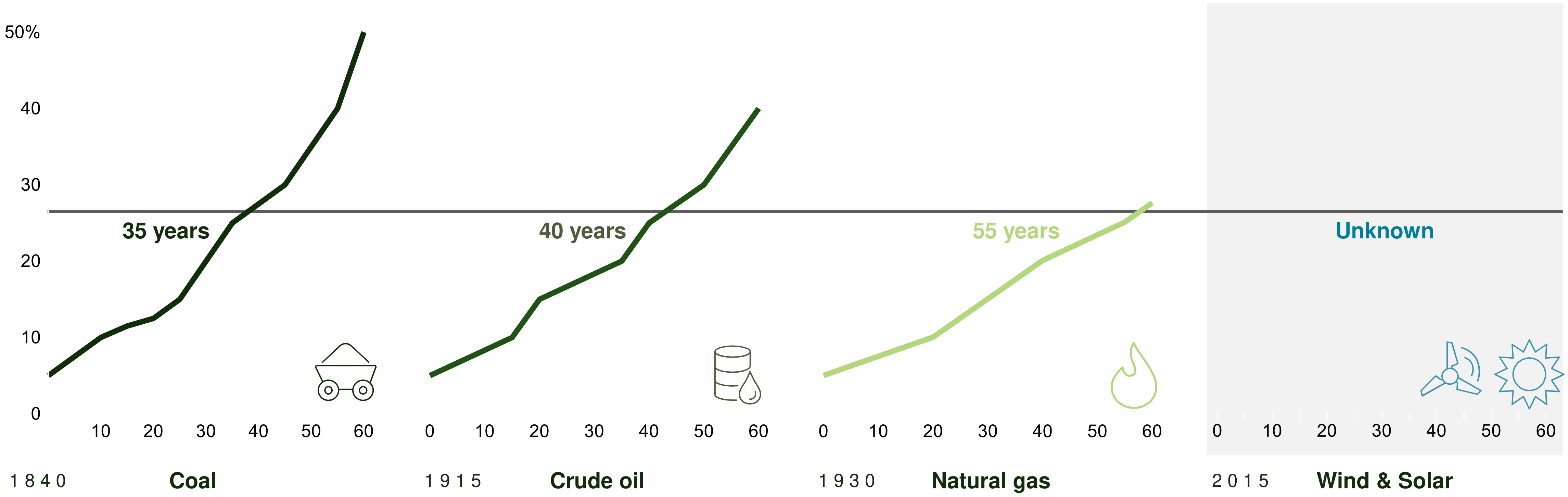
5.6% p.a.
increase in **speed of intercontinental travel** from 1900 to 1958 – but then ~0% p.a. thereafter

Source: Vaclav Smil, Moore's Curse

And history suggests the diffusion of new energy technologies takes decades

Years until supplying 25% of global primary energy supply

SHARE OF GLOBAL PRIMARY ENERGY SUPPLY



Note: Based on time from 5% to 25% of global energy supply
Source: Vaclav Smil, *Energy Transitions:* Global and National Perspectives (2017)

Technology

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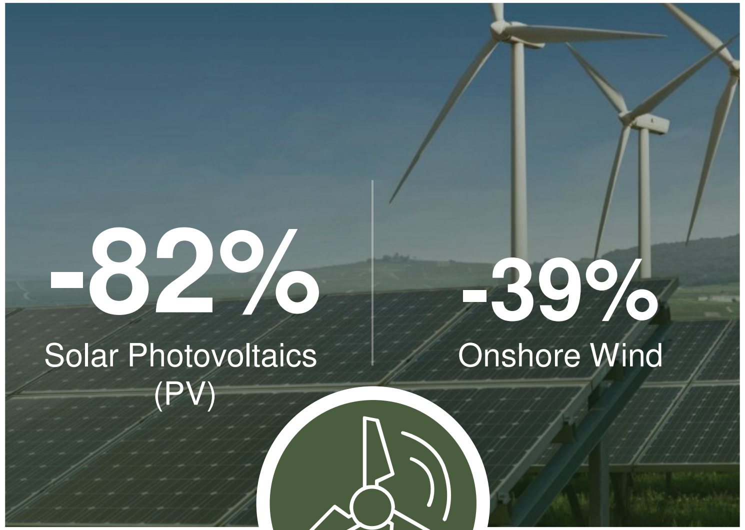
However, we have seen encouraging progress in a range of critical areas



Low-cost wind and solar

Over 2010-2019, there has been an 82% and 39% reduction in the cost of utility-scale PV and onshore wind systems, respectively.

Electric vehicle price parity

In Europe, passenger car EVs are expected to reach price parity with internal combustion engine (ICE) equivalents in the 2025-2027 timeframe, and many manufacturers have committed to EV sales targets.

Direct air capture scale up

The first large-scale direct air capture plant is being developed in the US, with a planned capacity of 1M tons of CO_2 per year.

Source: NREL; IRENA: Bloomberg NEF; IEA

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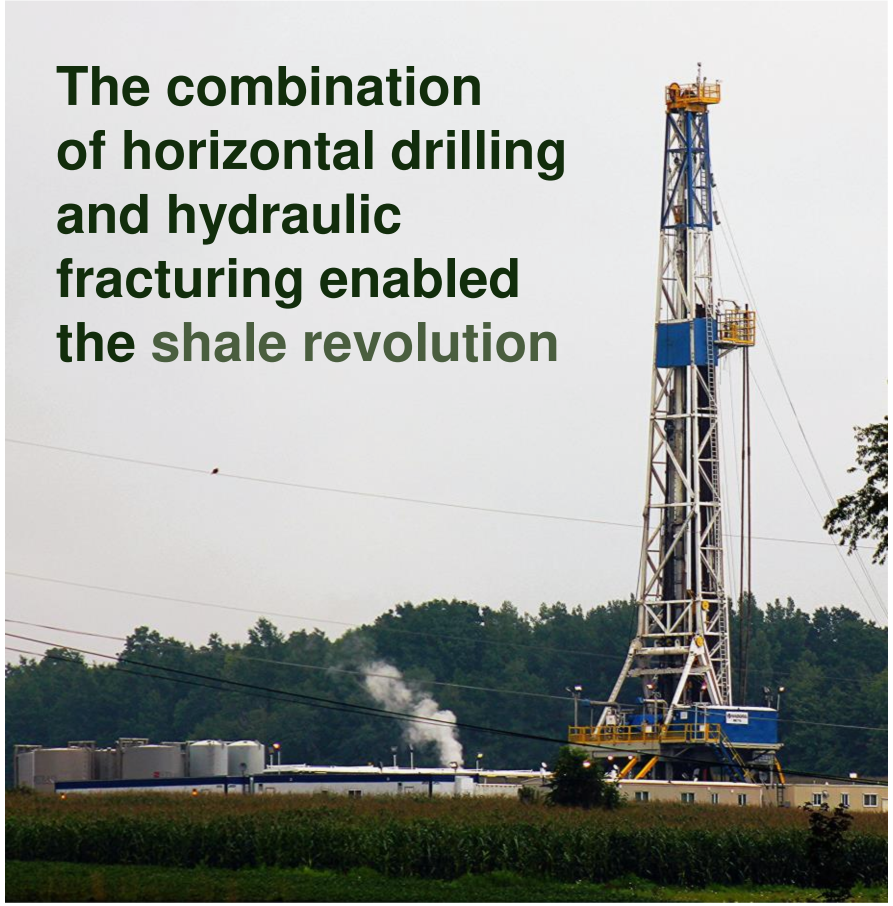
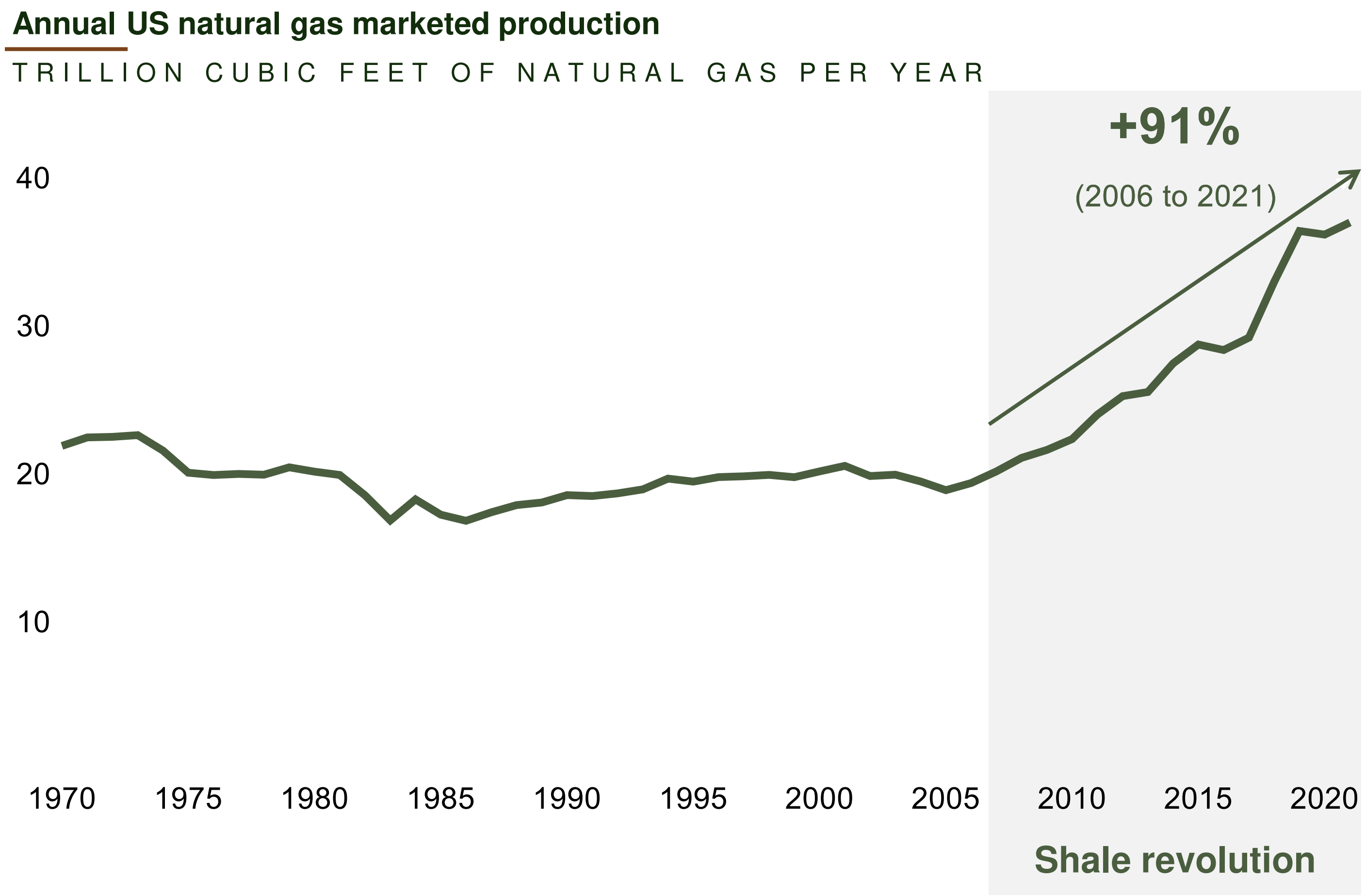
Technology

And the shale revolution suggests transitions can happen quickly at the scale of US oil & gas production

The combination of horizontal drilling and hydraulic fracturing enabled the shale revolution





Source: EIA

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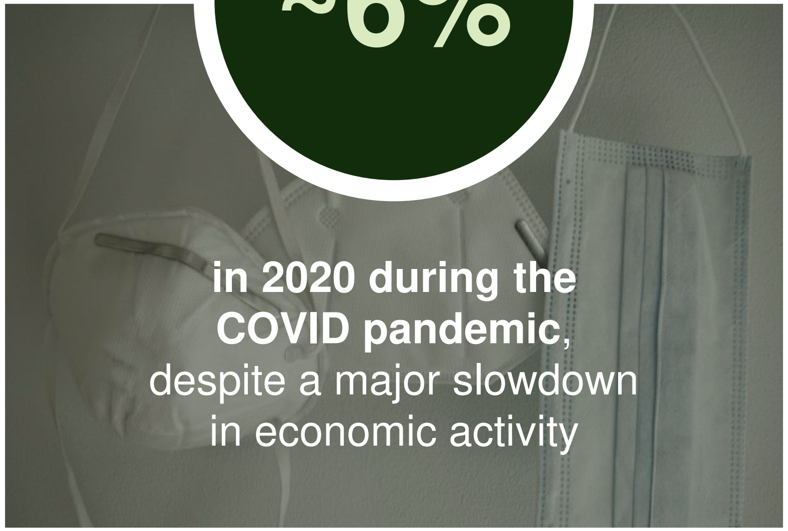
Policy

Whether policy- or market-driven, seemingly large actions may have only modest impacts on emissions

Global emissions dropped

~6%



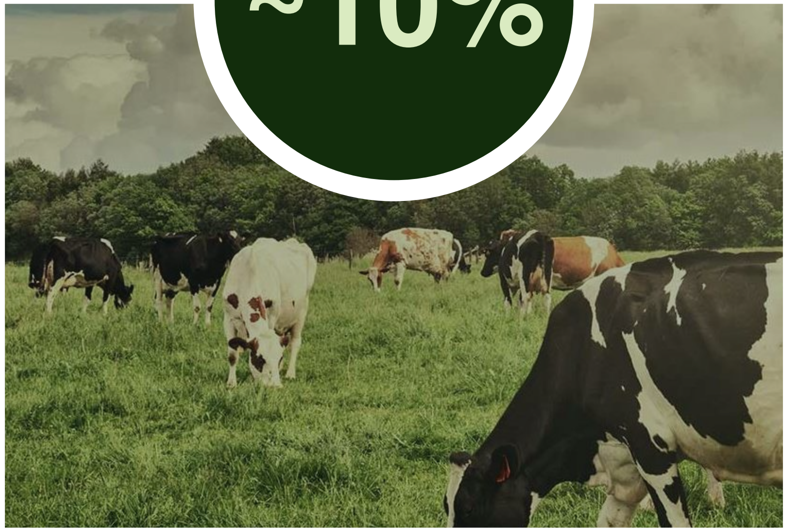
in 2020 during the COVID pandemic, despite a major slowdown in economic activity

Removing GHG emissions from **all passenger vehicles** in the world would reduce emissions by

~8%

Completely eliminating beef from global diets would reduce emissions by

~10%



Source: Carbon Brief; IEA; ICCT (International Council on Clean Transportation); Bill Gates, How to Avoid a Climate Disaster (2021)

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Policy

Global cooperation is required, but competing priorities and different levels of development complicate coordination

Developing nations

need affordable and reliable energy to support economic development

Developed nations

want to reduce emissions, but vary in their ambition and willingness to invest

Nations with high climate change risk

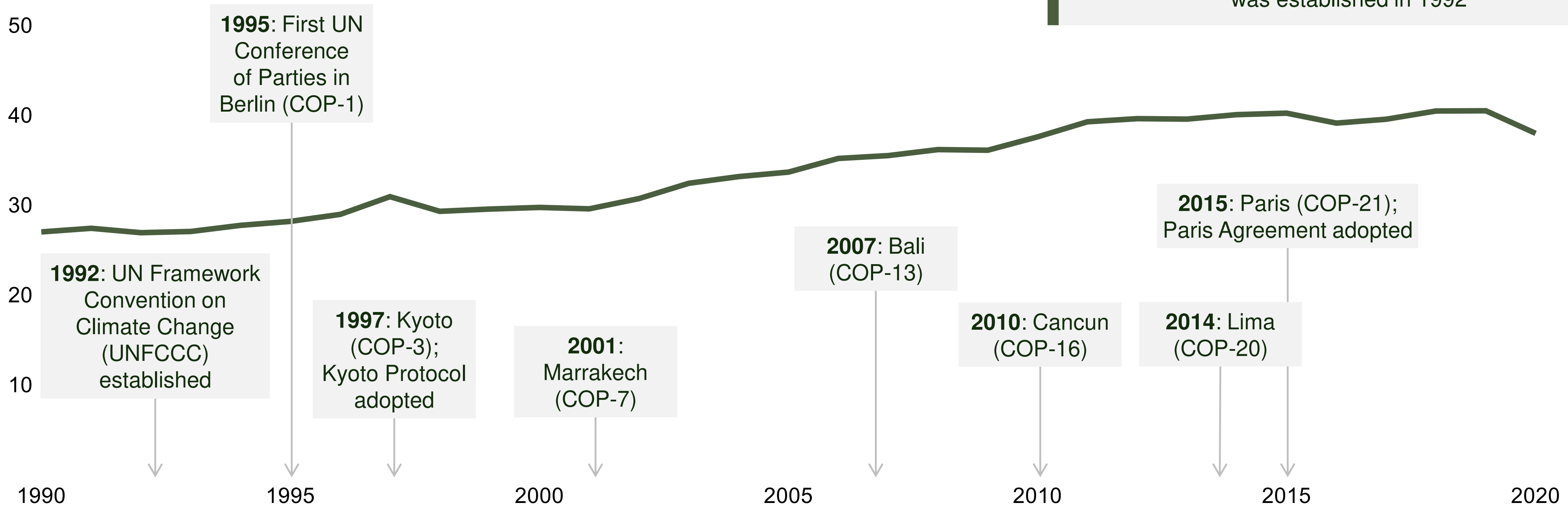
want ambitious change, but need additional resources

Three decades of international climate conferences have not yet “bent the curve” on global emissions

Annual global CO_2 emissions from energy and land use change

BILLIONS OF TONS OF CO_2; EXCLUDES NON-CO_2 GHGS

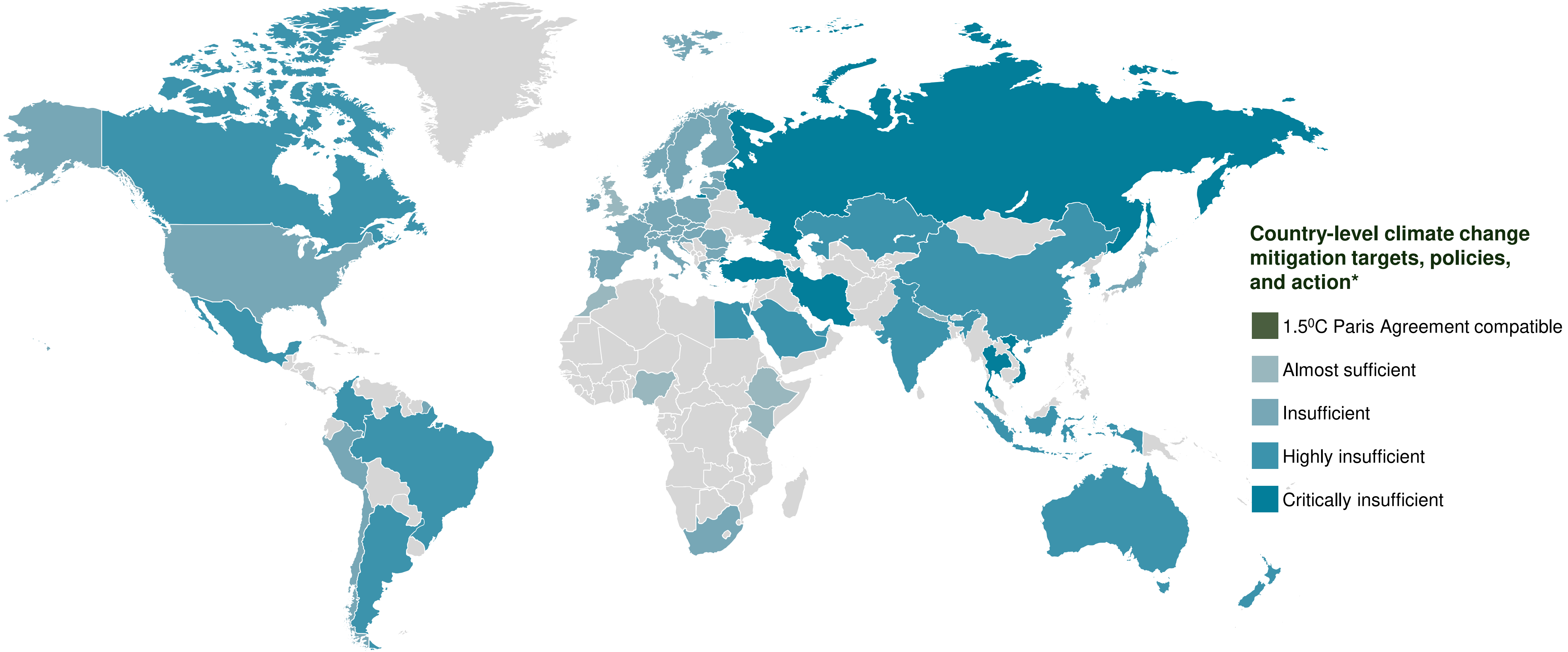
65% **Rise in global CO_2 emissions** since the UN Framework Convention on Climate Change was established in 1992



Source: Global Carbon Project; Vaclav Smil, How the World Really Works

Policy

And today, nearly all Paris Agreement participants are behind agreed-upon aims

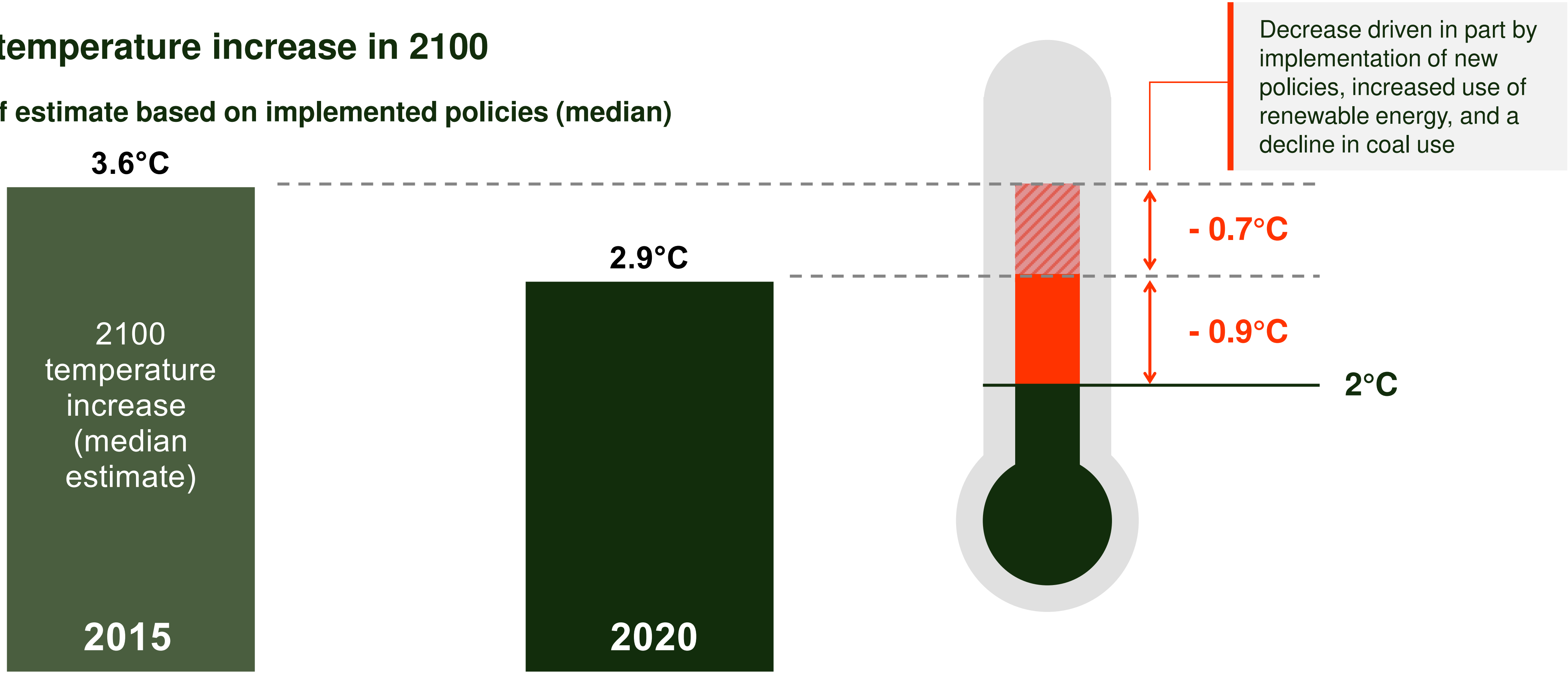


Note: * Measured against globally agreed Paris Agreement aim of "holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C."
Source: Climate Action Tracker (updated March 2022)

However, the climate outlook through 2100 has improved, due at least in part to action spurred by Paris

Global temperature increase in 2100

By year of estimate based on implemented policies (median)



Note: Temperature estimates reflect end-of-century warming above the pre-industrial average based on implemented policies
Source: Bain & Company analysis; Climate Action Tracker, “Paris Agreement turning point”, December 2020

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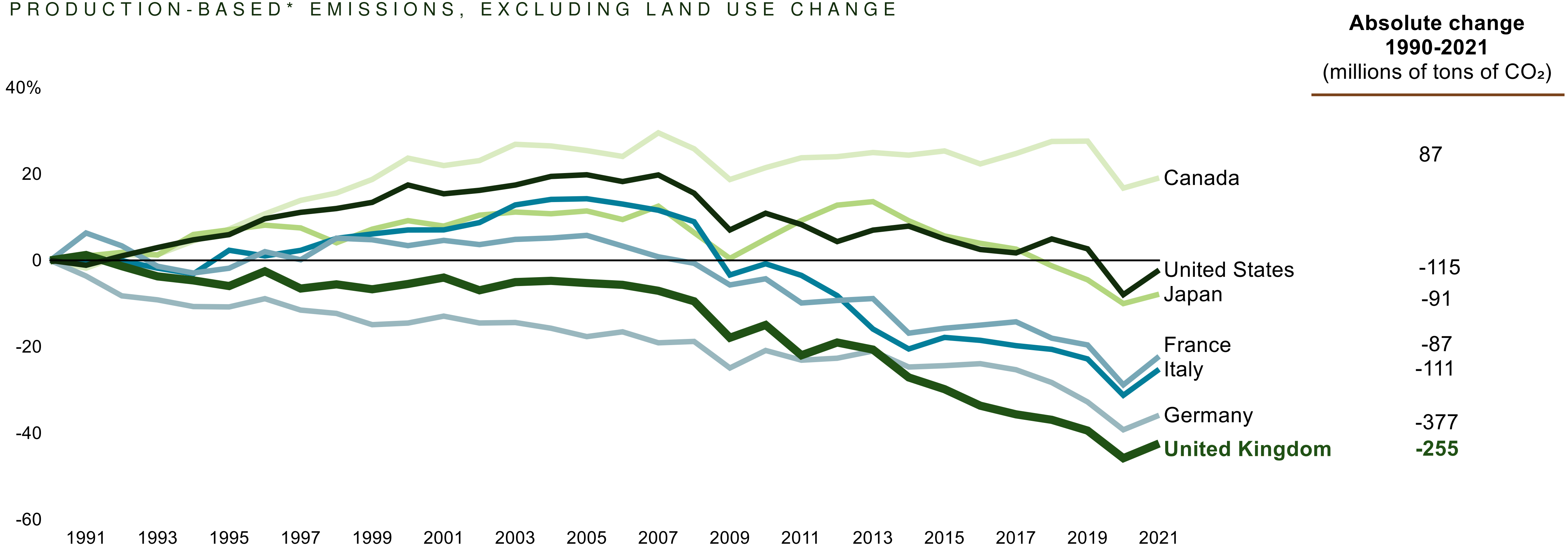
The United Kingdom and Germany have each cut CO_2 emissions significantly since 1990

Change in CO_2 emissions, 1990-2019

PRODUCTION-BASED* EMISSIONS, EXCLUDING LAND USE CHANGE



Note: Production-based emissions are not adjusted for trade (i.e., do not factor in emissions embedded in exports or imports)
Source: Global Carbon Project

Policy

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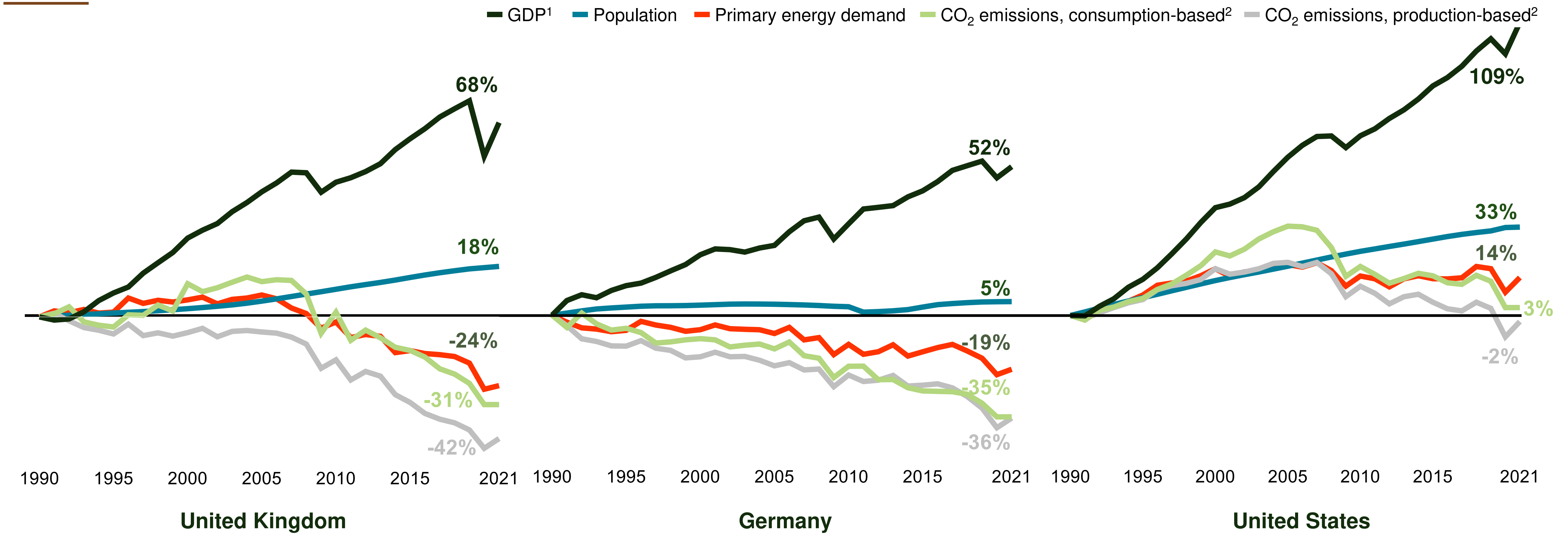
In both cases, emissions reductions occurred in parallel with meaningful economic and population growth

Change in GDP, CO_2 emissions, and population, 1990-2021 for select countries



Note: (1) GDP is measured in real 2015 US dollars; (2) consumption-based emissions are adjusted for trade (i.e., production emissions minus emissions embedded in exports plus emissions embedded in imports), and neither consumption-based nor production-based include emissions from land use change

Source: World Bank; Global Carbon Project; BP Statistical Review of World Energy, 2021

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Germany is an example of a country with a strong political commitment to transition away from fossil fuels

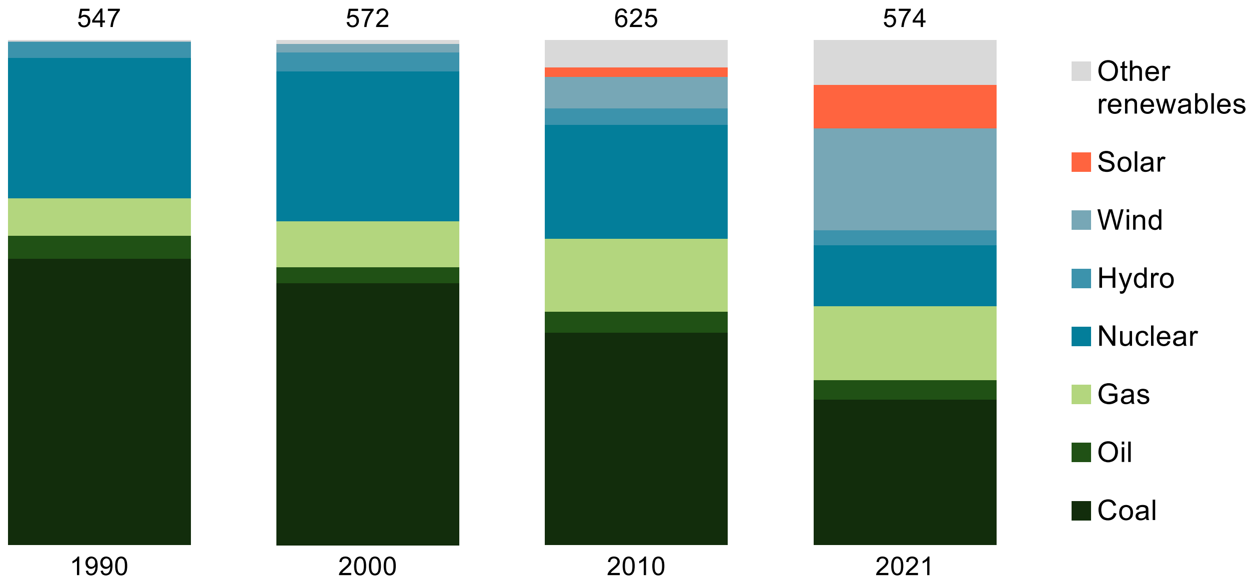
Germany's transition has been underway since the early 2000s

- ✓ In 2000, Germany embarked on an ambitious plan (*Energiewende*) to transition from fossil fuels to renewables
- ✓ The objective: Generate almost all electricity from renewable sources by 2035, in service of a broader 2045 net-zero target
- ✓ As part of this plan, Germany plans to retire its nuclear and coal fleets by 2022 and 2030, respectively

The result so far: meaningful progress in shifting electricity production to renewable sources

Germany electricity production by source

TWH



	1990	2000	2010	2021
Renewables %	3%	**6%**	17%	**41%**

Note: "Renewables" includes hydro, wind, solar, and other renewables (e.g., bioenergy)
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021; Ember Global Electricity Review (2022); Bloomberg

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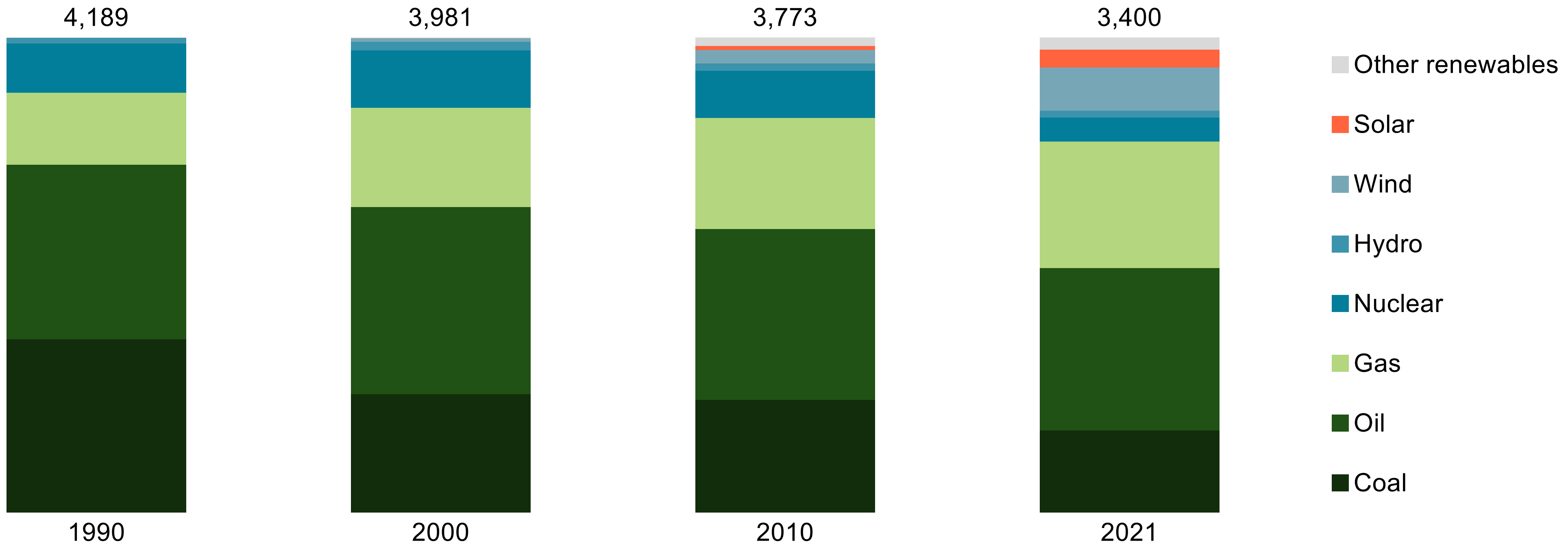
But the impact of *Energiewende* on Germany's *overall* energy consumption (not just electricity) has been more muted

Germany primary energy consumption by source

TWH



	1990	2000	2010	2021
Renewables %	1%	**3%**	7%	**17%**
Fossil fuel %	88%	**85%**	83%	**78%**

Note: "Renewables" includes hydro, wind, solar, and other renewables (e.g., bioenergy)
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021

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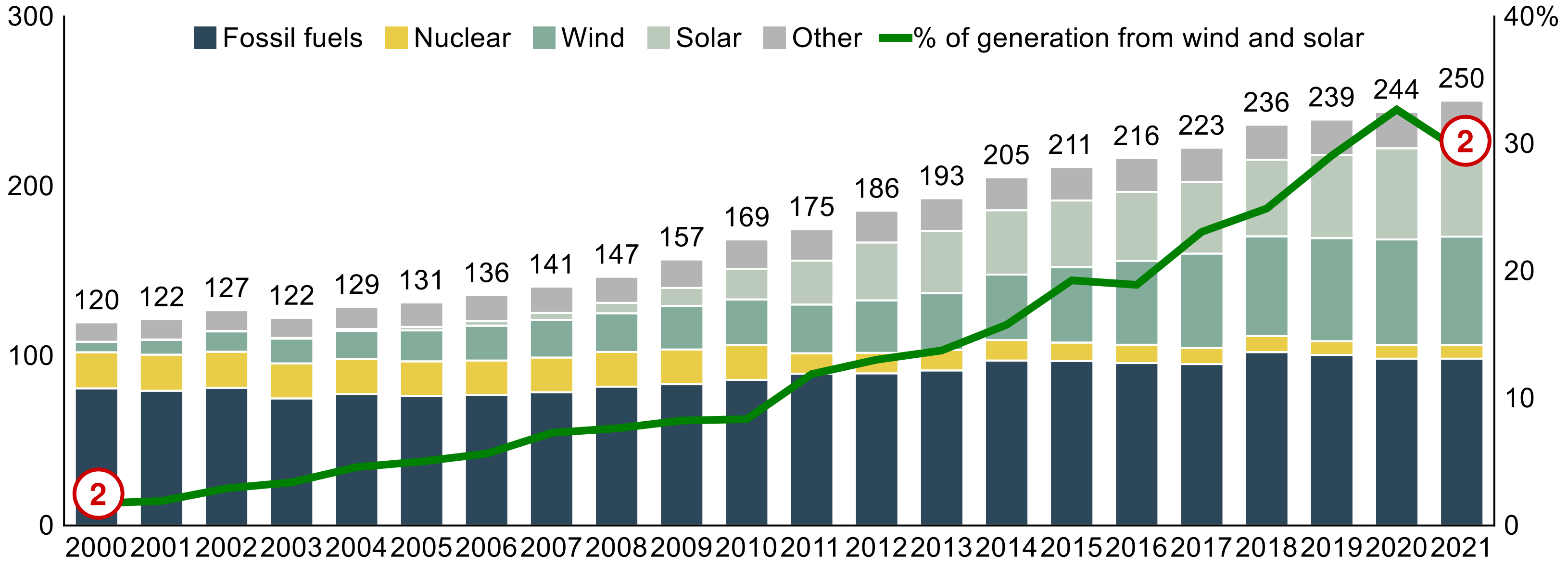
And with the transition to wind & solar, Germany has had to maintain all of its fossil fuel generation capacity

Germany electricity generation capacity
(measured in gigawatts, shown as bars)

Solar + wind share of German electricity production
(% of electricity generation in terawatt-hours, shown as line)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fossil fuel capacity (GW)	81 (3)	79	81	75	77	76	77	79	82	83	86	89	90	91	97	97	96	95	102	101	98	98 (3)
Total generation (TWh)	540 (1)	550	550	573	580	578	594	599	600	558	593	576	591	601	592	612	616	620	608	578	545	557 (1)

Source: EIA

1. Over 2000-2021, total electricity *generation* (TWh) in Germany grew 3%
2. Over the same period, wind and solar's share of *generation* expanded from 2% to 30%, on 116 GW of capacity additions
3. Despite the wind and solar expansion and roughly flat total electricity generation, fossil fuel generation *capacity* (GW) grew 20%

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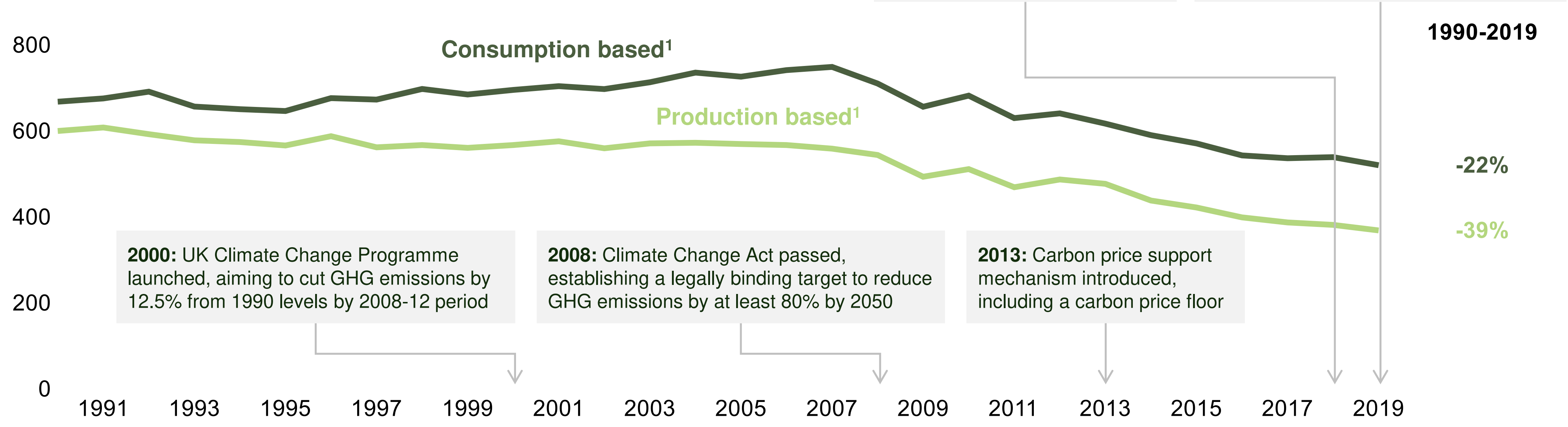
The UK's emissions decline unfolded against a backdrop of comprehensive climate policy, including carbon pricing

United Kingdom CO_2 emissions

MILLIONS OF TONS OF CO_2; EXCLUDES NON-CO_2 EMISSIONS

2018: 25-year environment plan, focused on agriculture and land use, and plan to double offshore wind capacity introduced

2019: UK becomes first major economy to pass law committing to net zero GHG emissions by 2050; the next year, a ban on sale of ICE vehicles is set at 2030



Emissions per capita[2]	12 tons / cap	11	12	12	11	9	8	**-33%**
Emissions per GDP[2]	0.37 kg / $	0.33	0.30	0.28	0.26	0.19	0.16	**-56%**

Note: (1) Consumption-based emissions are adjusted for trade (i.e., production emissions minus emissions embedded in exports plus emissions embedded in imports); (2) denominator of data row figures reflects consumption-based CO_2 emissions, and GDP is measured in 2015 real USD

Source: World Bank; Global Carbon Project; Gov.uk, UK becomes first major economy to pass net zero emissions law (2019); UK Parliament, Carbon Price Floor (CPF) and the price support mechanism (2018)

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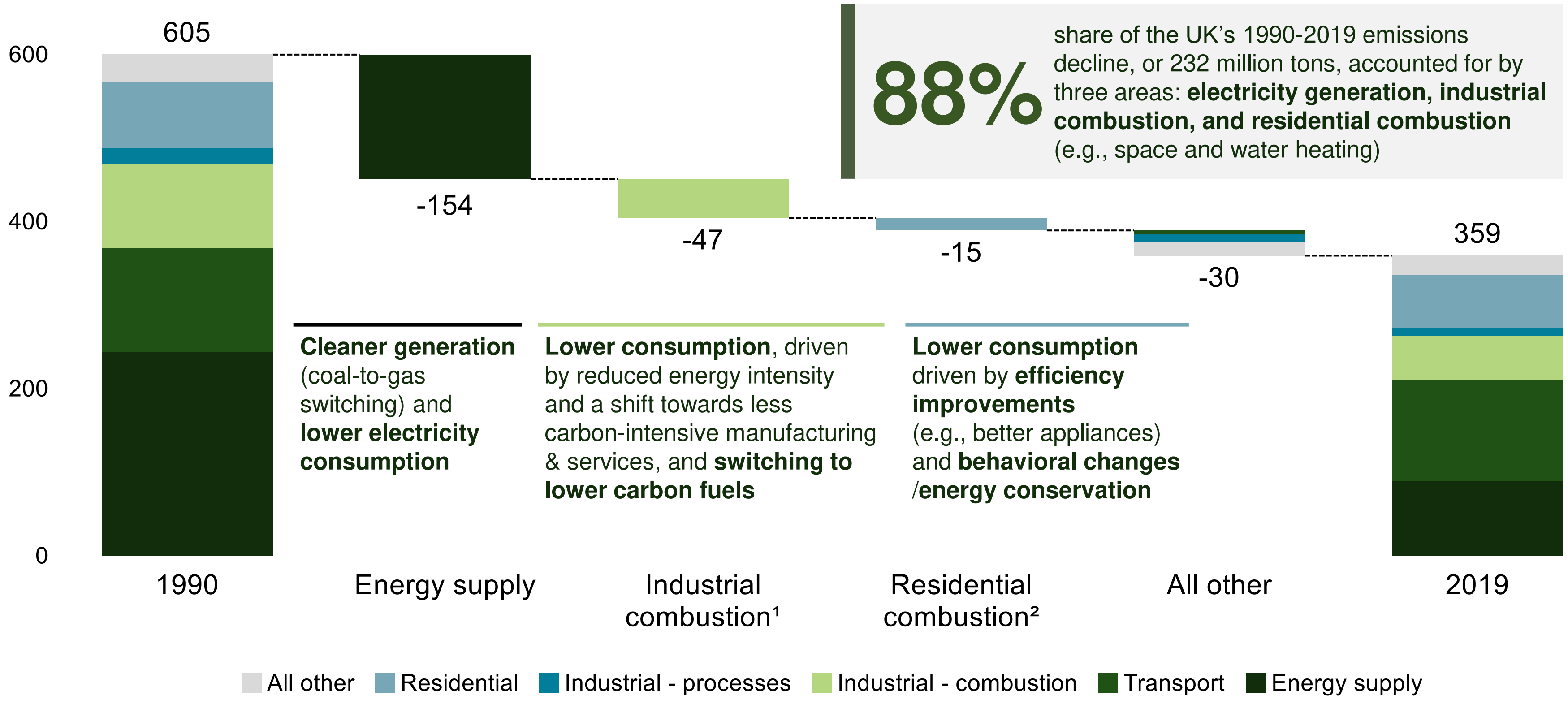
UK emissions reductions stemmed from several sources, notably cleaner power generation and reduced energy use

UK CO_2 emissions, 1990-2019

MILLIONS OF TONS OF CO_2; EXCLUDES NON-CO_2 EMISSIONS



1990-2019

% change	Share of total change
-41%	6%
-19%	**6%**
-50%	4%
-47%	**19%**
-3%	2%
-63%	**63%**
-40%	**100%**

Note: (1) Industrial combustion includes fossil fuel combustion in iron/steel production, chemicals manufacturing, cement production, and other industrial processes; (2) Residential combustion includes fossil fuel (primarily natural gas) combustion for space and water heating. Source: UK Department for Business, Energy, & Industrial Strategy, Final UK greenhouse gas emissions national statistics: 1990 to 2020

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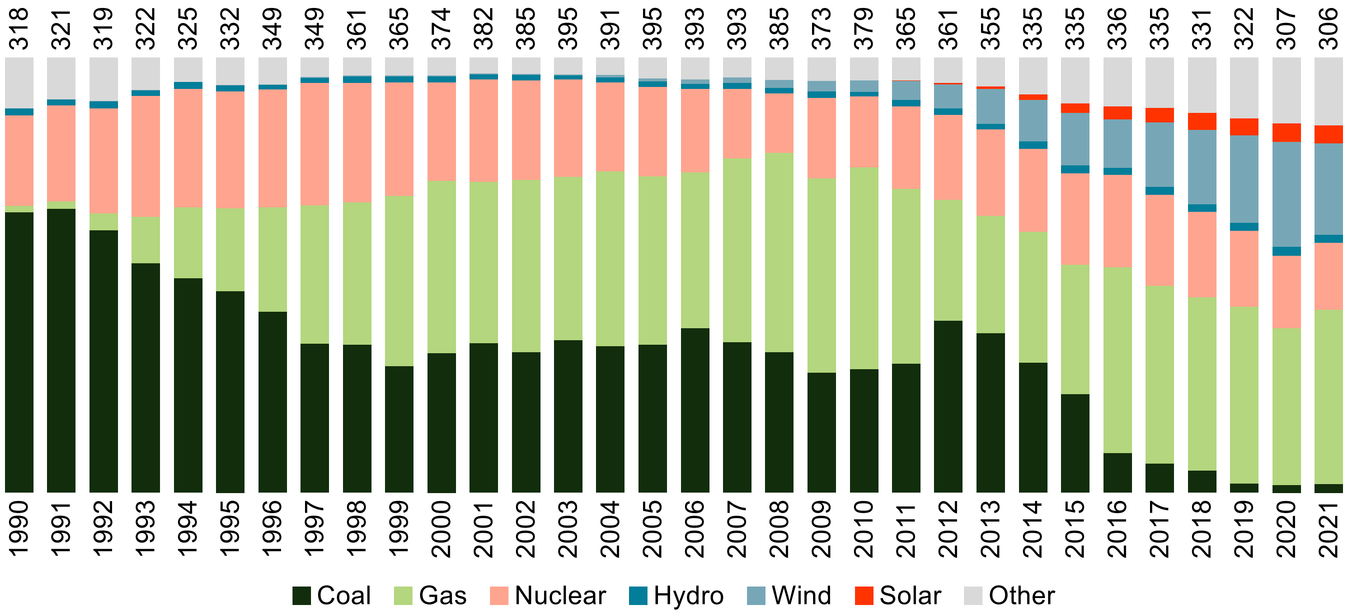
Coal-to-gas switching in power generation was a major source of UK emissions reductions, driven in part by climate policy

Over 1990-2021, UK electricity production from coal dropped by 97% and was replaced mostly by gas

United Kingdom electricity production by generation source

TWH



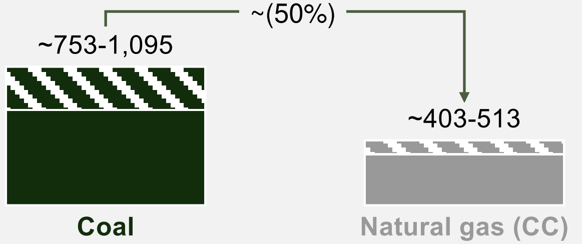
This switch was partially driven by climate change policy

1990s: Coal power generation drops by 50%, a result of the "dash for gas". **This was not an achievement of climate change policy**; rather, it was triggered by privatization in the UK electricity supply

2010s: Coal power generation falls by a further 93%, largely a consequence of **increased renewables output**, due in turn to **falling costs** and **government subsidies**, and **carbon price support** (i.e., a carbon tax), which together made coal uncompetitive

Lifecycle greenhouse gas emissions

G OF CO_2 - EQUIVALENT PER KWH



Note: Other includes other renewables (e.g., bioenergy). Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021; Sheffield Hallam University, Coal Transition in the United Kingdom (2017); UN Economic Commission for Europe, Life Cycle Assessment of Electricity Generation Options (2021)

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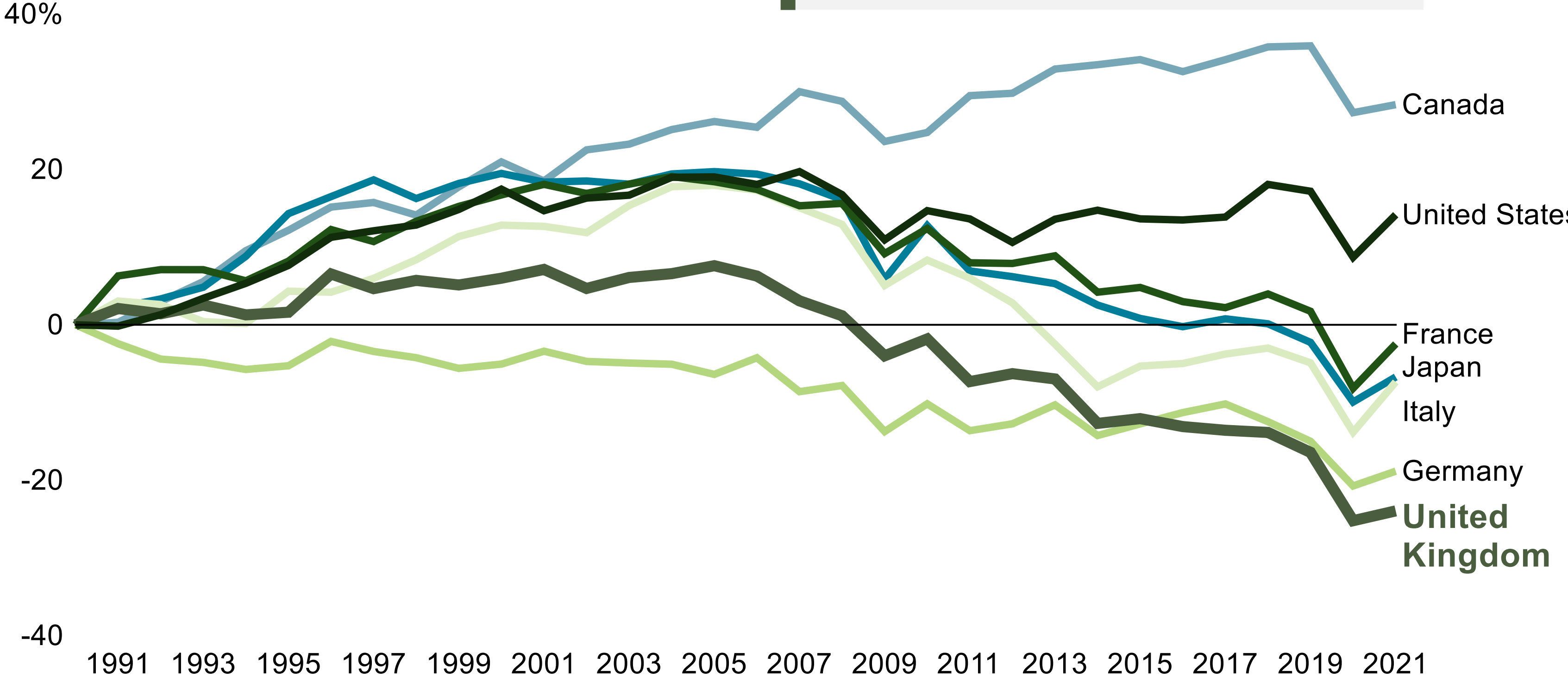
Lower overall energy use has also played a role: the UK consumes less energy today than it did 50 years ago

Change in primary energy demand, 1990-2021

-25% change in the UK's **primary energy demand between 1970 and 2021**



	% change	
	1990-2021	**2005-2021**
Canada	28%	2%
United States	14%	-4%
France	-2%	-18%
Japan	-7%	-22%
Italy	-7%	-21%
Germany	-19%	-13%
United Kingdom	**-24%**	**-29%**

Note: Production-based emissions are not adjusted for trade (i.e., do not factor in emissions embedded in exports or imports)
Source: Bain & Company analysis; Our World in Data; Global Carbon Project

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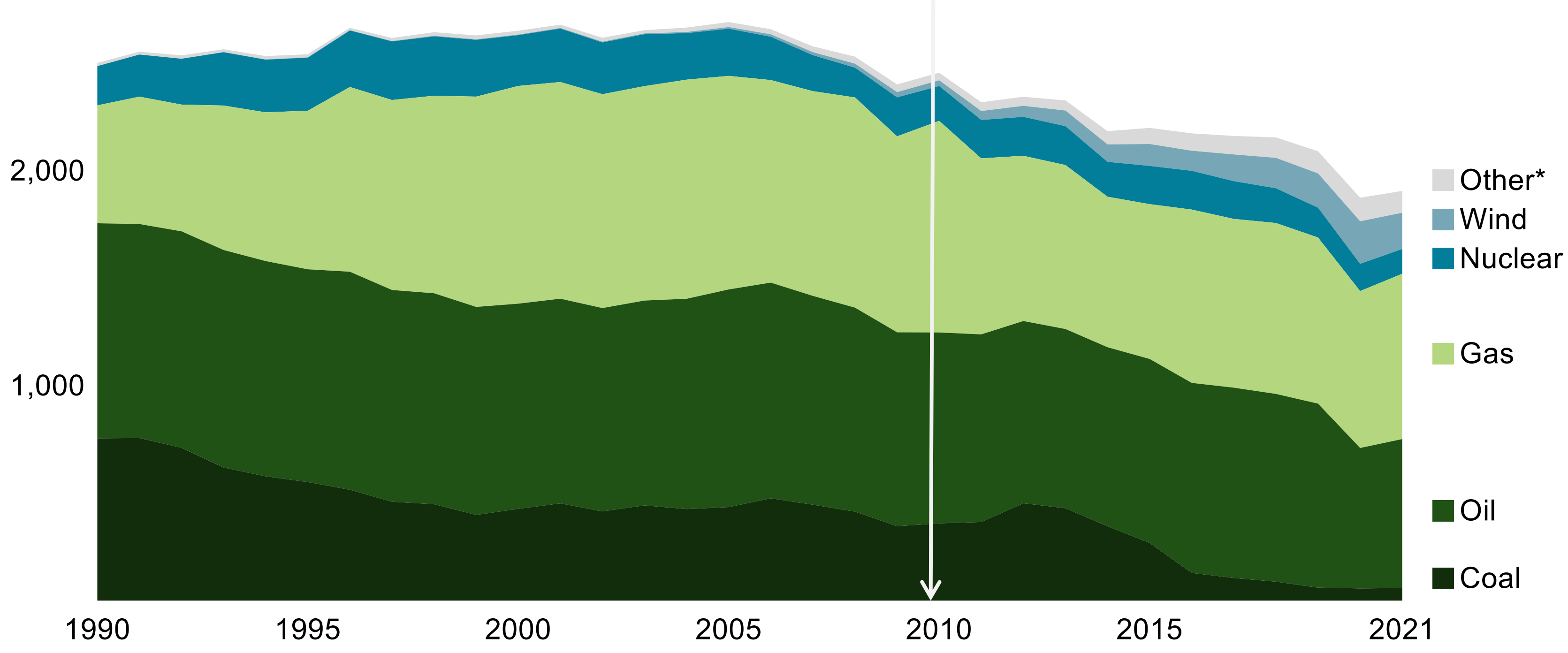
Energy supplied by all fuel sources, except renewables, is down meaningfully since the mid-2000s

UK primary energy demand

TERAWATT-HOURS

2008: Climate Change Act passed, establishing a legally binding target to reduce GHG emissions by at least 80% by 2050



% change

	1990-2021	2005-2021
Other*	--	--
Wind	--	--
Nuclear	-37%	-48%
Gas	40%	-23%
Oil	-31%	-32%
Coal	-92%	-87%
	-24%	**-29%**

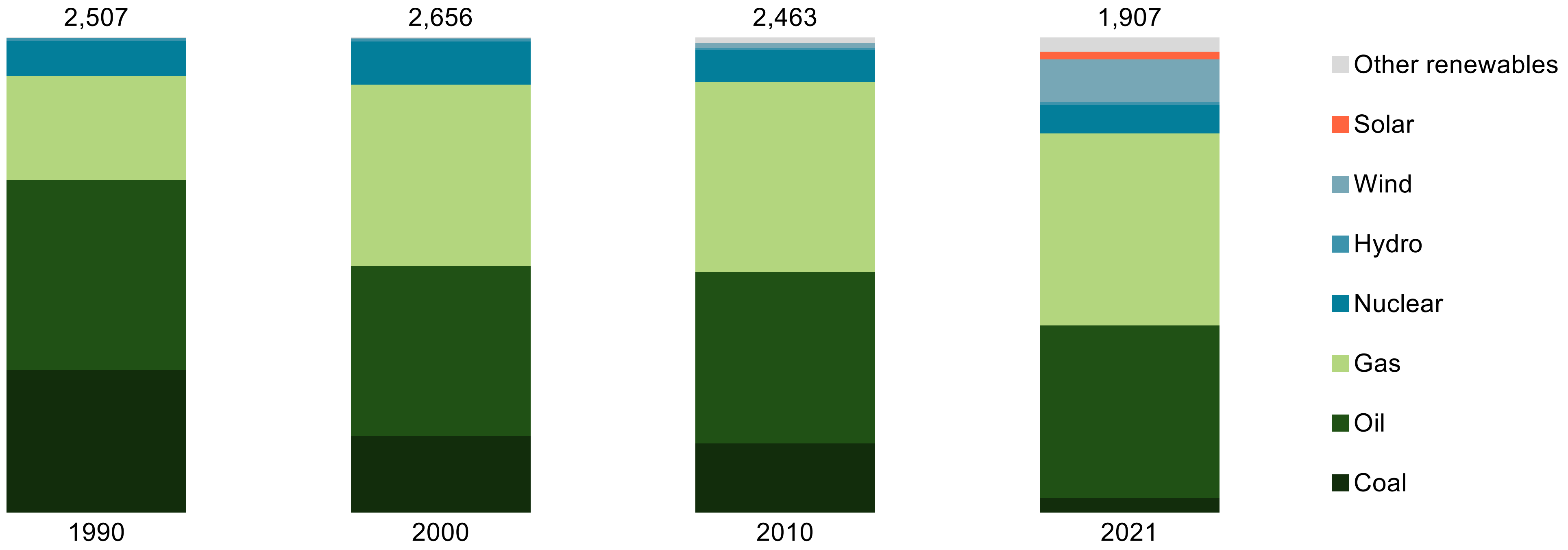
Note: Other includes solar, hydro, and other renewables (e.g., bioenergy)
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021

Policy

Overall, the UK has reduced its reliance on fossil fuels modestly but remains heavily dependent

UK primary energy consumption by source

TWH



	1990	2000	2010	2021
Renewables %	1%	**1%**	3%	**14%**
Fossil fuel %	92%	**90%**	91%	**80%**

Note: “Renewables” includes hydro, wind, solar, biofuels, and other renewable sources
Source: Bain & Company analysis; Our World in Data; BP Statistical Review of World Energy, 2021

Contrasting the approach of the Germany with that of the US reveals the challenges of decarbonizing

		Germany	United States
Energy transition pathway		Deliberate, highly centralized, government-led with targets and mandates	No-target, no-mandate, market-driven
Significantly reduce emissions	Fossil fuels as share of primary energy supply	**-7 pts** (86% to 79%, 2000-21)	**-6 pts** (88% to 82%, 2000-21)
	Renewables as share of electricity production	**+34 pts** (6% to 41%, 2000-21)	**+12 pts** (9% to 21%, 2000-21)
	Total GHG emissions	**-15%** (951M tons of CO_2-e to 812M, 2000-18)	**-10%** (6,594M tons of CO_2-e to 5,939B, 2000-18)
	GHG emissions per capita	**-15%** (11.6t CO_2-e to 9.8, 2000-18)	**-22%** (23.4t CO_2-e to 18.2, 2000-18)
Deliver affordable, reliable, secure energy	Residential electricity price	**+139%** (€0.13/kWh to €0.31/kWh, 2000-21)	**+67%** ($0.08/kWh to $0.14/kWh, 2000-21)
	Industrial electricity price	**+270%** (€0.05/kWh to €0.19/kWh, 2000-21)	**+59%** ($0.05/kWh to $0.07/kWh, 2000-21)
	Energy dependence*	**More dependent** (61% to 70%, 2000-19)	**Less dependent** (27% to -2%, 2000-19)

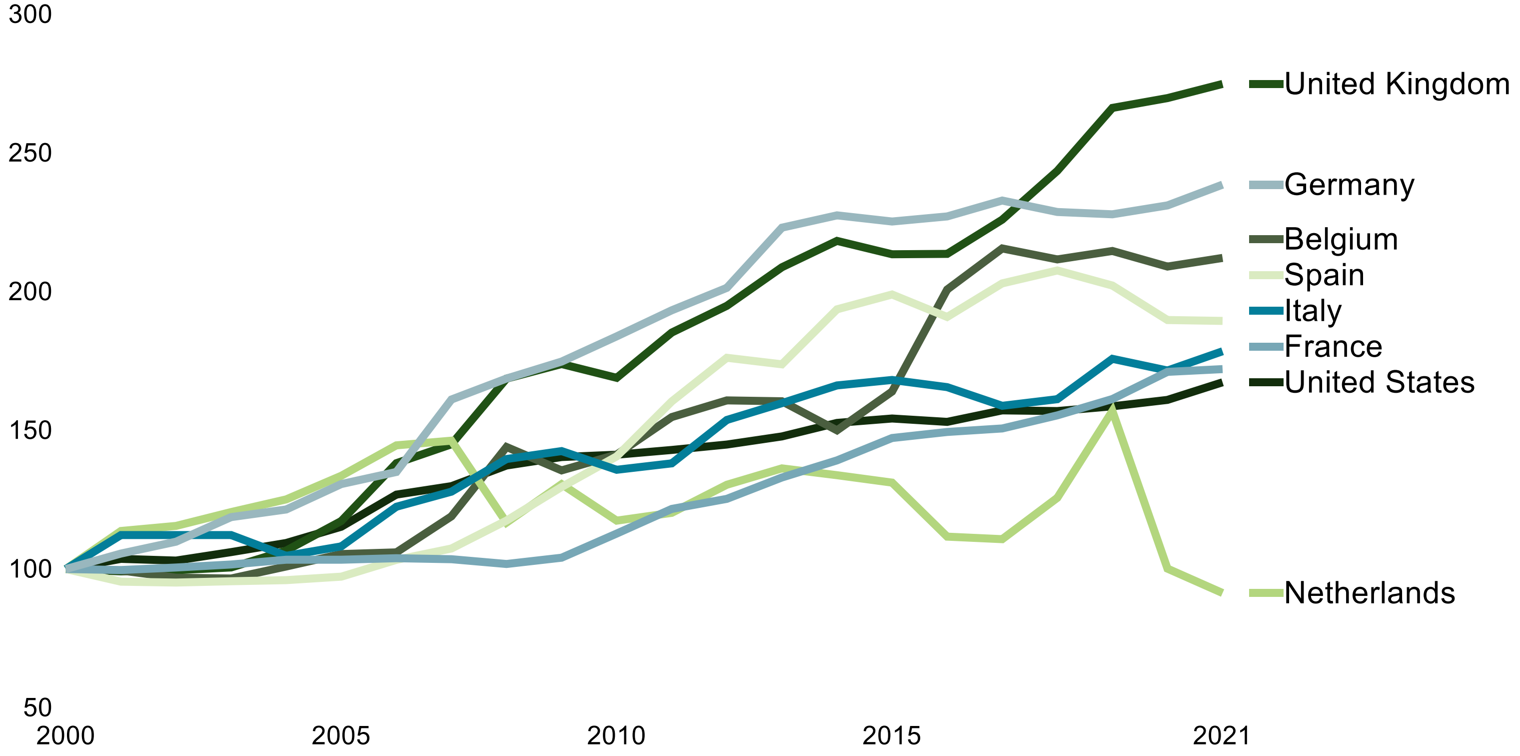
Note: * Energy dependence = (energy imports – energy exports) / total primary consumption, measured in millions of tons of oil equivalent (Mtoe)
Source: Euromonitor; Eurostat; Enerdata; CAIT; World Bank; BP Statistical Review of World Energy, 2021

Policy

Progress in both Germany and the UK has come at a cost: electricity prices have risen rapidly in both countries

Residential electricity price

LOCAL CURRENCY PER MWH, INDEXED TO 2000 =100



	2000-2021 growth	2021 price in local currency	2021 price in USD
United Kingdom	**175%**	**£194**	**$261**
Germany	**139%**	**€312**	**$357**
Belgium	112%	€279	$319
Spain	89%	€241	$276
Italy	79%	€262	$300
France	72%	€190	$217
United States	67%	$137	$137
Netherlands	-9%	€130	$149

Note: Prices are measured in current (rather than constant) currency. USA data is in USD; all other countries are in EUR
Source: Euromonitor

It is critically important for developing countries to participate in the global decarbonization project

India and low-income developing countries' annual CO_2 emissions could **grow by nearly 10 billion tons by 2050, about the amount emitted by all advanced economies in 2019**, given population growth projections and assuming CO_2 emissions per capita reach the level of emerging economies like Mexico and Botswana

Future emissions for select developing countries			India	Low-income developing countries	Total
2022	**Population**		1.4 billion	1.6 billion	3.0 billion
	Emissions per capita (actual)	✖	1.9 tons/person	0.6 tons/person	1.2 tons/person
	Total CO_2 emissions	=	**2.7 billion tons**	**0.9 billion tons**	**3.6 billion tons**
2050	**Population** (UN forecast)		1.7 billion	2.7 billion	4.3 billion
	Emissions per capita (assumed)	✖	3.0 tons/person	3.0 tons/person	3.0 tons/person
	Total CO_2 emissions	=	**5 billion tons**	**8 billion tons**	**13 billion tons**

Mexico, Botswana, and Jamaica each emit about 3 tons per capita today

Note: Emissions and emissions per capita are production-based CO_2 (excludes non-CO_2 emissions like methane); low-income developing countries are those with per capita income levels below $2,700 (2016 $), structural features consistent with limited development, and insufficiently close external financial linkages to be seen as emerging market economies. Source: Global Carbon Project; UN Population Division; IMF

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Across nations, energy security is an increasingly important policy concern

Of the top 10 economies (countries by GDP), **8 were dependent on energy imports**

The Winter 2021-22 energy crunch, and Russia's invasion of Ukraine, **shined a spotlight on energy security risk for importers**

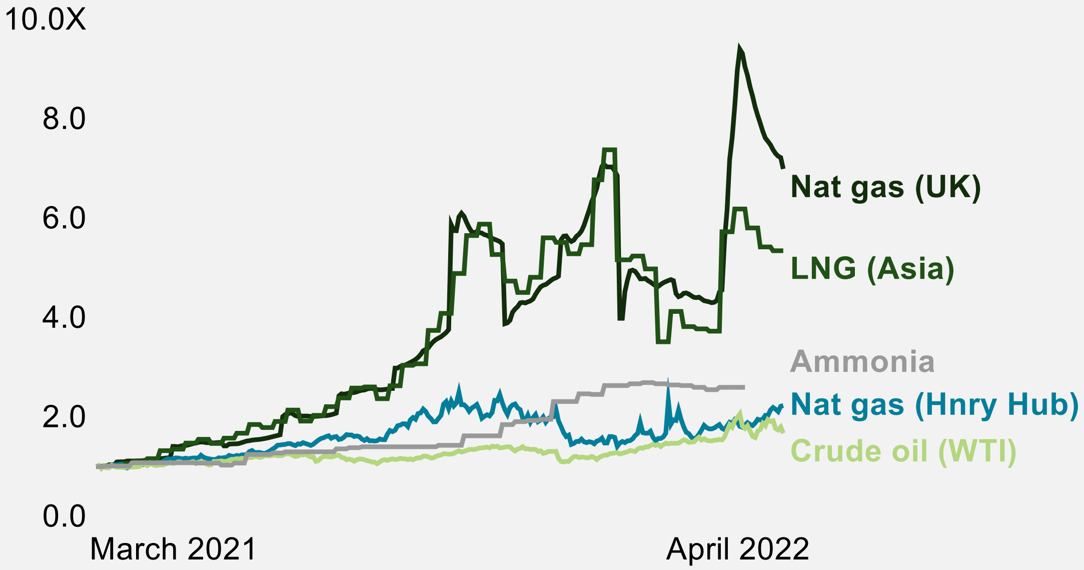
Shortage conditions drove energy prices up 5-10X, creating inflationary pressure, demand destruction, and unpredictability

There are two pathways countries will consider **to sustain or increase energy supply**:

- **Path 1**: Focus on security of supply of fossil fuels – minimize counterparty risk, at reasonable cost
- **Path 2**: Transition more quickly to renewable fuels to address *both* climate change *and* energy security

Commodity prices

SHOWN FOR SELECT COMMODITIES, INDEXED TO MAR 2021 = 1.0



Energy security is likely to be a **key macro consideration for the foreseeable future** and will **shape responses to the "dual challenge"** for developed and developing economies

Source: Refinitiv, Eikon, World Bank

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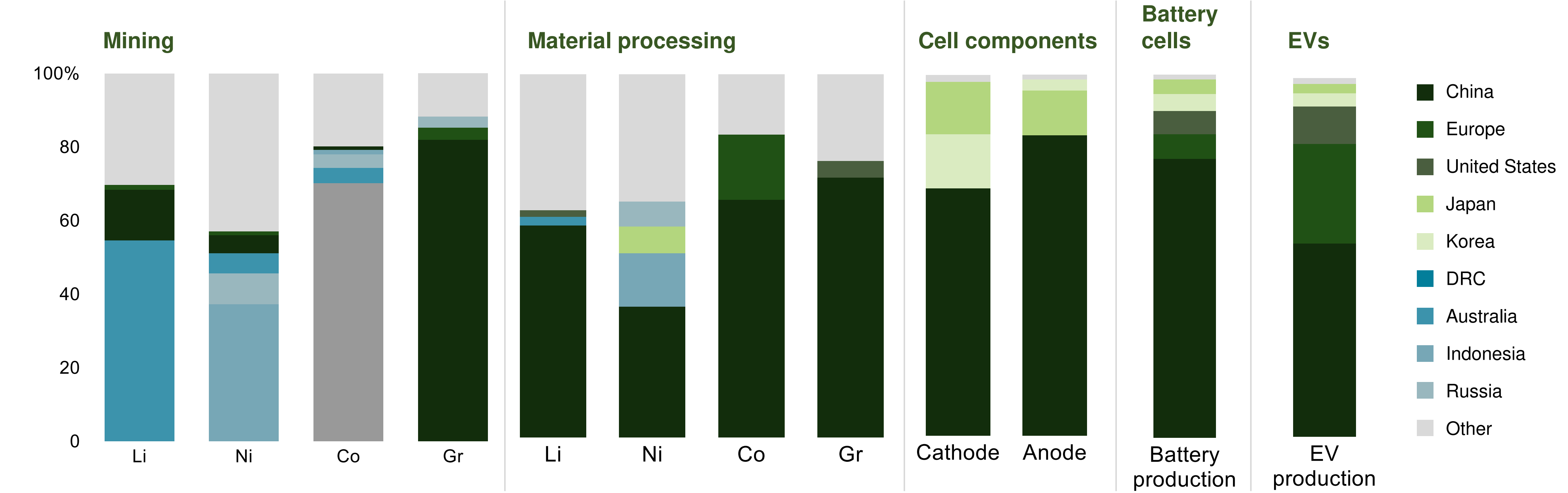
Some clean solutions come with their own set of security concerns; electrical vehicle batteries are an example

China dominates the entire downstream EV battery supply Chain

Geographical distribution of the global EV battery supply chain



Note: Li=lithium; Ni=nickel; Co=cobalt; Gr=graphite; DRC=Democratic Republic of Congo. Geographical breakdown refers to the country where the production occurs. Mining is based on production data. Material processing is based on refining production capacity data. Cell component production is based on cathode and anode material production capacity data. Battery cell production is based on battery cell production capacity data. EV production is based on EV production data. Although Indonesia produces around 40% of total nickel, little of this is currently used in the EV battery supply chain. The largest Class 1 battery-grade nickel producers are Russia, Canada and Australia.
Source: IEA analysis based on: EV Volumes; US Geological Survey (2022); Benchmark Mineral Intelligence; Bloomberg NEF

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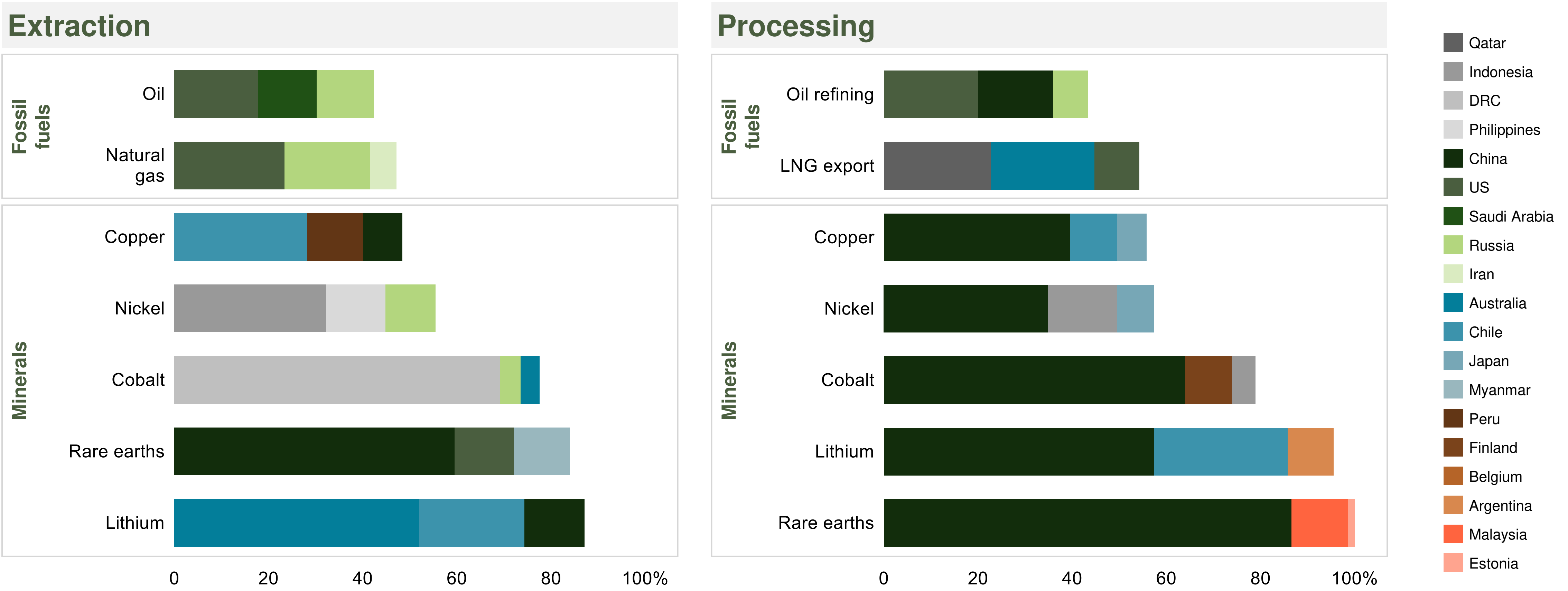
Production of minerals key to low carbon tech is highly concentrated, more so than oil and gas

Share of top three producing countries in production of selected minerals and fossil fuels, 2019



Note: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations
Source: IEA, The Role of Critical Minerals in the Energy Transition (2021), license: Creative Commons Attribution CC BY-NC-SA 3.0 IGO

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In developing countries, “affordable, reliable, secure” have historically been prioritized over “clean” in energy

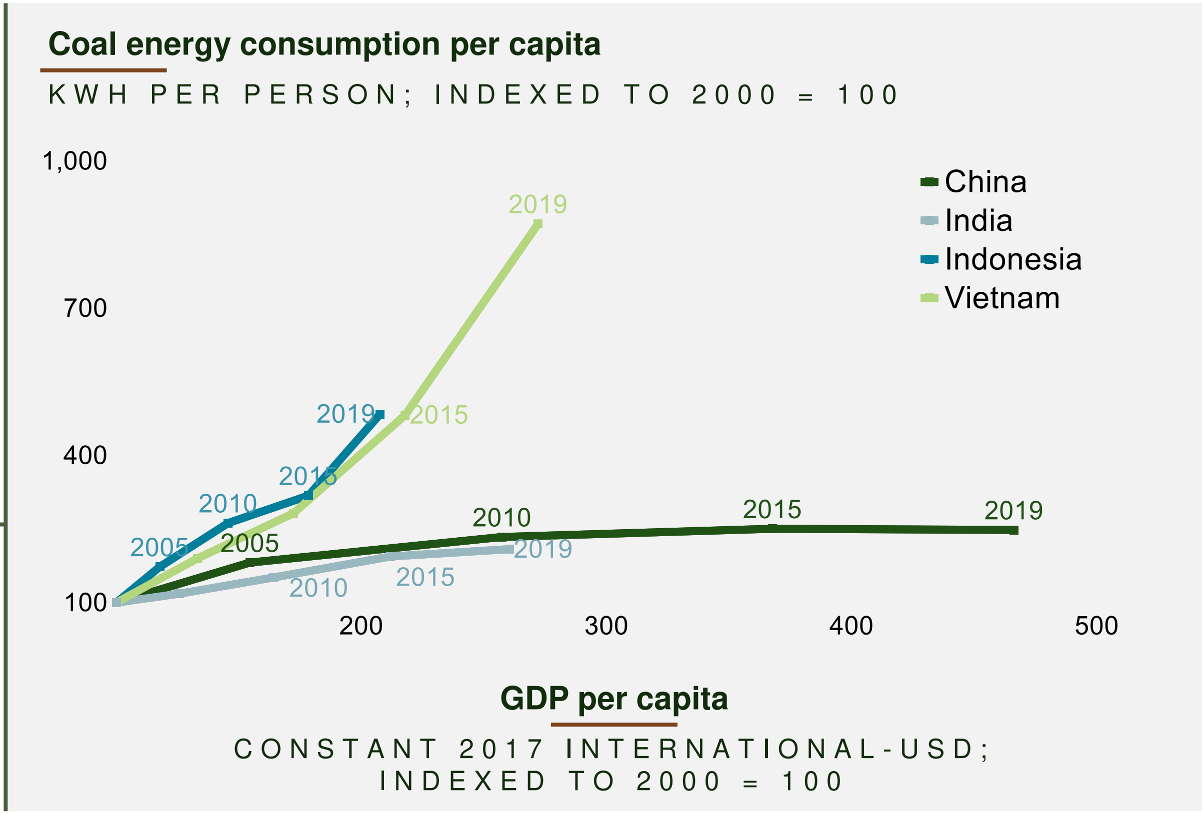
In the “calculus” of energy decisions, developing countries have historically **prioritized affordability, reliability, and security over clean/green**

Coal was, and to a certain degree remains, **the solution of choice to satisfy increasing electricity demand** in many countries, particularly in Asia

- China and India were almost entirely responsible for the doubling in global coal-fired power capacity over 2000-2019
- Today, there are nearly 200 coal plants under construction in Asia

In these countries, the expansion in energy supply driven by coal contributed meaningfully to **GDP growth** and **improvements in living standards**

In the **absence of viable alternative solutions** (i.e., as affordable, as reliable, and as secure), many countries will **continue to rely on fossil energy sources**



We cannot significantly reduce emissions without viable energy solutions for developing countries

Policy

Source: IEA; IMF; World Bank; BP Statistical Review of World Energy, 2021; Reuters

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Looking at living standards in developing countries, it is understandable why

Metric	Nigeria	United States	Difference
Population[1]	206 million	329 million	--
Gross national income per capita[1] (current USD)	$2,030	$65,970	**33X higher** in USA
Energy consumption per capita[2] (MWh per year)	2.4	77.5	**29X higher** in USA
Share of population with electricity access[1]	55%	100%	**45 pts higher** in USA
Life expectancy at birth[1]	55	79	**24 years higher** in USA
Mean years of schooling[3]	6.7	13.4	**6.7 more years** in USA
Infant mortality rate[1] (per 1,000 live births)	72	5	**14X lower** in the USA
Poverty rate[3] (% of population living below $1.90/day, 2011 PPP)	39%	1%	**39X lower** in the USA

Policy

Source: (1) World Bank (infant mortality rate; poverty rate, access to electricity); (2) BP Statistical Review of World Energy; (3) UN Development Programme (Human Development Index)

5

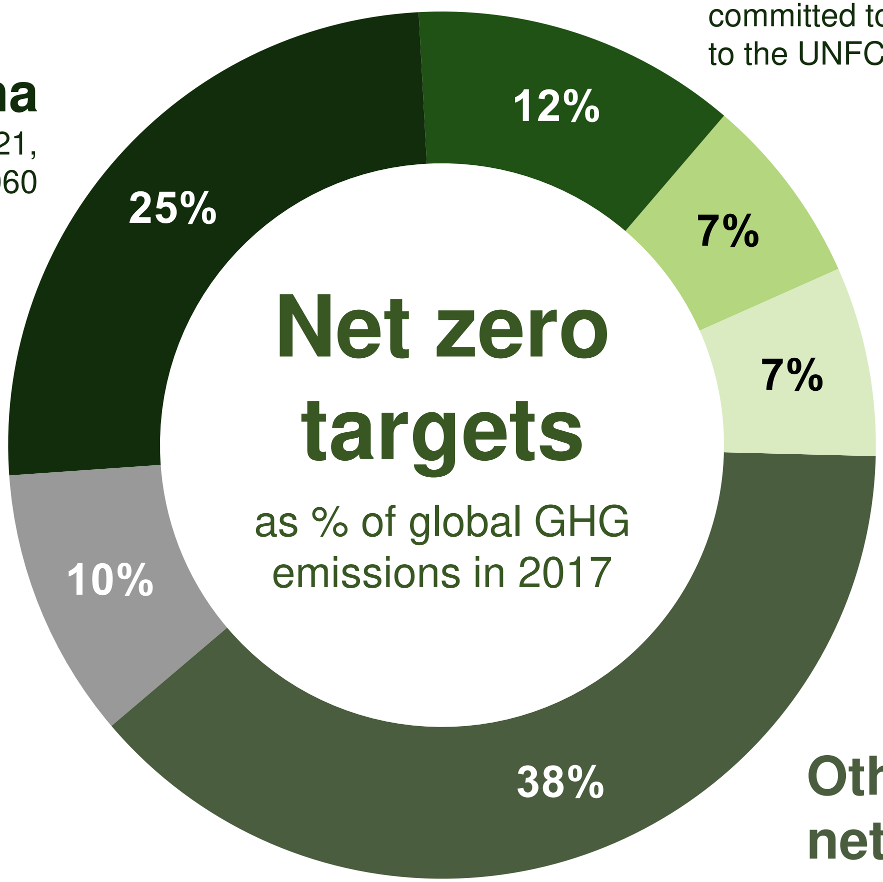
There are promising signs—countries accounting for 90% of global GHG emissions have made net zero pledges

United States
committed to net-zero GHG emissions by 2050, submitted to the UNFCCC in Nov 2021 under the Biden administration

China
submitted to the UNFCCC in Oct 2021, committing to net zero CO_2 emissions by 2060

European Union
European Climate Law adopted in June 2021, committing the EU to reach net zero GHG emissions by 2050

India
announced by Narendra Modi at COP26, committing India to net zero by 2070



Countries with no net-zero target

Other countries with similar net-zero announcements

Policy

Note: UNFCCC = United Nations Framework Convention on Climate Change
Source: Climate Action Tracker

DRAFT

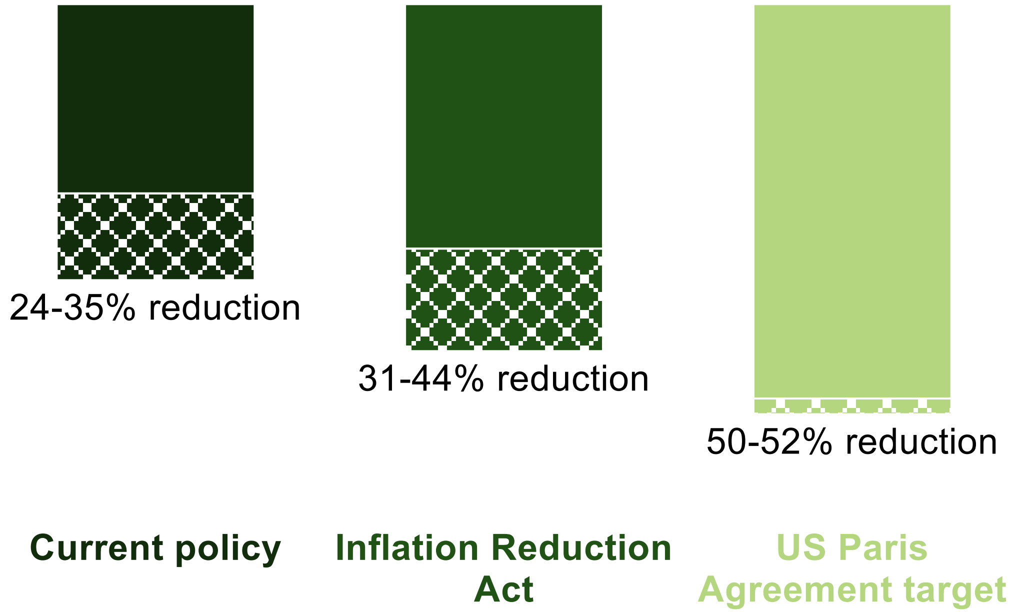
In the US, the Inflation Reduction Act (IRA) is a breakthrough policy shift

The IRA is the most significant climate action ever taken by Congress

- ✔ The Act includes $369B of investment over 10 years directed toward reducing emissions and improving climate resilience
- ✔ Specifically, the Act includes new or extended tax credits for hydrogen, wind, solar, nuclear, geothermal, electric vehicles, and carbon capture, among other provisions
- ✔ The Act also includes provisions for continued investment in oil & gas with geopolitical and energy security interests in mind

It will bring the US within striking distance of its Paris Agreement target

US greenhouse gas emissions percent reduction in 2030 from 2005 levels, Rhodium Group estimates



Source: Rhodium Group, A Congressional Climate Breakthrough; Moody's Analytics, Assessing the Macroeconomic Consequences of the Inflation Reduction Act of 2022; JPMorgan

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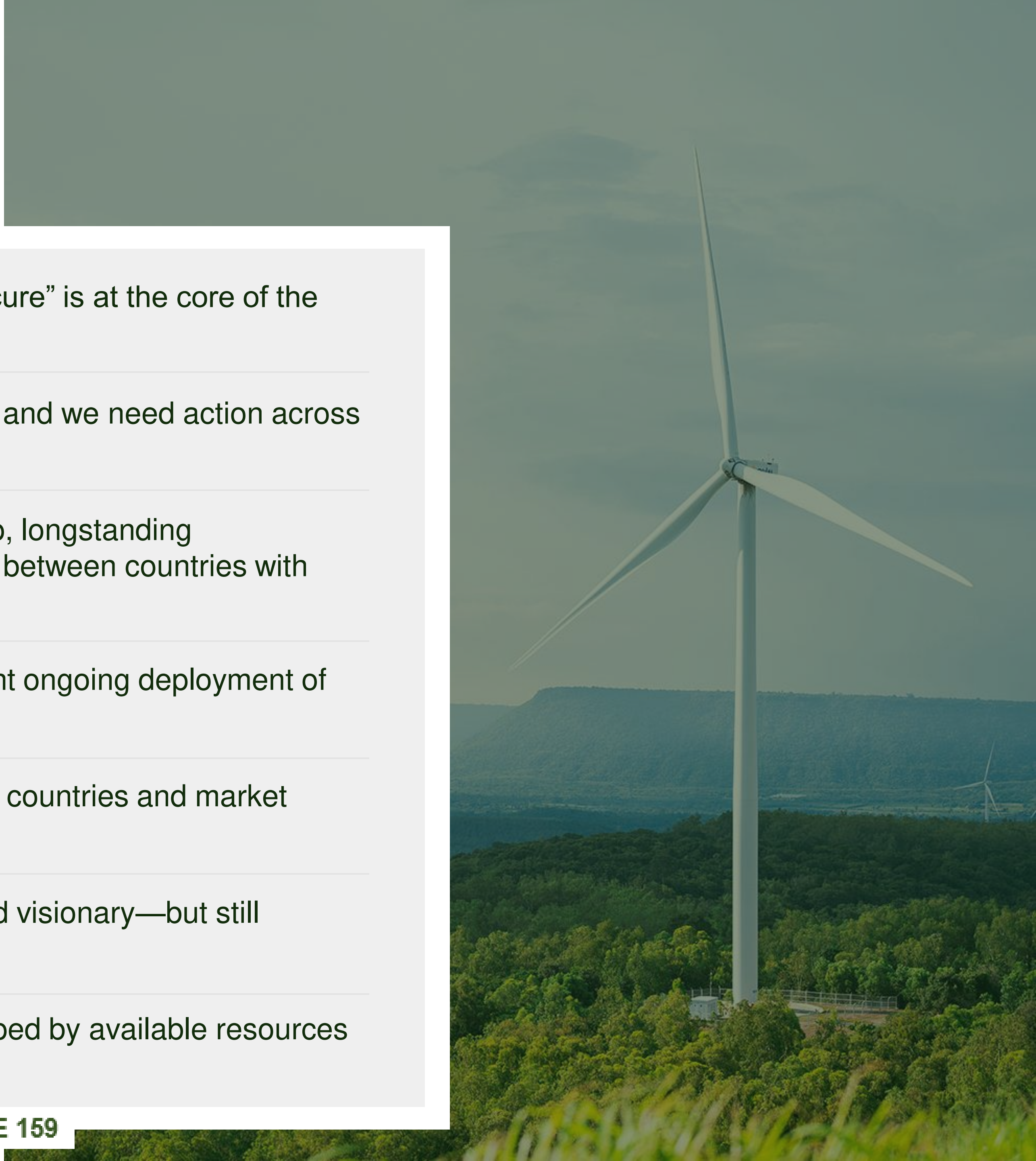
The Dual Challenge: Headwinds and Tailwinds



- Achieving “clean” without compromising “reliable, affordable, secure” is at the core of the Dual Challenge
- The momentum case based on current trend will not be enough, and we need action across policy, technology, corporates, and consumers
- We face considerable challenges in each area, such as our deep, longstanding dependence on fossil fuels, and the need for global coordination between countries with different national priorities
- However, encouragingly, we see signs of progress, like significant ongoing deployment of wind and solar
- We also see clear tailwinds, like broadening commitment among countries and market stakeholders
- As we consider solutions to this difficult, global problem, we need visionary—but still pragmatic—voices and system-oriented thinking
- Solution portfolios will look different from country to country, shaped by available resources and national priorities, and implementation will span decades

Appendix

General backup
Prefixes and unit conversions

APPENDIX

Common (SI) prefixes

Factor	Name	Symbol
10^1	deka	da
10^2	hecto	h
10^3	kilo	k
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zotta	Z
10^{24}	yotta	Y

Energy unit conversions

1 joule *The amount of work done when a force of one newton is displaced through a distance of one meter*	2.78×10^{-4} watt-hours
	1.63×10^{-10} BOE
	2.39×10^{-11} toe
	9.48×10^{-4} Btu
1 watt-hour *One watt of power sustained for one hour*	3,600 joules
	5.88×10^{-7} BOE
	8.60×10^{-8} toe
	3.4 Btu
1 BOE (barrel of oil equivalent) *Approximate amount of energy released by burning one barrel (42 gal / 159L) of crude oil*	6.12×10^{9} joules
	1.70×10^{6} watt-hours
	0.15 toe
	5.80×10^{6} Btu
1 toe (ton of oil equivalent) *Approximate amount of energy released by burning one metric ton (1,000 kg) of crude oil*	4.19×10^{10} joules
	1.16×10^{7} watt-hours
	6.84 BOE
	3.97×10^{7} Btu
1 Btu (British thermal unit) *Defined as the amount of heat required to raise the temperature of one pound of water by one degree*	1,055 joules
	0.29 watt-hours
	1.72×10^{-7} BOE
	2.52×10^{-8} toe

General backup
IMF economy groupings

APPENDIX

The main criteria used by the IMF to classify economies are: (1) per capita income level; (2) export diversification; and (3) degree of integration into the global financial system. **Low-income developing countries** are those with per capita income levels below $2,700 (2016 $), structural features consistent with limited development, and insufficiently close external financial linkages to be seen as emerging market economies

Advanced

Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Macao SAR, Malta, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, San Marino, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Taiwan Province of China, United Kingdom, United States

Emerging

Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Aruba, Azerbaijan, Bahrain, Barbados, Belarus, Belize, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cabo Verde, Chile, China, Colombia, Costa Rica, Croatia, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eswatini, Fiji, Gabon, Georgia, Grenada, Guatemala, Guyana, Hungary, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kosovo, Kuwait, Lebanon, Libya, Malaysia, Maldives, Marshall Islands, Mauritius, Mexico, Micronesia, Mongolia, Montenegro, Morocco, Namibia, Nauru, North Macedonia, Oman, Pakistan, Palau, Panama, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Samoa, Saudi Arabia, Serbia, Seychelles, South Africa, Sri Lanka, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Syria, Thailand, The Bahamas, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Tuvalu, Ukraine, United Arab Emirates, Uruguay, Vanuatu, Venezuela

Low-income developing

Afghanistan, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the, Congo, Republic of, Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, Gambia, The, Ghana, Guinea, Guinea-Bissau, Haiti, Honduras, Kenya, Kiribati, Kyrgyz Republic, Lao P.D.R., Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Moldova, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Papua New Guinea, Rwanda, São Tomé and Príncipe, Senegal, Sierra Leone, Solomon Islands, South Sudan, Somalia, Sudan, Tajikistan, Tanzania, Timor-Leste, Togo, Uganda, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe

Source: IMF (https://www.imf.org/external/pubs/ft/weo/faq.htm#q4b)

General backup
IPCC likelihood and confidence scale

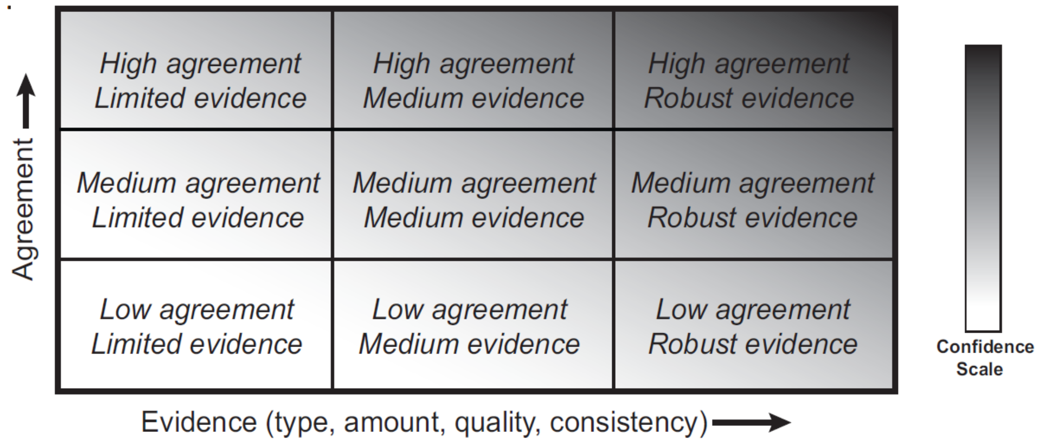
Likelihood

- Used to express a probabilistic estimate of the occurrence of a single event or outcome (e.g., a climate parameter, observed trend, or projected change)

Likelihood scale	
Term	**Likelihood of the outcome**
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Confidence

- Used to synthesize judgment about the validity of findings as determined through evaluation of evidence and agreement



Source: IPCC, Fifth Assessment Report (AR5), *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*

Chapter 2

Energy accounting: There is an important difference between primary energy and final consumption

APPENDIX

Non-combustible energy sources

- Flowing water
- Nuclear radiation
- Wind
- Sunlight
- Geological heat
- Wave / tidal action

Conversion (non-combustible)

- Hydropower
- Nuclear power
- Wind power
- Solar PV power
- Solar thermal power
- Geothermal power
- Wave / tidal power

To produce a complete profile of an energy system's supply, a method of primary energy equivalency can be used for each non-combustible fuel, and included alongside statistics of primary energy for combustibles fuels

Energy currency/carrier

- Electricity
- Heat
- Hydrogen (H_2)

Primary production

The sum of the embodied energy in produced primary fuel sources (e.g., tons of oil extracted multiplied by calorific value per ton of oil)

Primary energy

Labelled Total Energy Supply (TES) by the IEA, and Primary Energy Consumption by BP. This is the energy supplied by each fuel to an energy system prior to any conversions such as coal to electricity. For each energy source (fuel), this equals respective Total Primary Production plus imports, minus exports, plus or minus bunkers and stock changes

Final consumption

Labelled Total Final Consumption by the IEA. This is consumption of energy in final forms by an economy, e.g. combustion of coal and gas for heat, consumption of electricity, consumption of petrol/gasoline and diesel in vehicles, consumption of electricity in homes, etc.

Final energy consumption by sector / end-use

- Residential
- Industry
- Transport
- Commercial
- Agriculture
- Fishing
- Other

Combustible energy sources

- Coal
- Oil
- Gas
- Biofuels
- Waste

Relevant for country energy balances

Annual imports and exports (+ / −)

Annual bunkers and stock changes (+ / −)

Conversion (combustible)

- Conversion from primary source to another form of energy (e.g., coal or gas to electricity)
- 60-70% of embodied energy is lost in conversion to electrical or mechanical energy due to thermal efficiency

Conversion losses and energy industry own use

Energy currency/carrier

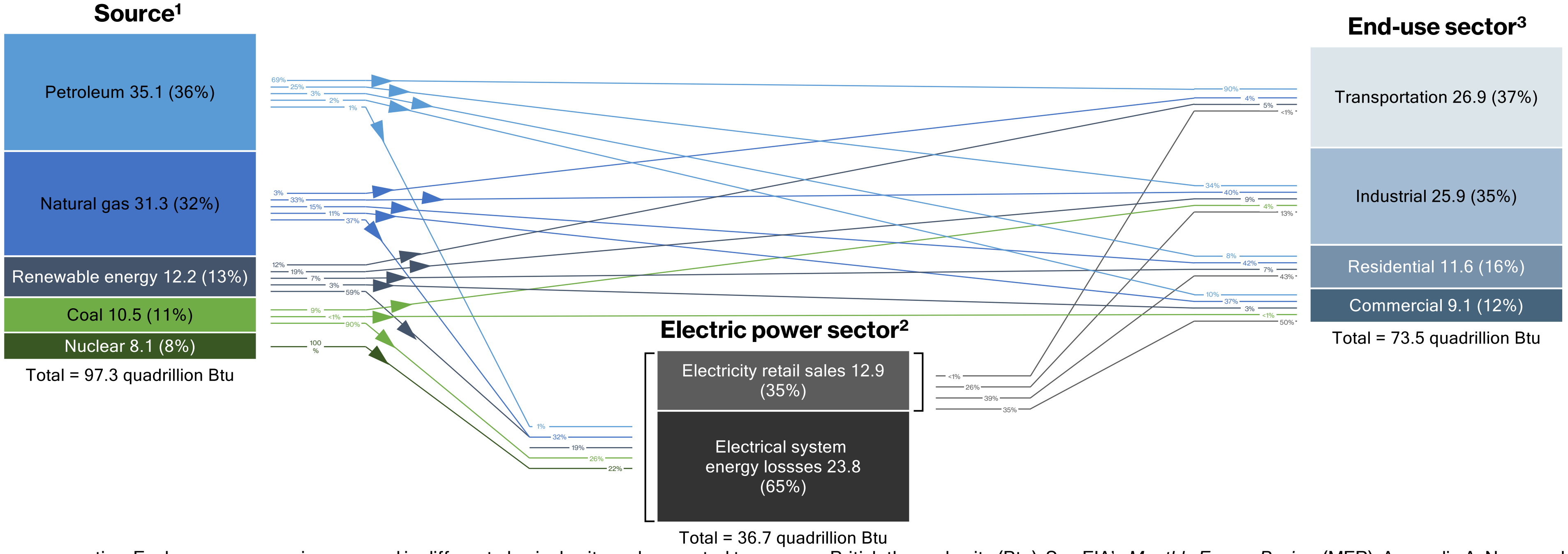
- Electricity
- Heat
- Coal, oil, gas
- Biofuels
- Waste
- Hydrogen (H_2)

Source: IEA, World Energy Balance Documentation (2021); UN, International Recommendations for Energy Statistics (IRES); WorldEnergyData.org

Chapter 2
Energy accounting: In the US (EIA) example, conversion losses account for 24% of primary consumption

APPENDIX

U.S. energy consumption by source and sector, 2021 (quadrillion British thermal units, Btu)



1. Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Non-combustible renewable energy sources are converted to Btu using the "Fossil Fuel Equivalency Approach", see MER Appendix E.; 2. The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses calculated as the primary energy consumed by the electric power sector minus the heat content of electricity retail sales. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.; 3. End-use sector consumption of primary energy and electricity retail sales, excluding electrical system energy losses from electricity retail sales. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants contained within the sector.

Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended chart notes" on next pages.

Source: U.S Energy Information Administration (EIA), *Monthly energy review* (April 2022), Tables 1.3 and 2.1-2.6

Chapter 2

Energy accounting: Methods for estimating primary energy for nuclear and renewables differ

APPENDIX

There are different primary energy estimation methods for nuclear and renewables

- When measuring electricity generation from renewables or nuclear power, we measure direct output, and the notion of upstream embodied energy is less well-defined vs. fossil fuels
- Consequently, different energy outlook publishers use different methods to compare the primary energy of fossil fuels vs. that of nuclear and renewables. Two such methods are
  - **"Input-equivalent" method**: primary energy for renewables and nuclear is based on the equivalent amount of fossil fuel input required to generate that amount of electricity in a standard thermal power plant
    - For example, if wind power output for a country was 100 TWh, and the efficiency of a thermal power plant was 38%, the input-equivalent primary energy would be 100/38% = 263 TWh
    - This approach is used by BP and EIA for most forms of non-fossil-based electricity (nuclear, hydro, wind, solar, geothermal, and biomass)
  - **"Captured energy" method**: assumes the primary energy content equals the energy content of the produced electricity for hydropower, wind, solar, and other renewable sources; this approach assumes no energy is lost in the conversion process
    - For example, if wind power output for a country was 100 TWh, the primary energy would be 100 TWh
    - This approach is used by IEA

Primary energy conversion efficiency assumptions differ for IEA, EIA, and BP

Primary energy source	IEA (benchmark)	EIA	BP (source most used in this document)
Nuclear	33%	32%	40%
Hydropower	100%	42%	40%
Wind	100%	42%	40%
Solar PV	100%	42%	40%
Geothermal	10%	33%	40%
Biomass	35%	32%	32%

Differences in these assumptions drive differences in total primary energy and the primary energy mix from one source/outlook to another

Source: BP Statistical Review of World Energy Methodology; Resources for the Future, Global Energy Outlook Comparison Methods: 2022 Update

Chapter 2
Energy demand scenario descriptions (1/2)

APPENDIX

Scenario	Description	Projected temperature outcome
Net Zero Emissions by 2050 (NZE)	This scenario is "normative", in that it was designed to reach a specific outcome, which is **net zero energy sector emissions globally by 2050**. The scenario meets key UN Sustainable Development Goals (SDGs), including achieving universal energy access by 2030 and major improvements in air quality.	Global average temperature rise limited to **1.5°C**, without a temperature overshoot (with a 50% probability). Temperature peaks around 2050, then stabilizes.
Sustainable Development Scenario (SDS)	Similar to NZE, but **the world reaches net zero by 2070** (with many countries and regions achieving net zero much earlier). This scenario is in line with the Paris Agreement and assumes a **significant increase in the adoption of clean energy policies**, with advanced economies reaching net zero by 2050, China around 2060, and all other countries by 2070	Global average temperature rise limited to **1.65°C**, with a 50% probability. With net negative emissions post-2070, the temperature rise could be reduced to **1.5°C** in 2100
Announced Pledges Scenario (APS)	This scenario assumes that all governments around the world **meet their existing emissions targets on time** (with targets set as of mid-2021). Targets include Nationally Determined Contributions (NDCs) and longer-term net zero targets	Global average temperature rise in 2100 is **2.1°C** above pre-industrial levels. However, **net zero is not achieved**, so temperature continues rising thereafter
Stated Policies Scenario (STEPS)	This scenario provides a **more conservative benchmark** and **does not assume all governments will reach their announced goals**. Instead, it takes a sector-by-sector approach to explore how the energy ecosystem may evolve **under current and under-development policies** and with no additional major steer from policy makers.	Global average temperature rise in 2100 is **2.6 °C** above pre-industrial levels. However, **net zero is not achieved**, so temperature continues rising thereafter.
ExxonMobil 2021 Outlook for Energy (XOM)	This scenario is **similar to the IEA APS** and **assumes emissions track within the estimated range of emissions implied by the Nationally Determined Contributions** (NDCs) as currently submitted via the Paris Agreement. Total emissions peak by roughly 2030, and by 2050 emissions are ~15% lower versus 2019.	Unclear, but likely between IEA's STEPS and APS scenarios

Source: IEA World Energy Outlook 2021; ExxonMobil 2021 Outlook for Energy

Chapter 2
Energy demand scenario descriptions (2/2)

APPENDIX

Scenario	GDP growth per annum: 2019-2050	Global population in 2050	Energy demand change: 2019-2050	CO_2 emissions change: 2019-2050	Peak CO_2 emissions year
Net Zero Emissions by 2050 (NZE)	About 3.0%	9.7 billion	-12%	-100%	Before 2025
Sustainable Development Scenario (SDS)	About 3.0%	9.7 billion	-6%	-77%	By 2025
Announced Pledges Scenario (APS)	About 3.0%	9.7 billion	+10%	-42%	By 2025
Stated Policies Scenario (STEPS)	About 3.0%	9.7 billion	+21%	-6%	Between 2025-2030
ExxonMobil 2021 Outlook for Energy (XOM)	About 3.0%	9.7 billion	+15%	-15%	Between 2025-2030

Source: IEA World Energy Outlook 2021; ExxonMobil 2021 Outlook for Energy

Chapter 3
A note on the Global Warming Potential (GWP) of various greenhouse gases

APPENDIX

- Greenhouse gases (GHGs) act like a blanket insulating the earth: they slow the rate at which energy escapes into space
- Different types of GHGs differ in their warming impact in two key ways:
  - (1) Their ability to absorb energy, or "**radiative efficiency**"
  - (2) How long they stay in the atmosphere, or "**lifetime**"
- The Global Warming Potential measure allows us to compare the impact of different types of GHGs versus CO_2
- The larger the GWP, the more a given gas warms the Earth compared to CO_2 over a particular time period
- GWP can be used to calculate the carbon dioxide equivalency (CDE, or CO_2-e) of a particular gas
  - In technical terms, CDE is the time-integrated radiative forcing of a quantity, or rate, of gas emissions

Greenhouse gas	Global anthropogenic emissions (unadjusted, in metric tons)	× Global Warming Potential (GWP): Radiative efficiency ($W*m^{-2}*ppb^{-1}$)	Global Warming Potential (GWP): Lifetime (years)	Global Warming Potential (GWP): Global Warming Potential over 100 years (GWP-100)	= Tons emitted globally, 2019 (in metric tons of CO_2-equivalent)
Carbon dioxide (CO_2)	36.9 billion	$1.3 \pm 0.2 \times 10^{-5}$	Of CO_2 emitted today, 60% remains after 20 years, 30-55% after 100, and 15-30% after 1,000 years	1	36.9 billion
Methane (CH_4)	0.36 billion	$5.7 \pm 1.4 \times 10^{-4}$ (~40X CO_2)	11.8±1.8	30±11 (fossil) 27±11 (non-fossil)	~8.6 billion
Nitrous oxide (N_2O)	0.09 billion	$2.8 \pm 1.1 \times 10^{-3}$ (~100X CO_2)	109±10	273±130	~3.1 billion
Fluorinated gases	<1 million	[*range*] x 10^{-1}, gas dependent (>1000X CO_2)	5-50 years, gas dependent	2,600 to >8,000, gas dependent	~1.2 billion

Uncertainty ranges are not shown but are large, e.g., ±30% for CH_4 and ±60% for N_2O, and ±30% for f-gases (on a CO_2-e basis) based on IPCC AR6, WG3, Figure SPM.1

Note: Global Warming Potential uncertainties expressed as 5-95% confidence interval based on IPCC AR6. Source: EPA; IPCC, Sixth Assessment Report (AR6), Working Group I, Chapter 7, Table 7.15; IPCC, Fifth Assessment Report (AR5), Working Group I, Box 6.1, Figure 1; Daniel A. Vallero, *Air Pollution Calculations* (2019), 8.3.2; Climate Watch

Chapter 3
IPCC modeled GHG emissions pathways

APPENDIX

IPCC pathway	Description	GHG emissions change: 2050 vs. 2019	Peak GHG emissions year	Cumulative CO_2 emissions (gigatons), 2020 to net-zero CO_2 *(year achieved)*
Trend from implemented policies	• Pathways with projected near-term GHG emissions in line with policies implemented until the end of 2020 and extended with comparable ambition levels beyond 2030	-29% (2.5°C, >50%) -5% (3°C, >50%) +24% (3.5°C, >50%)	2020-2025 2020-2025 2090-2095	1,760 (*after 2090*) 2,790* 4,220*
Limit warming to 2°C (>67%)	• Pathways that limit warming to 2°C with a 67% probability with immediate action after 2020	-63%	2020-2025	860 (*2070-2075*)
Limit warming to 2°C (>67%) or return warming to 1.5°C after a high overshoot, NDCs until 2030	• GHG emissions until 2030 associated with the implementation of Nationally Determined Contributions (NDCs) announced prior to COP26, followed by accelerated emissions reductions *likely* to limit warming to 2°C or to return warming to 1.5°C with a probability of 50% or greater after high overshoot	-75%	2020-2025	720 (*2055-2060*)
Limit warming to 1.5°C (>50%) with no or limited overshoot	• Pathways limiting warming to 1.5°C with no or limited overshoot, assuming immediate action after 2020	-84%	2020-2025	510 (*2050-2055*)

For reference, total anthropogenic CO_2 emissions 1990-2020 = ~1,000 gigatons

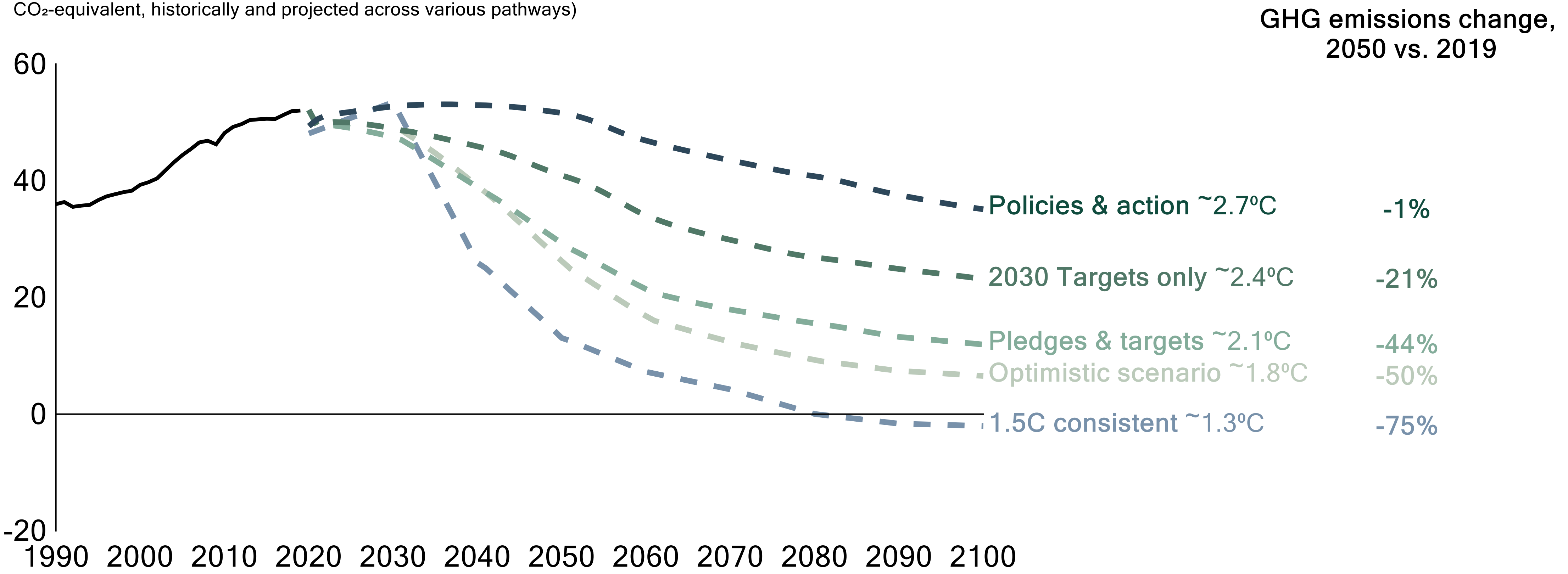
Note: * Net zero not achieved in these scenarios; figure represents net emissions 2020-2100
Source: IPCC, Sixth Assessment Report (AR6), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, Summary for Policymakers, Figure SPM.4 (2022)

Chapter 3
Climate Action Tracker modeled pathways through 2100

APPENDIX

Annual global greenhouse gas emissions by pathway

(annual global GHG emissions, measured in billions of tons of CO_2-equivalent, historically and projected across various pathways)



Source: Climate Action Tracker (as of Nov 2021)

Chapter 3
World Risk Index methodology

The WorldRiskIndex assesses the risk of disaster as a result of natural hazards. It incorporates both exposure and vulnerability and is used by the IPCC to gauge region- and country-level climate change risks

APPENDIX

World Risk Index

Exposure

Population exposed to…

1.0 ×
- Earthquakes
- Cyclones
- Floods

\+

0.5 ×
- Droughts
- Sea level rise

÷ Country population

Source: IPCC AR6; WorldRiskReport 2021

×

Vulnerability

Calculated as: 1/3 x (Susceptibility + [1 – Coping] + [1 – Adaptation])

Susceptibility

0.29 × **Public infrastructure**
- Share of the population without access to basic sanitation services × 0.5
- Share of the population without access to basic drinking water services × 0.5

\+

Housing conditions*
- Share of the population living in slums; proportion of semi-solid and fragile dwellings

\+

0.29 × **Nutrition**
- Share of the population that is undernourished

\+

0.29 × **Poverty and dependencies**
- Dependency ratio (share of under 15-and over 65-year-olds in relation to working population × 0.5
- Extreme poverty population living with USD 1.90 per day or less (purchasing power parity) × 0.5

\+

0.29 × **Economic capacity and income distribution**
- Gross domestic product per capita (purchasing power parity) × 0.5
- Gini index × 0.5

Coping

0.45 × **Government and authorities**
- Corruption Perceptions Index × 0.5
- Fragile States Index × 0.5

\+

Disaster preparedness and early warning*
- National disaster risk management policy according to report to the United Nations

\+

0.45 × **Medical services**
- Number of physicians per 1,000 inhabitants × 0.5
- Number of hospital beds per 1,000 inhabitants × 0.5

\+

Social networks*
- Neighbors, family, and self-help

\+

0.1 × **Material coverage**
- Insurance (life insurances excluded)

Adaptation

0.25 × **Education and research**
- Adult literacy rate × 0.5
- Combined gross school enrollment × 0.5

\+

0.25 × **Gender equality**
- Gender inequality index

\+

0.25 × **Environmental status/Ecosystem protection**
- Water resources × 0.25
- Biodiversity and habitat protection × 0.25
- Forest management × 0.25
- Agricultural management × 0.25

\+

Adaptation strategies*
- Projects and strategies to adapt to natural hazards and climate change

\+

0.25 × **Investment**
- Public health expenditure × 0.33
- Life expectancy at birth × 0.33
- Private health expenditure × 0.33

Chapter 3

Measuring historical CO_2 concentration levels

APPENDIX

800,000 BCE – 1950: Ice core record

Prehistoric CO_2 concentration is determined primarily by **measuring the composition of air trapped in ice cores** from Antarctica and Greenland. Each **deeper layer represents a slightly earlier** time in the Earth's climate history.

These ice-core measurements **agree with direct measurements from modern observatories**.

1950 – Today: Instrumental record

Direct measurements are taken from facilities like NOAA's **Mauna Loa Observatory** in Hawaii.

CO_2 mixes well throughout the atmosphere, so the trend at Mauna Loa is **statistically indistinguishable** from trends measured globally.

Source: NOAA; IPCC AR3, *The Carbon Cycle and Atmospheric Carbon Dioxide*

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