

BOOK 3

Climate Change Challenges

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Professor TPA

July 2026





TPA

Sharing Experience

Building bridges between the oil industry and academic circles by delivering technical or business-related presentations by professors or experts.



OIL & GAS and ENERGY GLOBAL ISSUES

A Toolbox to understand the World of Energy in the Global Economy

The Toolbox is updated twice a year and benefits from the contributions of TPA Professors:

Coordination: GUÉRITTE Christian

LUC Benoît, PERSILLON Philippe, CORDIER Jean-Pierre, PAPÉE Jean, MULLER Isabelle, DEUTSCH Denis, FOURCADE Bernard, MICHAUD Olivier, SAINCRY Daniel, FOURNIÉ François, CHOUX Jean-Claude, BERA Jean, GUYS Philippe, DE MERVILLE Eric, DUMAY Jean-Michel, VALDELIÈVRE Michel, FONTAINE Jean-Marc, FERRIER Jérôme, BITEAU Jean-Jacques, PETTEAU Pascal, NOSJEAN Nicolas



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What does that mean for you?

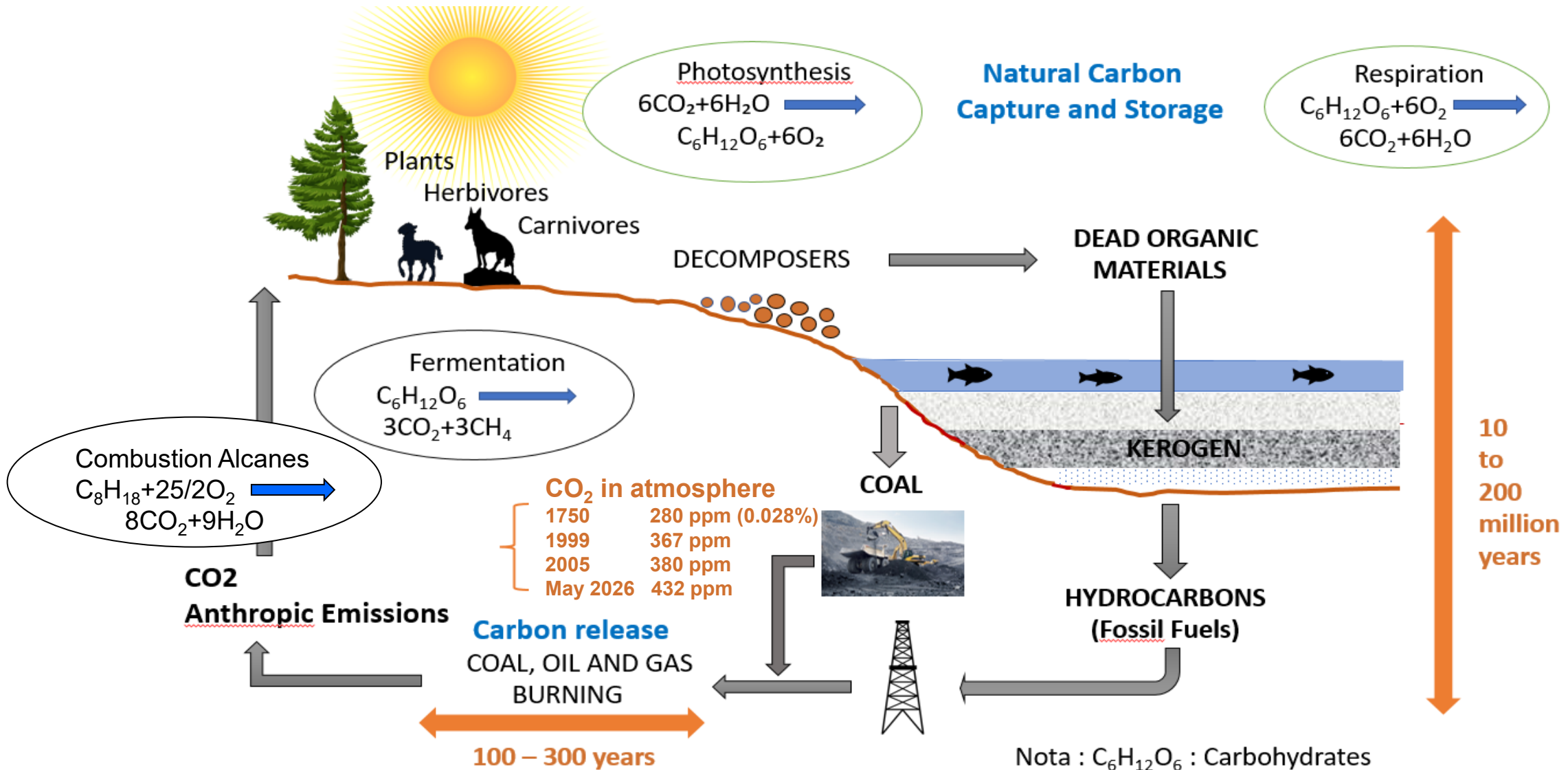
Climate words jungle !



10 |



Energy and Life: Carbon is a Vital Element for the day to day Life. It also creates nuisance in relation with the Climate change



**To Combat Climate Change is part of the
Sustainable Development Goals defined by
United Nations in their 2030 Agenda for
Sustainable Development**



United Nations 2030 Agenda



1 NO POVERTY

End poverty in all its forms everywhere

5 10 12 16



2 ZERO HUNGER

End hunger, achieve food security and improved nutrition and promote sustainable agriculture

1 5 10
11 12 14



3 GOOD HEALTH AND WELL-BEING

Ensure healthy lives and promote well-being for all at all ages

1 8 10
11 14 15



4 QUALITY EDUCATION

Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

1 8 12



5 GENDER EQUALITY

Achieve gender equality and empower all women and girls

1 2 3 4
6 7 8 9
10 11 12 13
14 15 16



6 CLEAN WATER AND SANITATION

Ensure availability and sustainable management of water and sanitation for all

1 12 15



7 AFFORDABLE AND CLEAN ENERGY

Ensure access to affordable, reliable, sustainable and modern energy for all

1 2 3 4 6
10 12 14 15



8 DECENT WORK AND ECONOMIC GROWTH

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

1 10 12



9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

1 2 4 8
10 12 13



United Nations 2030 Agenda



10 REDUCED INEQUALITIES
Reduce inequality within and among countries

1 12 14 15



11 SUSTAINABLE CITIES AND COMMUNITIES
Make cities and human settlements inclusive, safe, resilient and sustainable

1 2 3 8
9 12 13



12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Ensure sustainable consumption and production patterns

1 2 8
11 14 15



13 CLIMATE ACTION
Take urgent action to combat climate change and its impacts

1 7 8 11 12



14 LIFE BELOW WATER
Conserve and sustainably use the oceans, seas and marine resources for sustainable development

1 2 8 15



15 LIFE ON LAND
Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

1 3 6 8
9 11 12



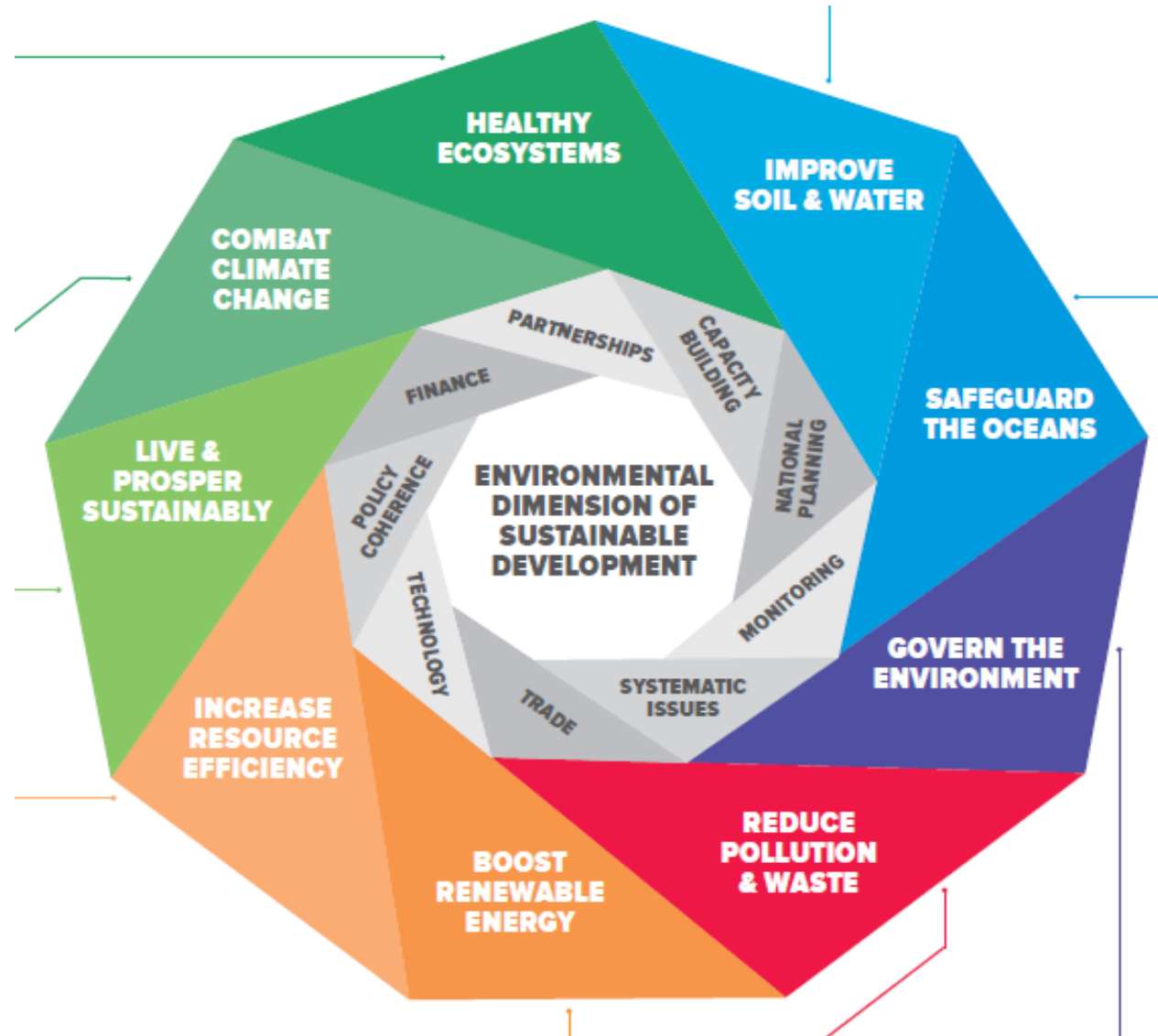
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

1 10 12

(x) = Related goal



United Nations 2030 Agenda



Source: UN Annual Report 2015



TABLE OF CONTENTS

- 1. What is science telling us about climate change ?**
- 2. Economic consequences for energy and industries**
- 3. The Kaya Equation**
- 4. Agenda for Climate Change Negotiations**
- 5. CO2 Markets, Pricing and Trading**
- 6. Carbon Capture and Storage technologies**
- 7. What implications for oil companies:
the case of TotalEnergies**



1

What is science telling us about climate change ?

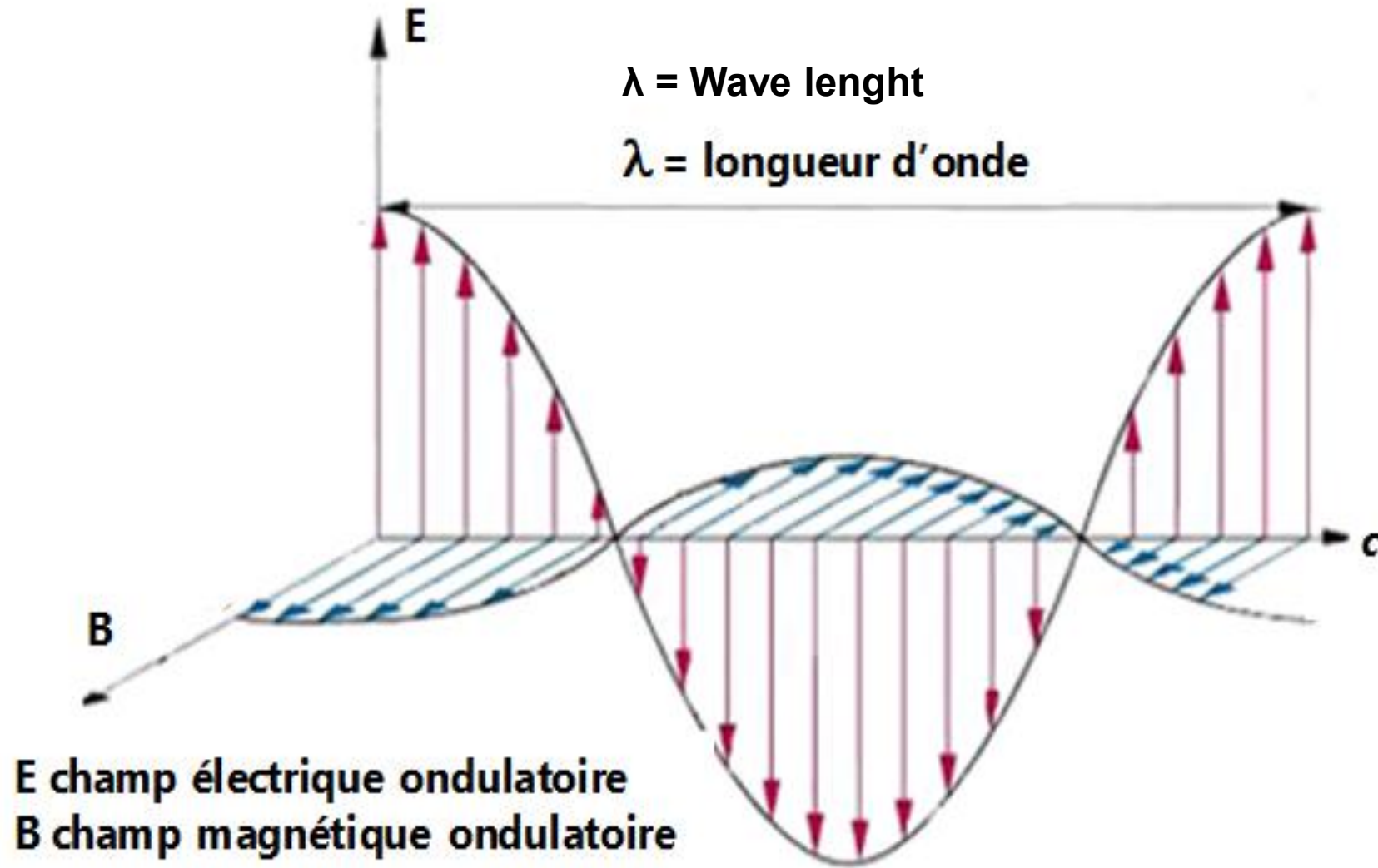


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The Light : A Electromagnetic Wave

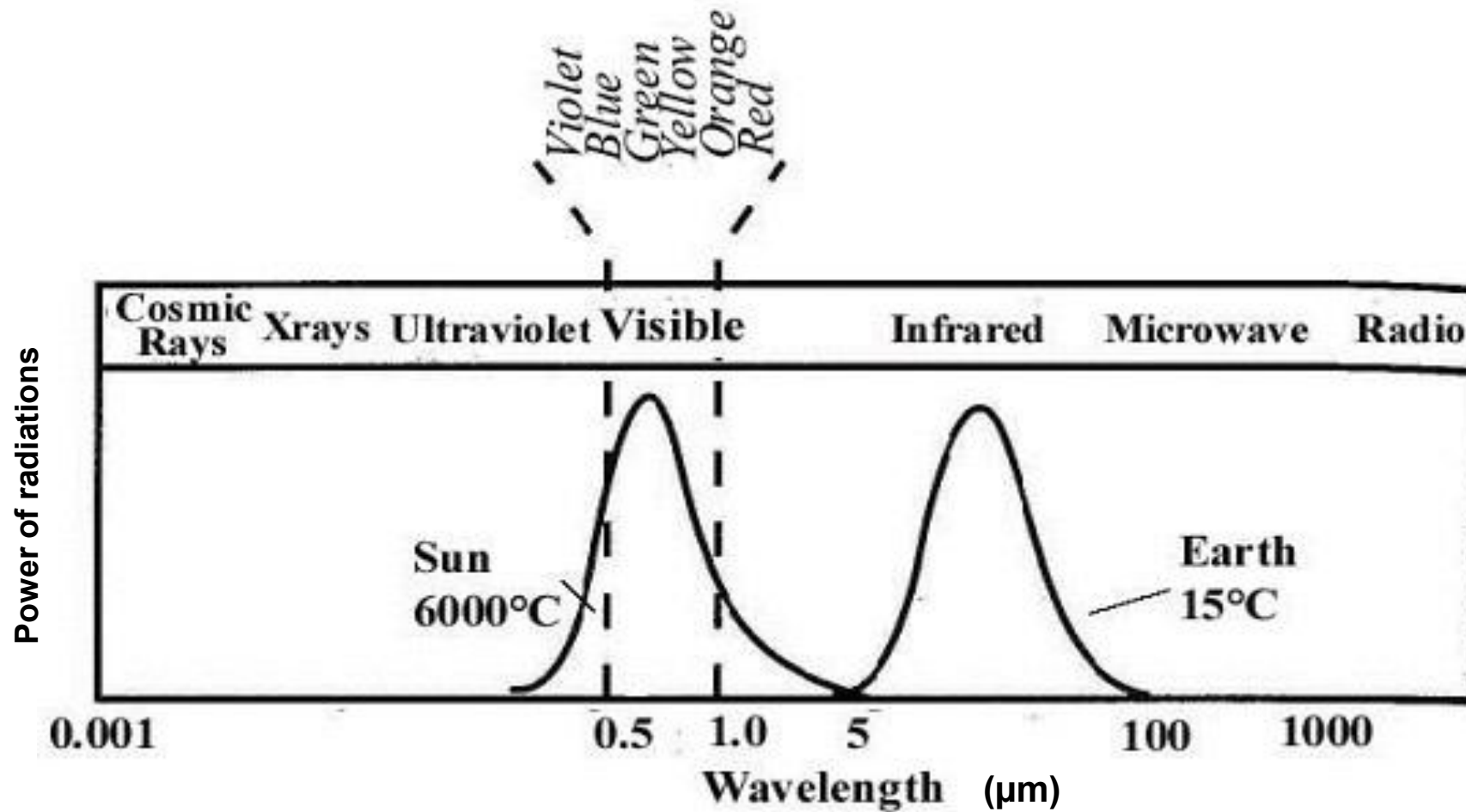


E champ électrique ondulatoire
B champ magnétique ondulatoire

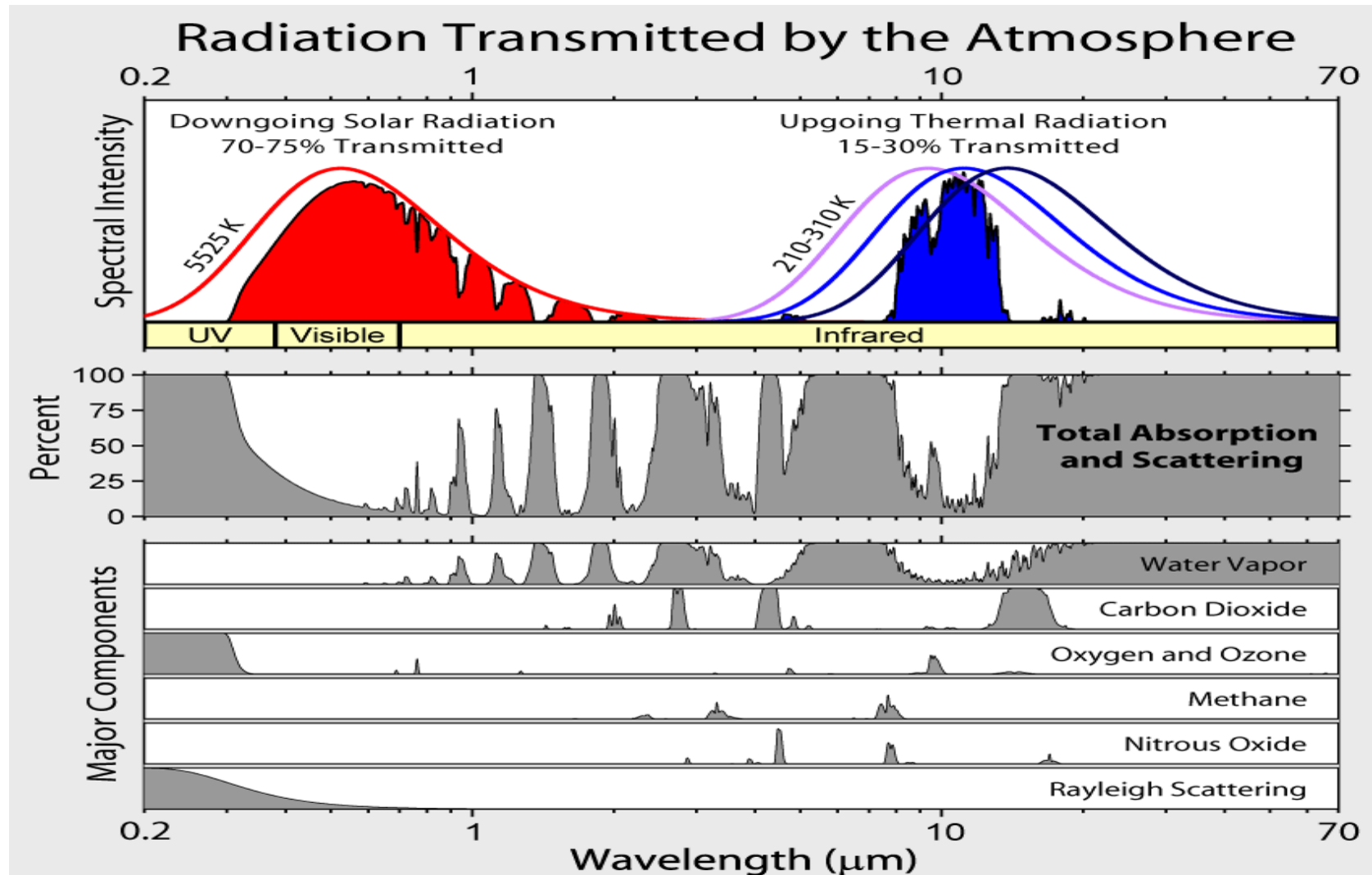
E = Wave electric field
B = Wave magnetic field



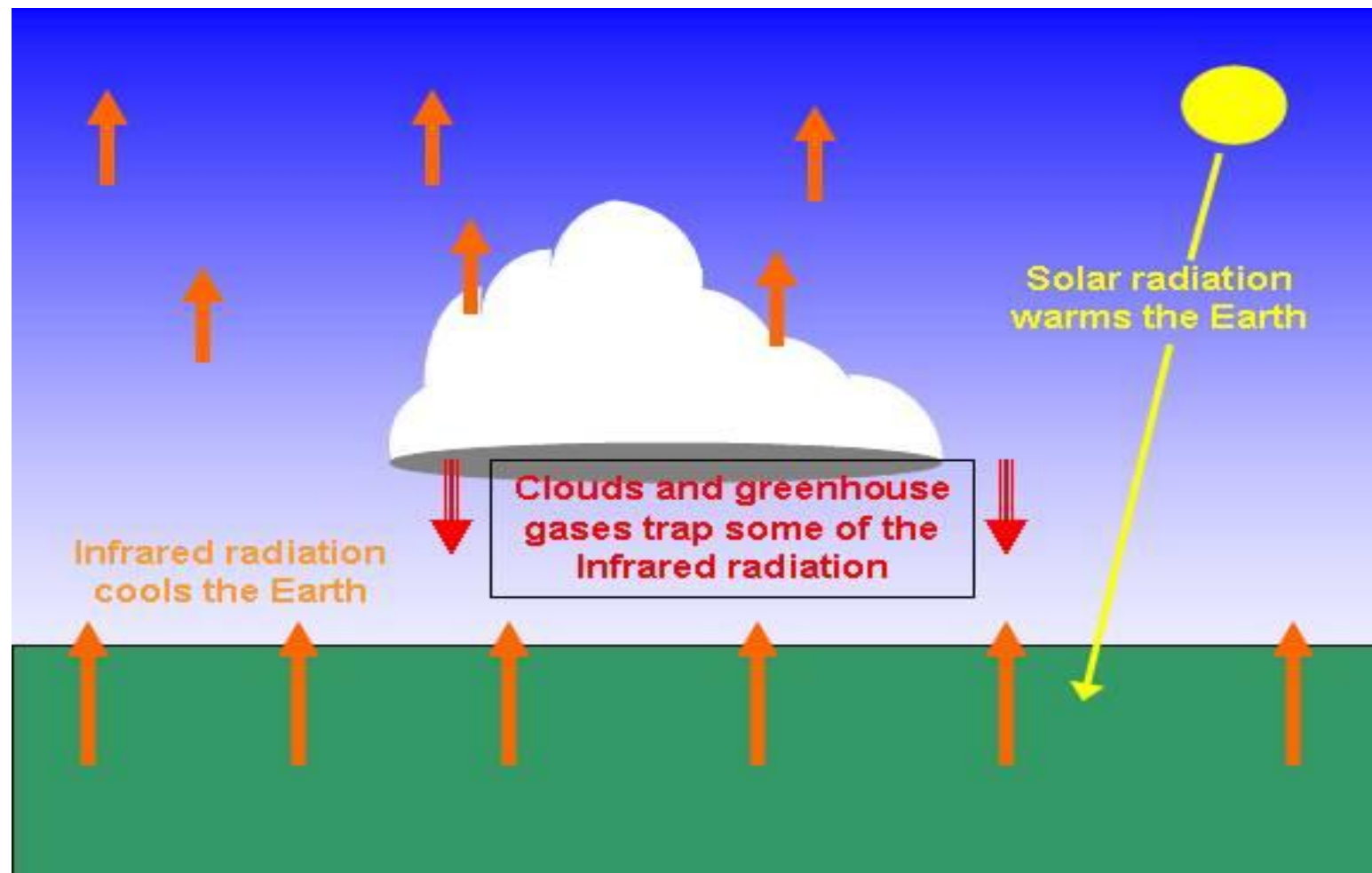
Sun and Earth emit electromagnetic radiations (1)



Sun and Earth emit electromagnetic radiations (2)



The Greenhouse Effect - Basics (1)

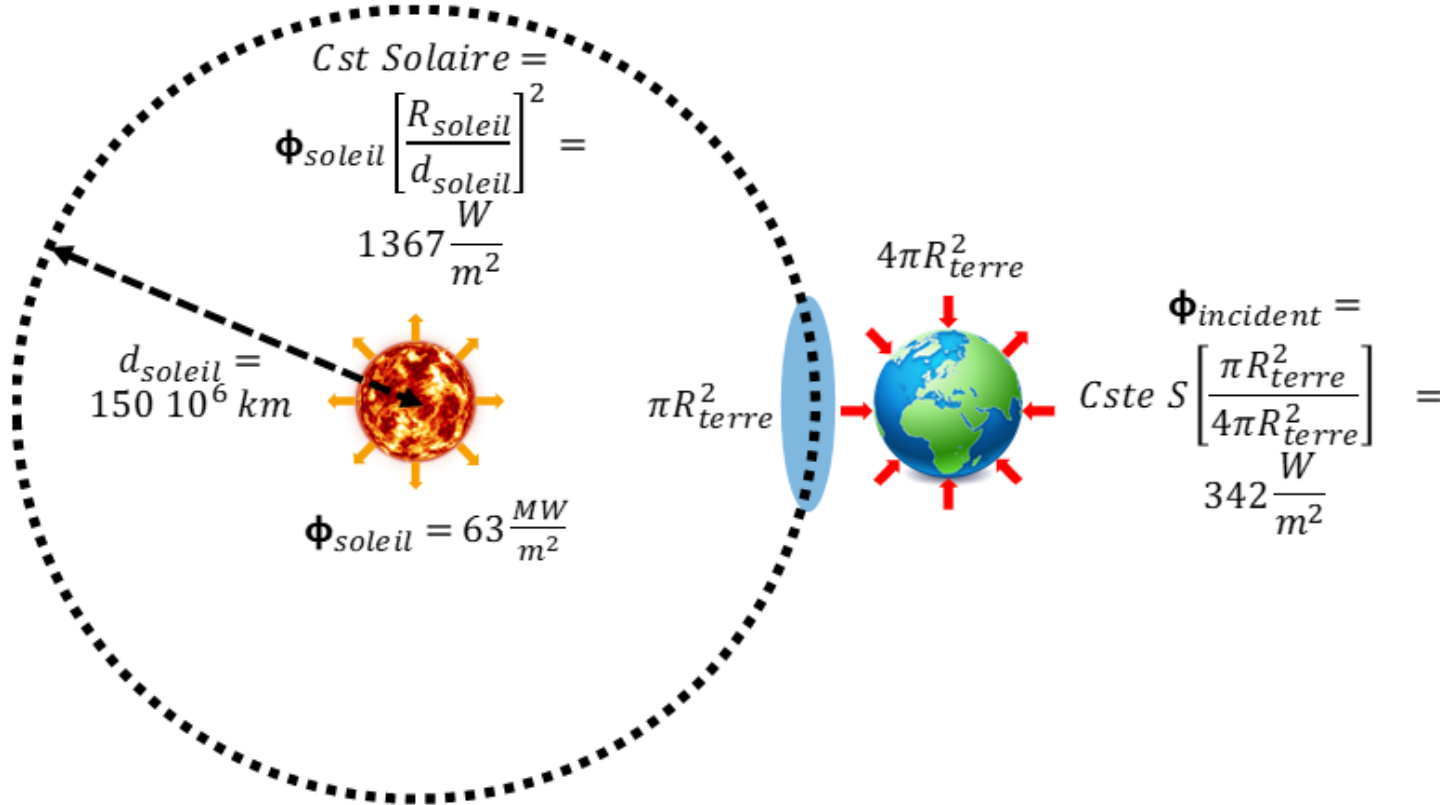


Nota: Assuming no air move

The Greenhouse Effect - Basics (2)



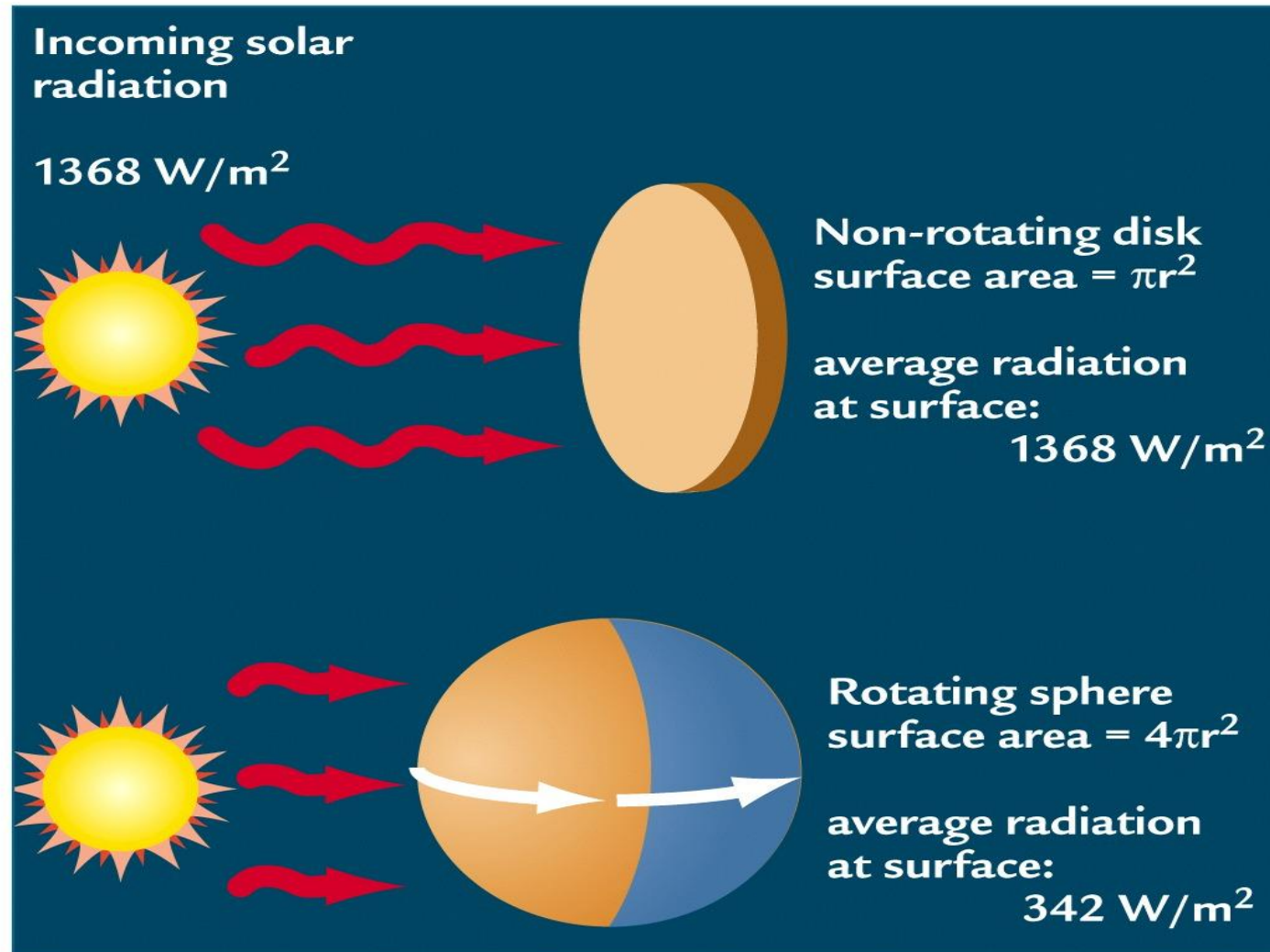
Solar Radiation or Total Solar Irradiance



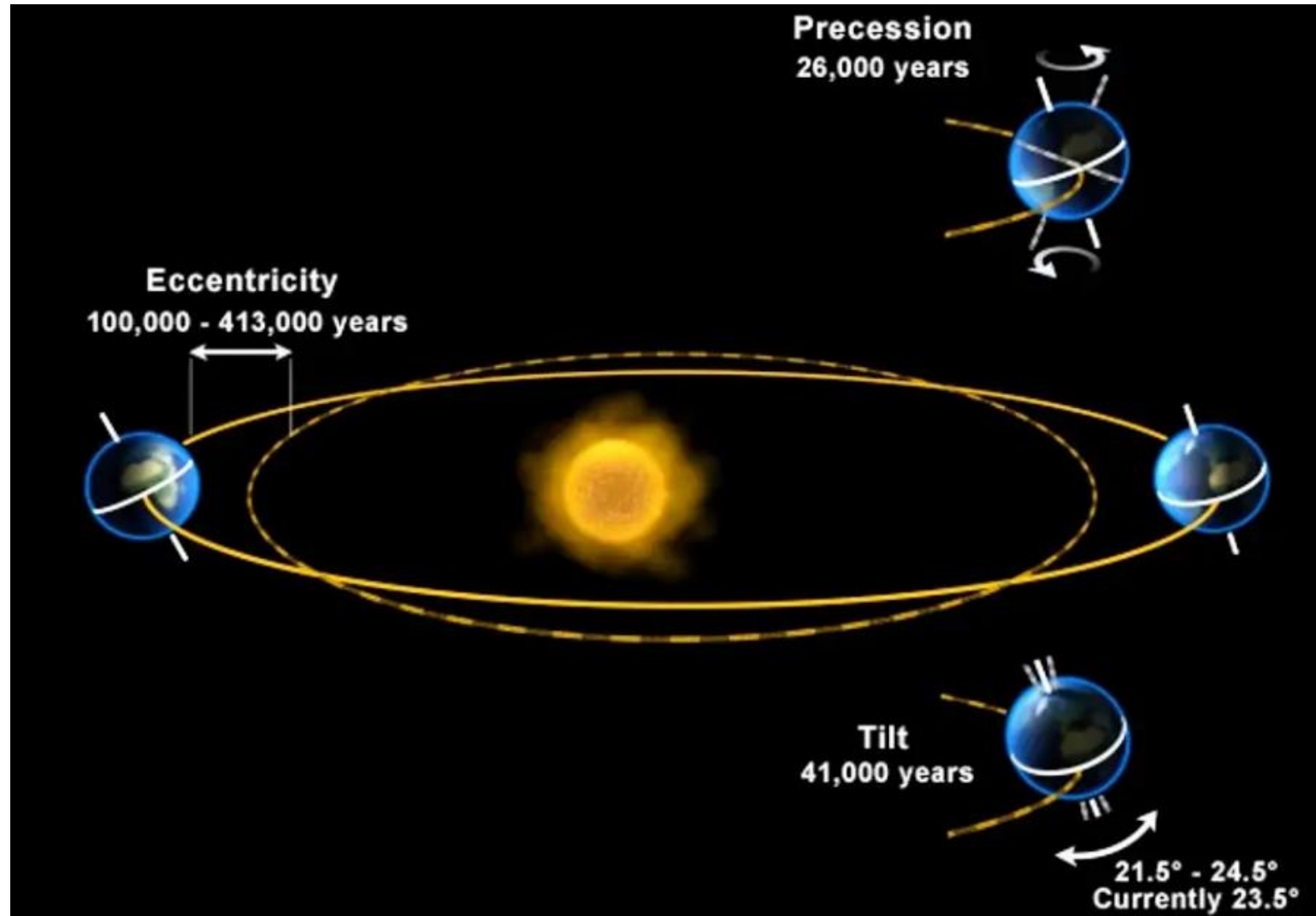
- Every object whose temperature is greater than 0°K (-273,15°C) emits electromagnetic radiations.
- Sun and Earth can be roughly considered as black bodies.
- Power emitted by a black body by surface unit, at given frequencies of its electromagnetic radiations only depends upon its temperature.
- Global power emitted by surface unit over the frequency spectrum depends only upon the temperature:
 $M_{tot} = \sigma T^4$, σ = Stephan-Boltzmann constant = $5,67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$
- Sun radiation:
 Sun temperature at surface : $T_s = 5777 \text{ }^\circ\text{K}$
 $M_{stot} = \sigma T_s^4 = 6,32 \times 10^7 \text{ Wm}^{-2} = 63 \text{ MWm}^{-2}$
 Sun radius = $r_s = 695\,700 \text{ km}$
 Global power emitted by sun at surface:
 $P_s = M_{stot} \times 4\pi r_s^2 = 3,84 \times 10^{26} \text{ W}$
- Sun radiation received on Earth's orbit = P_{s-E}
 Distance Sun-Earth = $d_{s-E} = 149,6 \times 10^6 \text{ km}$
 Surface of Earth's orbit sphere = $4\pi d_{s-E}^2 = 2,81 \times 10^{23} \text{ m}^2 = S_{seo}$
 $P_{s-E} = P_s / S_{seo} = 1367 \text{ Wm}^{-2}$
- Sun radiation received by Earth by surface unit at surface = E_E
 $E_E = P_{s-E} / 4 = 342 \text{ Wm}^{-2}$
- Earth temperature at surface:
 Thermal balance implies that energy received equals energy emitted:
 Energy received by Earth = 342 Wm^{-2}
 $\sigma T_E^4 = (1-A)E_E$
 A = Albedo = reflectivity # 0,30
 $T_E = \sqrt[4]{(1-A)E_E/\sigma}$ $T_E = 255^\circ\text{K} = -18^\circ\text{C}$
- Role of atmosphere:
 Energy emitted by Earth at surface = 390 Wm^{-2} , not 342 Wm^{-2}
 $T_E = \sqrt[4]{E_E/\sigma}$ $T_E = 288^\circ\text{K} = 15^\circ\text{C}$
- Thanks to the atmosphere, the average temperature at surface on Earth is not -18°C , but 15°C , permitting the life on Earth.
- This is due essentially to the concentration of water vapour in the atmosphere which is the dominant condensable greenhouse gas (55% in terms of radiative forcing). The atmosphere is self-limiting in terms of water vapour, notably through the water vapour saturation mechanism, together with evaporation, condensation, and clouds formation.



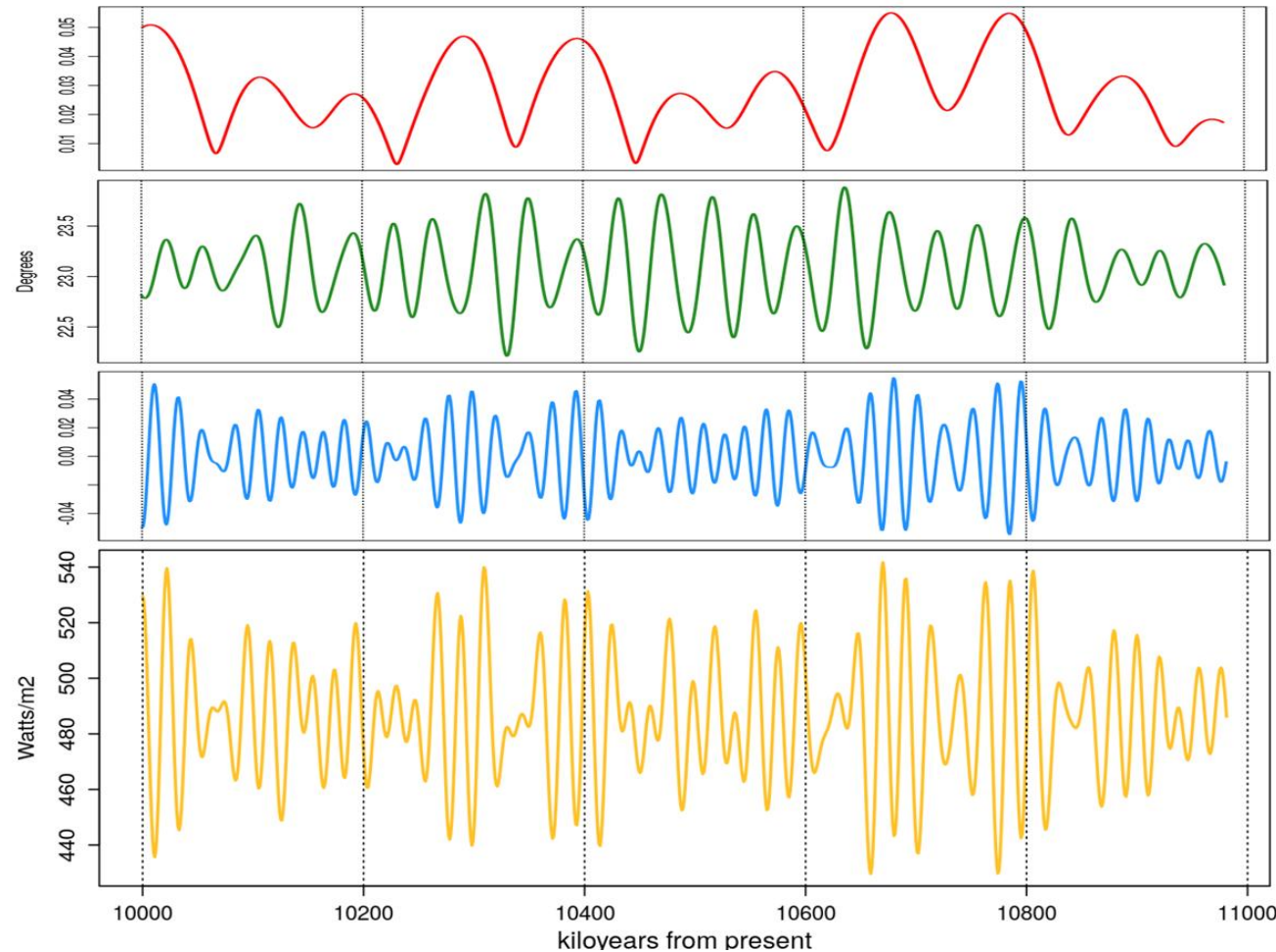
Solar Radiation or Total Solar Irradiance



Solar Irradiance is evolving upon time due to uneven movement of earth around the sun



Variations of earth's position on its orbit is due to 3 factors (Milankovitch orbital cycles) affecting solar irradiance over thousands of years

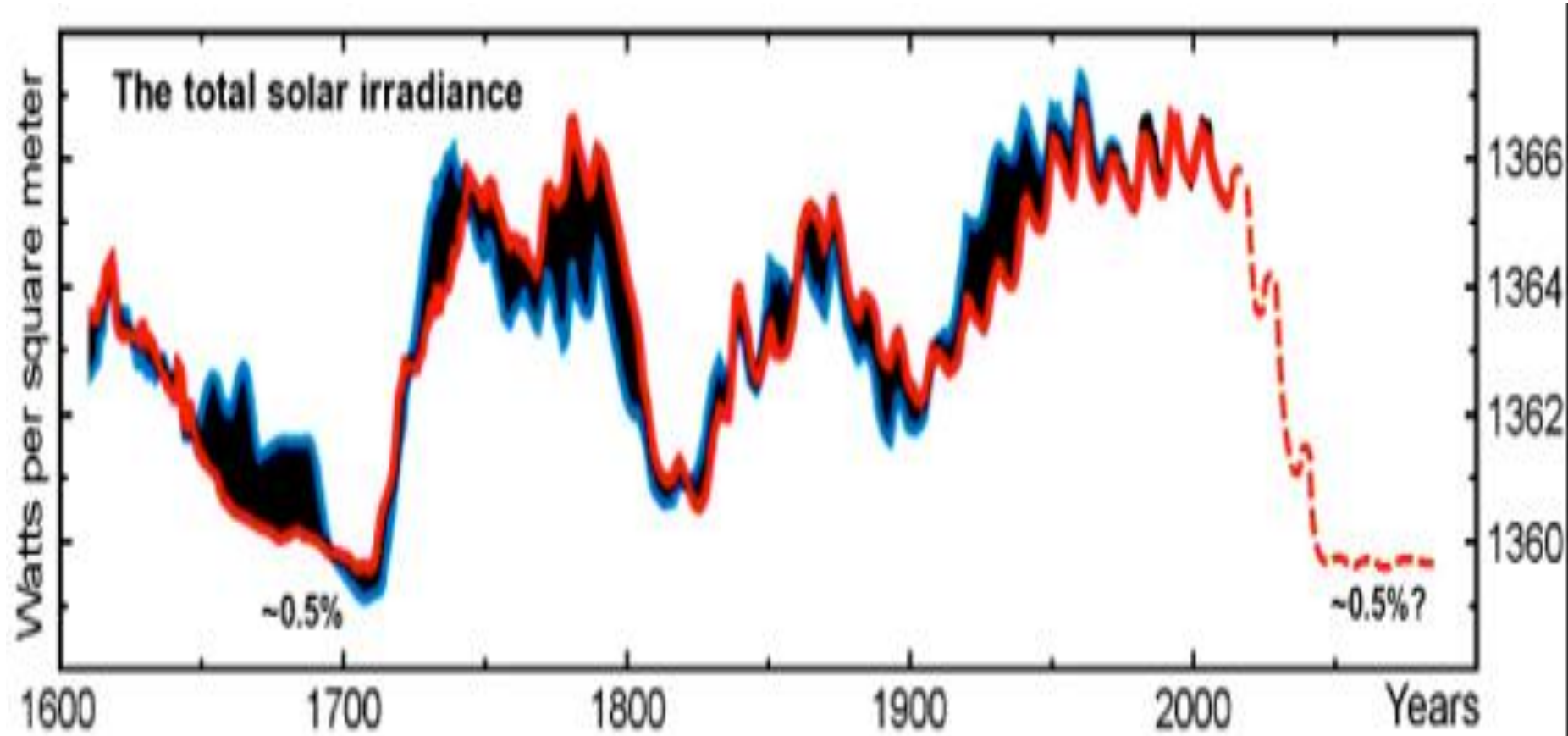


- **Eccentricity** varies slowly between nearly circular and slightly eccentric, with dominant periodicities of about 100 and 400 kyears
- **Obliquity** of the earth's axis of rotation varies between about 22.5° and 24.5° over a period of 40 kyears (currently ~ 23.5°)
- **Precession of equinoxes** or spinning toy like movement of earth's axis of rotation, varies over a period of about 25 kyears

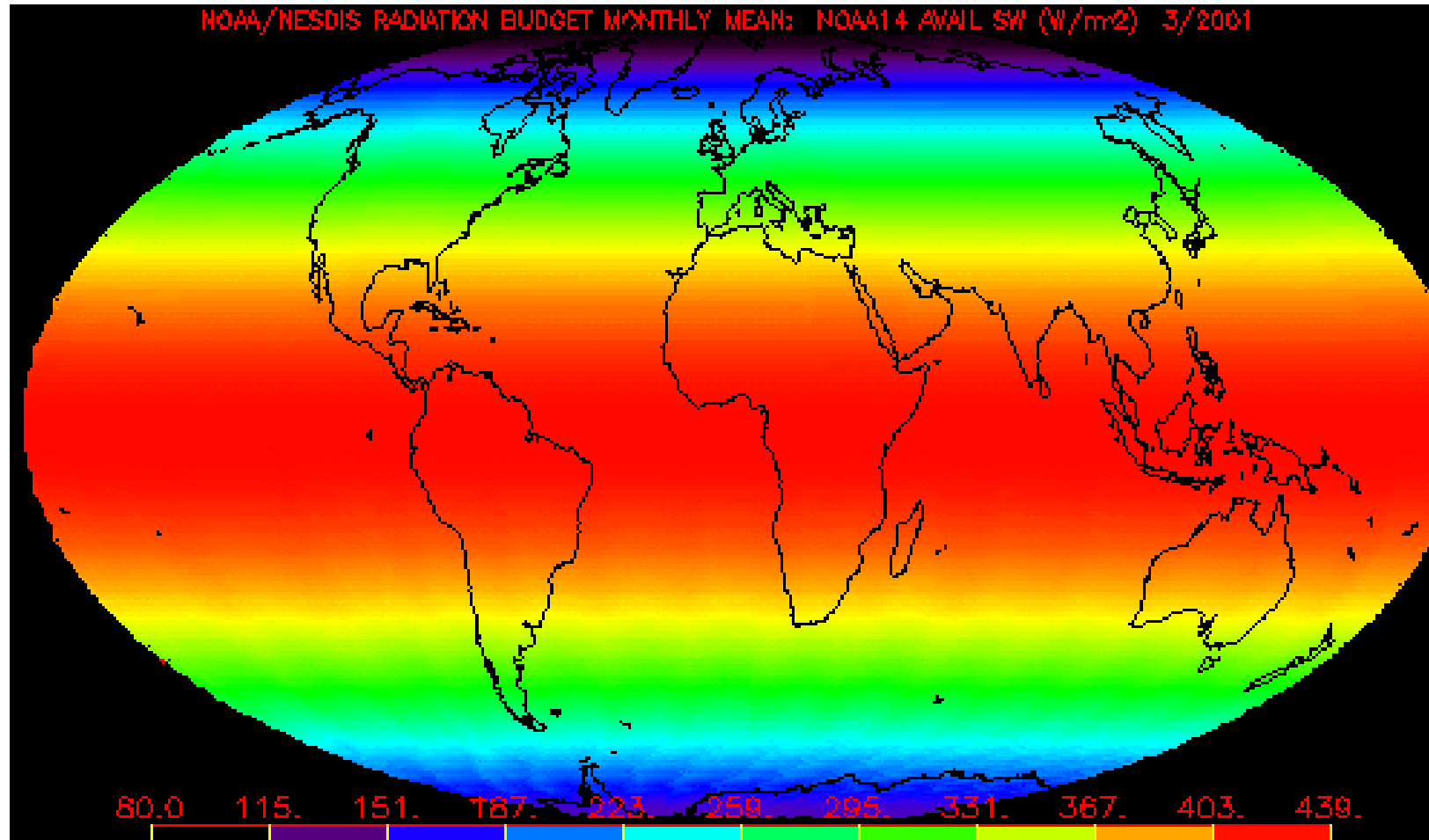
**consequence on earth
insulation at 65° of latitude
north at mid-July – W/m²**
(simulation Laskar & al – 2011)



Total Solar Irradiance is also slightly varying over decades

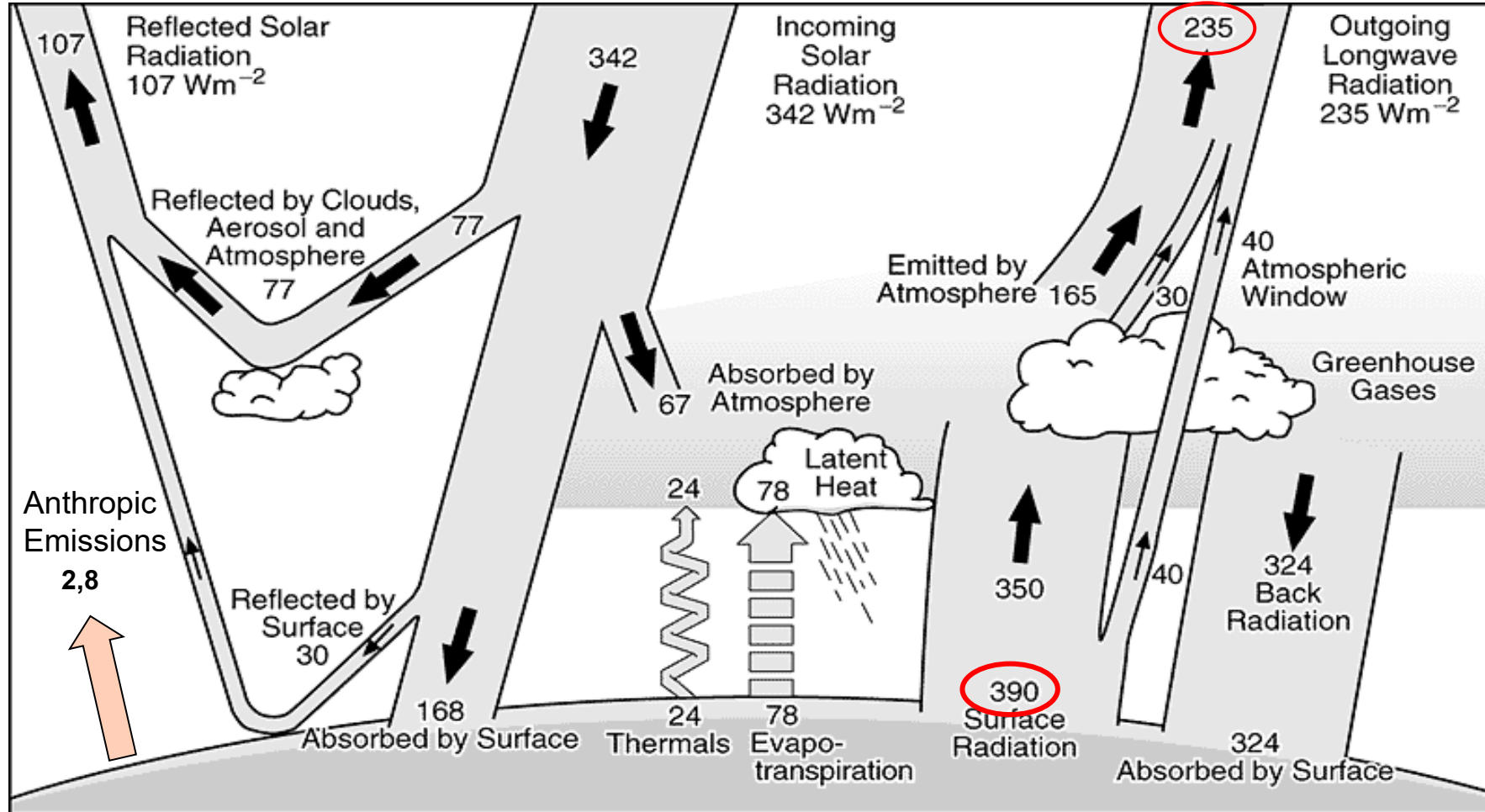


Average Solar Radiation on Earth = 342 W/m²



Global Energy Flows (W/m^2)

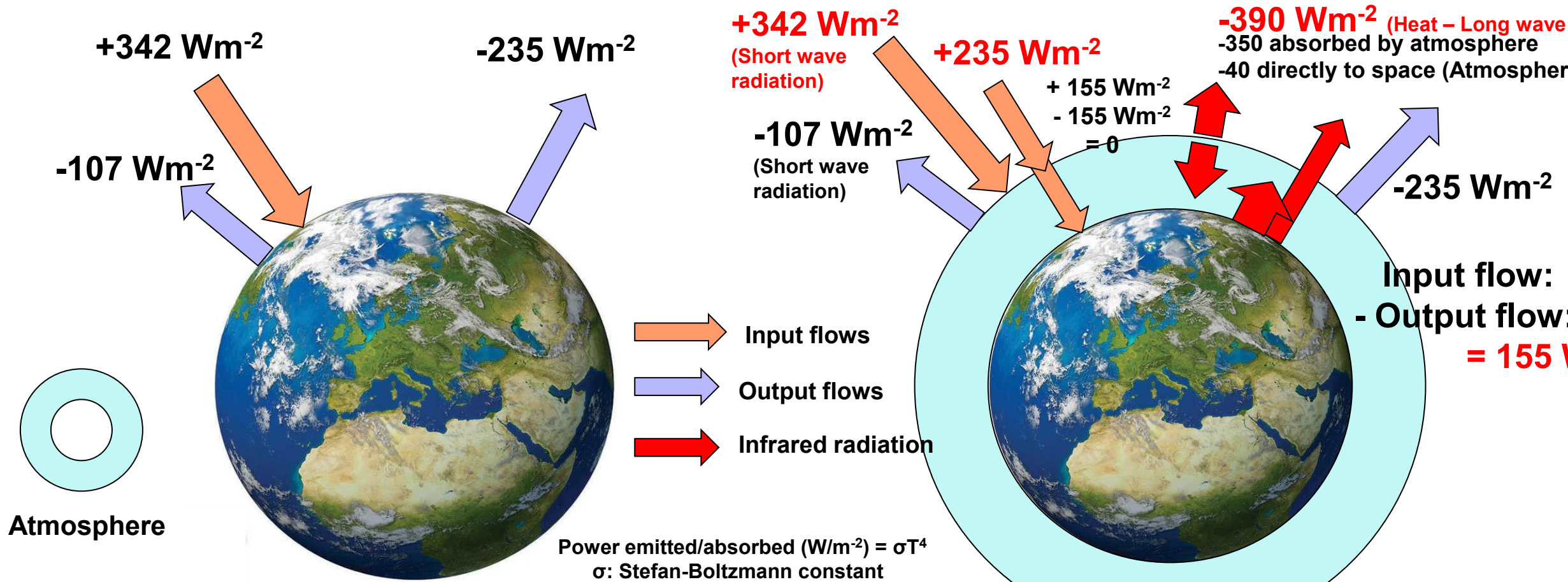
Natural Greenhouse Gas Effect # 155 W/m^2



Source: Kiehl & Trenberth 1997 Bulletin of Meteorological Association
 There are some minor timewise variations and uncertainties on the energy flows



Earth/Atmosphere Global Energy flows (Wm^{-2}) – Simplified illustration



If no atmosphere opaque to solar radiation (No Green House Gas effect) Earth Temperature: $255^\circ\text{K} = -18^\circ\text{C}$

With atmosphere and Green House Gas effect, Earth Temperature: $288^\circ\text{K} = 15^\circ\text{C}$

Source: ChG/Based on Kiehl and Trenberth 1997. Assuming albedo # 0,30 in both cases.
 Figures can slightly change according to sources. Arrows not at scale. $\sigma = 5,67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$



Global Energy Flows (W/m²)

Natural Greenhouse Gas Effect # 155 W/m²

The incoming solar radiation = 342 W/m² is splitted into:

- 77 W/m² reflected by atmosphere
- 30 W/m² reflected by Earth surface
- Total reflected = 107 W/m² (Albedo = 30,6%)
- 67 W/m² absorbed by atmosphere by air molecules and clouds (UV are absorbed by O₃, infrared are absorbed by water vapor and CO₂)
- 168 W/m² absorbed by Earth surface (land and oceans)
- Net Energy flow arriving on Earth including its atmosphere = 235 W/m²

The Atmosphere receives 519 W/m² splitted into:

- 67 W/m² from incoming solar radiation
- 78 W/m² from latent heat of evaporation when water vapor condenses to form the clouds. This energy is transformed into heat
- 24 W/m² from air convection at the Earth surface
- 350 W/m² by absorption of infrared variation emitted by Earth surface

The Atmosphere re-emits 519 W/m² splitted into:

- 324 W/m² re-emitted to Earth surface through infrared radiation to warm the Earth surface
- 195 W/m² re-emitted to the space through infrared radiation



Global Energy Flows (W/m^2)

Natural Greenhouse Gas Effect # 155 W/m^2

The Earth surface receives = 492 W/m^2 is splitted into:

- 168 W/m^2 coming from incoming solar radiation arriving at Earth surface
- 324 W/m^2 coming from Atmosphere as infrared variation

The Earth surface re-emits 492 W/m^2 splitted into:

- 78 W/m^2 in the form of latent heat of evaporation
- 24 W/m^2 in the form of air convection at the Earth surface
- 350 W/m^2 in the form of infrared radiation emitted by Earth surface
- 40 W/m^2 in the form of infrared radiation directly to the space

The space receives 342 W/m^2 splitted into:

- 107 W/m^2 reflected by the Atmosphere and the Earth surface
- 195 W/m^2 emitted by the Atmosphere to the space through infrared radiation
- 40 W/m^2 in the form of infrared radiation directly to the space



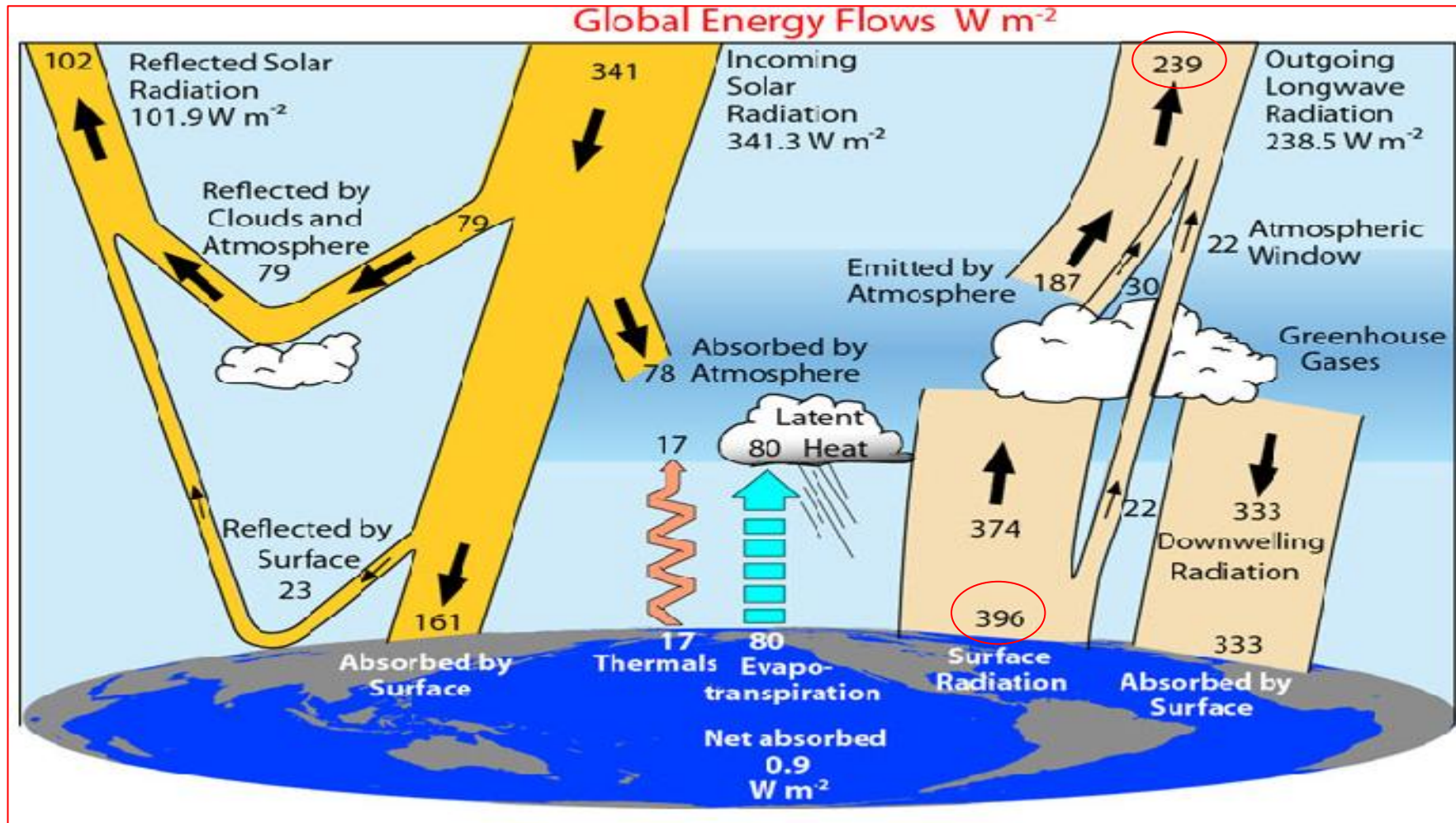
Basic Principles guiding the Earth Energy balance

- In order to keep a stable temperature of the system Earth - Atmosphere, it is necessary that the Energy flows both **on top of the atmosphere** and **at the Earth surface remain balanced**.
- Energy balance at the top of the Atmosphere (see figure above):
 - Incoming solar radiation: 342 W/m²
 - Reflected solar radiation: 107 W/m²
 - Outgoing long wave radiation: 235 W/m²
 - = 0 W/m²
- Energy balance at the Earth surface (see figure above):
 - Absorbed by surface: 168 W/m²
 - Thermals: 24 W/m²
 - Evapo-transpiration: 78 W/m²
 - Surface radiation: 390 W/m²
 - + Back radiation absorbed by surface: 324 W/m²
 - = 0 W/m²
- Natural Greenhouse effect (see figure above):
Surface radiation (390 W/m²) – Outgoing radiation (235 W/m²) = 155 W/m²
- The figures are evolving, the natural balance is no longer respected due to the anthropic emissions.



Global Energy Flows (W/m²)

Trenberth's update (2012)



Source: Trenberth/Fasullo 2012 Surv. Geophysics (based on Trenberth 2009)
There are some variations and uncertainties on the energy flows



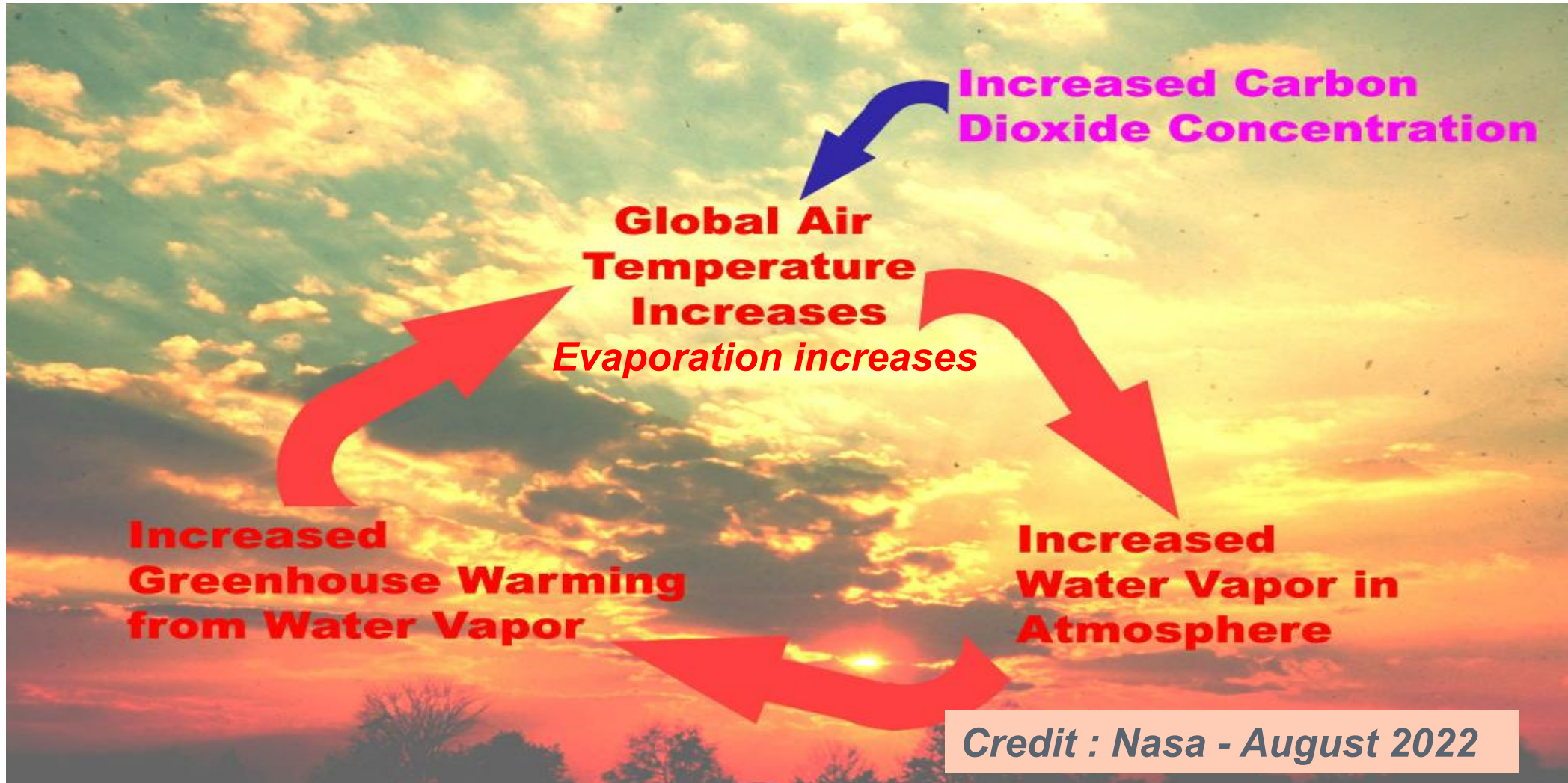
Climate issues – More Basics (1)

- Water vapor is the natural dominant absorber in the Earth's greenhouse effect.
- Water vapor doesn't control the Earth's temperature, but is instead controlled by temperature.
- CO₂ emissions increase the Earth's temperature.
- More CO₂ (non-condensable GHG) emissions will increase temperature, which will lead to an increase in water vapour in the atmosphere, which will contribute to a further increase of the temperature (positive feed-back effect)
- The atmosphere is self-limiting in terms of water vapour, notably through the water vapour saturation mechanism, together with evaporation, condensation, and clouds formation.
- The **natural** greenhouse effect has maintained the Earth's temperature at 15°C in average (compared with -18°C if no such effect)
- The Sun's energy (6000 °C) is mostly short wave radiation (**UV and visible**)
- The absorbed energy by Earth (15°C) is emitted from the surface as long wave radiation or **infrared radiation**.
- The higher the temperature, the lower the wavelength.



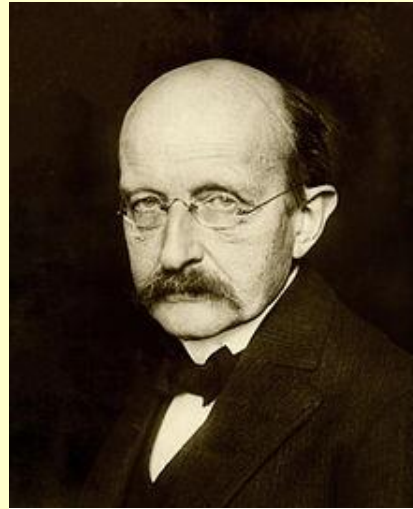
Climate issues – More Basics (1 bis)

Positive water vapor feedback loop

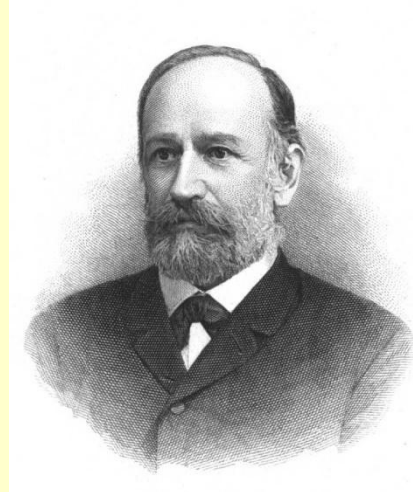


Climate issues – More Basics (2)

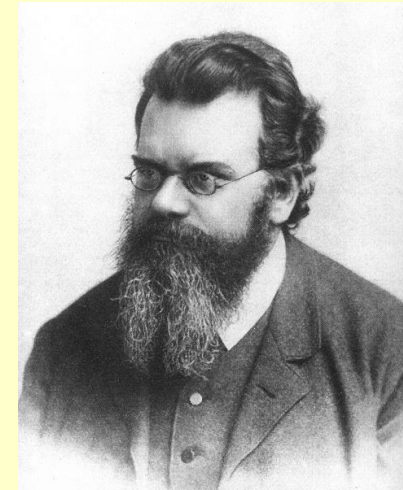
Max Planck
Germany
1858 - 1947



Jozef Stefan
Austria/Hung.
1835 - 1893



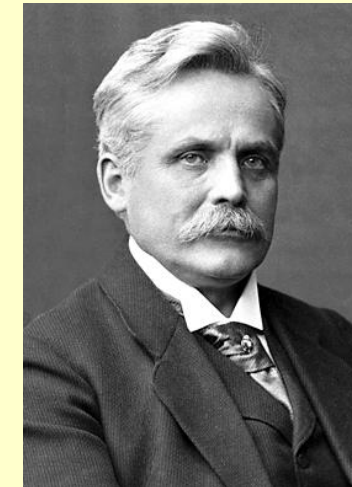
Ludwig Boltzmann
Austria
1844 - 1906



The Physicians/ Founders

Quantum mechanics
Statistical physics

Wilhem Wien
Germany
1864 - 1928



Climate issues – More Basics (3)

- Spectral radiance emitted by a black body per unit surface area, per unit solid angle and per unit frequency, for a given frequency or wavelength of its electromagnetic radiations only depends upon its temperature:

Planck law:

per **unit frequency** $I(\nu, T) = \frac{2h\nu^3}{c^2} * 1/(e^{\frac{h\nu}{kT}} - 1) \text{ (Wm}^{-2}\text{sr}^{-1}\text{Hz}^{-1}\text{)}$

or per **unit wavelength** $I(\lambda, T) = \frac{2hc^2}{\lambda^5} * 1/(e^{\frac{hc}{\lambda kT}} - 1) \text{ (Wm}^{-3}\text{sr}^{-1}\text{)}$

I = Energy emitted by surface unit and spectral unit

ν = Frequency (Hz, s⁻¹)

λ = Wavelength = c/ ν (m)

T = Temperature at black body surface (°K)

h = Planck constant = 6,63x10⁻³⁴ Js

c = Light speed in the medium = 299 800 000 ms⁻¹

k = Boltzmann constant = 1,38x10⁻²³ JK⁻¹



Climate issues – More Basics (4)

- The two previous equations are related through:

$$I(\nu, T) d\nu = - I(\lambda, T) d\lambda \quad (\nu\lambda = c)$$

$$d\nu = d(c/\lambda) = cd(1/\lambda) = -c/\lambda^2 d\lambda$$

$$I(\lambda, T) = c/\lambda^2 I(\nu, T)$$

- **Frequency** at which the black body emits the most:

Maximum of $I(\nu, T)$ is reached when:

$$3 \left(e^{\frac{h\nu}{kT}} - 1 \right) = \frac{h\nu}{kT} e^{\frac{h\nu}{kT}} \quad \text{or} \quad (x - 3)e^x + 3 = 0 \quad \text{with} \quad \frac{h\nu}{kT} = x$$

➡ $h\nu_{\text{max}} = 2,82 kT = 2,82 \times 1,38 \times 10^{-23} T = 3,89 \times 10^{-23} T$
 $\nu_{\text{max}} = 3,89 \times 10^{-23} / 6,63 \times 10^{-34} T = 5,88 \times 10^{10} T$



Climate issues – More Basics (5)

- The two previous equations are related through:

$$\begin{aligned} I(\nu, T) d\nu &= - I(\lambda, T) d\lambda \quad (\nu\lambda = c) \\ d\nu &= d(c/\lambda) = cd(1/\lambda) = - c/\lambda^2 d\lambda \\ I(\lambda, T) &= c / \lambda^2 I(\nu, T) \end{aligned}$$

- **Wavelength** at which the black body emits the most:

Maximum of $I(\lambda, T)$ is reached when:

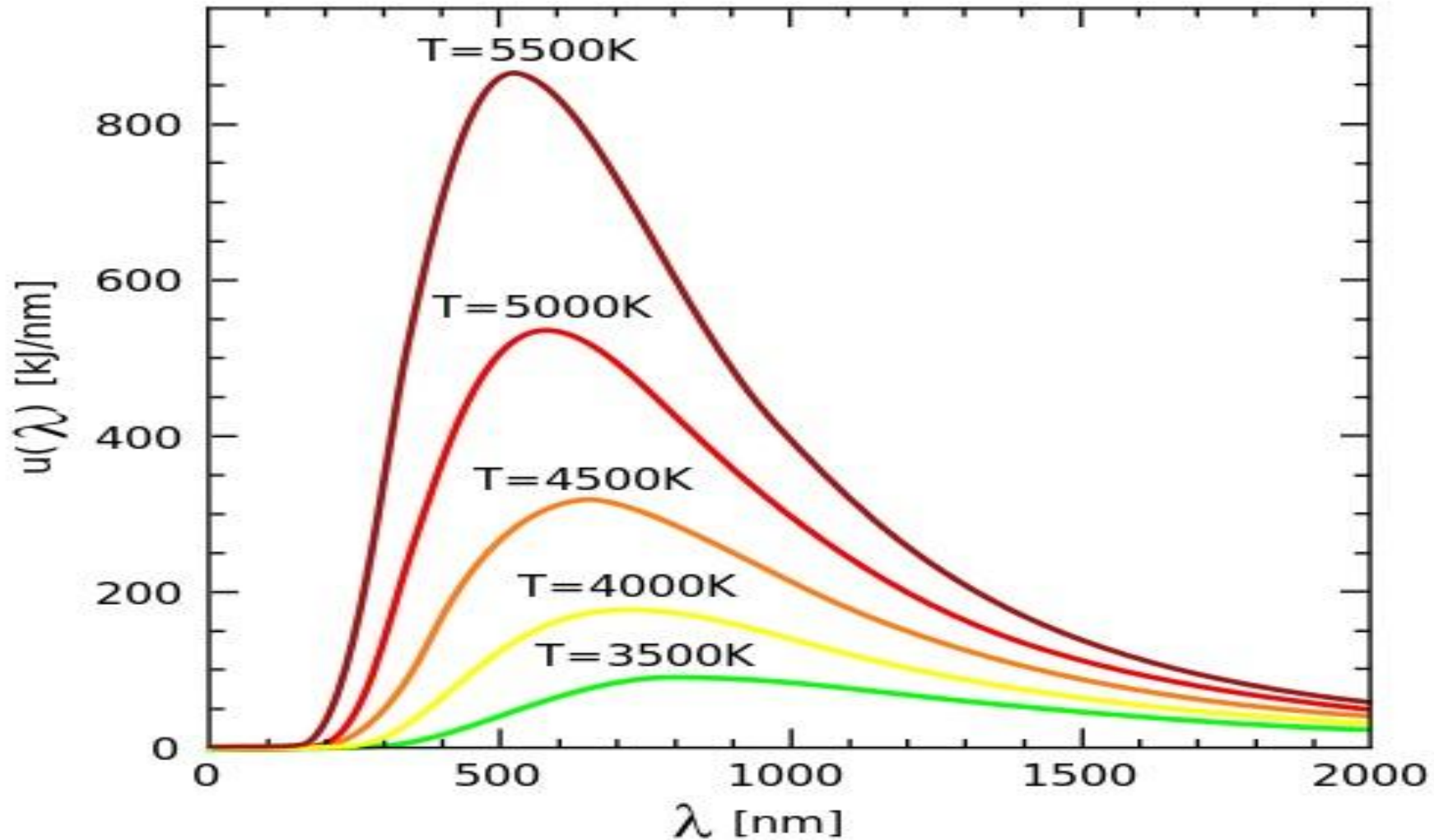
$$5 \left(e^{\frac{hc}{\lambda kT}} - 1 \right) = \frac{hc}{\lambda kT} e^{\frac{hc}{\lambda kT}} \text{ or } (x - 5)e^x + 5 = 0 \text{ with } \frac{hc}{\lambda kT} = x$$

➡ $\lambda_{\max} = \sigma_w / T$
 $\sigma_w = \text{Wien constant} = 2,90 \times 10^{-3} \text{ mK}$



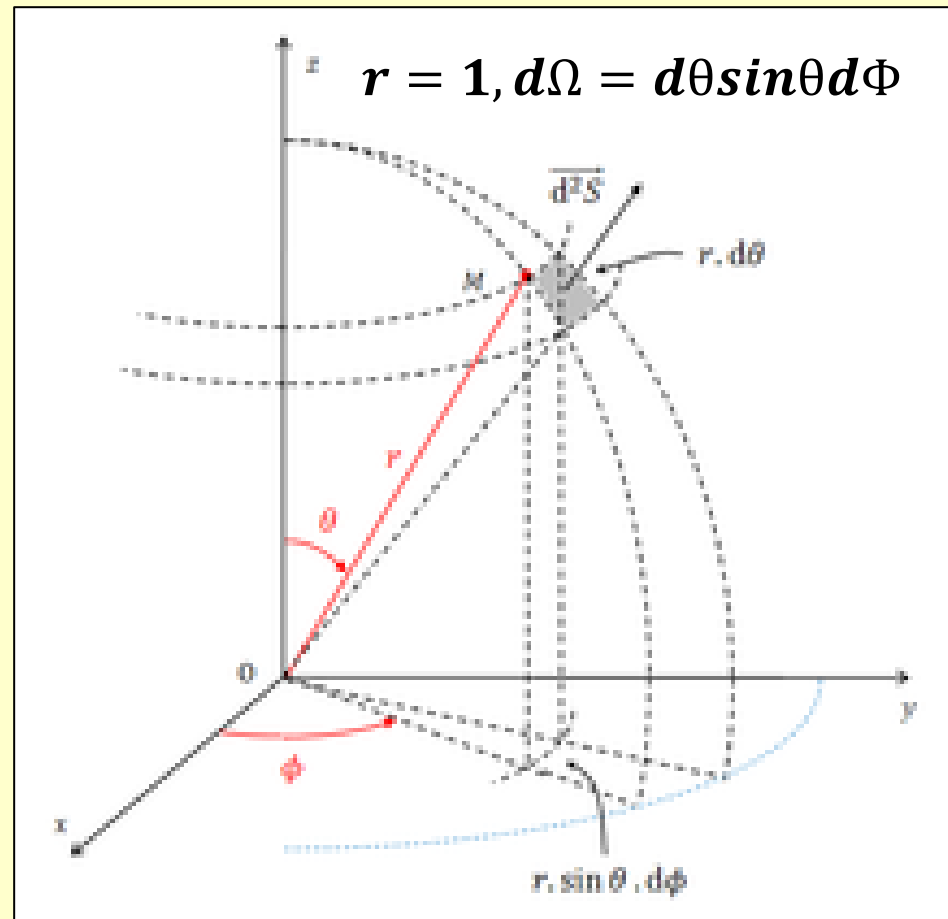
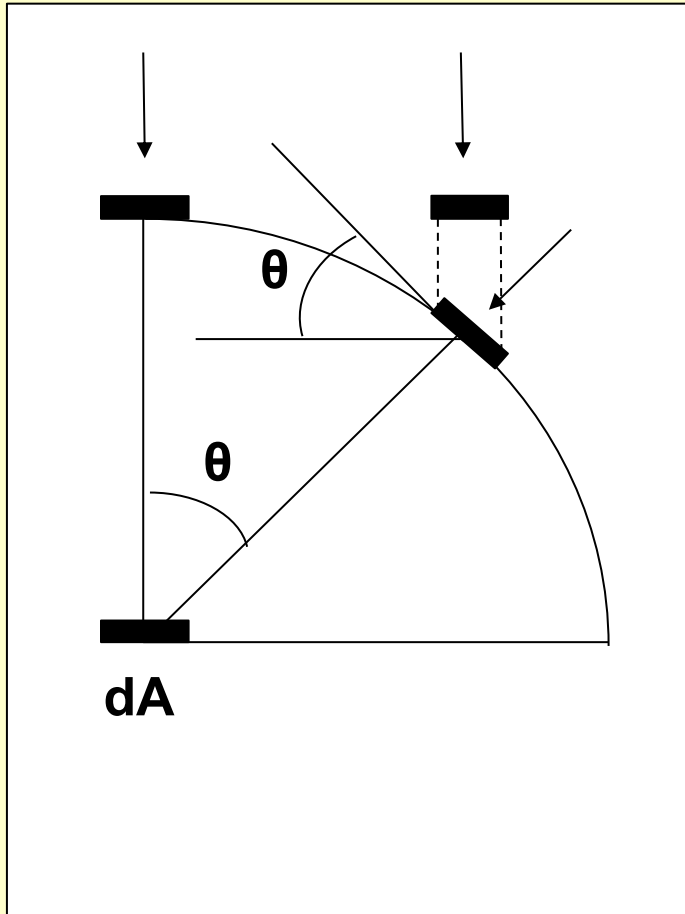
Climate issues – More Basics (6)

Energy vs Wavelength



Climate issues – More Basics (7)

- Reminder: Equal brightness effect & Solid angle from the source of emissions:



Climate issues – More Basics (8)

- **Spectral radiance emitted by a surface area dA , in a range of frequency between ν and $\nu + d\nu$, in a solid angle $d\Omega$:**

$$I(\nu, T) \cos\theta dA d\nu d\Omega = \frac{2h\nu^3}{c^2} * 1/(e^{\frac{h\nu}{kT}} - 1) \cos\theta dA d\nu d\Omega$$

- **Total power emitted by the surface dA of a black body over the solid angles corresponding to a hemisphere (h) above the surface dA is obtained by integrating the spectral flux over all frequencies :**

$$P(T)dA = \int_0^\infty I(\nu, T) d\nu dA \int_h \cos\theta d\theta \sin\theta d\Phi = \int_0^\infty I(\nu, T) d\nu dA \int_0^{2\pi} d\Phi \int_0^{\pi/2} \cos\theta \sin\theta d\theta$$

Per unit of surface: $P(T) = \pi \int_0^\infty I(\nu, T) d\nu = 2\pi h/c^2 \int_0^\infty \nu^3 * 1/(e^{\frac{h\nu}{kT}} - 1) d\nu$

With $x = h\nu/kT$, $P(T) = 2\pi k^4 T^4 / c^2 h^3 \int_0^\infty \frac{x^3}{(e^x - 1)} dx = 2\pi^5 k^4 T^4 / 15 c^2 h^3 = \sigma T^4$

$\sigma = 2\pi^5 k^4 / 15 c^2 h^3 \# 5,67 \times 10^{-8} \text{ Wm}^{-2} \text{K}^{-4}$: Stefan-Boltzmann constant

Nota: $\int_0^\infty \frac{x^3}{(e^x - 1)} dx = \pi^4 / 15$



Climate issues – More Basics (9)

- Every object whose temperature is greater than 0°K (-273,15°C) emits electromagnetic radiations.
- Sun and Earth can be roughly considered as black bodies.
- Power emitted by a black body by surface unit, at given frequencies of its electromagnetic radiations only depends upon its temperature.
- Global power emitted by surface unit over the frequency spectrum depends only upon the temperature:

$$M_{\text{tot}} = \sigma T^4, \sigma = \text{Stefan-Boltzmann constant} = 5,67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$$

- Sun radiation:

Sun temperature at surface : $T_s = 5777 \text{ }^\circ\text{K}$

$$M_{s\text{tot}} = \sigma T_s^4 = 6,32 \times 10^7 \text{ Wm}^{-2} = 63 \text{ MWm}^{-2}$$

Sun radius = $r_s = 695\,700 \text{ km}$

Global power emitted by sun at surface:

$$P_s = M_{s\text{tot}} \times 4\pi r_s^2 = 3,84 \times 10^{26} \text{ W}$$

- Sun radiation received by Earth = P_{s-E}

Distance Sun-Earth = $d_{s-E} = 149,6 \times 10^6 \text{ km}$

Earth radius = $r_E = 6371 \text{ km}$

$$P_{s-E} = P_s \times \pi r_E^2 / 4\pi d_{s-E}^2 = 1,74 \times 10^{17} \text{ W}$$

$$\text{Equivalent at the level of Earth: } E_s = M_{s\text{tot}} \times (r_s / d_{s-E})^2 = 1367 \text{ Wm}^{-2}$$

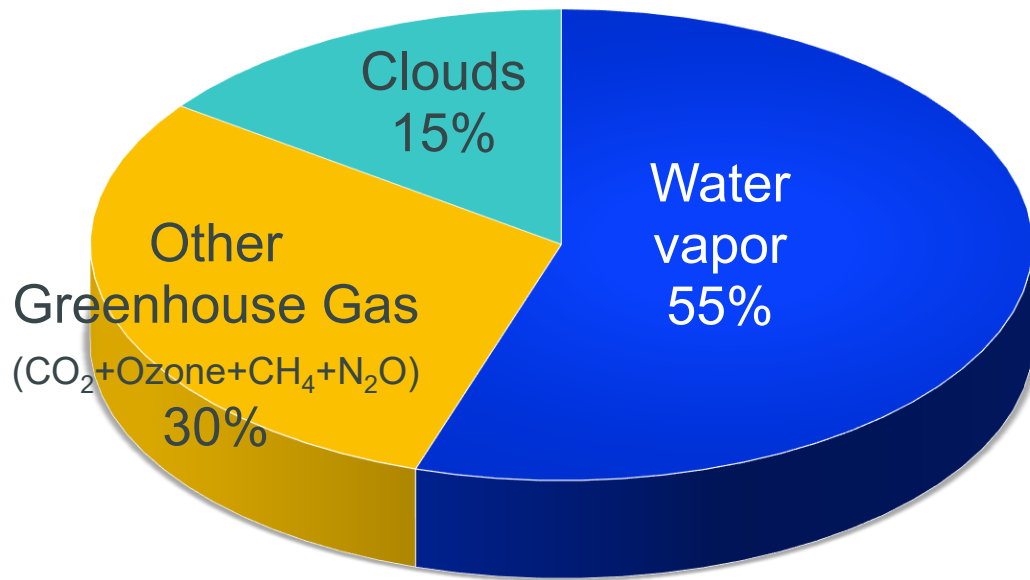


Climate issues – More Basics (10)

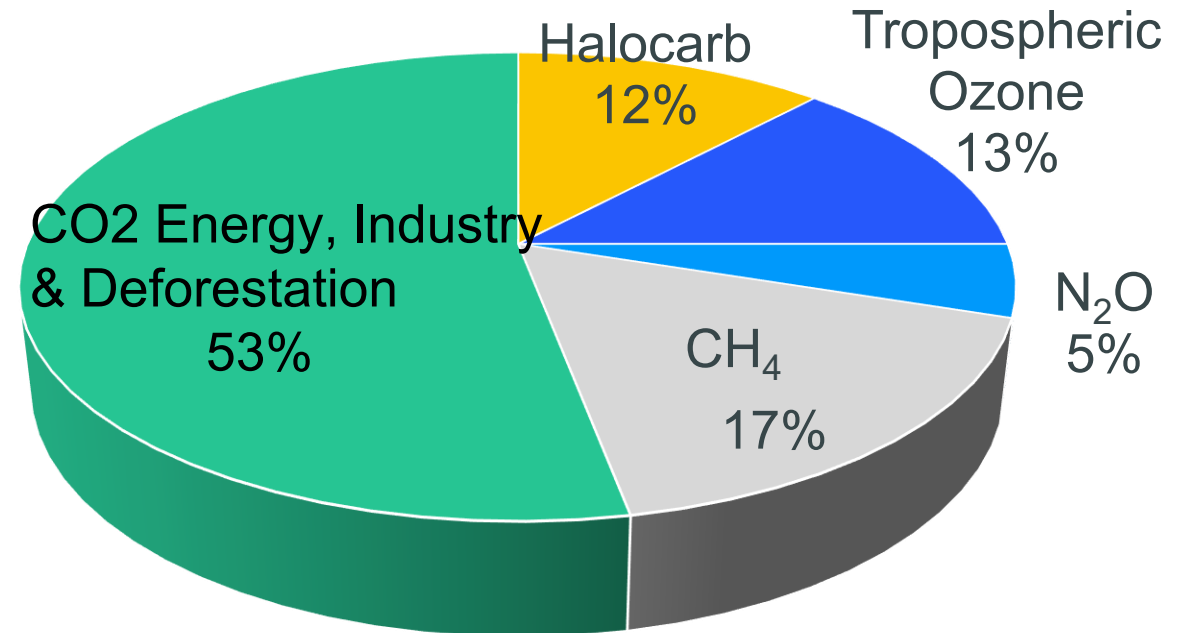
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 $T_E = \sqrt[4]{(1-A)E_E/\sigma} \longrightarrow T_E = 255^\circ\text{K} = -18^\circ\text{C}$
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Atmospheric contributions to greenhouse effect Radiative Forcing (**2,8 W/m²** from human activity) - Period 1750-2000



Natural 155 W/m² *



Anthropogenic 2.8 W/m² **

** including a negative (= cooling) feedback from aerosols of ~ 1,1 W/m²

• Figures & percentages can slightly change upon time or sources.

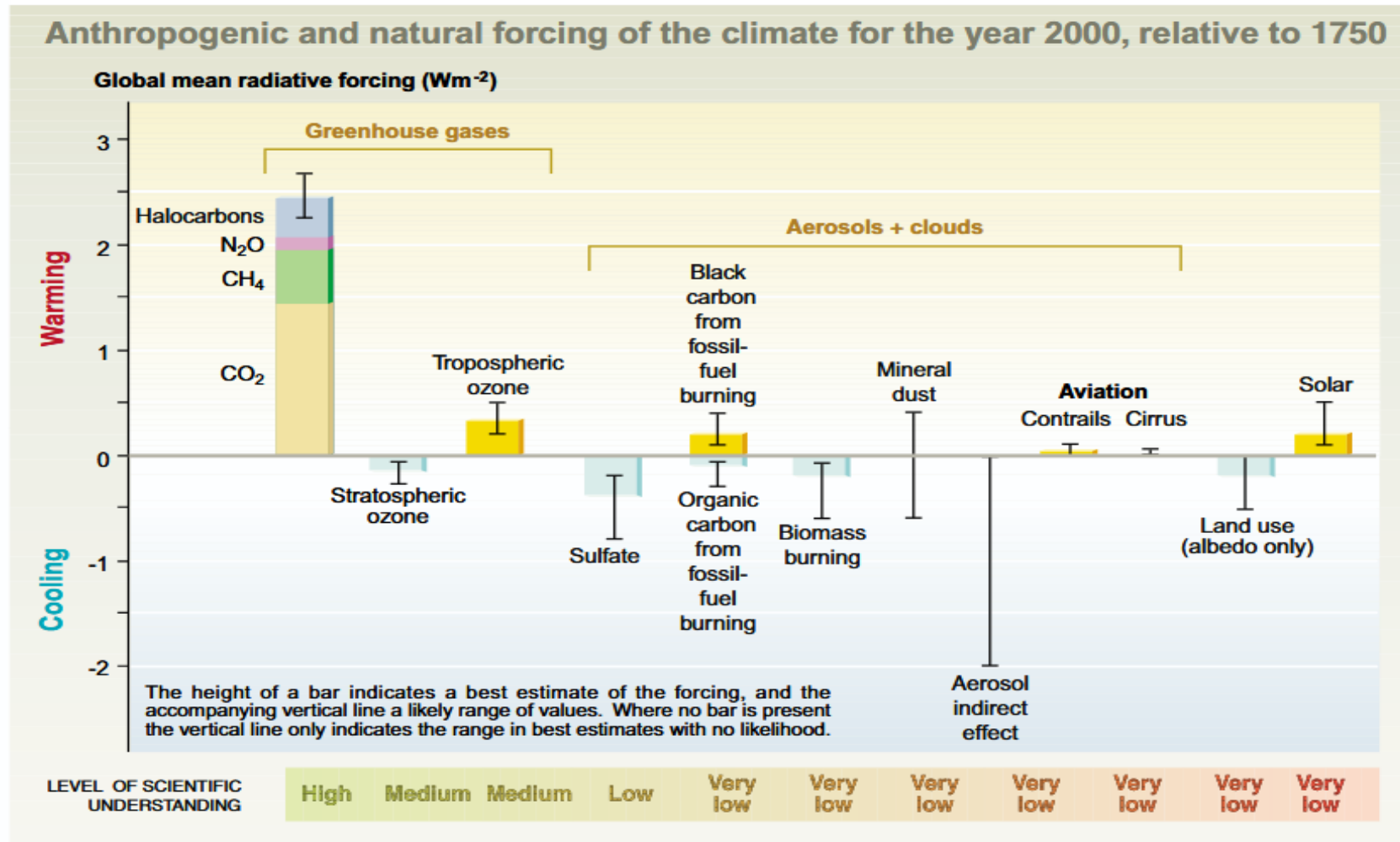
Halocarbons: chlorofluorocarbons + hydrochlorofluorocarbons. Halocarbons absorb infra red radiations.

Stratospheric Ozone has no direct emissions

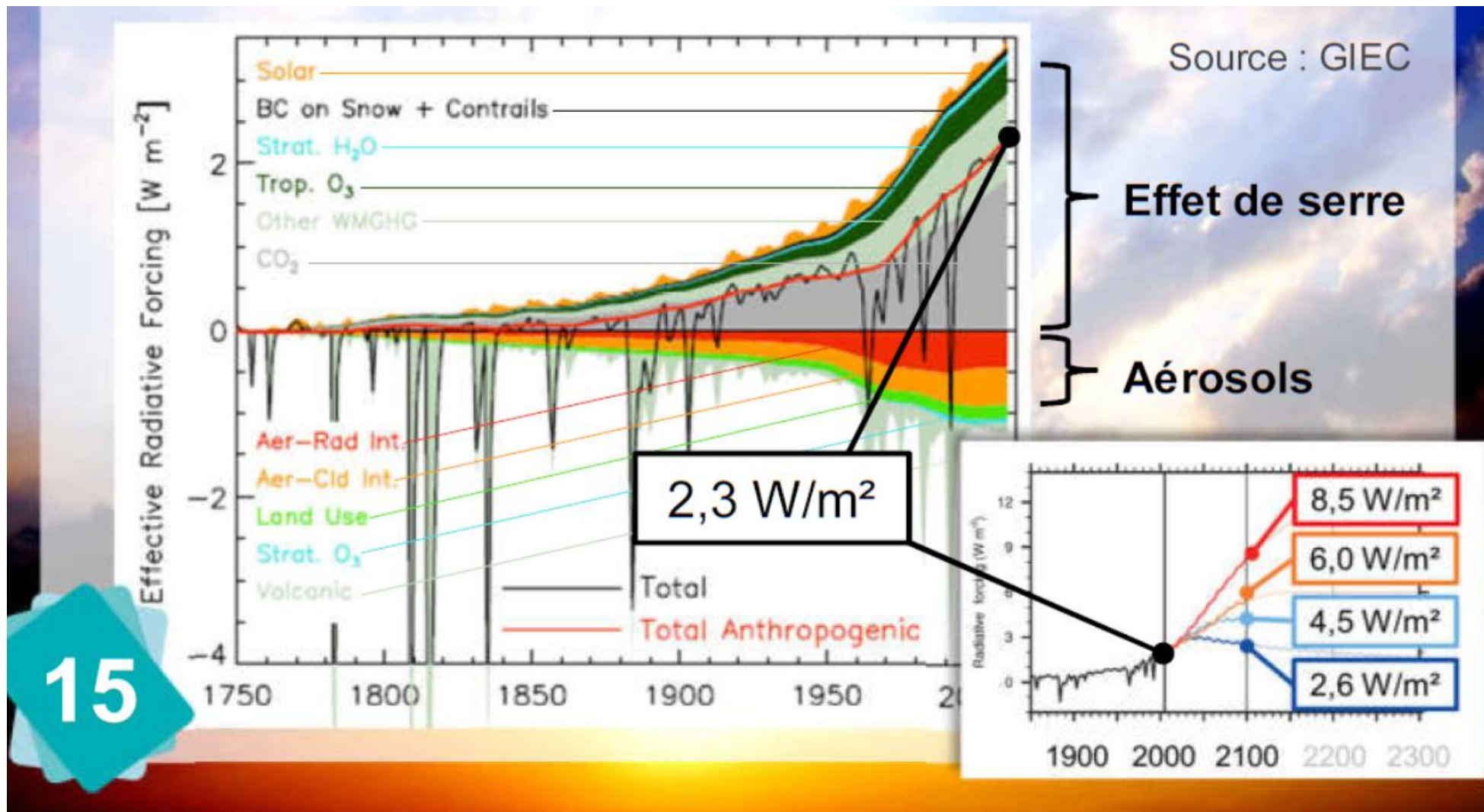
Source: Data from IPCC Climate Change 2001 & 2005



Atmospheric contributions to greenhouse effect Radiative Forcing (**2,8 W/m²** from human activity) - Period 1750-2000

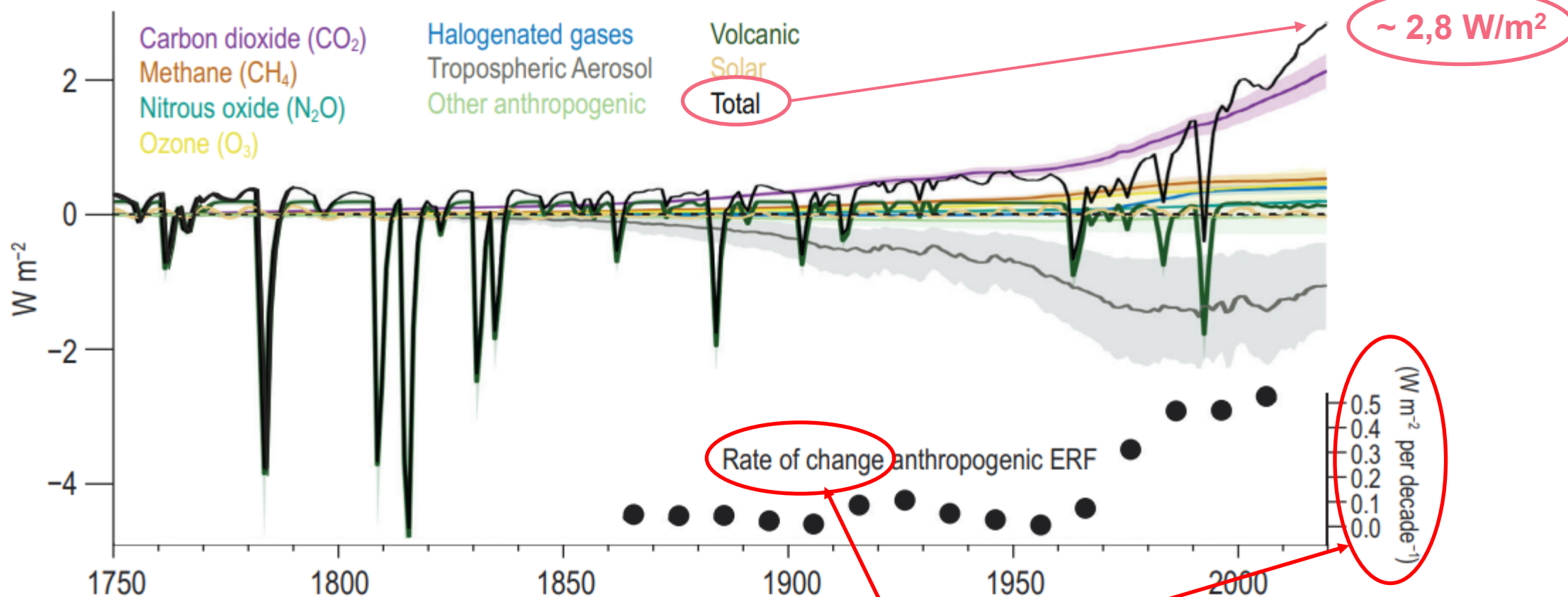


Anthropogenic Effective Radiative Forcing (ERF) and Solar + Volcanoes



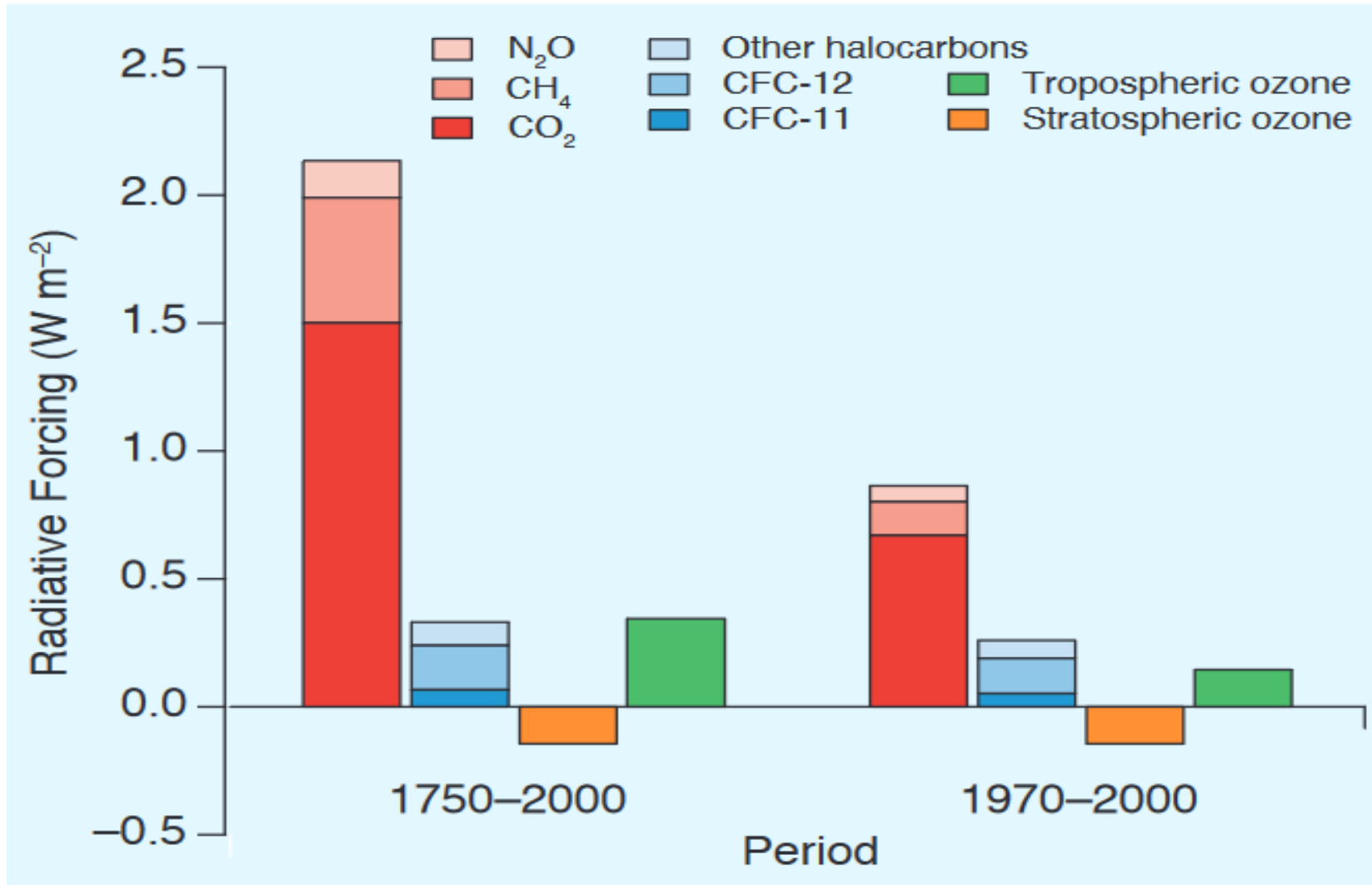
Anthropogenic Effective Radiative Forcing (ERF) and Solar + Volcanoes – update 2021

The increase in effective radiative forcing (ERF) since the late 19th century is driven predominantly by warming GHGs and cooling aerosol. ERF is changing at a faster rate since the 1970s



Source: IPCC AR6 WG1 - figure TS.9 - August 2021

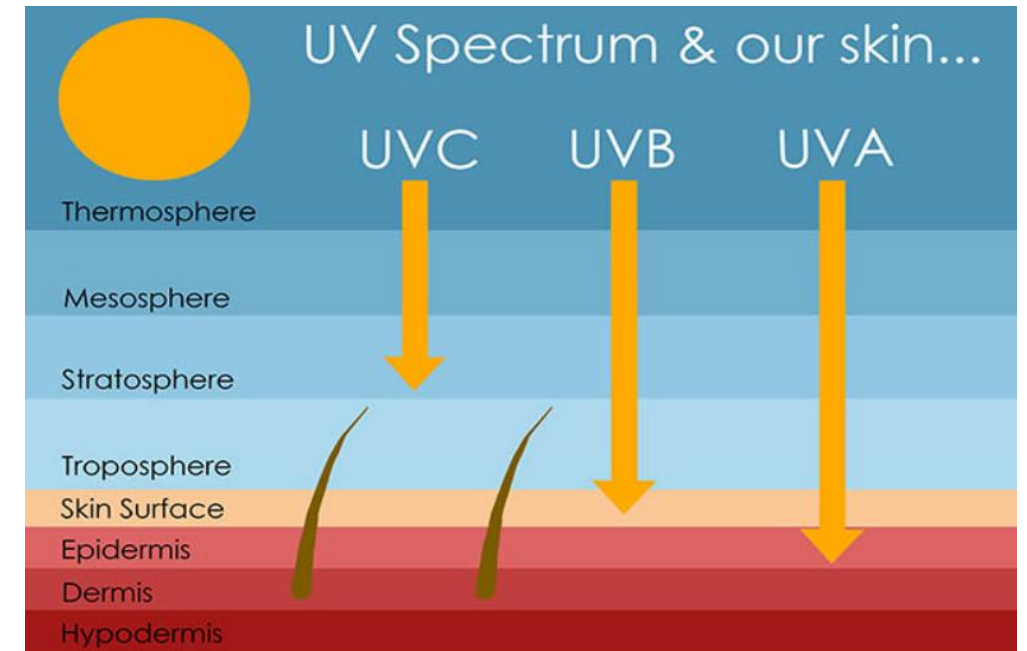
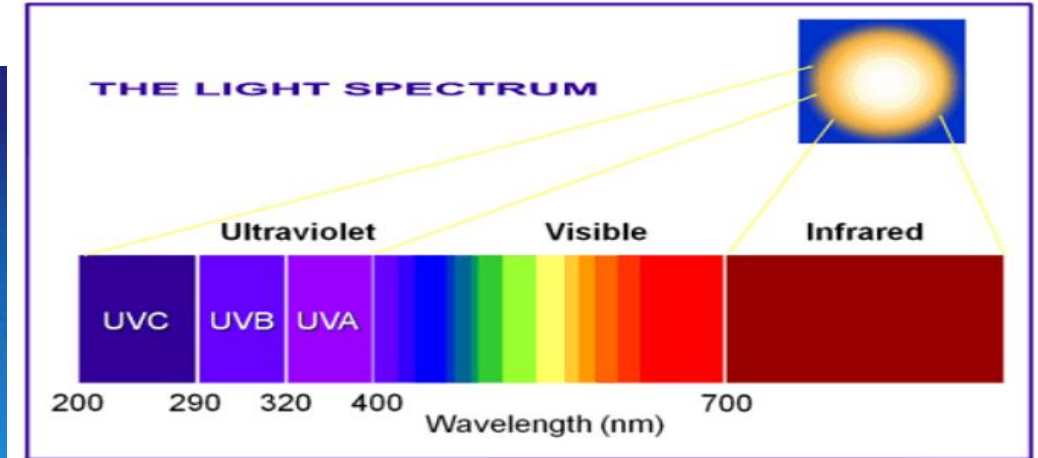
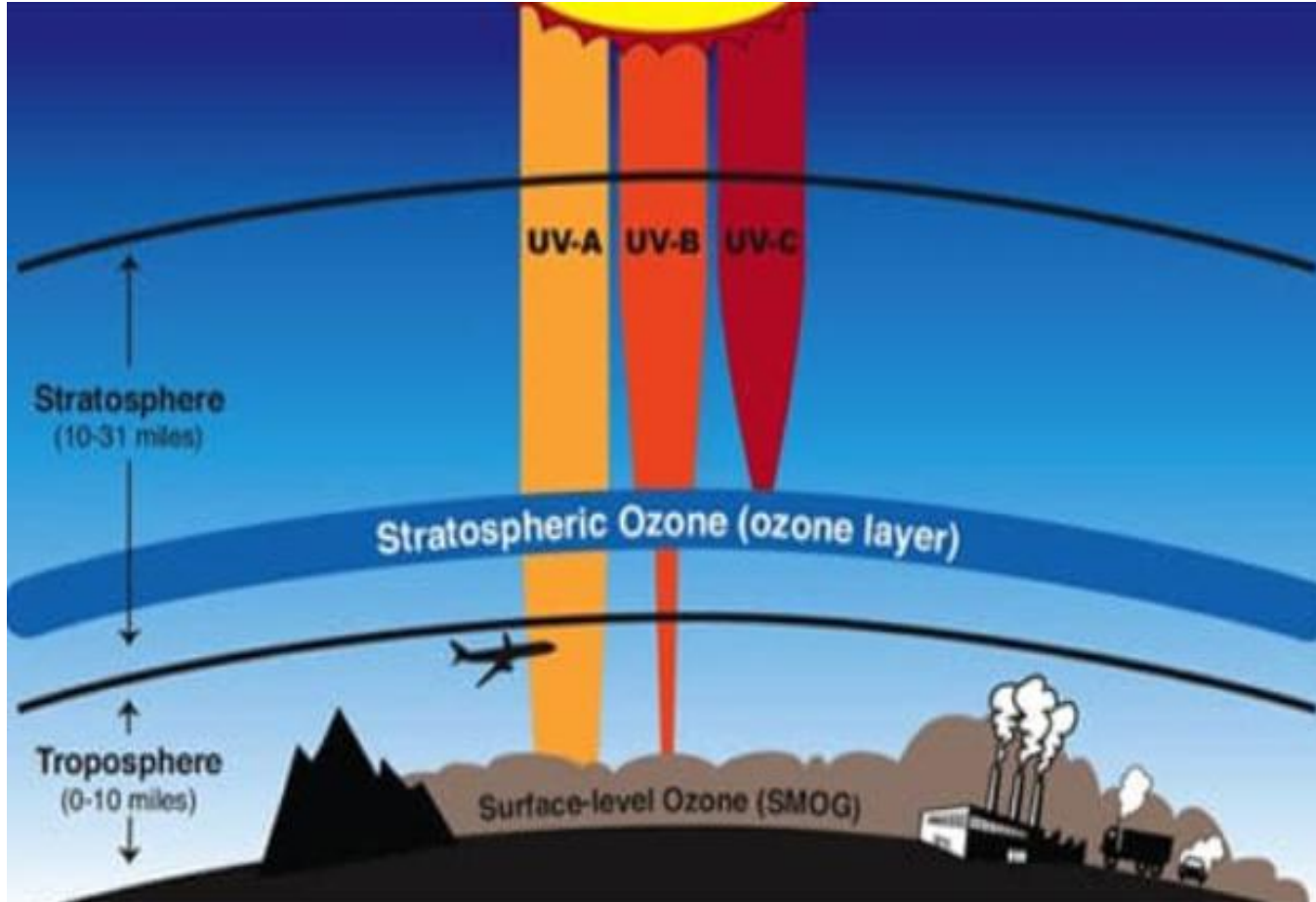
Impact of GHG on Radiative Forcing



Source: IPCC/TEAP (Technology and Economic Assessment Panel) 2005
Special Report Ozone and Climate - Interconnections



Stratospheric vs Tropospheric Ozone - The protective role of Ozone layer



Role of Ozone and Halocarbons

- Ozone is technically a greenhouse gas. earth's atmosphere. Ozone is helpful or harmful depending on where it is found in the atmosphere. Ozone occurs naturally at higher elevations in the atmosphere (the stratosphere) where it forms a layer that blocks ultraviolet (UV) light, which is harmful to plant and animal life, from reaching the earth's surface. The protective benefit of **Stratospheric Ozone** outweighs its contribution to the greenhouse effect and to global warming. However, at lower elevations of the atmosphere (the troposphere), **Tropospheric Ozone** is harmful to human health.
- There are human-made industrial chemicals that break down ozone in the stratosphere and create holes in the Ozone layer (Ozone-Depleting Substances, ODSs, like halocarbons). Countries all around the world ban and control production and use of several of these industrial gases under the Montreal Protocol.
- Stratospheric Ozone has been depleted over the last 25 years following anthropogenic emissions of a number ODSs, which are now regulated under the Montreal Protocol. The Protocol has been effective in controlling the net growth of these compounds in the atmosphere. As halocarbons slowly decrease in the future, ozone levels are expected to increase in the coming decades, although the evolution will also depend on the changing climate system.
- Halocarbons are particularly strong greenhouse gases (gases that absorb and emit thermal infrared radiation); a halocarbon molecule can be many thousands of times more efficient at absorbing radiant energy emitted from the Earth than a molecule of carbon dioxide. Ozone is a greenhouse gas that also strongly absorbs ultraviolet and visible radiation. Changes in these gases have affected the Earth's radiative balance in the past and will continue to affect it in the future.



Role of Ozone and Halocarbons

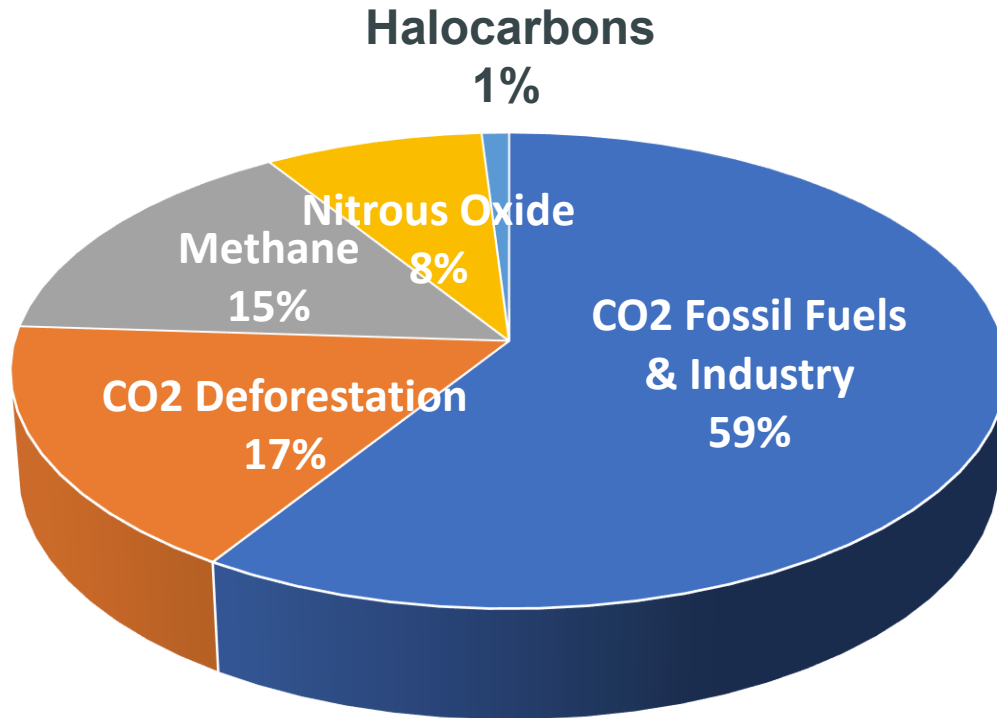
- Interactions between chemical reactions involving halocarbons and the various components of atmosphere including ozone are complex and difficult to modelize.
- Over the period 1750–2000 halocarbon gases have contributed a positive direct radiative forcing of about 0.33 Wm^{-2} which represents about 12% of the total well-mixed greenhouse gas radiative forcing over this period. Over the period 1970–2000 halocarbon gases represent about 23% of the total well-mixed greenhouse gas radiative forcing.
- Stratospheric ozone depletion has led to a negative radiative forcing of about 0.15 Wm^{-2} with a range of $\pm 0.1 \text{ Wm}^{-2}$ from different model estimates. Therefore the positive radiative forcing due to the combined effect of all ODSs (0.32 Wm^{-2}) over the period 1750–2000 is larger than the negative forcing due to stratospheric ozone depletion.



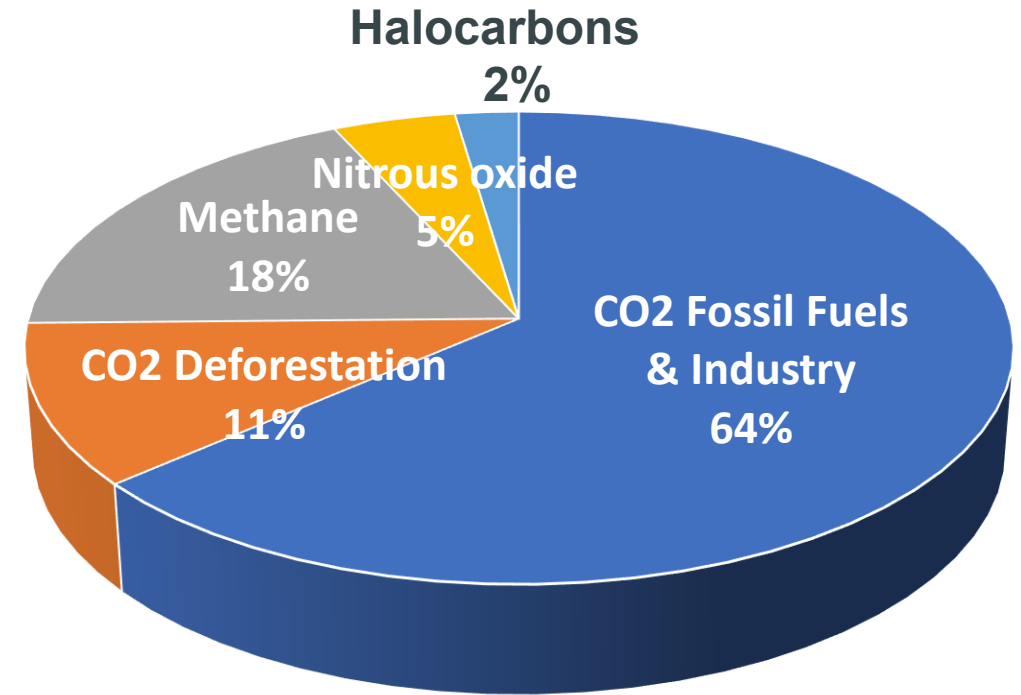
Contribution of Anthropogenic GHG Direct Emissions (% in CO₂eq based on GWP)

Year 2004 (# 44 GtCO₂eq.)

Year 2019 (# 59 GtCO₂eq. +/- 6,6 GtCO₂eq.)



Source: IPCC 2007



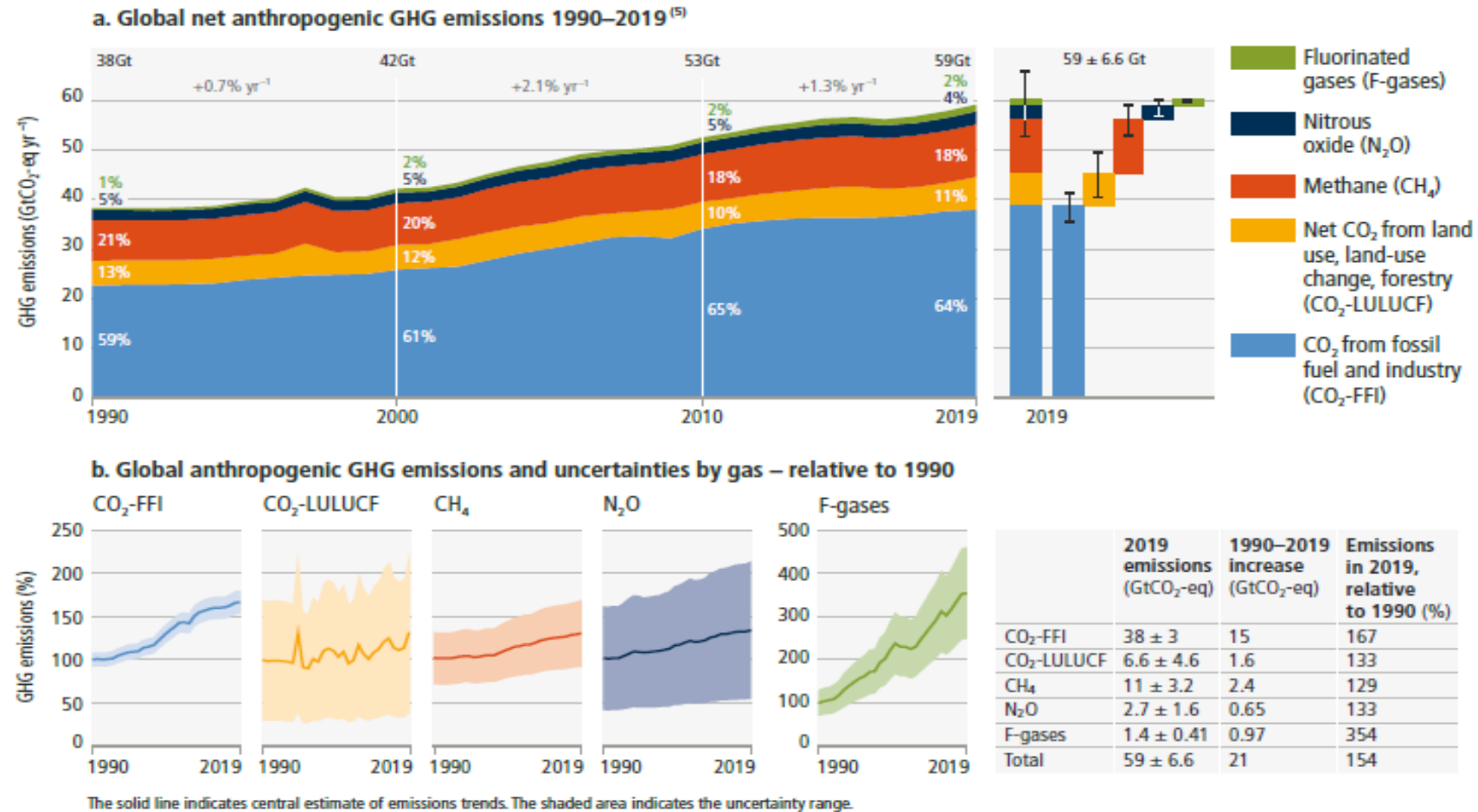
Source: IPCC 2022

GWP: Global Warming Power



Contribution of Anthropogenic GHG Direct Emissions (% in CO₂eq based on GWP)

Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.



Anthropogenic Sources of GHG – IPCC AR6 WGIII

	2019 emissions (GtCO ₂ eq)	1990–2019 increase (GtCO ₂ eq)	1990–2019 increase (%)
CO ₂ FFI	38±3	15	67
CO ₂ LULUCF	6.6±4.6	1.6	33
CH ₄	11±3.2	2.4	29
N ₂ O	2.7±1.6	0.65	33
F-gases	1.4±0.41	0.97	250
Total	59±6.6	21	54

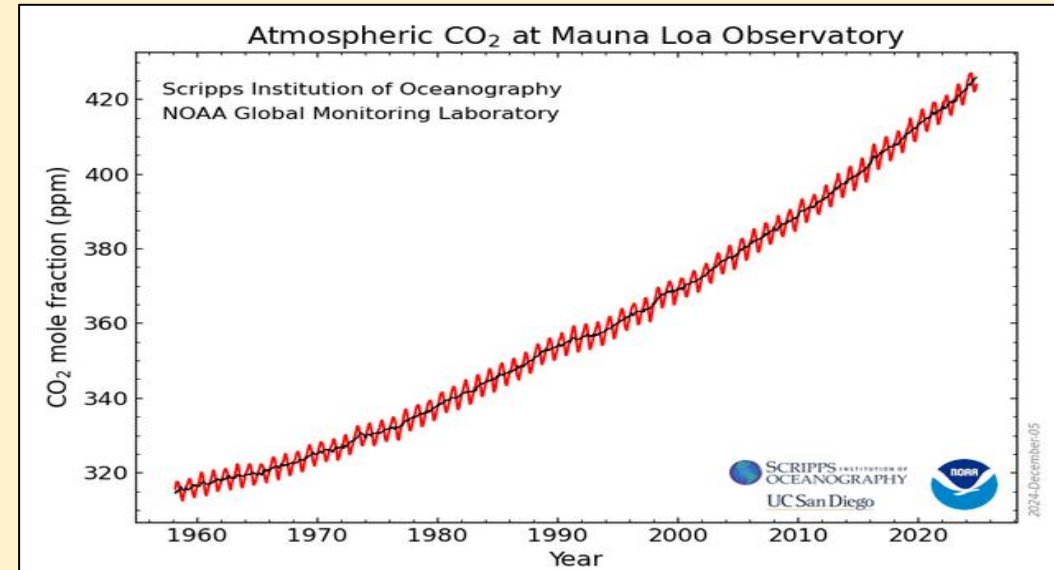
Source: IPCC AR6 WGIII



The three most important Greenhouse Gases

The three most important Greenhouse Gas (GHG) are:

- Carbon Dioxide – CO_2
- Methane – CH_4
- Nitrous Oxide – N_2O



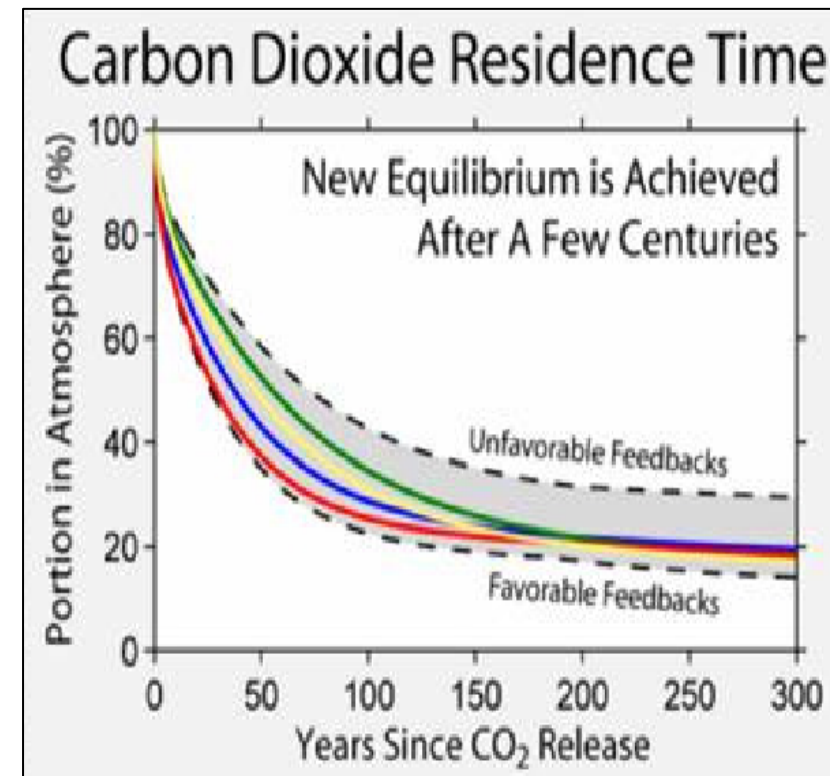
Source: NOAA Global Monitoring Laboratory – November 2025

In order to illustrate the global effects of GHG, it is usual to convert the mass of CH_4 and N_2O in mass of CO_2 equivalent ($\text{CO}_2\text{eq.}$)



Greenhouse Gas Lifetimes & Global Warming Potentials (GWPs)

GHG	Chemical Formula	Lifetime Years	100 years GWP
Carbon Dioxide	CO ₂	> 100	1
Methane	CH ₄	12	28
Nitrous Oxide	N ₂ O	114	300

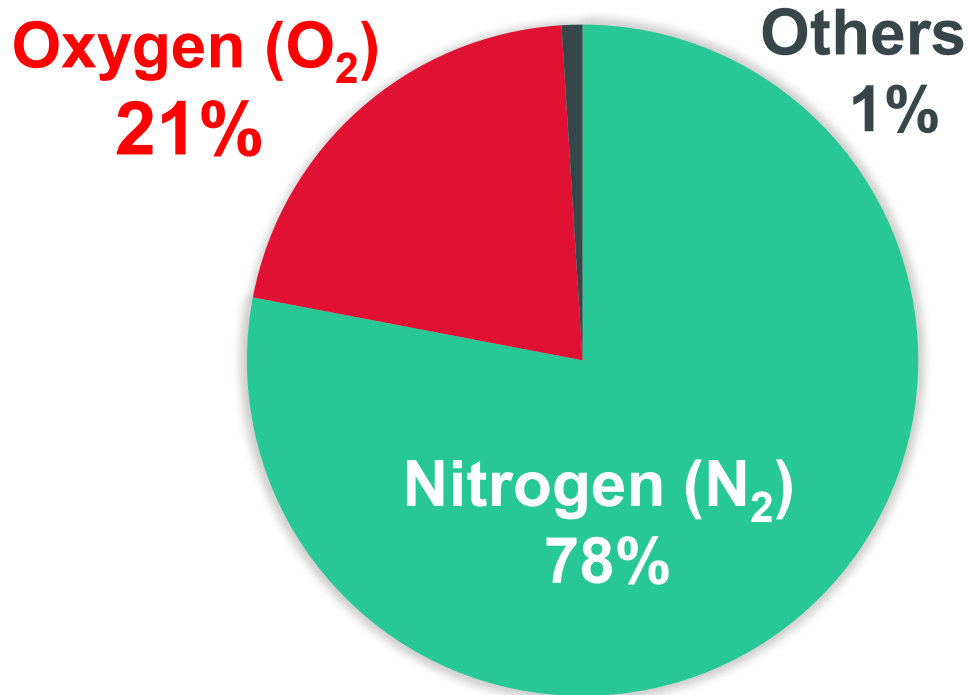


GWP = Heat absorbed by any GHG in the atmosphere as a multiple as the heat that would be absorbed by the same mass of CO₂.

Source: Data from Climate Change Connection
 IPCC 4th Assessment Report (AR4) – R.A. Rohde
 GWP 28 years for Methane recommended by IPCC (AR5, 5th Assessment Report vs 25 years in AR4)



Composition of Atmosphere



Argon : 0,9%
Carbon Dioxide (CO₂) : 0,04% (# 400 ppm)



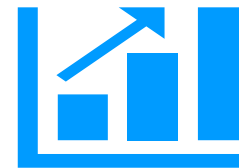
CO₂ concentration

280 ppm in 1750

432 ppm in May 2026

(Mauna Loa Observatory - Hawaiï)

CO₂ Concentration is increasing after a slight decrease in 2020 due to the Covid 19.



A minor variation of CO₂ content in the atmosphere has important consequences in term of greenhouse effect.

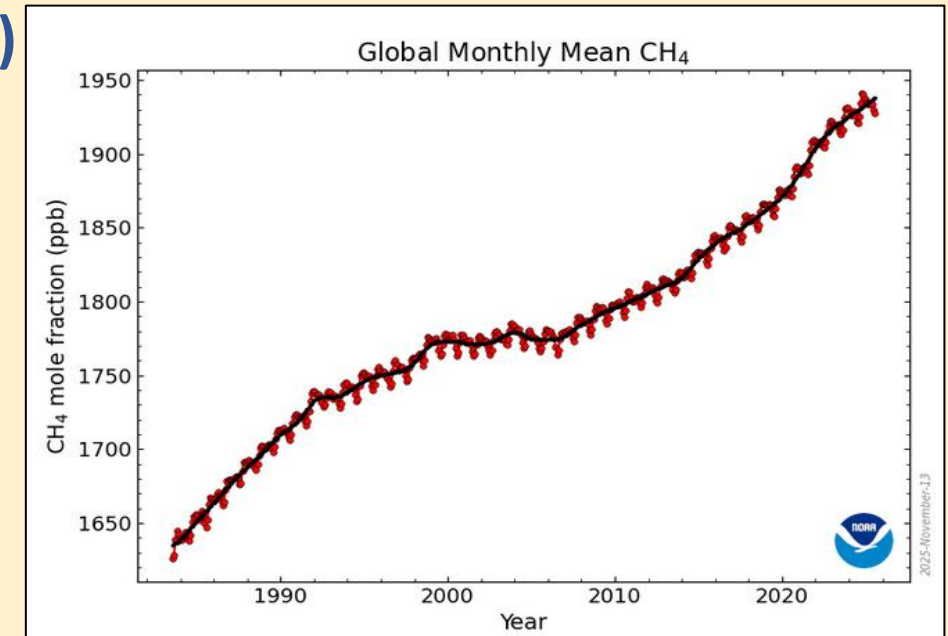
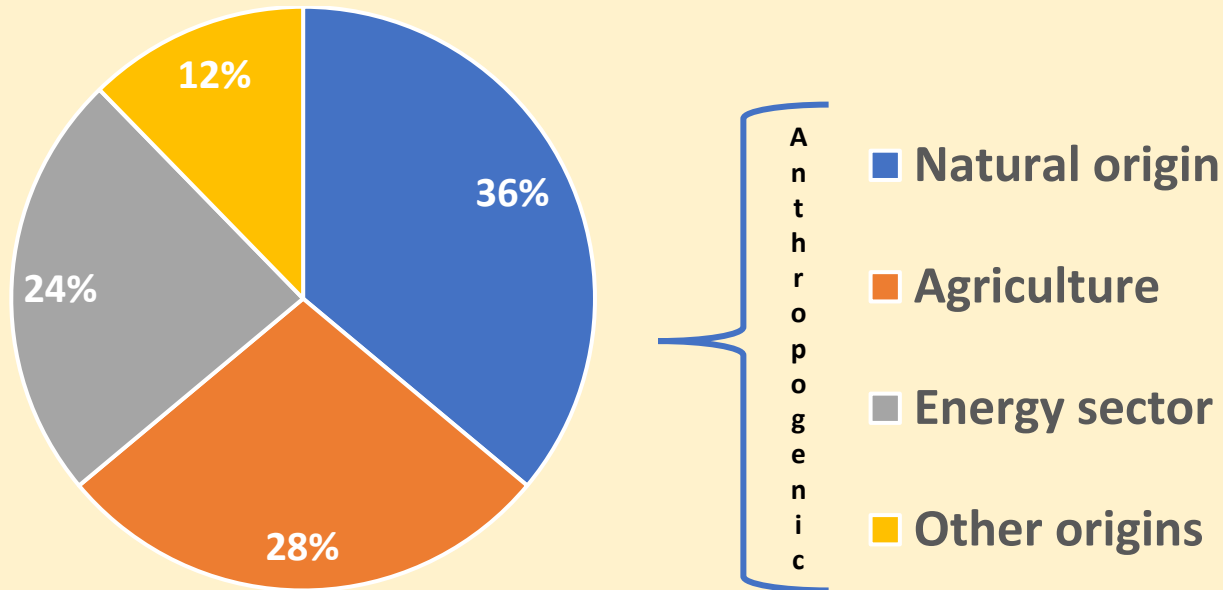


Focus on Methane

Methane is the second-largest GHG after CO₂. Concentration July 2025 = 1928 ppb.

Methane emissions come from natural and anthropogenic sources.

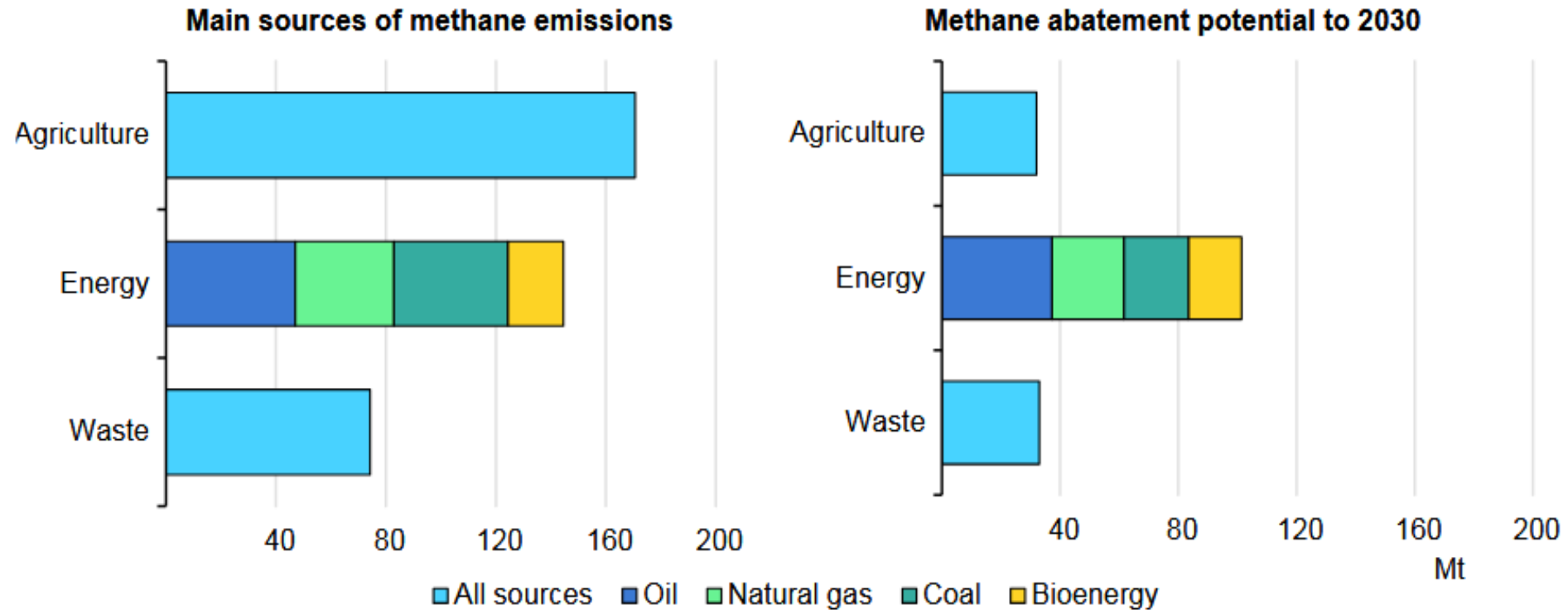
Estimates of Methane emissions are subject to uncertainties. Global estimates for 2024 are 610 MtCH₄ # 17 GtCO₂eq. (Natural + Anthropogenic)



Anthropogenic Methane Emissions 2024

Agriculture + Energy + Waste # 390 GtCH₄

Methane emissions from human activity and their abatement potential



IEA. CC BY 4.0.

Sources: Methane emissions for agriculture and waste are based on data from the [Global Methane Budget](#) (2024).

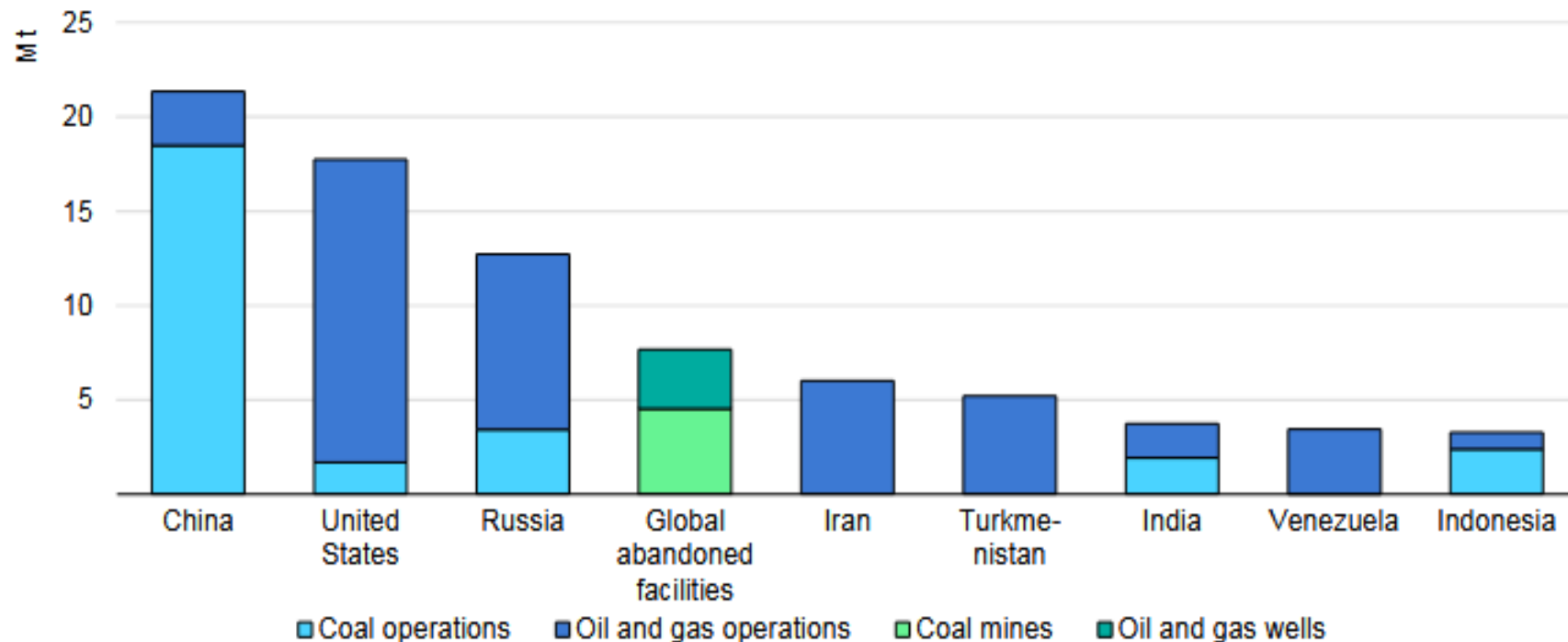
Methane abatement for agriculture and waste is taken from [UNEP's Global Methane Assessment](#) (2021).

Source: Global Methane tracker 2025



Methane Emissions from Fossil Fuels sector - 2024 by selected countries

Methane emissions from fossil fuel operations for the top eight emitters and from abandoned facilities globally, 2024



IEA. CC BY 4.0.

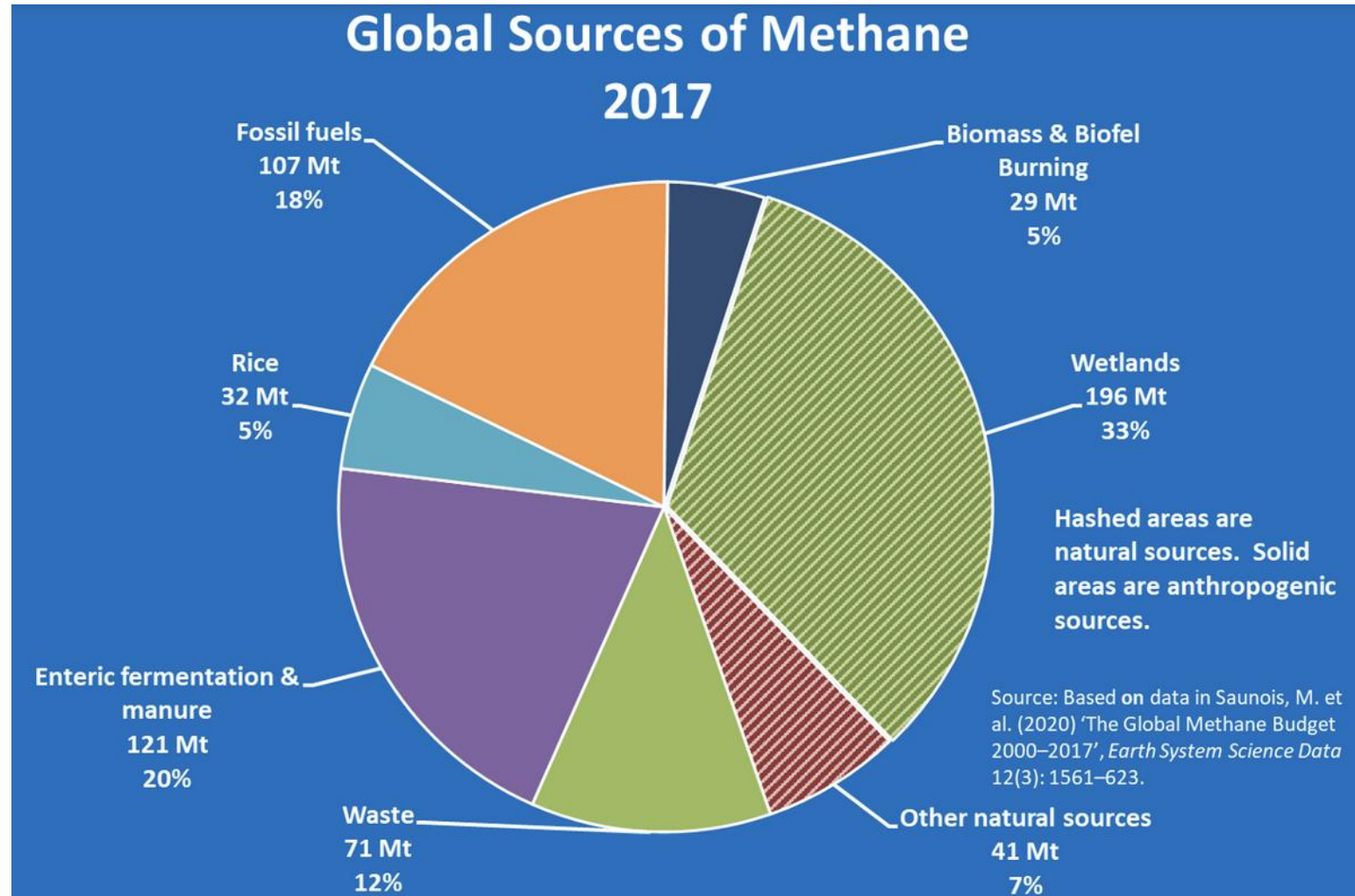
Note: Emissions from abandoned facilities are not included in fossil fuel operations. Abandoned facilities refer to facilities that have been closed and where there are no plans to restart production.

Source: Global Methane Tracker 2025



Reminder - Global Methane emissions by sources – Year 2017

600 MtCH₄ # 16 GtCO₂eq., out of which # 60% anthropic



Focus on Nitrous Oxide

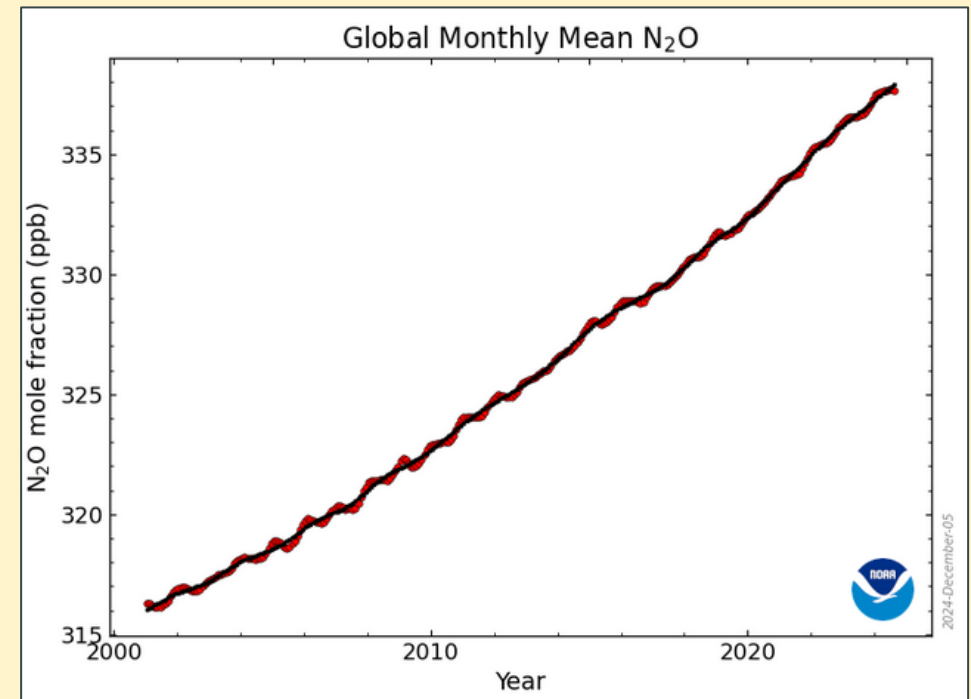
N₂O is a important GHG, the third one after CO₂ and Methane, with potential negative effects on Climate Change.

Concentration July 2025 = 339 ppb.

Agriculture causes around 70% of global N₂O emissions, due to the use of nitrogen in synthetic fertilisers.

Other human sources of N₂O include chemical industry, waste waters and the burning of fossil fuels.

N₂O emissions in 2023 # 10 Mt # 3,0 GtCO₂ eq.



Source: NOAA Global Monitoring Laboratory – November 2025



Stocks & Flux of Carbon



Warning

Figures related to anthropogenic Carbon emissions are subject to large uncertainties, which are expressed by International Panel for Climate Change (IPCC)

Historical series of CO₂ emissions can differ slightly depending upon various sources: International Energy Agency (IEA), Energy Intelligence (EI), Global Carbon Project (GCP), World Bank,

Carbon emissions series concern several items: combustion of Fossils Fuels, emissions from Cement industry and other industrial activities, impact of Cement carbonation, Flaring, changes of Forest and Land use (FOLU).

Anthropogenic Greenhouse Gas (GHG) comprise CO₂ GHG plus non-CO₂ GHG (Methane, nitrous Oxide, halocarbons, tropospheric ozone)

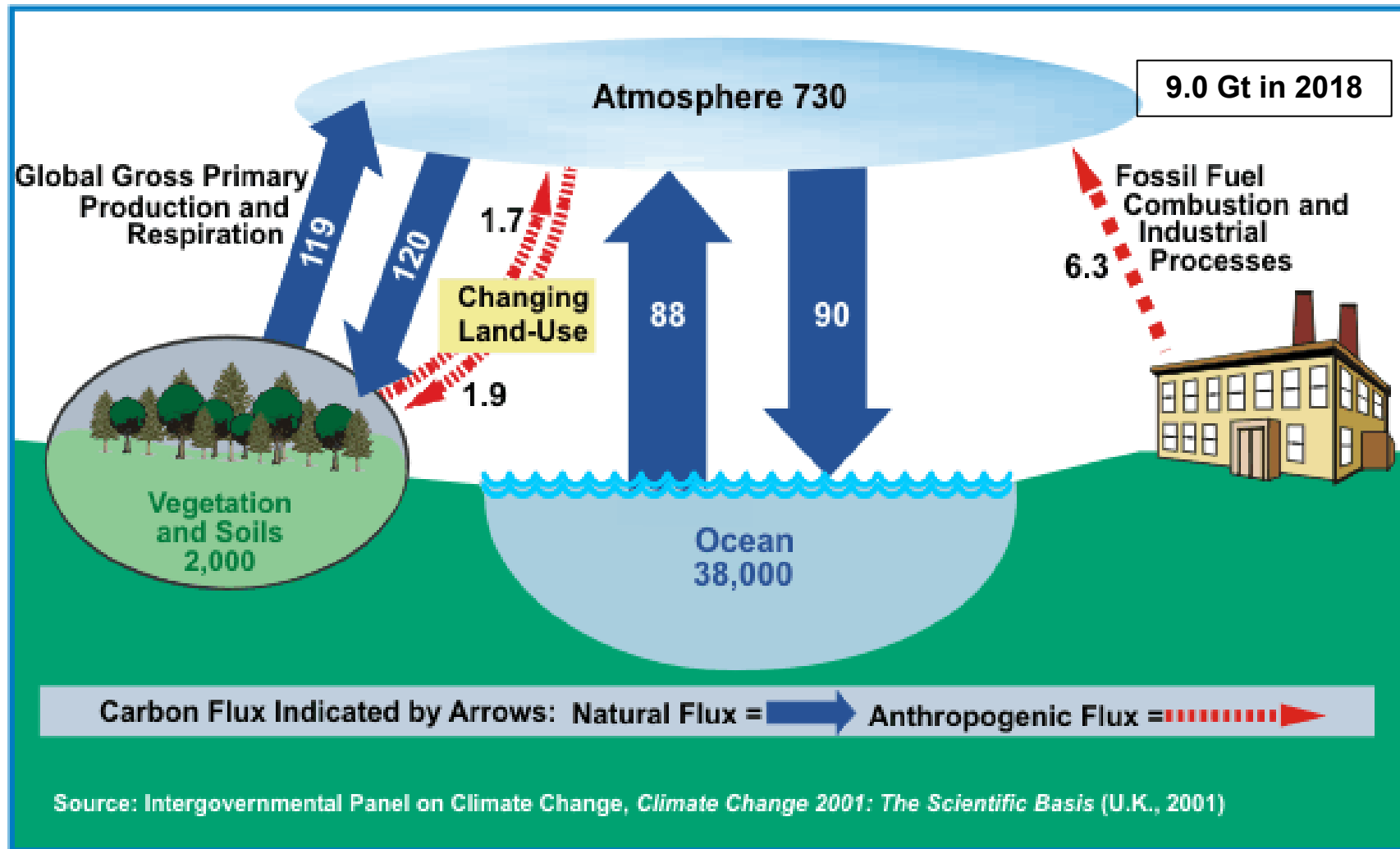


Categorization of CO₂ and GHG elements used by various organizations and study groups

CO ₂ Emissions include	Energy combustion				Industrial processes & Flaring							
	Coal combustion	Oil combustion	Gas combustion	Bioenergy & Waste	Cement	Flaring	Other	Methane & Industrial Process	FOLU	Methane	Nitrous Oxide	F Gas
Energy Institute	X	X	X	X		X		X				
Global Carbon Project	X	X	X		X	X	X		X			
IEA	X	X	X	X	X	X	X			X		
IPCC	X	X	X	X	X	X	X		X	X	X	X
World Bank	X	X	X							X	X	X



Stocks & Net Carbon Flux Earth/Atmosphere IPCC Analysis **2001**(GtC for stocks, GtC/year for flux)

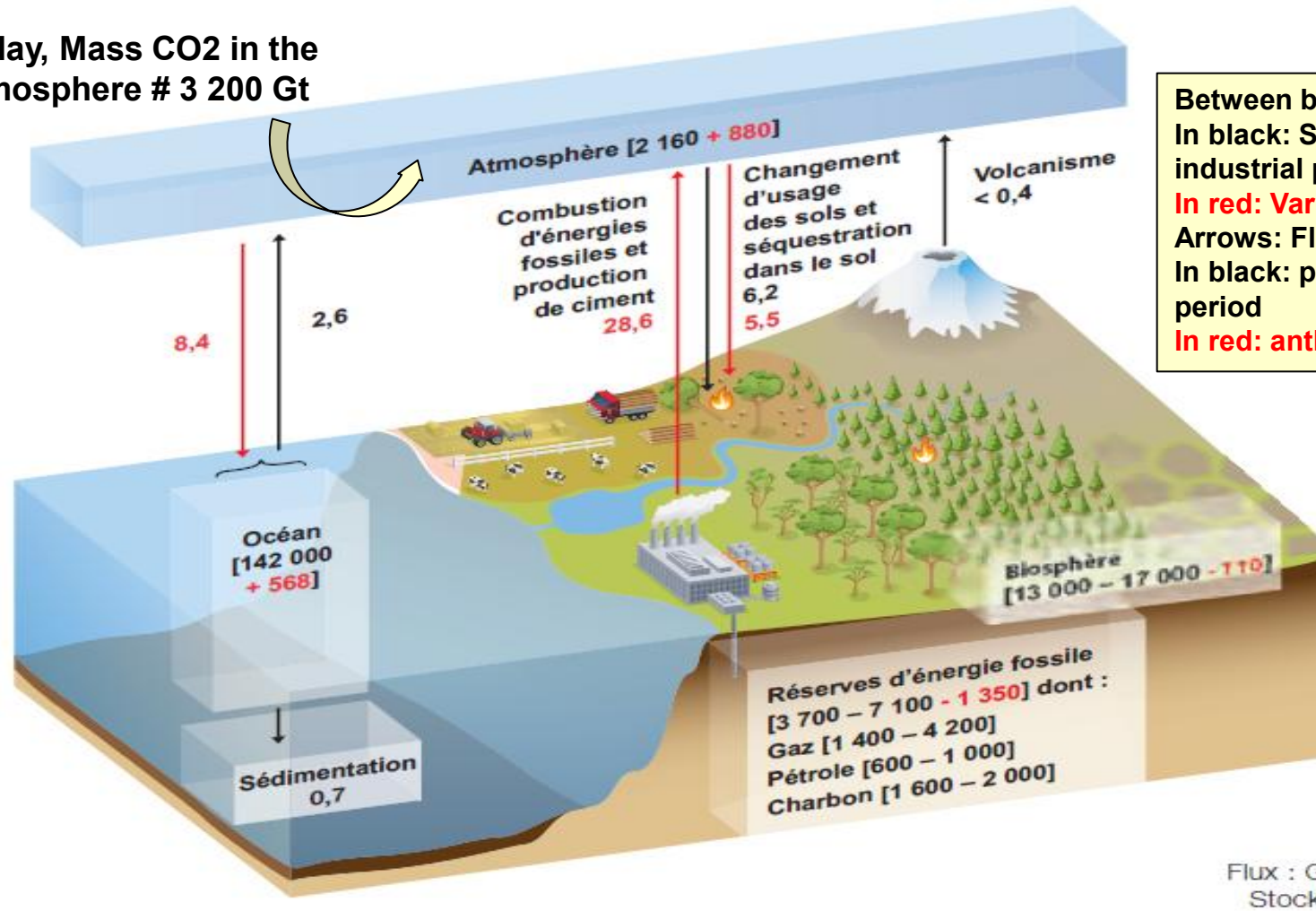


Nota: 1t C = 3,667t CO₂



Stocks & Net Carbon Flux Earth/Atmosphere Situation **2011** (GtCO₂ for stocks, GtCO₂/year for flux)

Today, Mass CO₂ in the
Atmosphere # 3 200 Gt

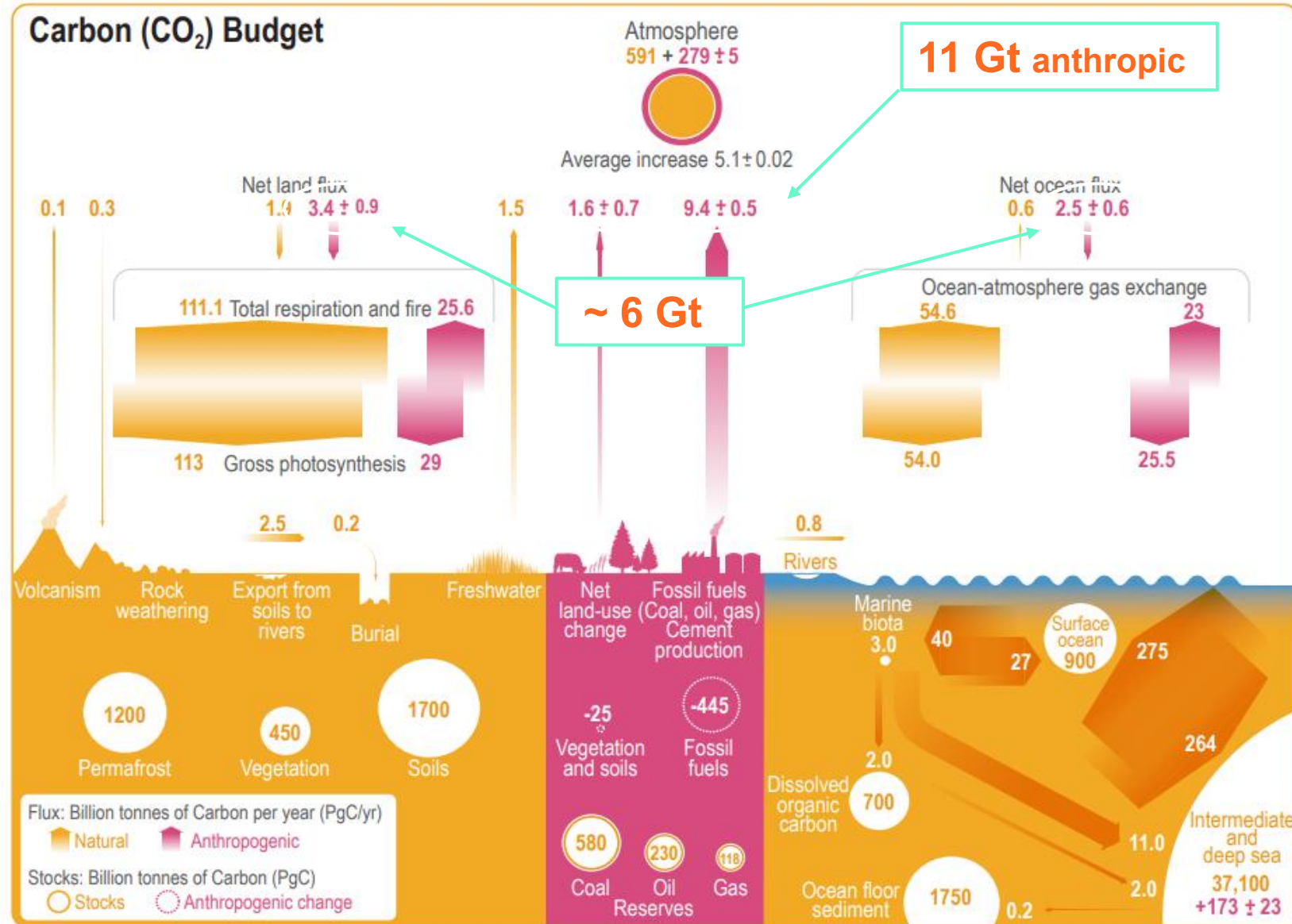


Between brackets:
In black: Stocks before pre-industrial period.
In red: Variation 1750-2011.
Arrows: Flux:
In black: pre-industrial period
In red: anthropic activity

Source: IPCC 2013/Ministère de l'Écologie, du Développement Durable et de l'Énergie – France 2015 Nota: 1t C = 3,667t CO₂



Stocks & Net Carbon Flux Earth/Atmosphere - Situation **2021** from IPCC AR6



Stock in air :
~ 870 Gt carbon
or ~ 3200 Gt CO₂

~ 2%

numbers
are for
'carbon'

italic
stands for
CO₂

Stock on land :
~ 4300 Gt carbon
or ~ 15700 Gt CO₂

~ 9%

Numbers in circles :
represent carbon stocks
(in PgC = Gt carbon
= billion tons C)

Yellow numbers =
carbon stock before the
industrial period

Pink numbers =
anthropogenic stock
variation since 1750

Numbers with arrows :

Yellow numbers give yearly
fluxes of carbon for the
period before ~ 1750

Arrows / pink numbers are
for anthropogenic yearly
fluxes averaged over the
2010–2019 decade

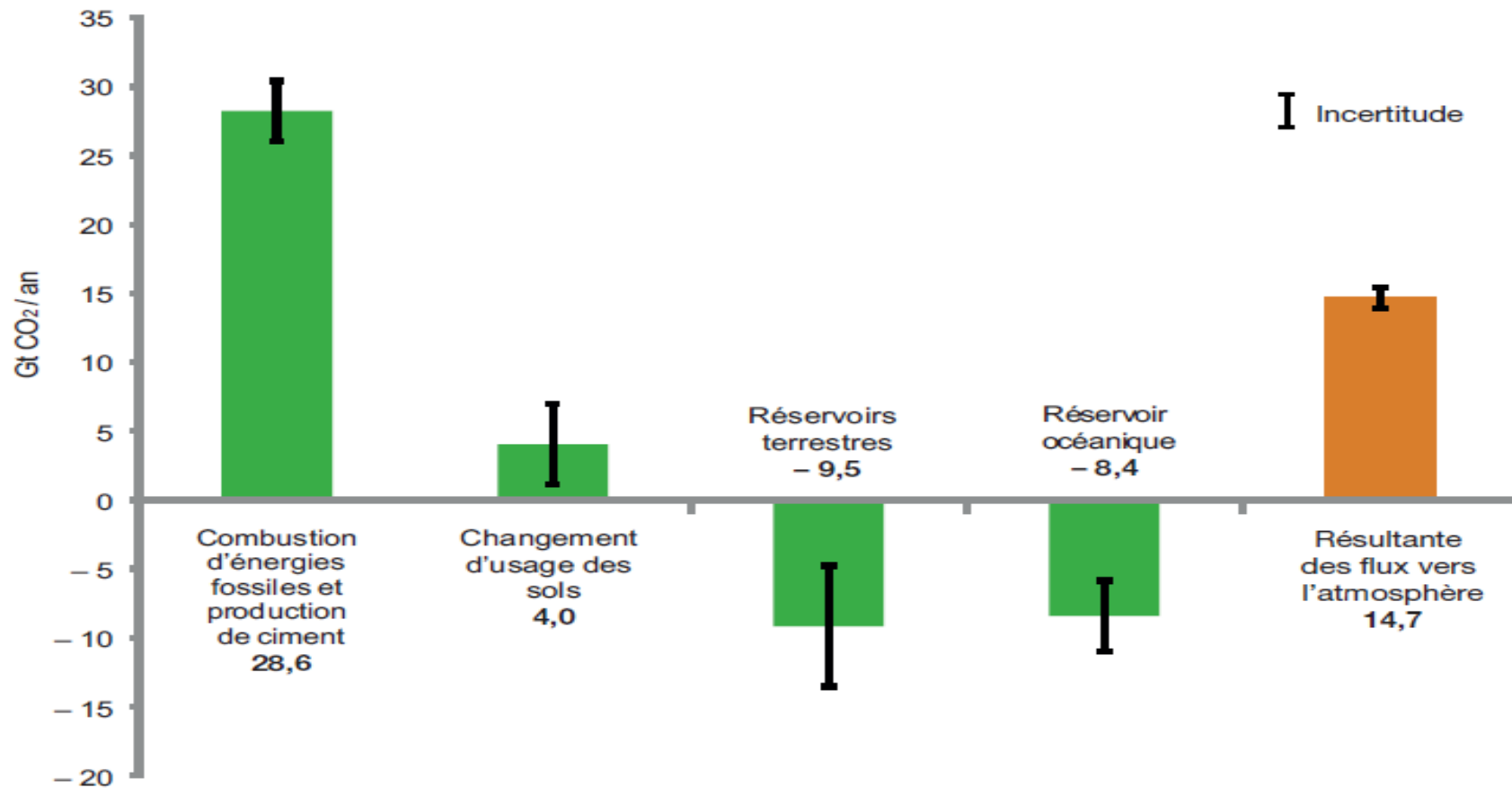
Stock in water :
~ 40400 Gt carbon
or ~ 148000 Gt CO₂

~ 89%



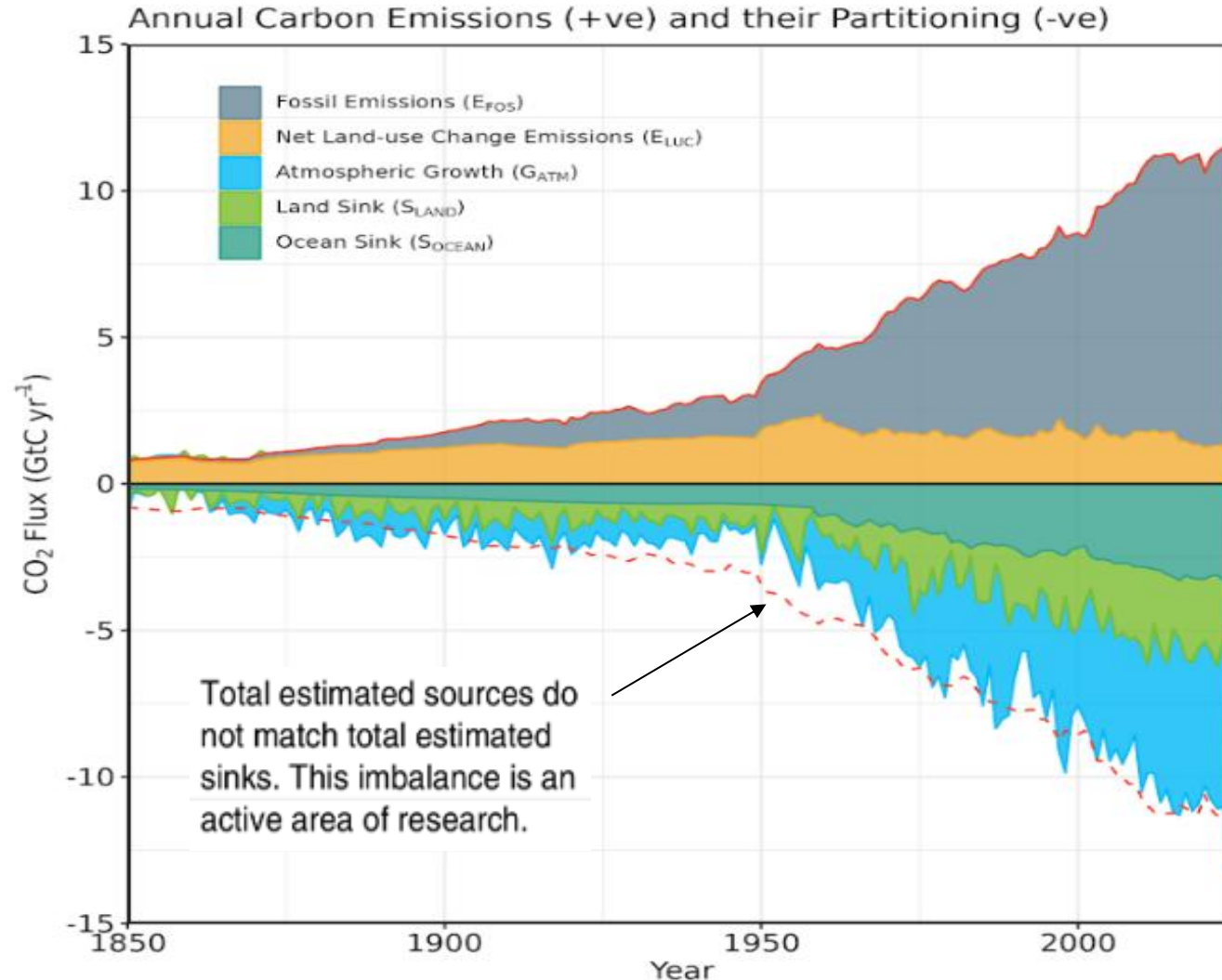
Net Carbon Flux Earth/Atmosphere - Situation **2011**

50% of gross Emissions are absorbed by oceans and biosphere
(GtCO₂/year)



Source: IPCC 2013/Ministère de l'Écologie, du Développement Durable et de l'Énergie – France 2015 Nota: 1T C = 3,667 T CO₂

Global Gross Carbon Emissions are partly absorbed by the environment. Net Carbon Emissions remaining in the atmosphere increase its CO₂ content

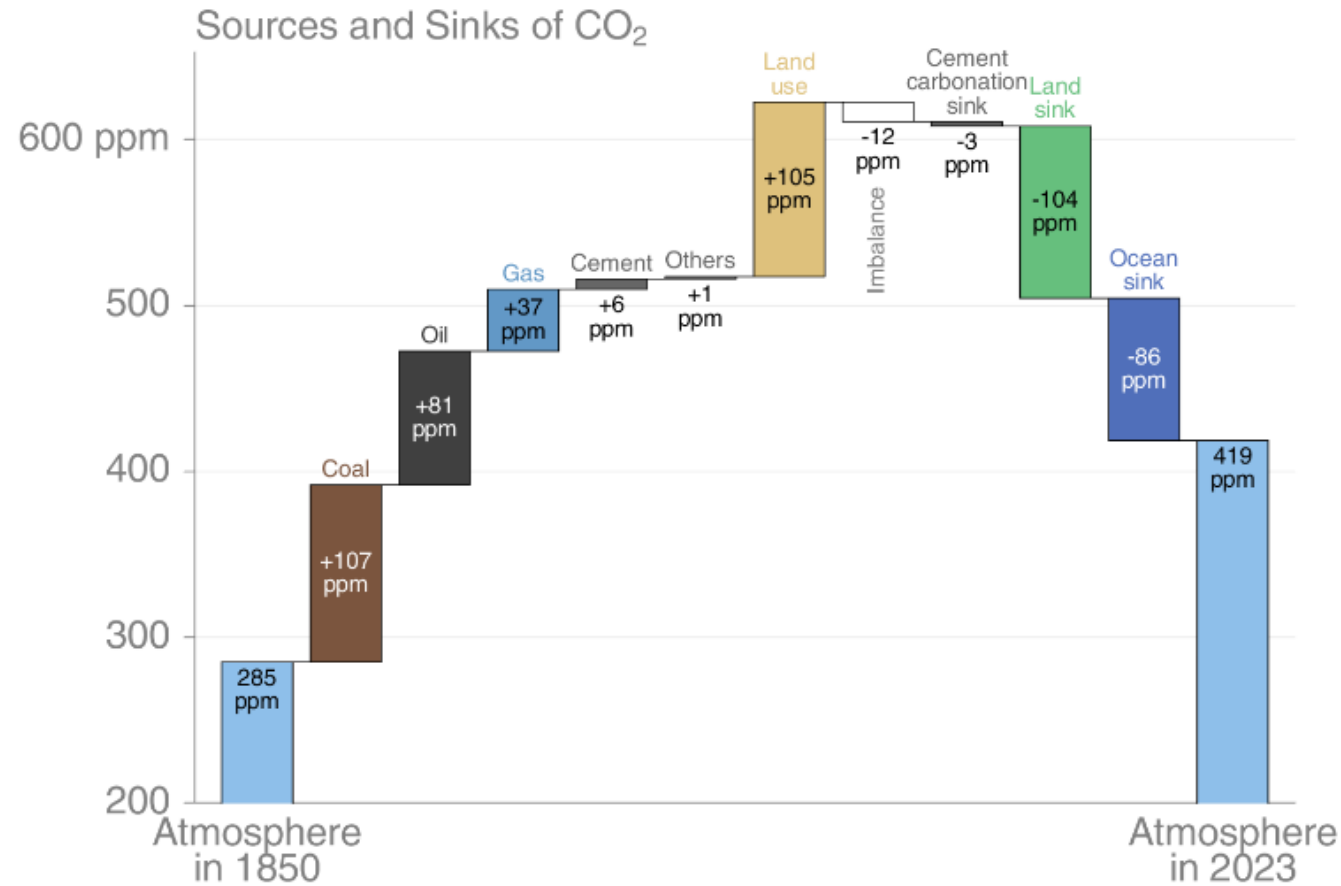


Combined components of the Global Carbon Budget as a function of time, for fossil CO₂ emissions (E_{FOS} , including a small sink from cement carbonation) and emissions from land-use change (E_{LUC}), as well as their partitioning among the atmosphere (G_{ATM}), ocean (S_{OCEAN}), and land (S_{LAND})



Global Gross Carbon Emissions are partly absorbed by the environment. Net Carbon Emissions remaining in the atmosphere increase its CO₂ content

The cumulative contributions to the global carbon budget from 1850
The carbon imbalance represents the gap in our current understanding of sources & sinks



© Global Carbon Project



Carbon Stocks and Flux Earth/Atmosphere

Basic figures current period 2020 – 1ppm # 8GtCO₂

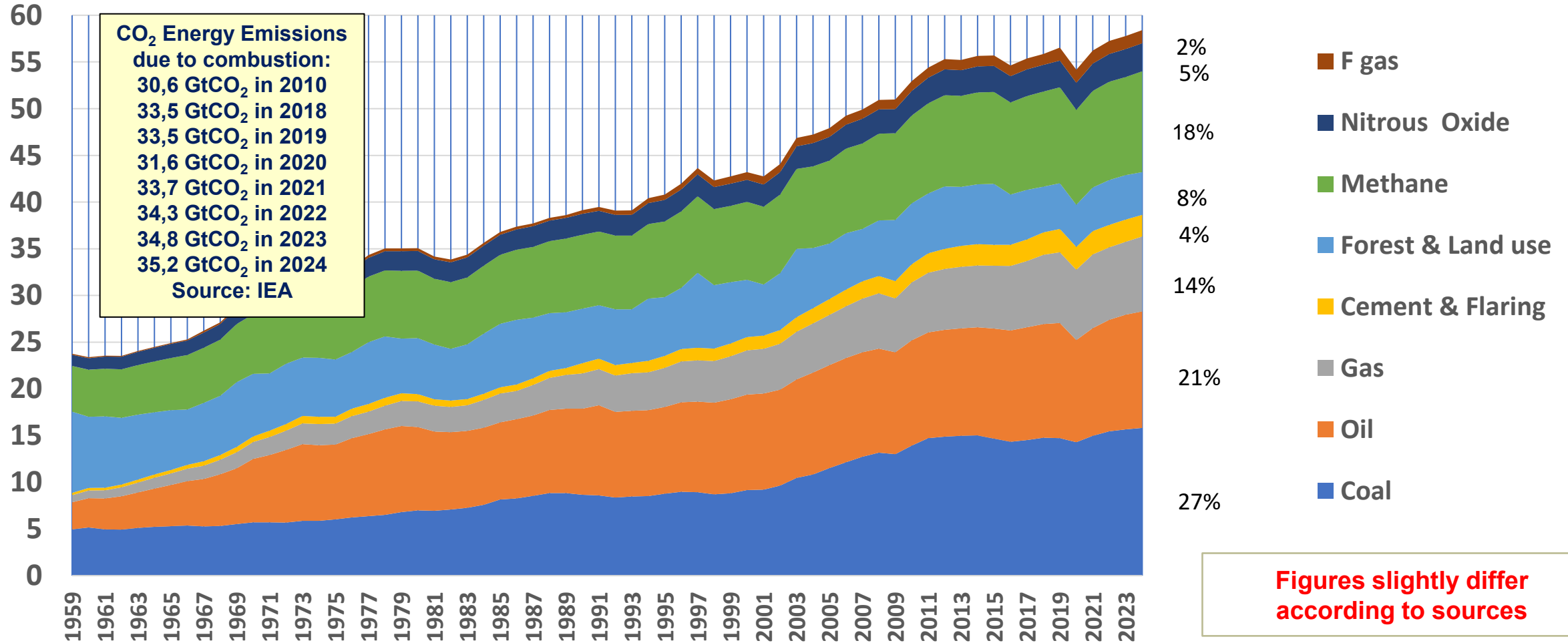
Data	Volumes/Mass
Volume Earth + Atmosphere	1,08737x10 ¹² k.m ³
Volume Earth	1,08330x10 ¹² k.m ³
Volume Atmosphere	4,05x10 ⁹ k.m ³
Mass Atmosphere	5,15x10 ¹⁸ kg
CO ₂ Energy content: # 400 ppm	1,62x10 ⁶ k.m ³
1 mole C/CO ₂ (22,4l = 22,4 dm ³)	12 g/44 g
Mass Carbone in Atmosphere	# 870 Gt
Mass CO ₂ in Atmosphere	# 3200 Gt
Yearly CO ₂ Emissions	34 Gt
Net yearly Emissions assuming 50% absorption in oceans/biosphere	17 Gt
Potential impact on CO ₂ content	+ 2,1 ppm/year



Global anthropogenic related GHG emissions 1959 - 2024

CO₂ Energy is the most important contributor

(GtCO₂ eq.)



Source: Ch. Guérritte. Data from Global Carbon Project (Global Carbon Budget) , World Bank, IPCC, Our World in Data 2025

Forest & Land Use Includes CH₄ non energy and FOLU (Forest and Other Land Use)

1997-1998: El Nino & uncontrolled burning of tropical forests

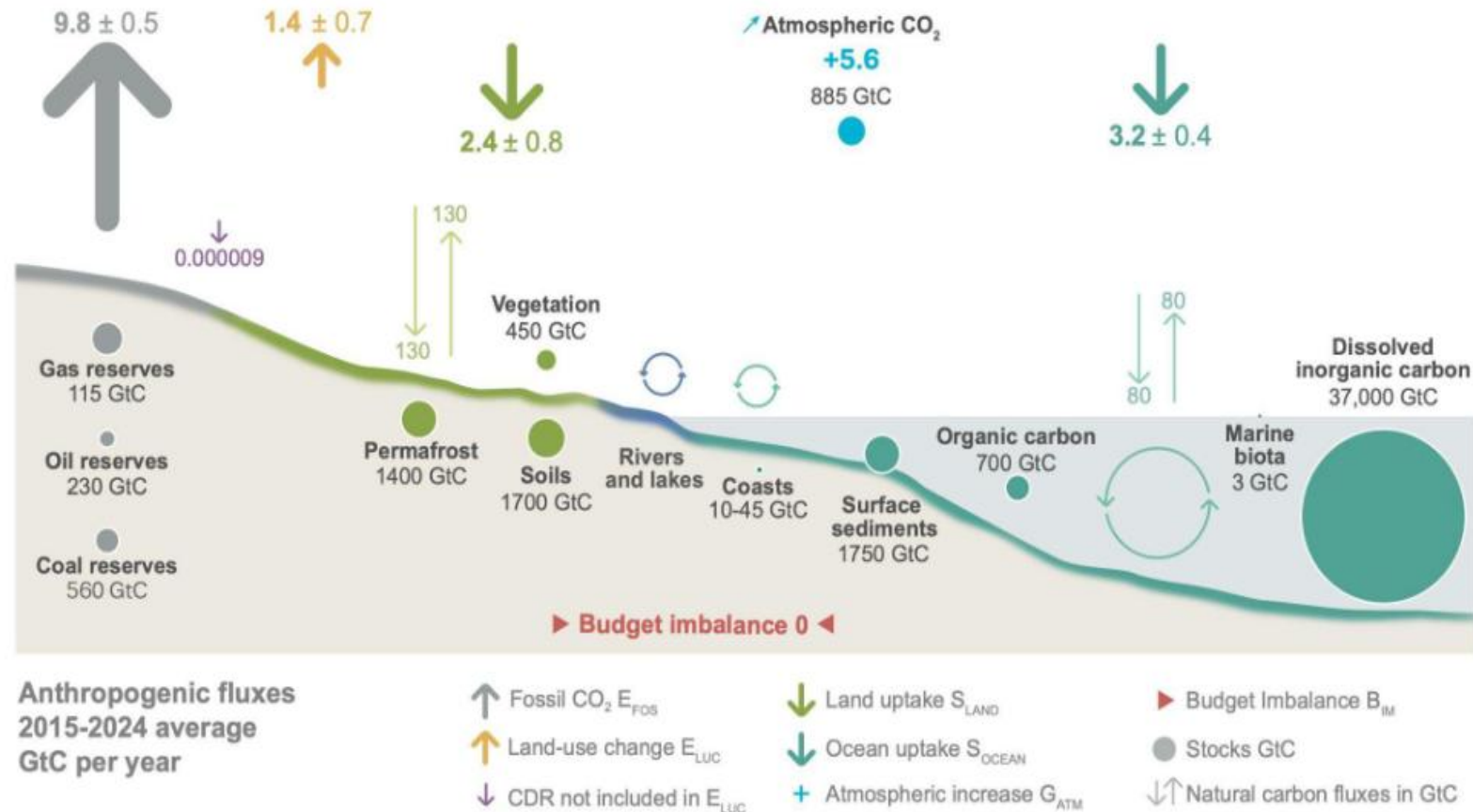
2020: Covid-19 – F gas: Fluorinated greenhouse gas



The Global Carbon Cycle (GtC)

Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2015-2024

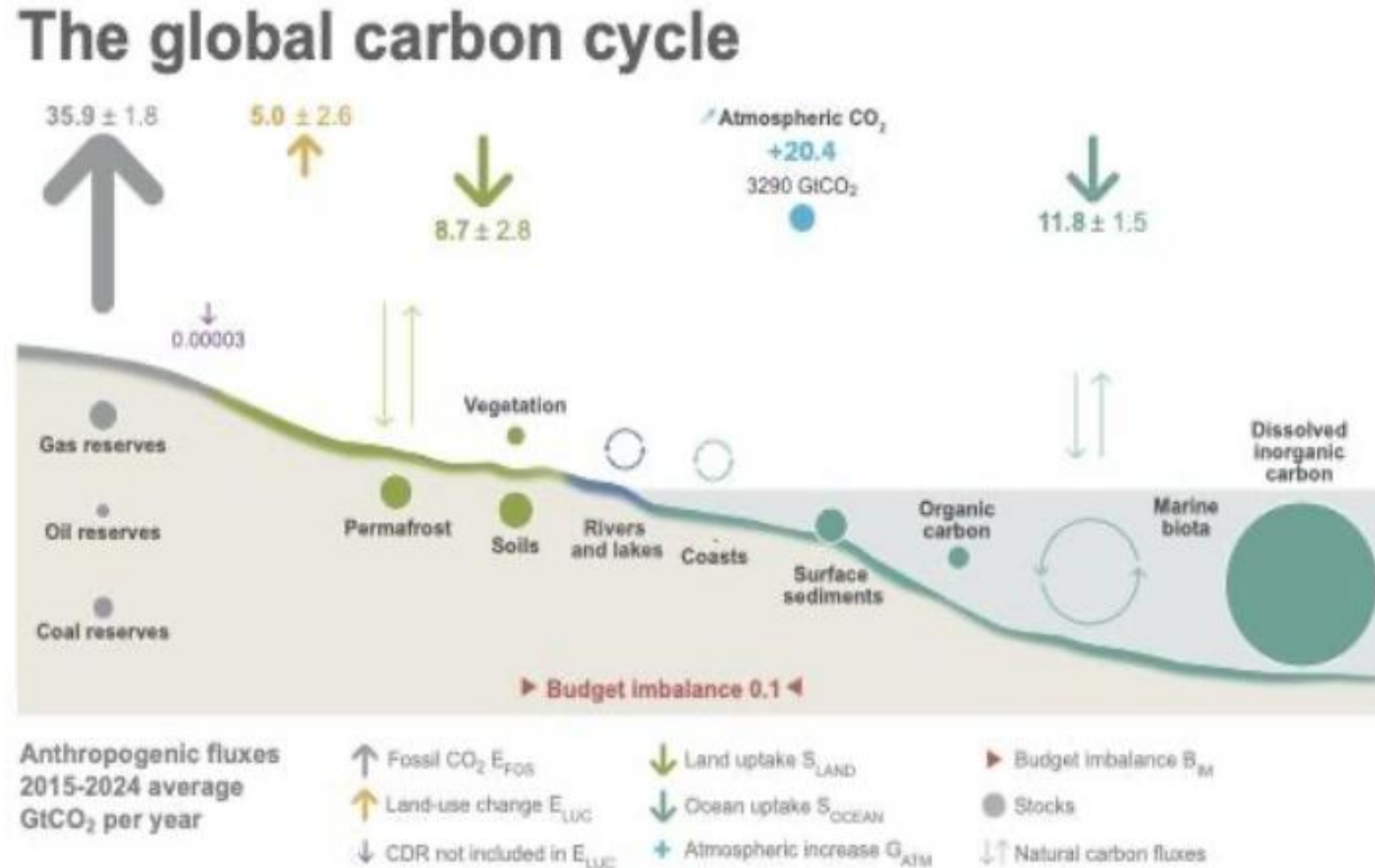
The global carbon cycle



Source: Global Carbon Project 2025

The Global Carbon Cycle (GtCO₂)

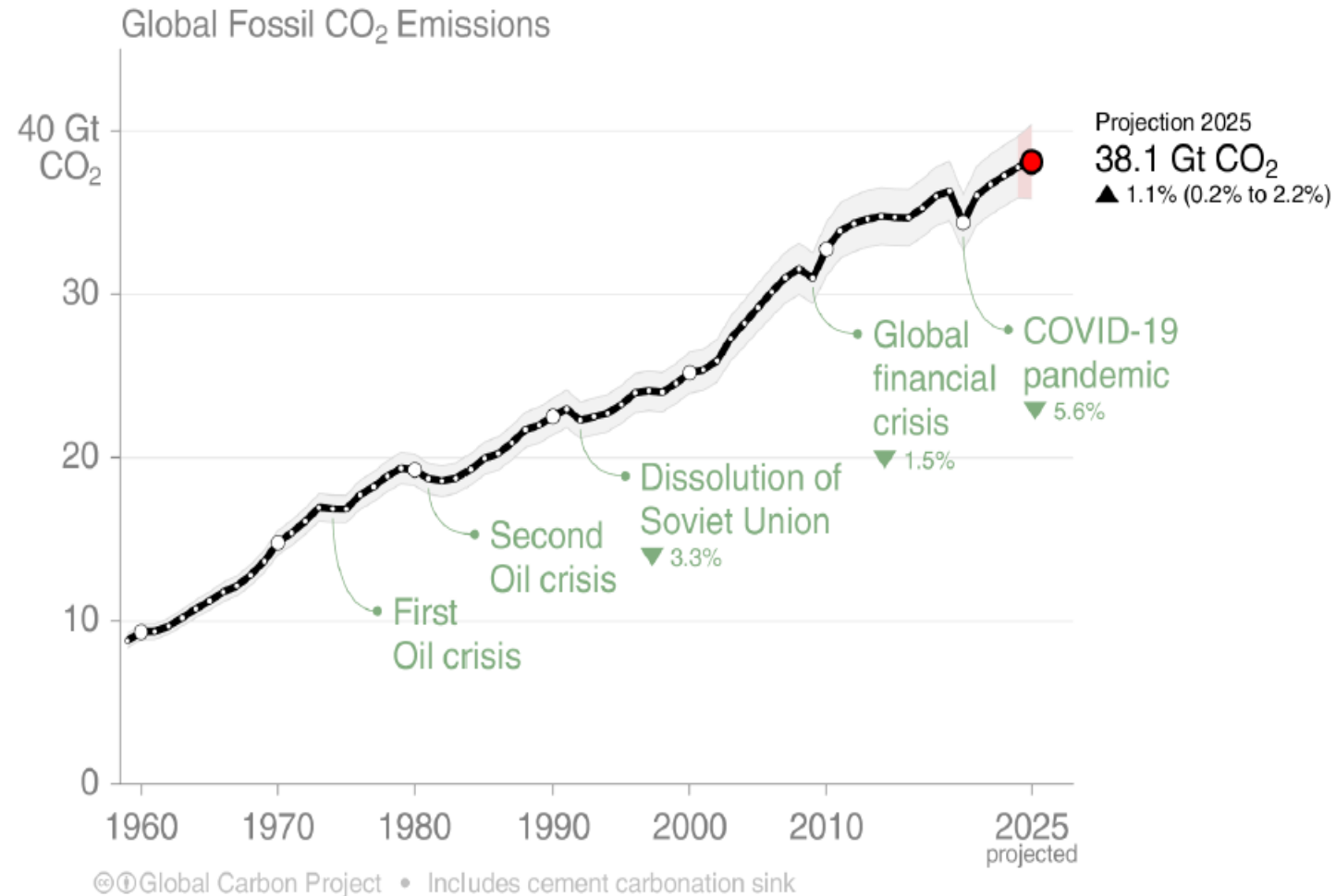
Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2015-2024



Source: Global Carbon Project 2025

Fossil CO₂ Emissions (GtCO₂)

Global fossil CO₂ emissions have risen steadily over the last decades. Emissions are set to grow 1.1% in 2025, after growing 1.1% in 2024, and 0.8%/yr from 2015 to 2024.



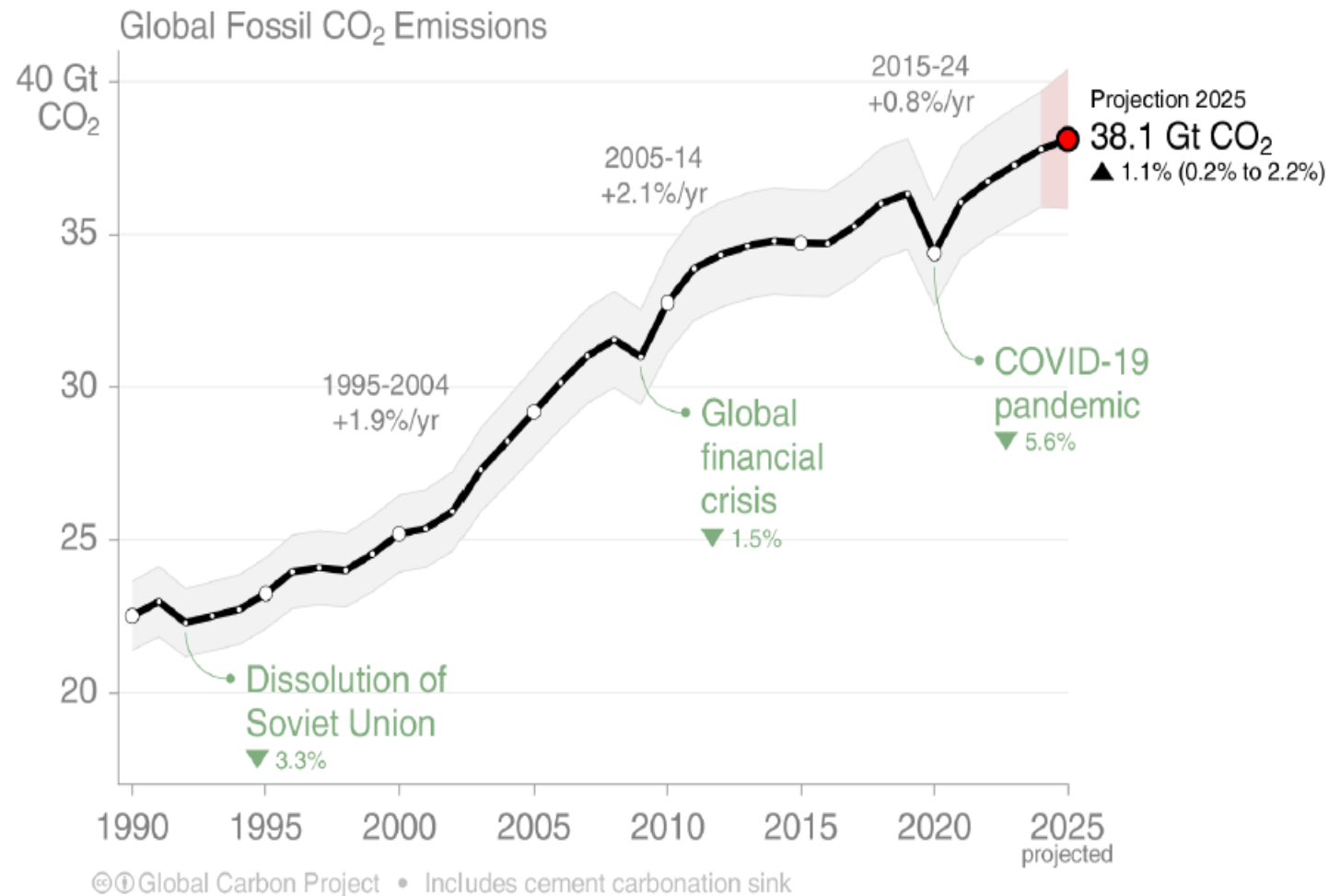
Source: Global Carbon Project 2025



Fossil CO₂ Emissions (GtCO₂)

Global fossil CO₂ emissions: 37.8 ± 2 GtCO₂ in 2024, 69% over 1990

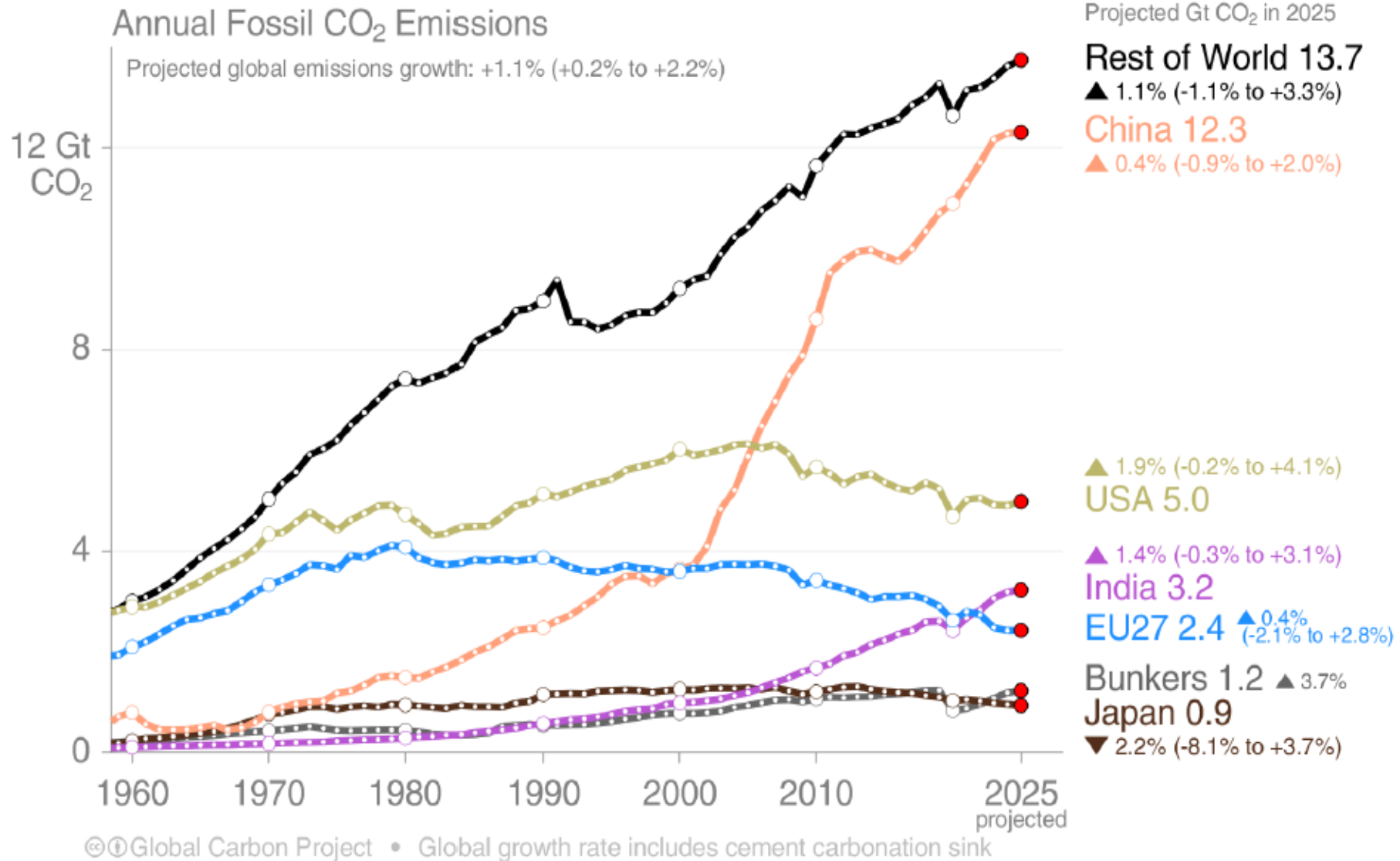
- Projection for 2025: 38.1 ± 2 GtCO₂, 1.1% [0.2% to +2.2%] higher than 2024



Uncertainty is ±5% for one standard deviation (IPCC “likely” range)

Source: Global Carbon Project 2025

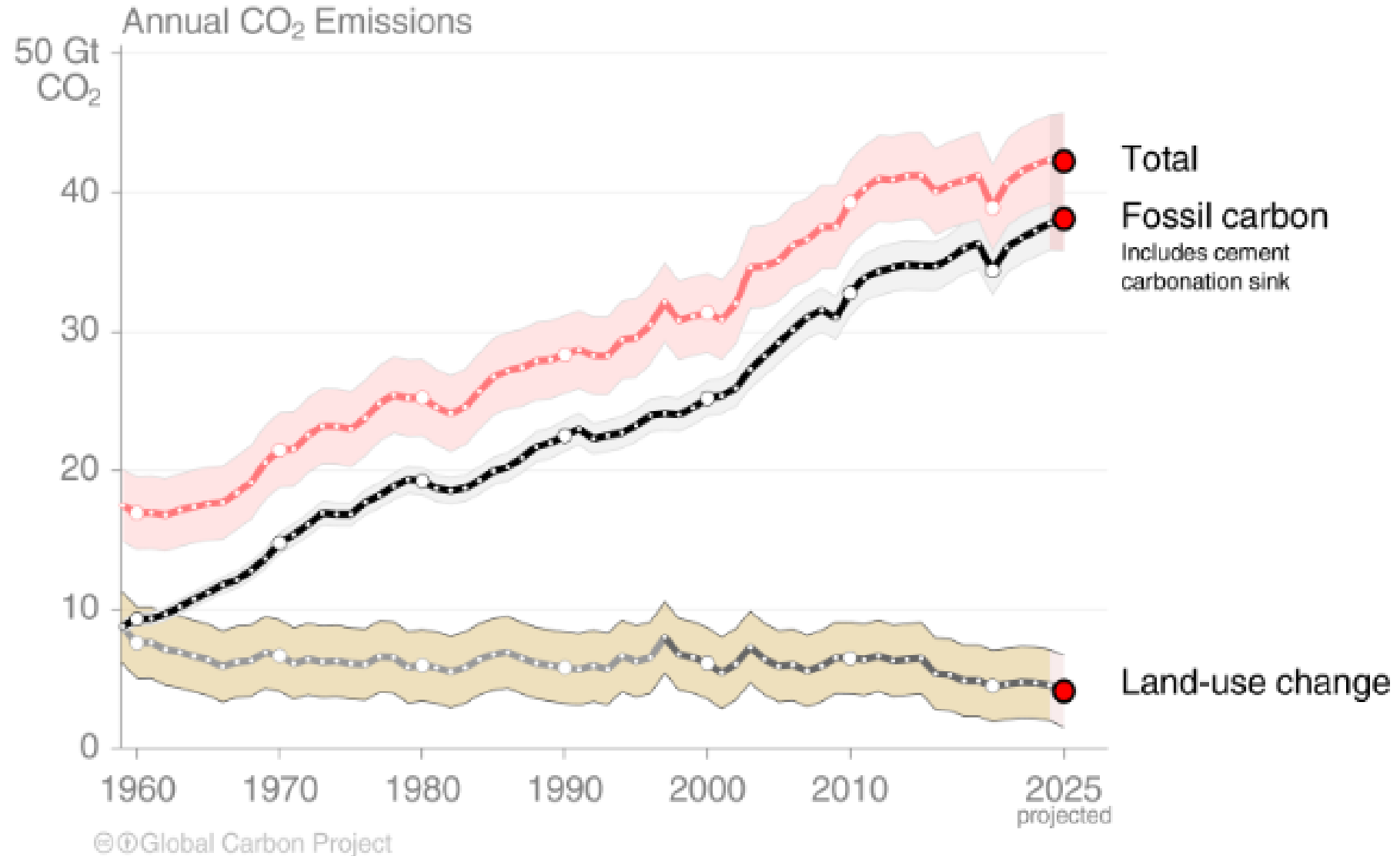
Fossil CO₂ Emissions (GtCO₂)



Source: Global Carbon Project 2025



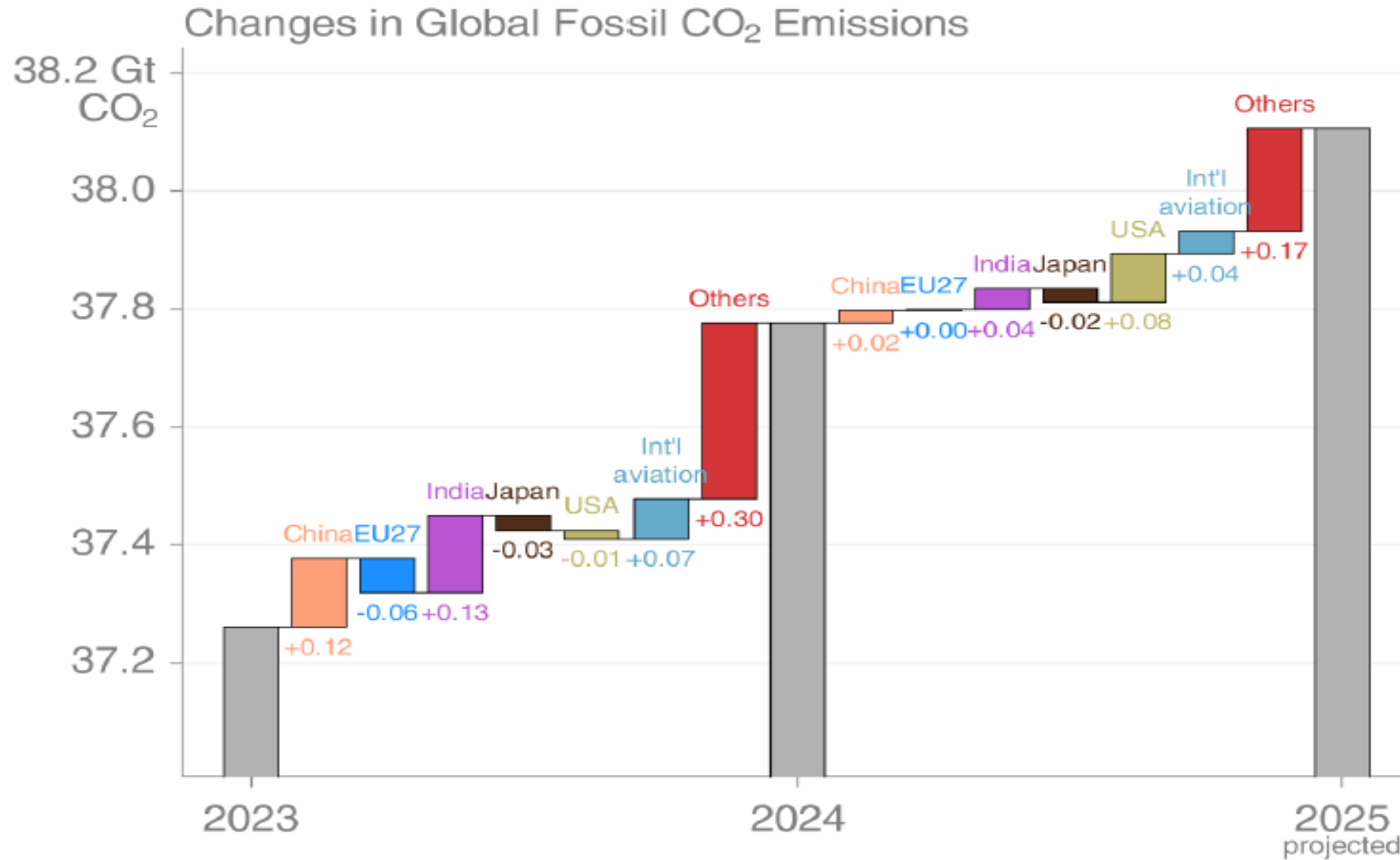
Fossil CO₂ Emissions (GtCO₂)



Source: Global Carbon Project 2025



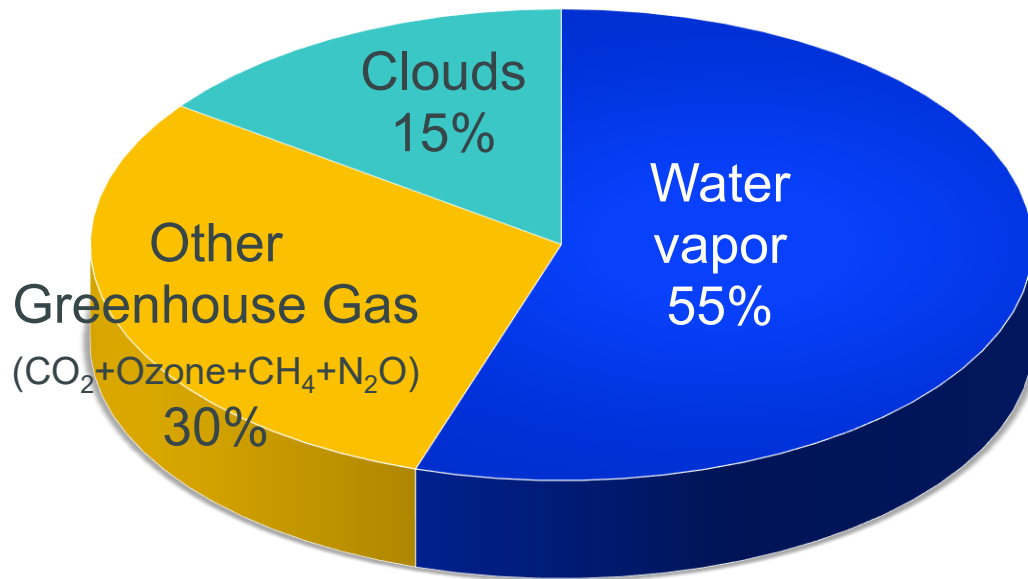
Fossil CO₂ Emissions (GtCO₂)



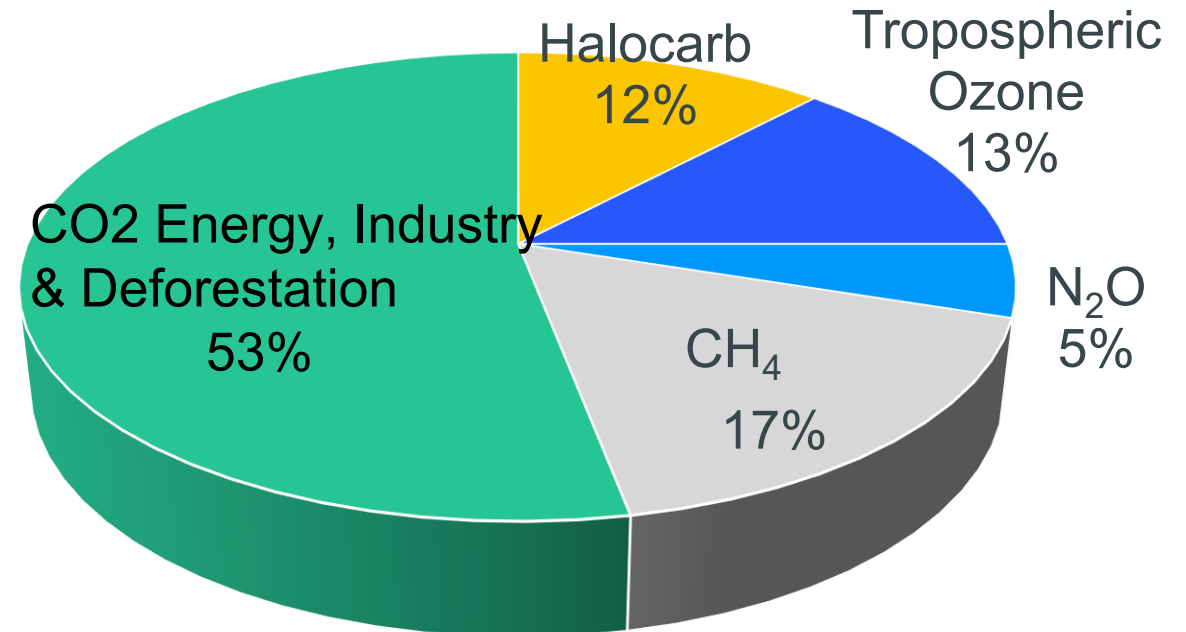
Source: Global Carbon Project 2025



Atmospheric contributions to greenhouse effect Radiative Forcing (**2,8 W/m²** from human activity) - Period 1750-2000



Natural 155 W/m² *



Anthropogenic 2.8 W/m² **

** including a negative (= cooling) feedback from aerosols of ~ 1,1 W/m²

• Figures & percentages can slightly change upon time or sources.

Halocarbons: chlorofluorocarbons + hydrochlorofluorocarbons. Halocarbons absorb infra red radiations.

Stratospheric Ozone has no direct emissions

Source: Data from IPCC 2001 & 2005



Basic simple elements to keep in mind



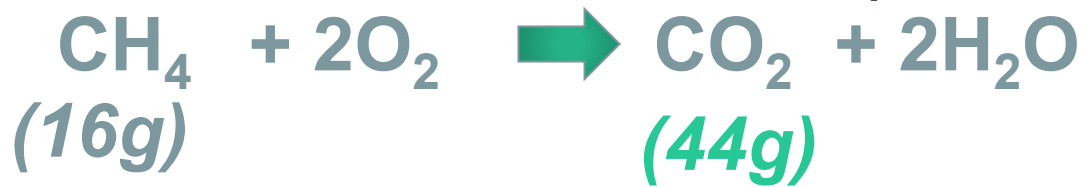
CO₂ Emissions vs type of Fuels

Simple chemical formulas

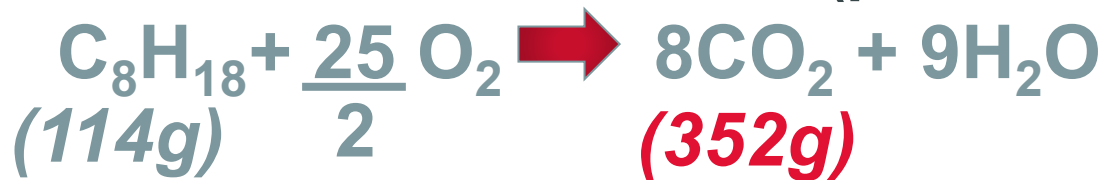
Combustion of carbon



Combustion of methane (natural gas)



Combustion of alkanes (petroleum product)



Those equations are applicable to simple molecules. In the real world, coal, natural gas and petroleum products contain different impurities, present variable qualities depending upon countries and usages. Therefore numbers can vary upwards and downwards.

CO₂/t



x 3,67



x 2,75



x 3,09 **Fossil Energy**

combustion of 1t of fossil
generates between
2,7 and 3,7 t of CO₂



CO₂ Emissions vs type of Fuels Combustion – Real figures 2024

➤ Combustion of **Coal**

178 EJ # 5,9 Gtce # 4,2 Gtoe ➡ 15,7 GtCO₂

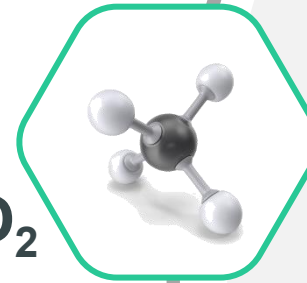


tCO₂/t_{Fossil}

x 2,7 tCO₂/tce
x 3,7 tCO₂/toe

➤ Combustion of **Natural Gas**

148 EJ # 4,2 T.m³ # 3,5 Gtoe ➡ 7,8 GtCO₂



x 2,2 tCO₂/toe

➤ Combustion of **Oil**

193 EJ # 92 Mboe/d # 4,6 Gtoe ➡ 11,5 GtCO₂



x 2,5 tCO₂/toe

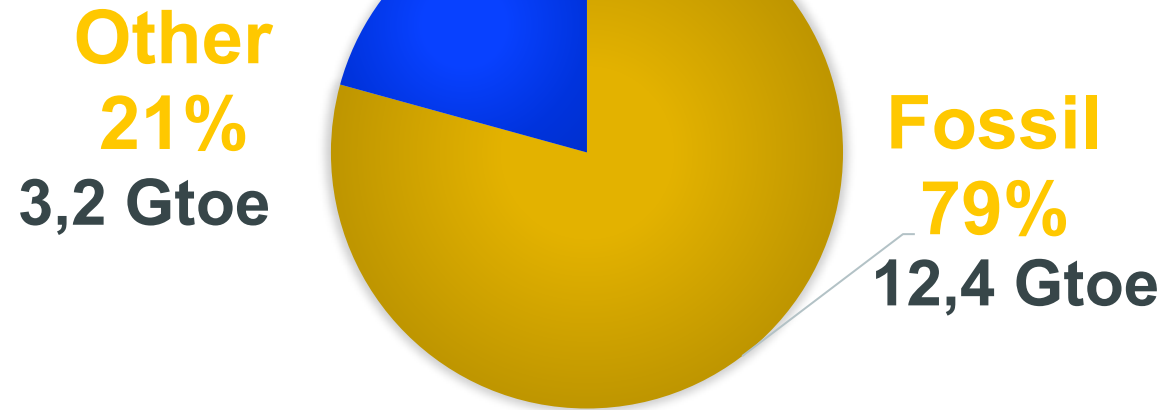
Data from IEA WEO 2025
tce : tonne of coal equivalent
toe : tonne of oil equivalent
1 TJ = 10¹² J = 23,88 toe



CO₂ Emissions VS type of Fuels

Simple chemical formulas

World 2024 Primary Energy Consumption:
15,6 Gtoe



World 2024 CO₂ Energy Emissions

≈ 35,2 Gt → 2,84 tCO₂/t_{fossil}

tCO₂/t_{Fossil}

Carbon
x 3,67



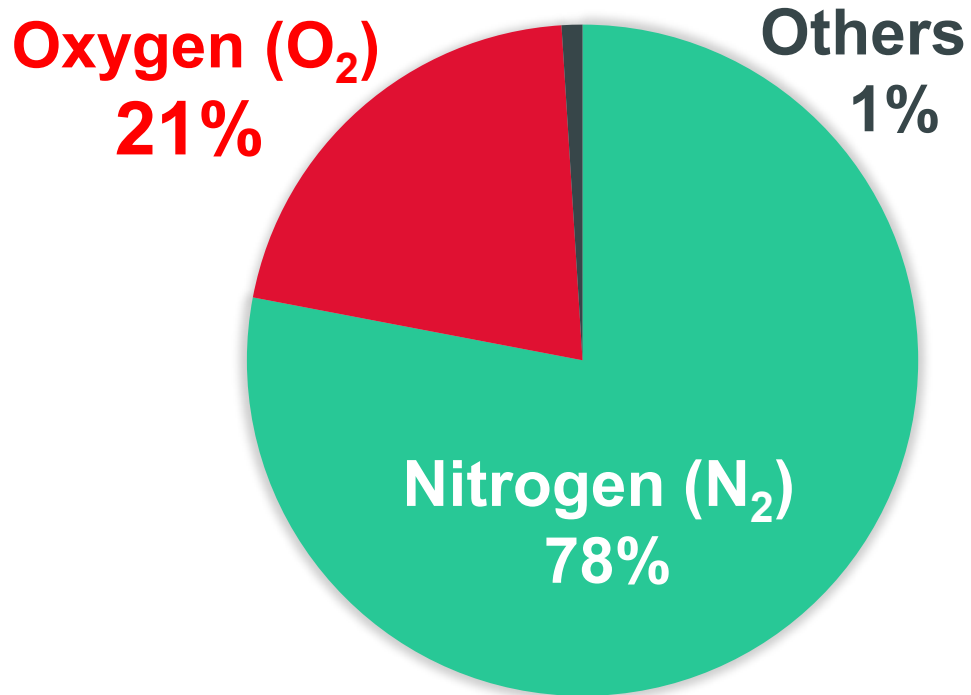
Methane
x 2,75



Alcanes
x 3,09



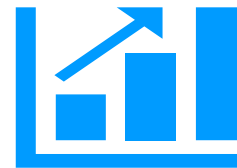
Reminder - Composition of Atmosphere



Argon : 0,9%
Carbon Dioxide (CO₂) : 0,04% (400 ppm)



CO₂ concentration



280 ppm in 1750

432 ppm in May 2026 (+54%)
(Mauna Loa Observatory - Hawai'i)

CO₂ Concentration is increasing after a slight decrease in 2020 due to the Covid 19.

A minor variation of CO₂ content in the atmosphere has important consequences in term of greenhouse effect.



Carbon Footprint vs CO₂ Emissions

A **Carbon Footprint** is the total Greenhouse Gas (GHG) emissions caused directly and indirectly by an individual, event, organization, service, site or product, expressed as CO₂eq.

Greenhouse gases, including the carbon-containing gases Carbon Dioxide (CO₂) and Methane (CH₄), can be emitted through the burning of fossil fuels, land clearance and the **Production and Consumption** of food, manufactured goods, materials, wood, roads, buildings, transportation and other services.

It includes:

- **Direct Carbon/CO₂ Emissions** coming from sources that are directly from the site which is producing a product or delivering a service.
- **Indirect Carbon Emissions** coming from external sources and consumed by the concerned individual, company, organization or site.

It is also represented by the quantities of Consumption – based CO₂ emissions and equal to:
National emissions – emissions embedded in exports + emissions embedded in imports.



Carbon Footprint vs CO₂ Emissions (excludes other GHG)

International comparison – Year 2023

Carbon Footprint (Consumption based) = Production based emissions minus emissions embedded in exports plus emissions embedded in imports
Worldwide, Net Exports balance Net Imports. Includes combustion activities & industrial processes.

Countries	Carbon Footprint (Consumption based) (CO ₂ /capita)	CO ₂ Emissions (Production based) (CO ₂ /capita)
Australia	14,1	14,5
Canada	13,2	13,9
China	7,6	8,6
EU 27	7,3	5,5
France*	6,1	4,1
Germany	9,1	7,0
India	1,8	2,1
Japan	9,2	7,9
Luxembourg	11,0	10,3
Qatar	27,6	40,1
US	15,8	14,3
World	4,4	4,4



Various anthropogenic effects

- **Various effects: CO₂ Energy is the most important. According to different sources, life time of CO₂ in the atmosphere is between 30 and 100 years.**
- **Other contributors: CO₂ other industrial processes (cement manufacture,...), CH₄, Ozone, N₂O, F-gases (HFC's, PFC's, SF₆,...)**
- **Contribution of land use, land use change and forestry.**
- **In this document, focus is done on CO₂ Energy.**
- **To convert tC into tCO₂, multiply by 3,67**



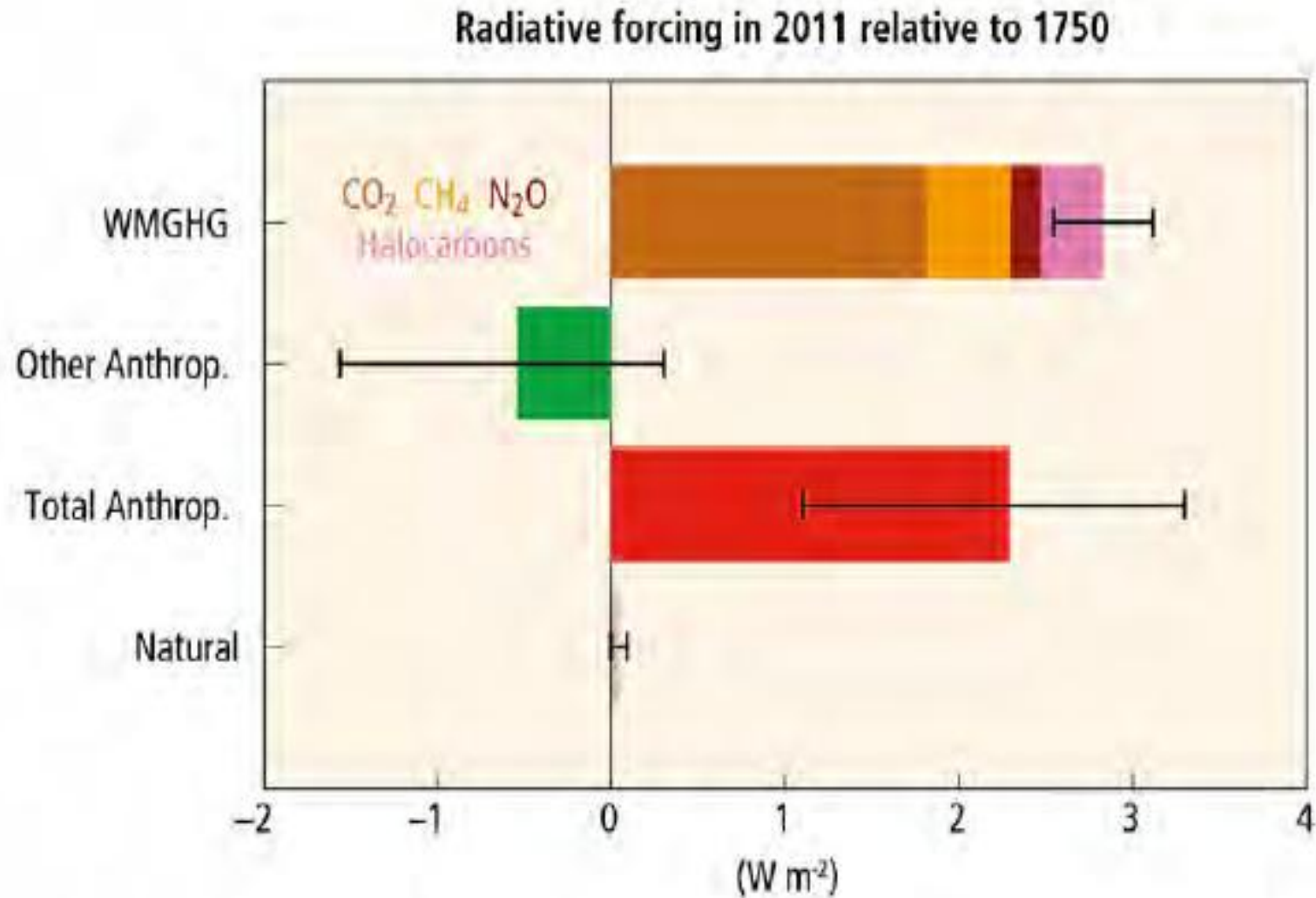
History & Evolution of annual IPCC reports



**The IPCC 5th Assessment Synthesis Report
November 2014 served as a basis for the
COP 21 in Paris (December 2015)**



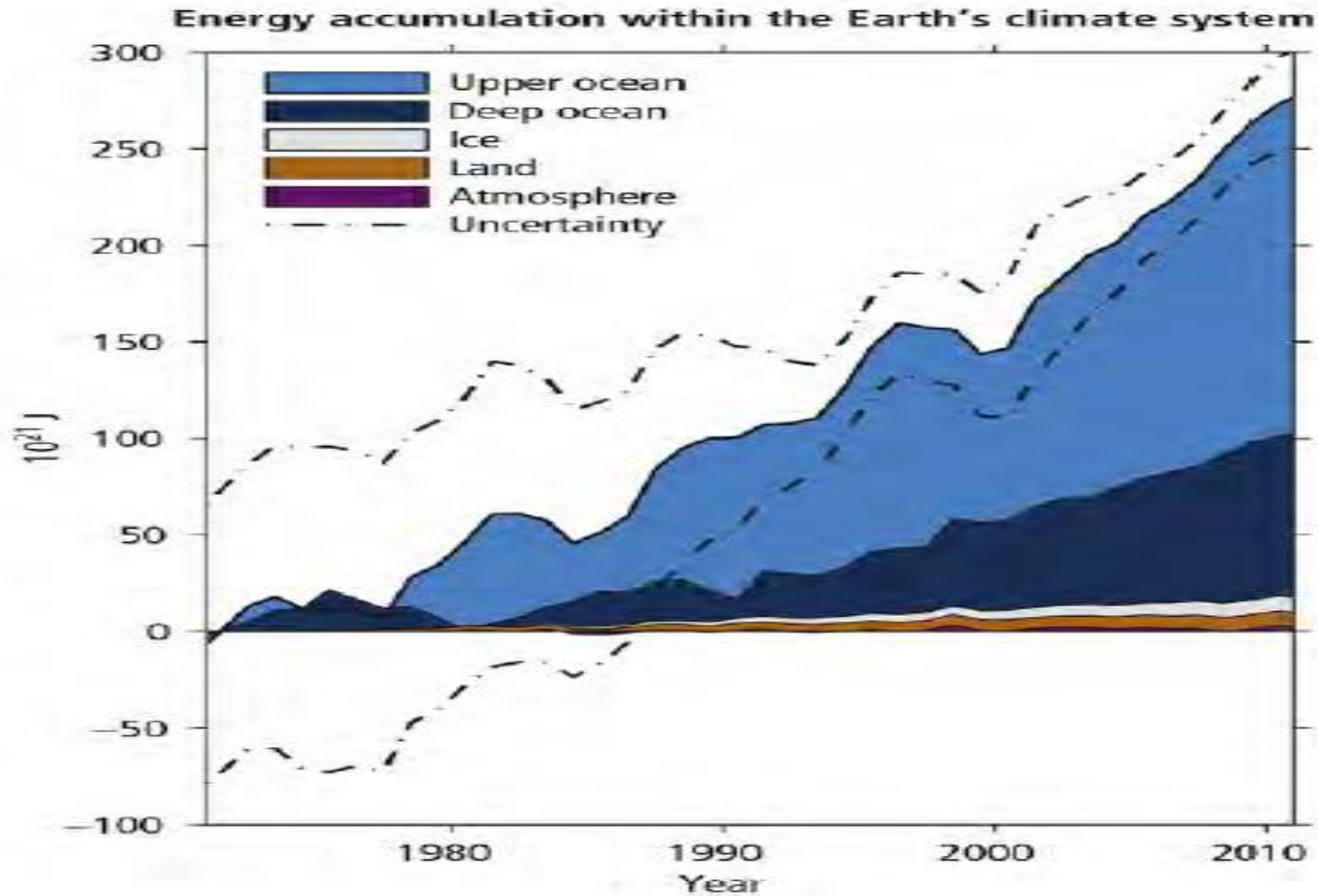
Radiative Forcing is increasing



Source: IPCC 5th Assessment Synthesis Report November 2014



Energy Accumulation on Earth

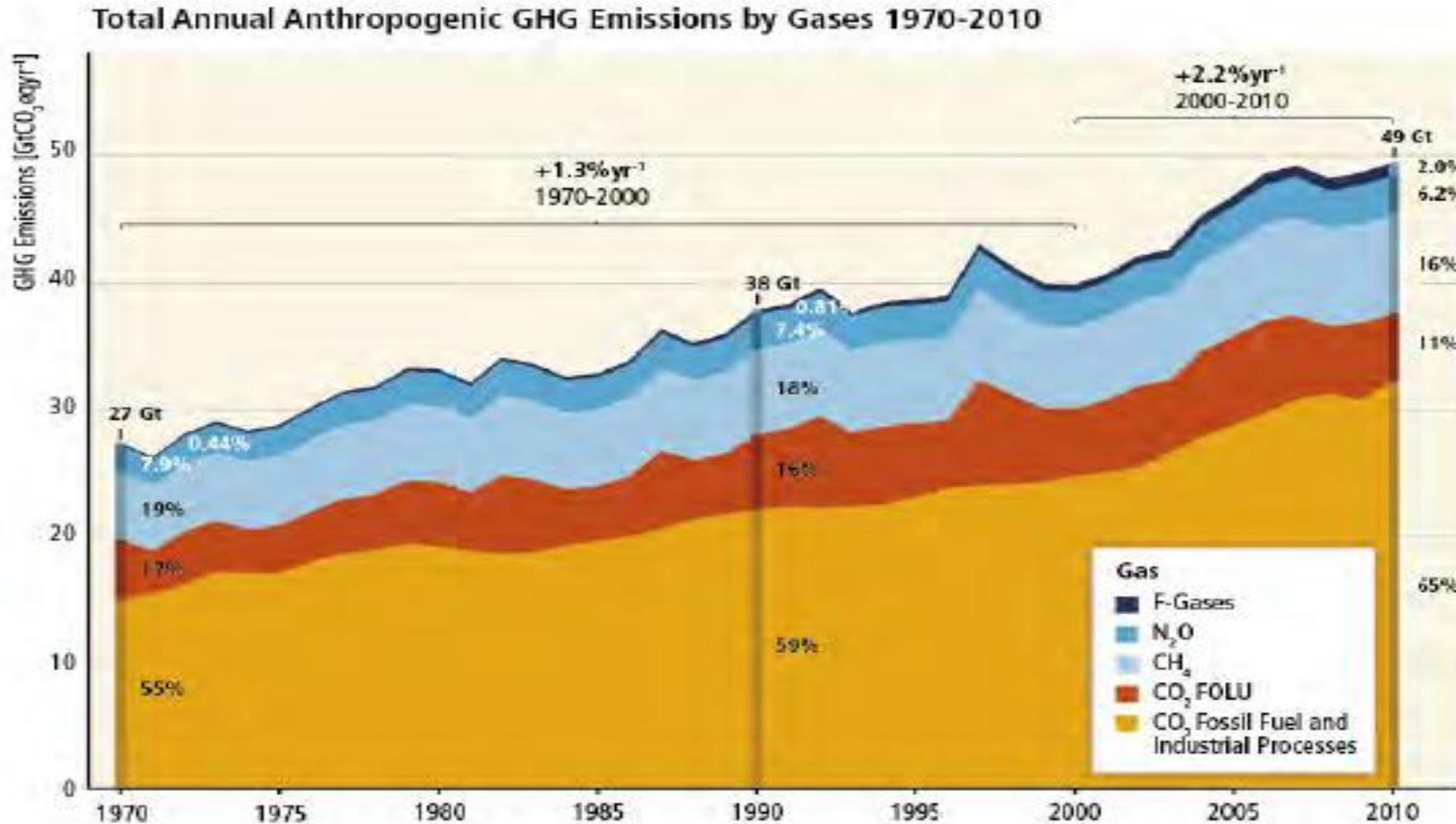


Source: IPCC 5th Assessment Synthesis Report November 2014



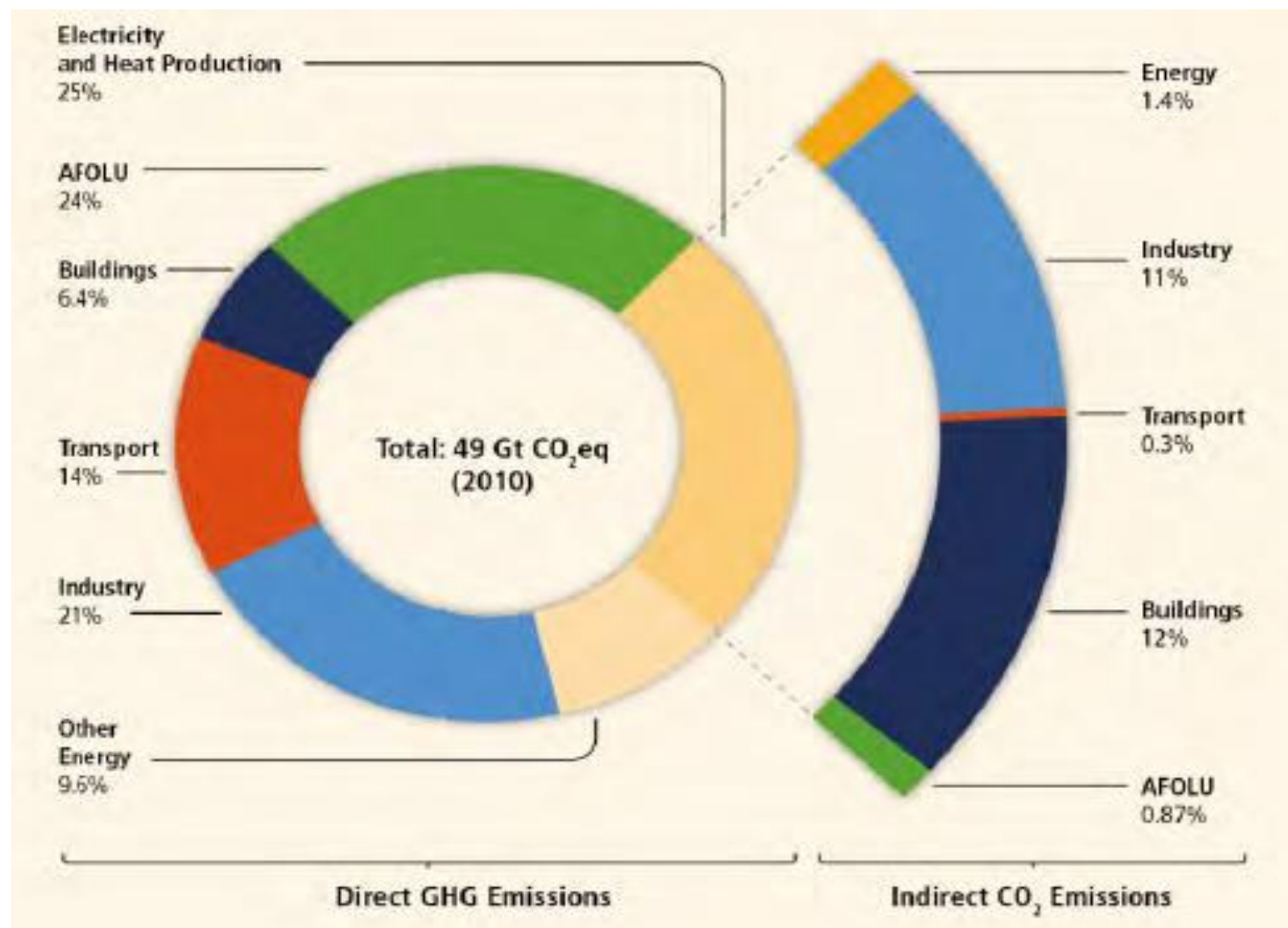
Global Anthropogenic GHG Emissions

CO₂ Energy is the most important contributor



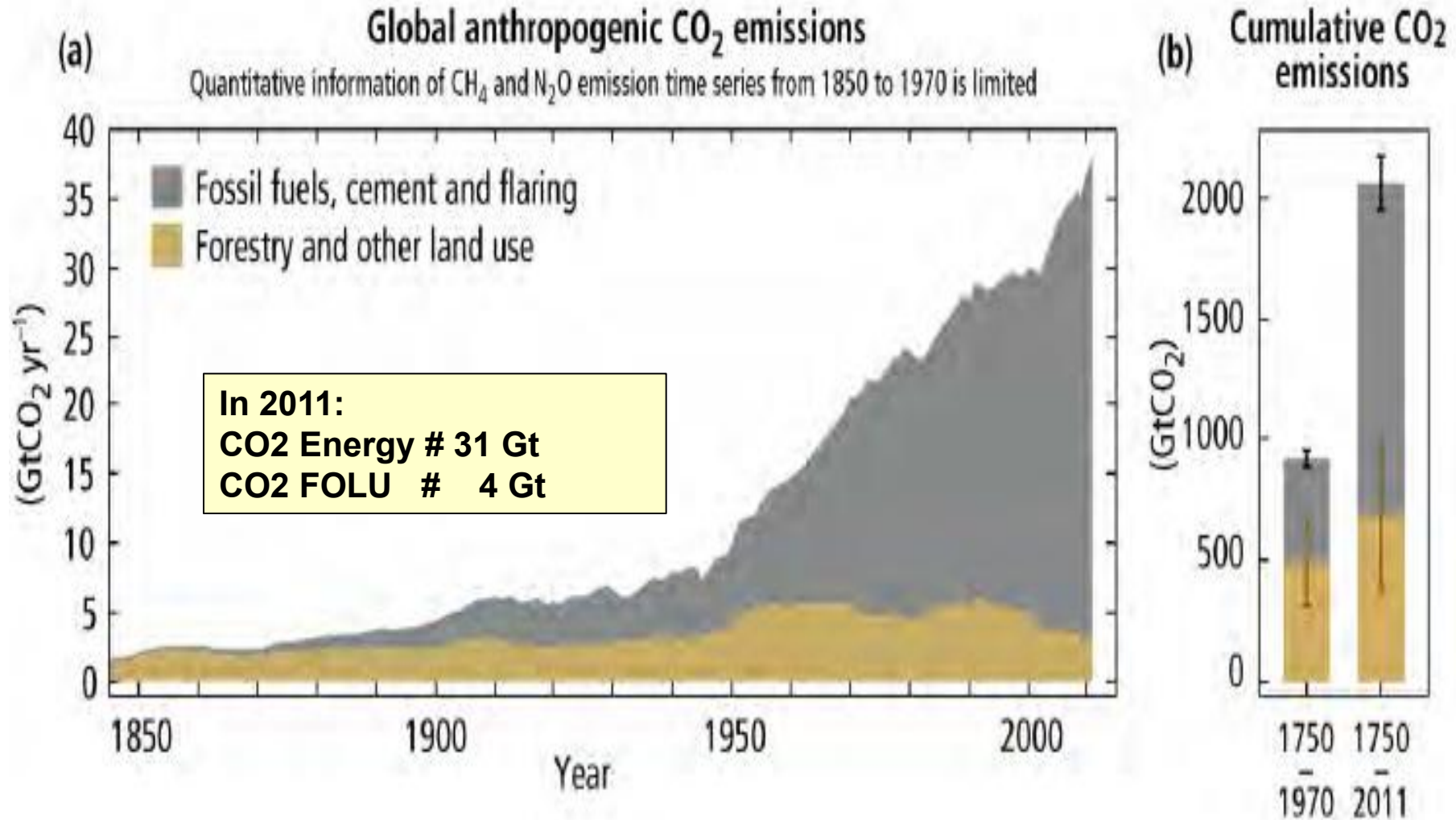
Source: IPCC 5th Assessment Synthesis Report November 2014

GHG Emissions by Sectors in 2010



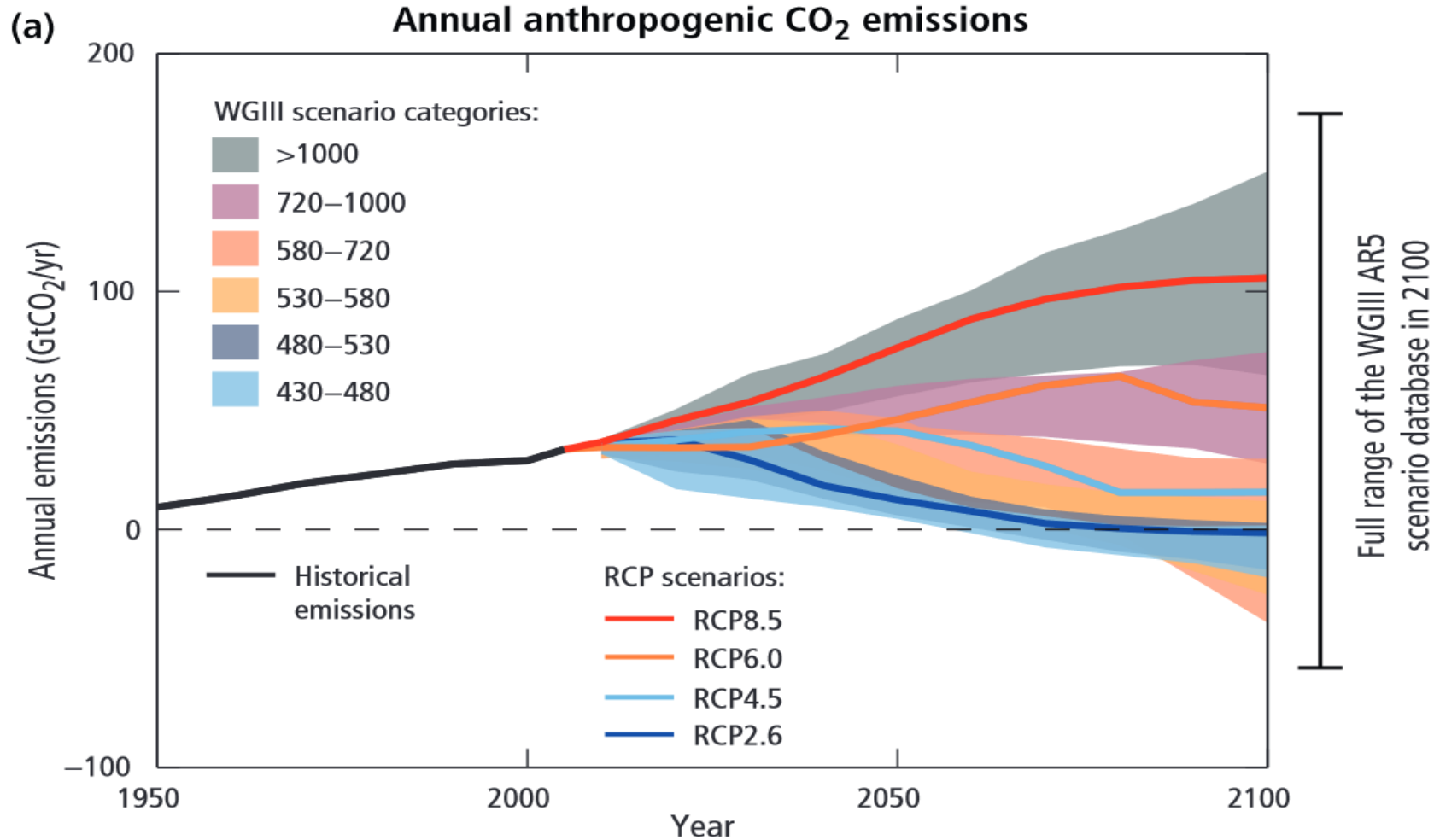
Source: IPCC 5th Assessment Synthesis Report November 2014

Global Anthropogenic CO₂ Emissions



Source: IPCC 5th Assessment Synthesis Report November 2014

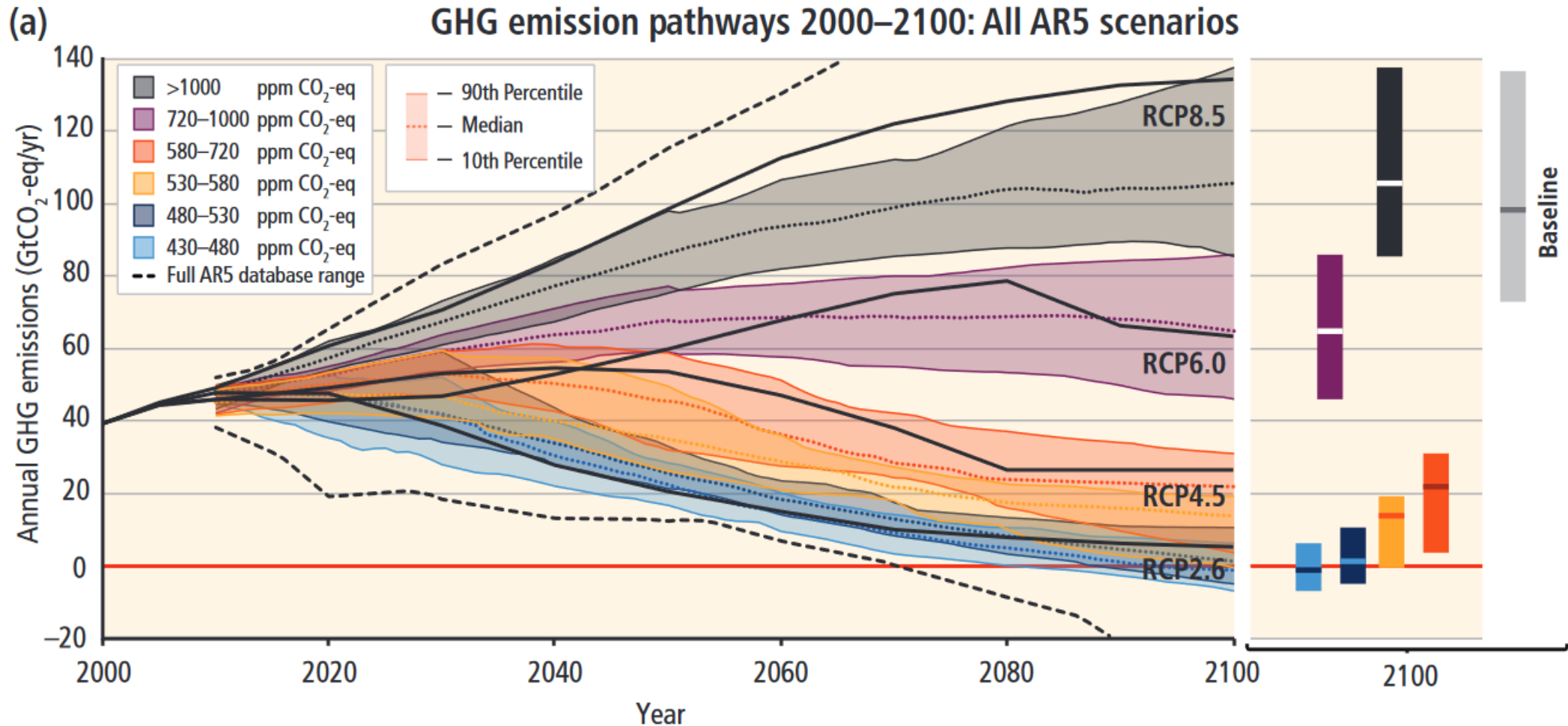
Global Anthropogenic CO₂ Emissions IPCC Projections – ASR 2014



Source: IPCC 5th Assessment Synthesis Report November 2014
RCP: Representative Concentration Pathway (W/m²)



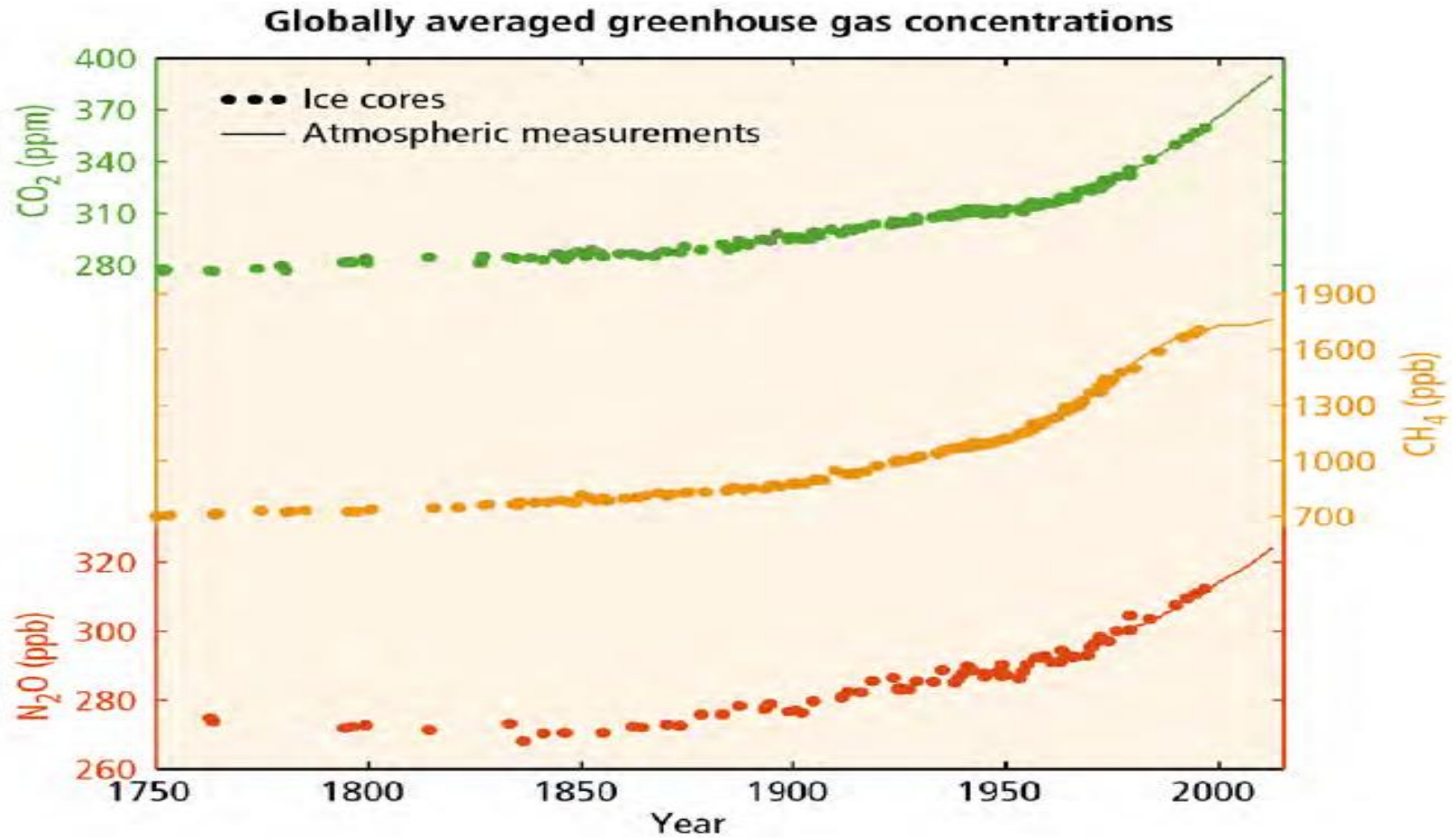
Global Anthropogenic CO₂ Emissions IPCC Projections – ASR 2014



Source: IPCC 5th Assessment Synthesis Report November 2014
RCP: Representative Concentration Pathway (W/m²)



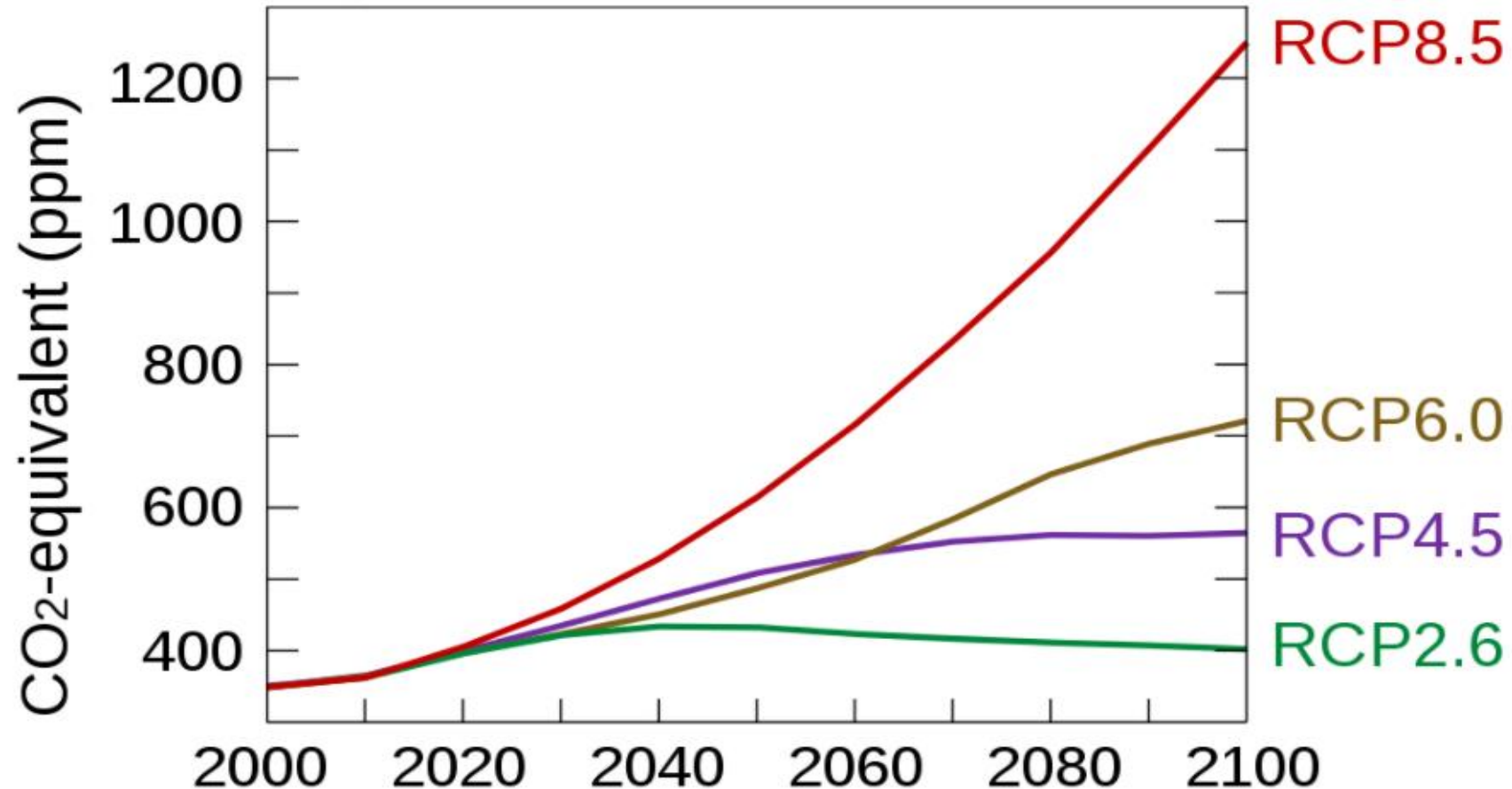
GHG Concentrations



Source: IPCC 5th Assessment Synthesis Report November 2014



Climate Change RCP & Radiative Forcing – IPCC Projections

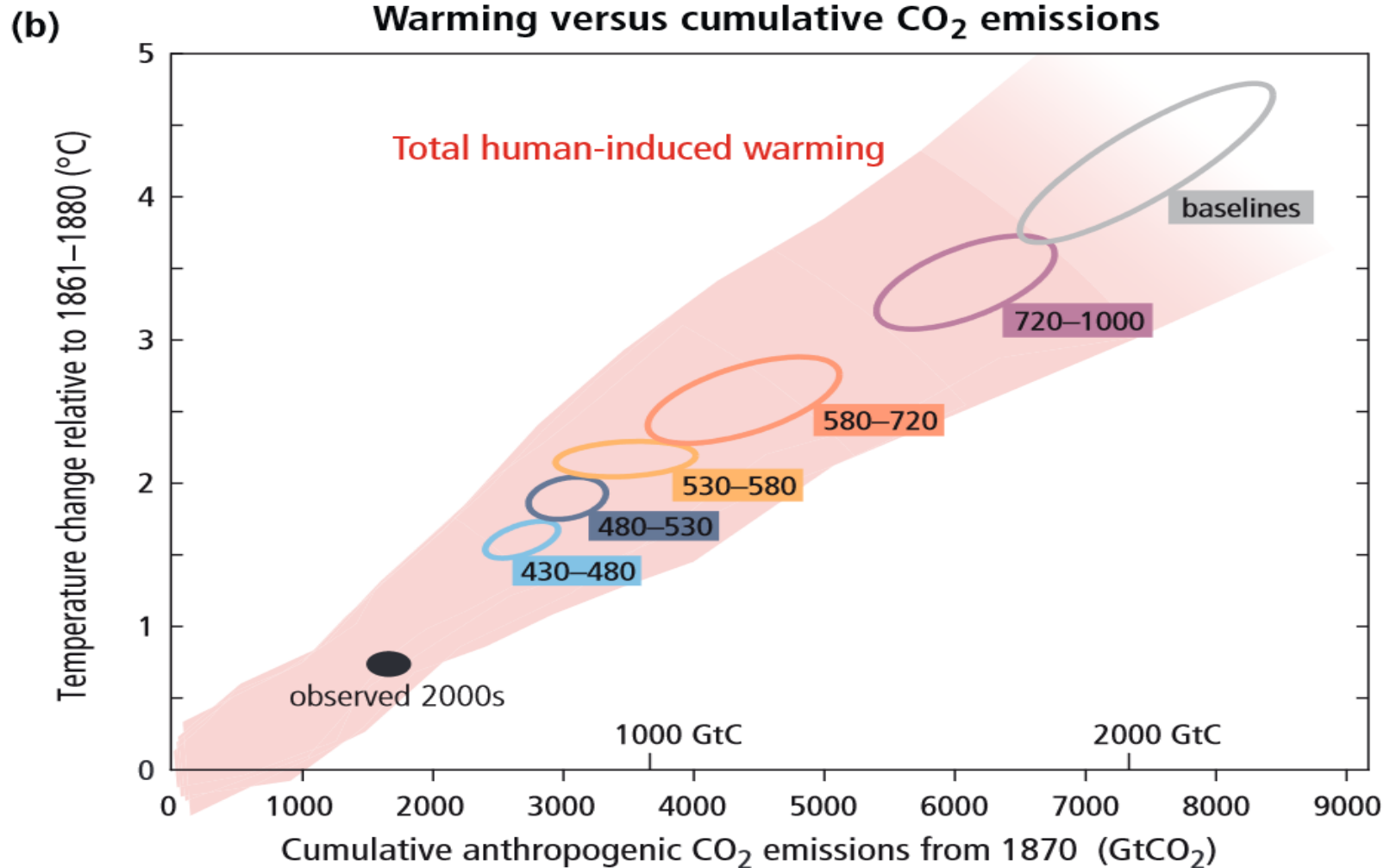


RCP: Representative Concentration Pathway as per Radiative Forcing
due to human activities (W/m²)

Source: IPCC 5th Assessment Synthesis Report November 2014



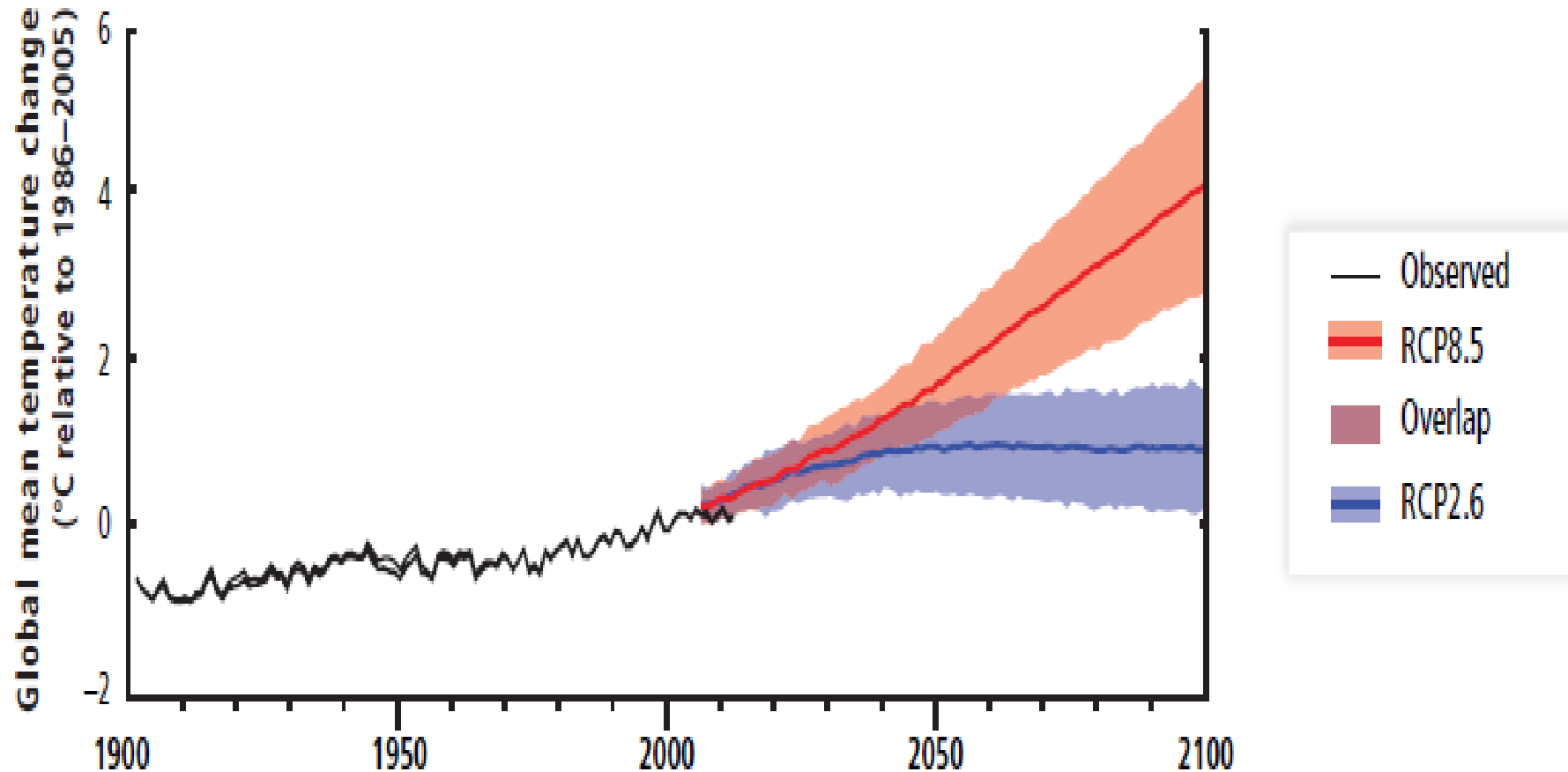
Global Anthropogenic CO₂ Emissions IPCC Projections – ASR 2014



Source: IPCC 5th Assessment Synthesis Report November 2014



Climate Change: the Earth's temperature – IPCC Projections



RCP: Representative Concentration Pathway as per Radiative Forcing
due to human activities (W/m²)

Source: IPCC 5th Assessment Synthesis Report November 2014

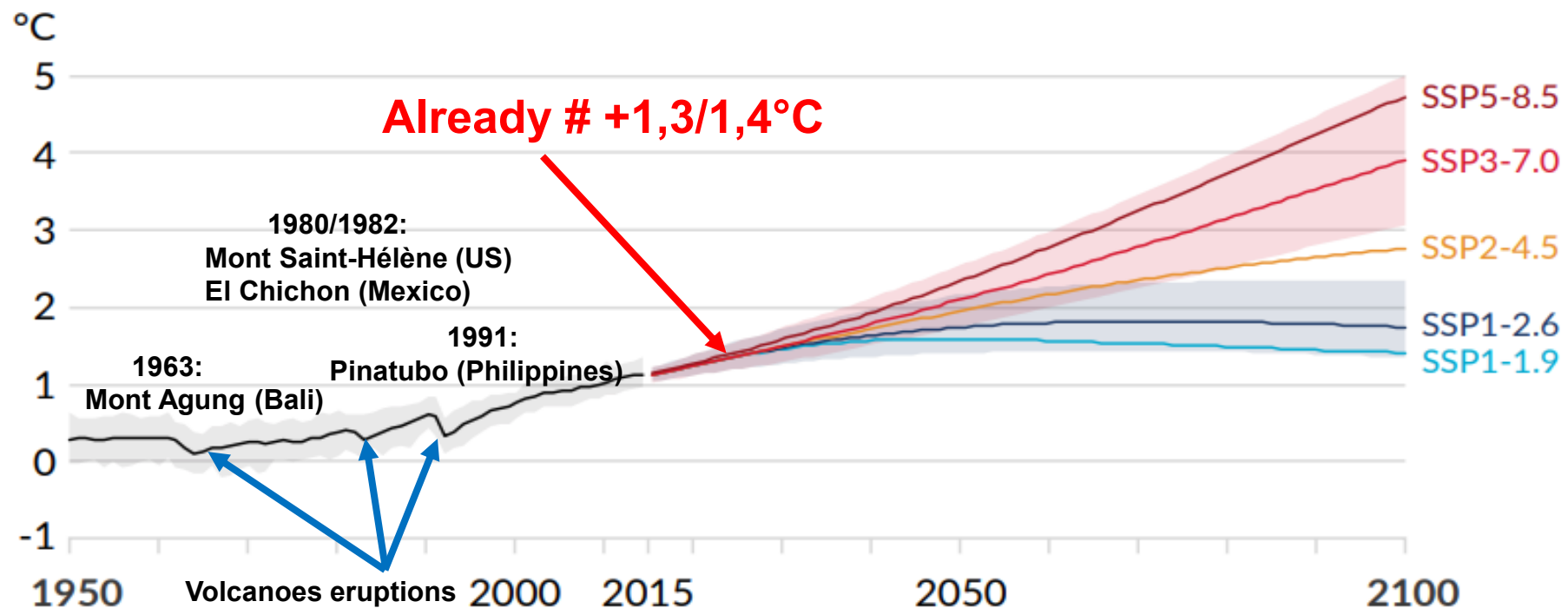


Climate Change

the Earth's temperature – IPCC Projections

Volcanoes eruptions effects : reduction of Radiative Forcing

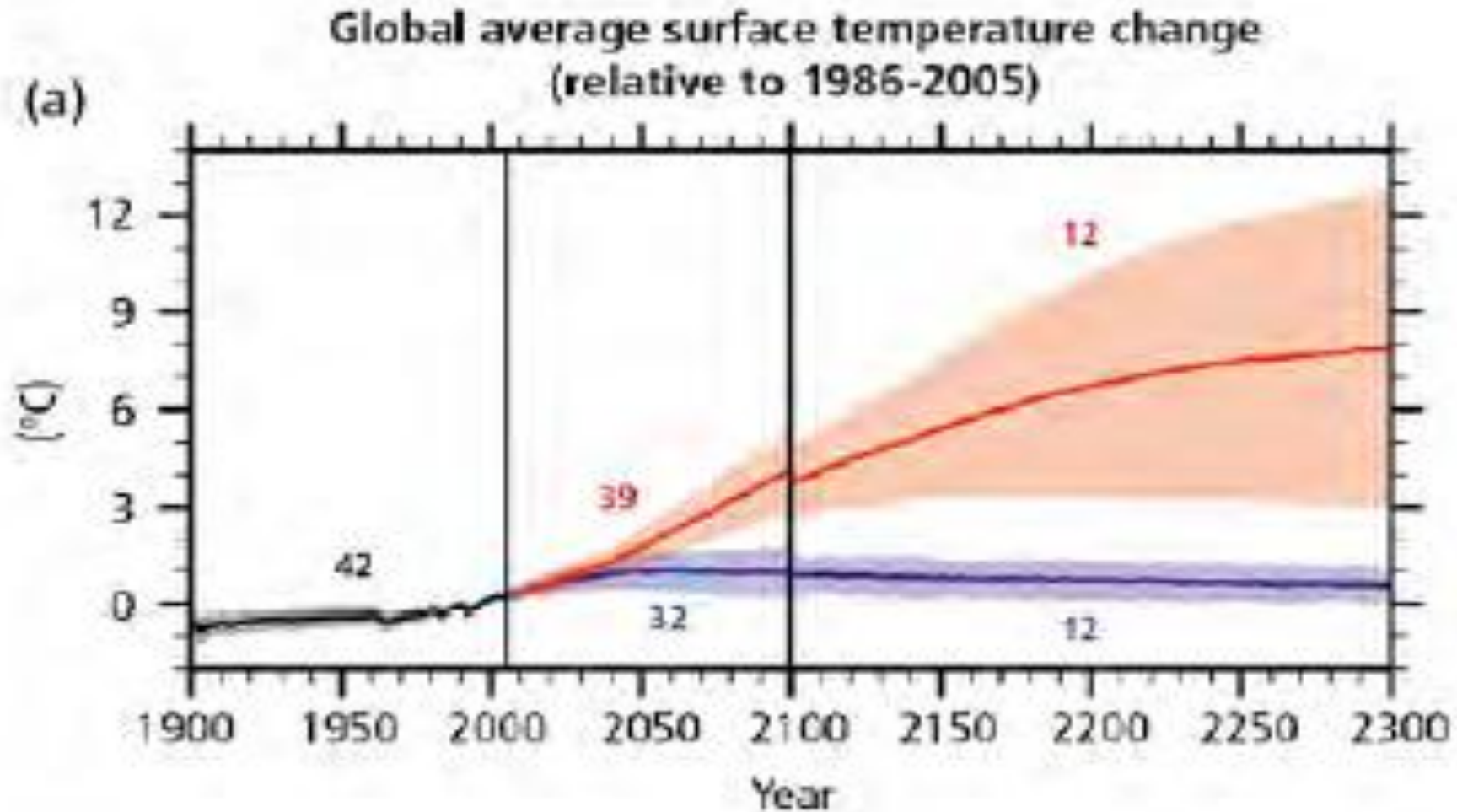
a) Global surface temperature change relative to 1850-1900



Dust & SO₂ emitted by volcanoes reduce Radiative Forcing and increase the cooling of atmosphere
Source: IPCC AR6 WG1 - Summary for Policy Makers - August 2021

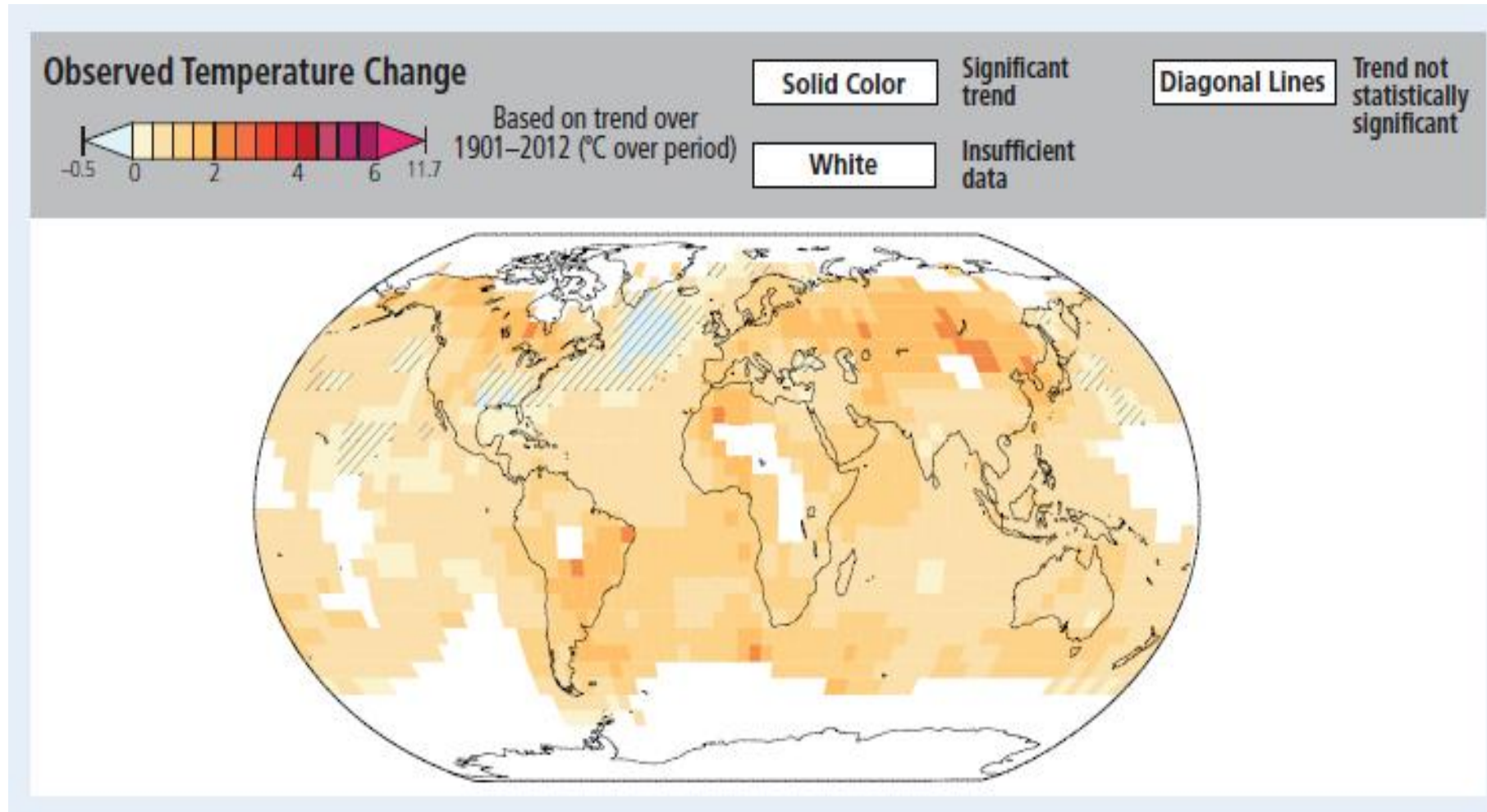


Climate Change: the Earth's temperature – IPCC Projections



Source: IPCC 5th Assessment Synthesis Report November 2014

Climate Change: the Earth's evolving temperature



Source: IPCC 5th Assessment Synthesis Report November 2014

Climate Change: the Earth's temperature – IPCC Projections

Projected Temperature Change



Difference from
1986–2005 mean (°C)

Solid Color

Very strong
agreement

White Dots

Strong
agreement

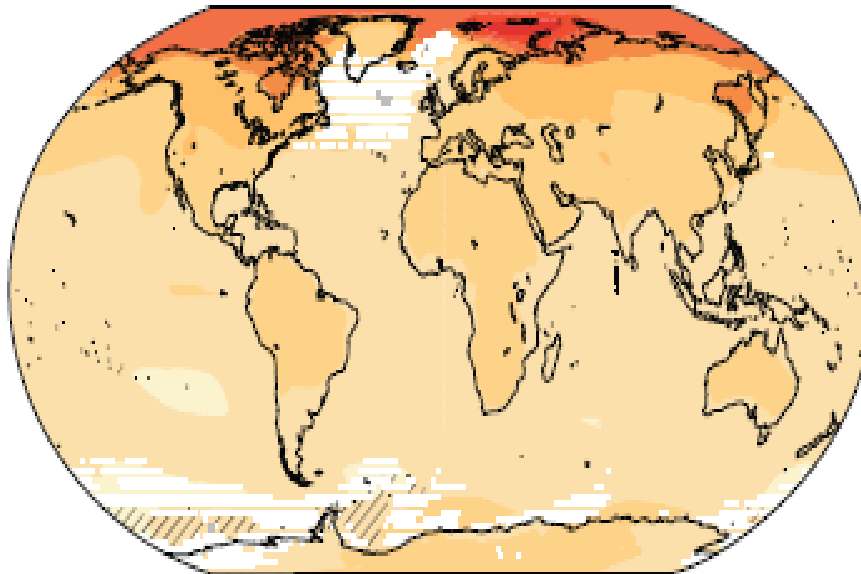
Gray

Divergent
changes

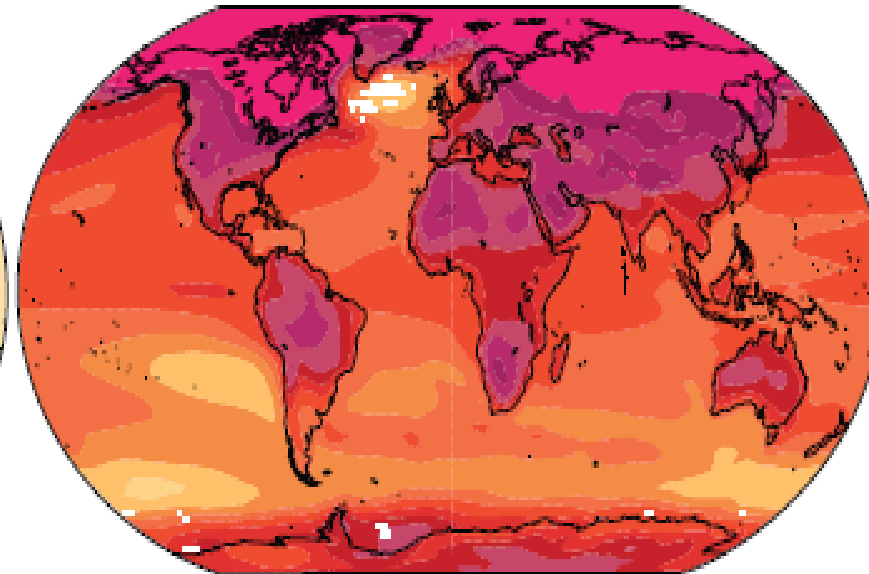
Diagonal Lines

Little or
no change

RCP2.6 2081–2100



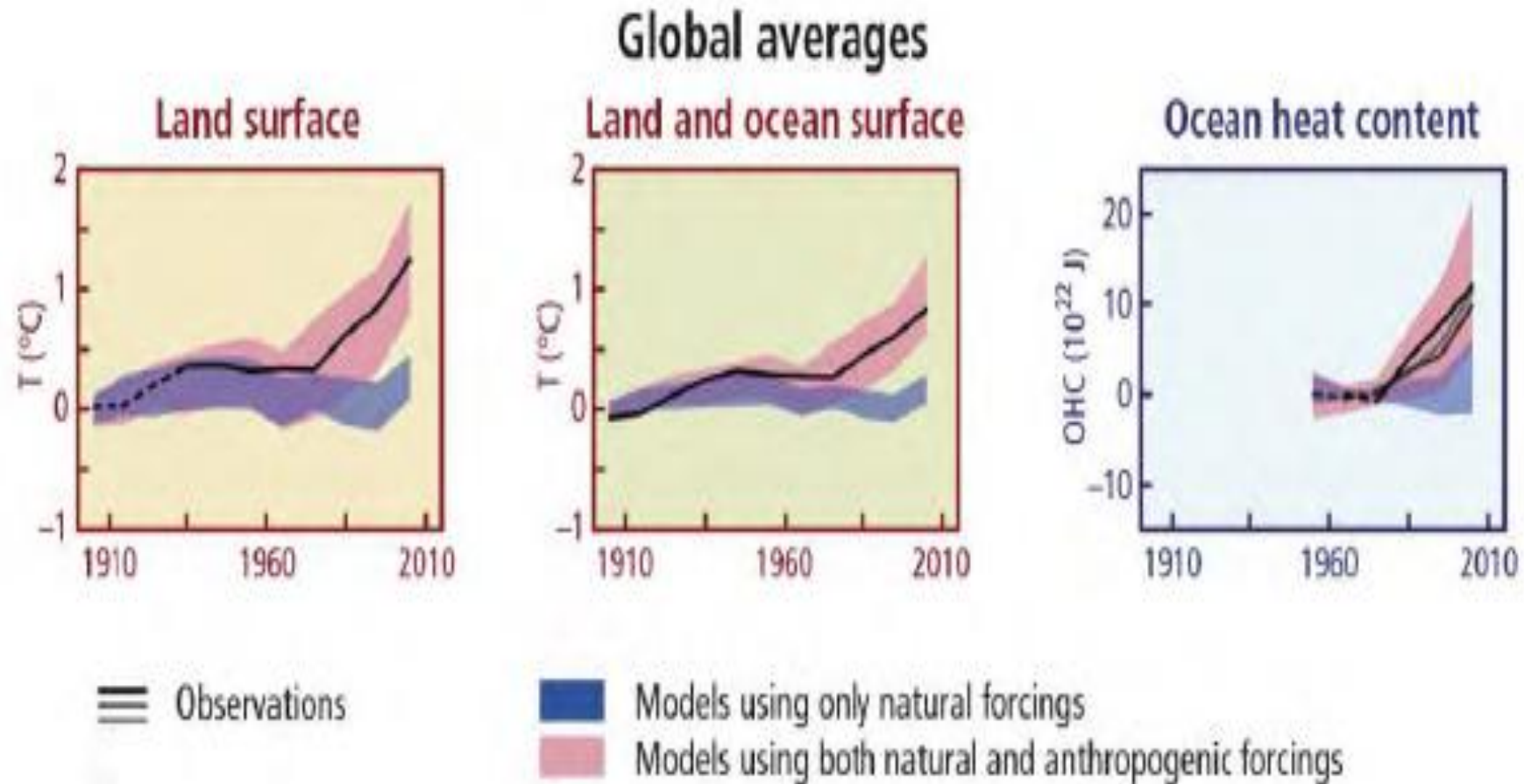
RCP8.5 2081–2100



Source: IPCC 5th Assessment Synthesis Report November 2014

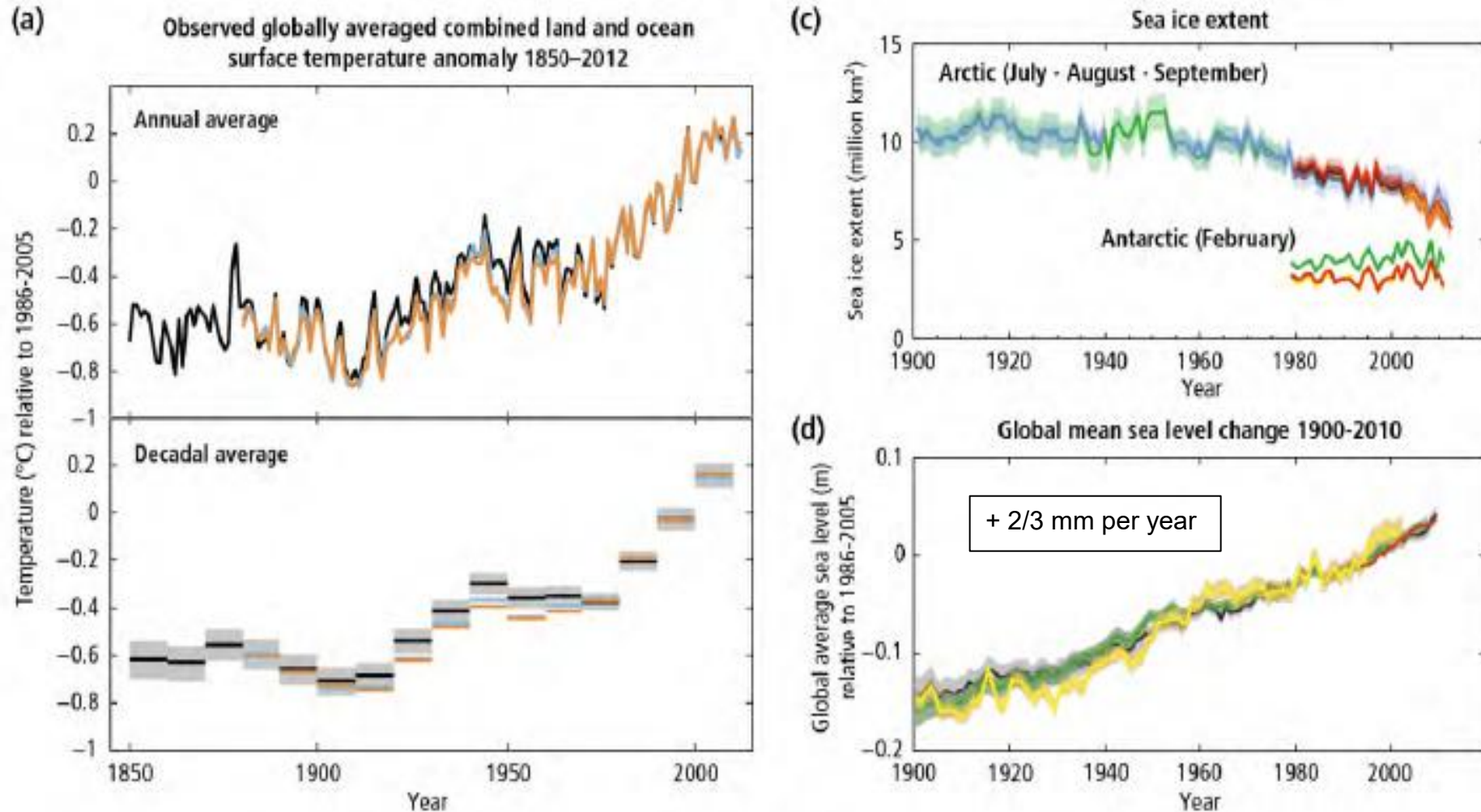


Global Impacts on Land & Ocean



Source: IPCC 5th Assessment Synthesis Report November 2014

Impacts on surface temperature, sea ice extent and mean sea level



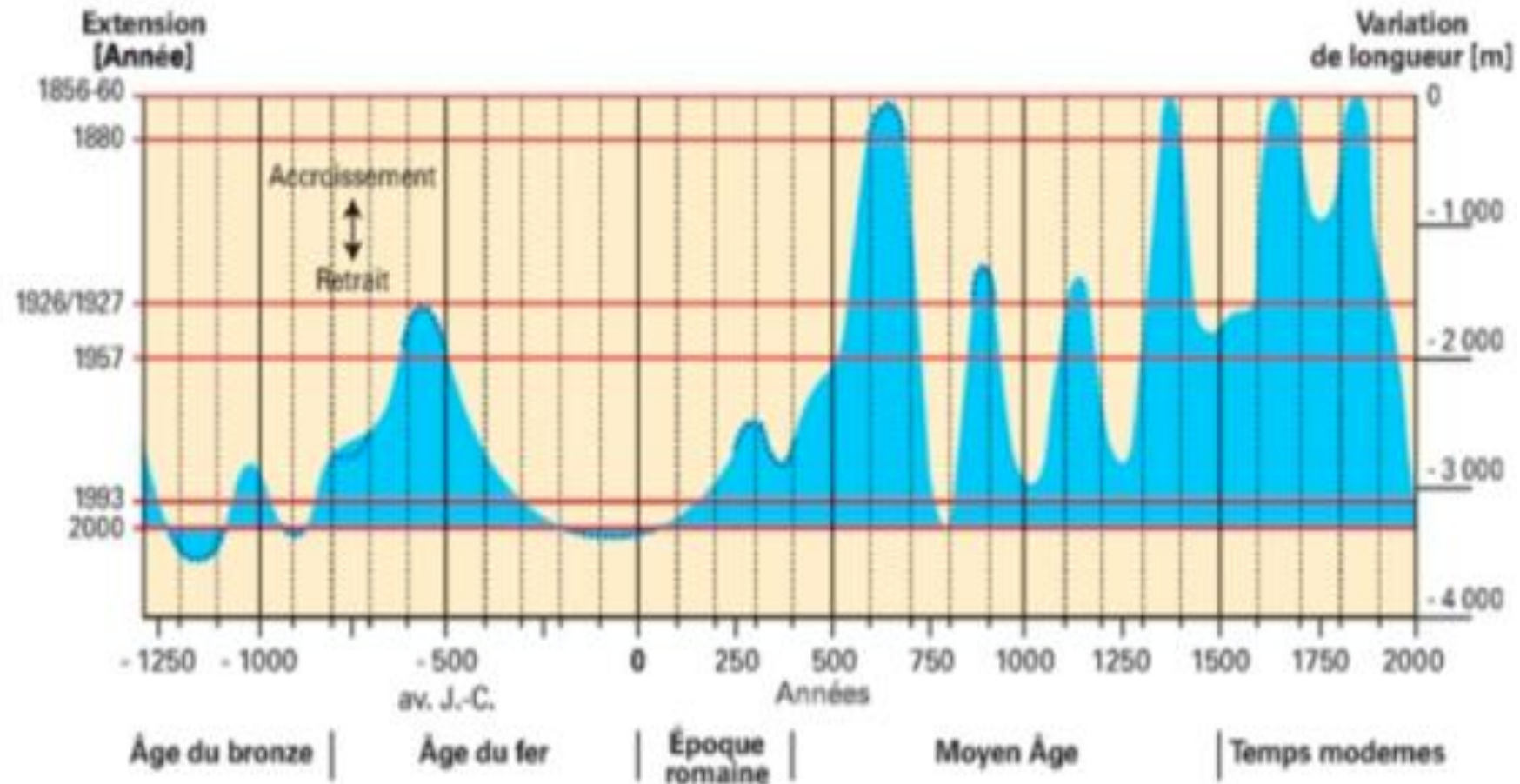
Source: IPCC 5th Assessment Synthesis Report November 2014

However, it must be noted that extension and retraction of glaciers have been a known phenomena during the previous centuries.

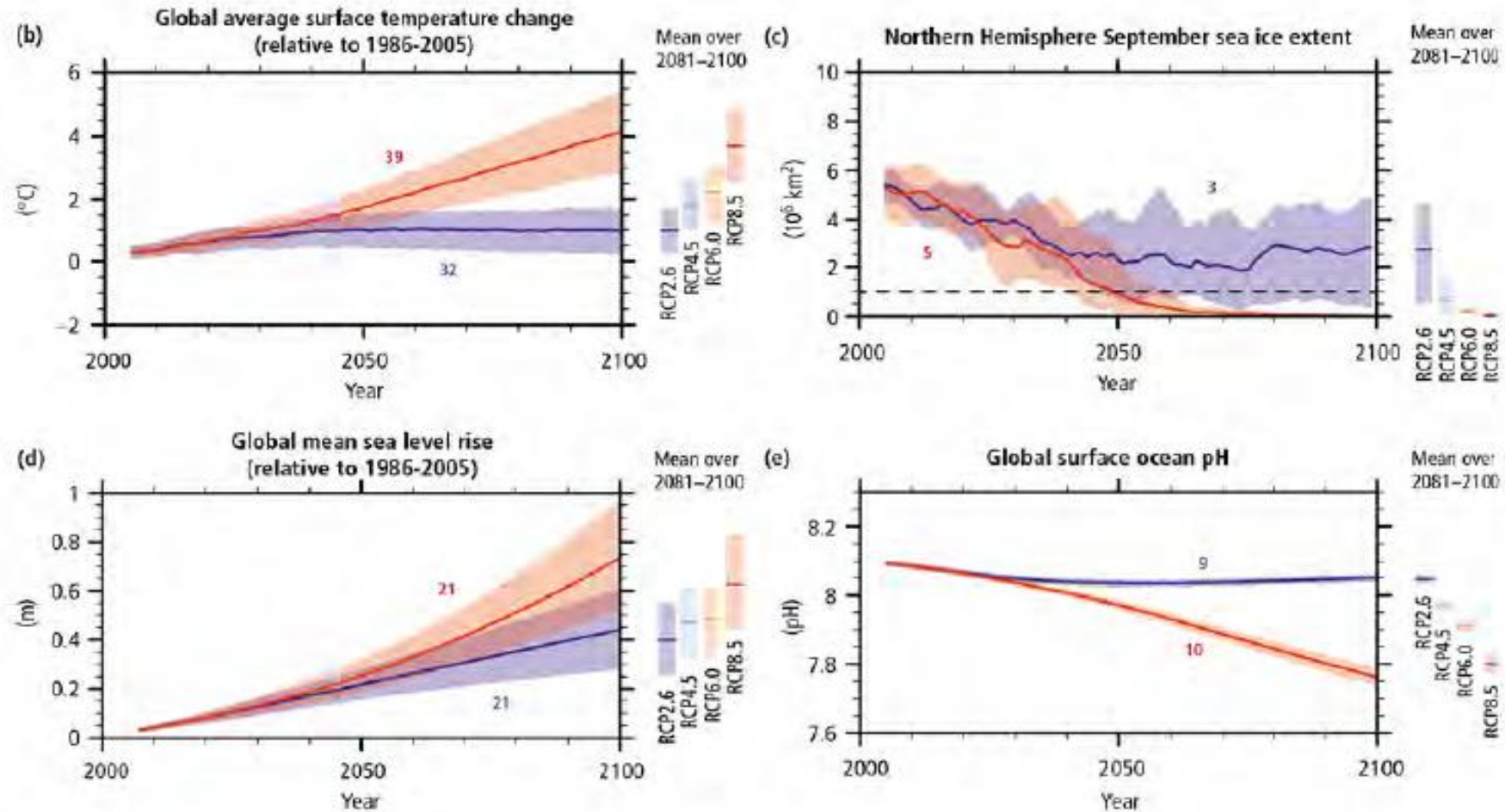
Example: Great Aletsch glacier – Alps of Valais – 23 km

Various phases of extension and retraction since 1300 BC

Reference period = 0 = Period of maximum extension: 1856-1860



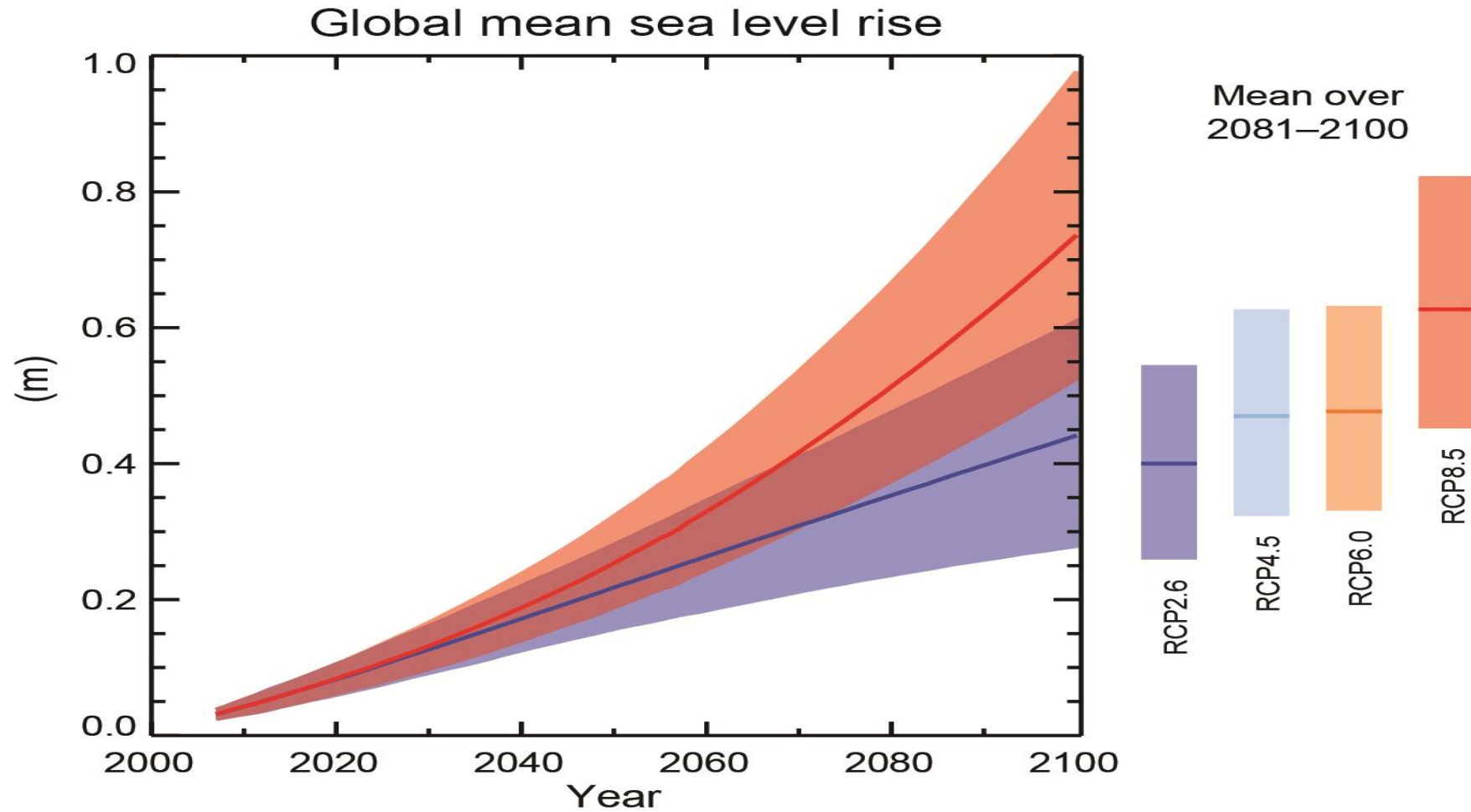
Scenarios IPCC – Temperature, Sea Ice extent, Sea level, Ocean PH



Source: IPCC 5th Assessment Synthesis Report November 2014

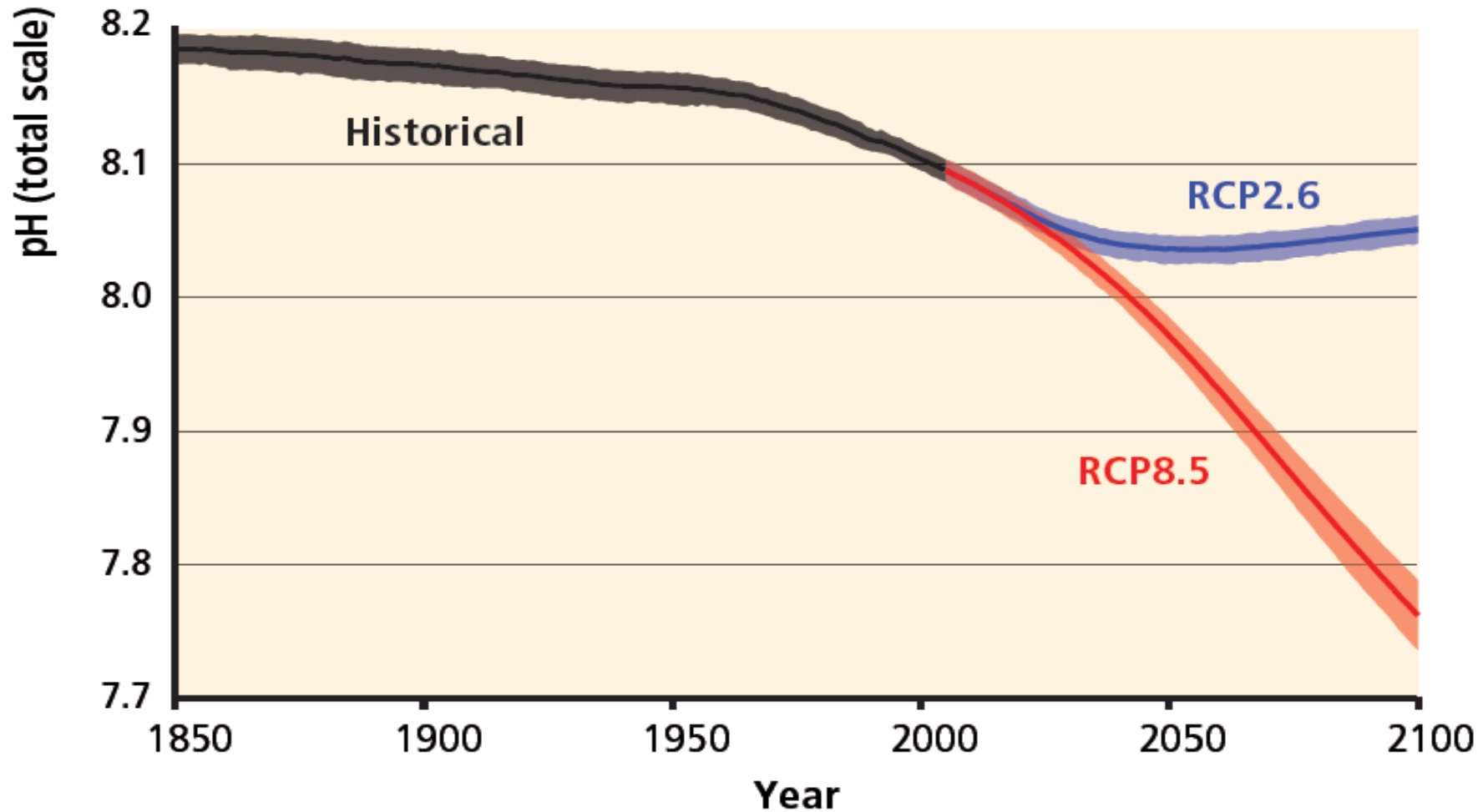


Global Sea Level Rise



Source: IPCC 5th Assessment Synthesis Report November 2014

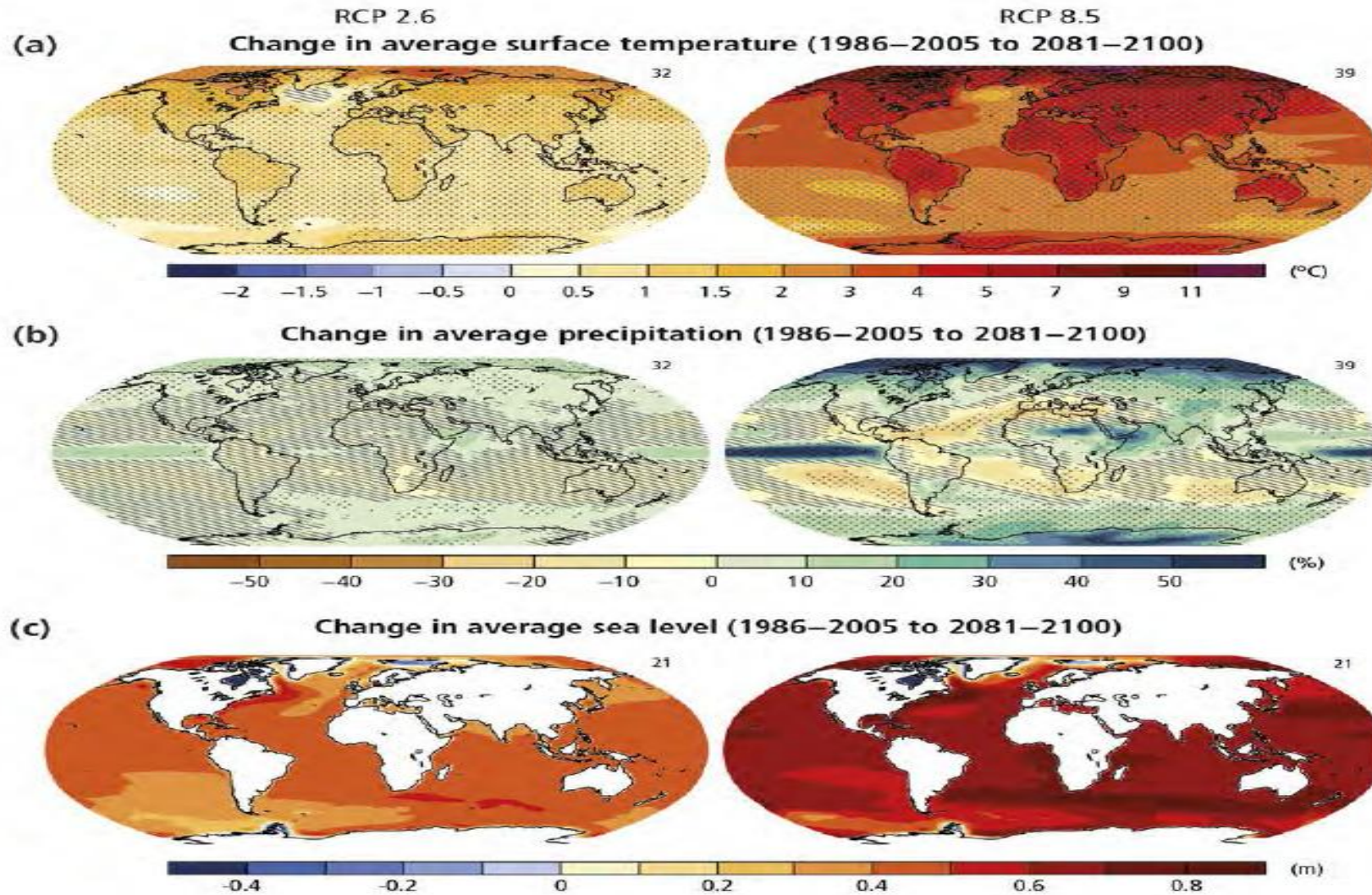
Impact on Ocean Acidity



Source: IPCC 5th Assessment Synthesis Report November 2014

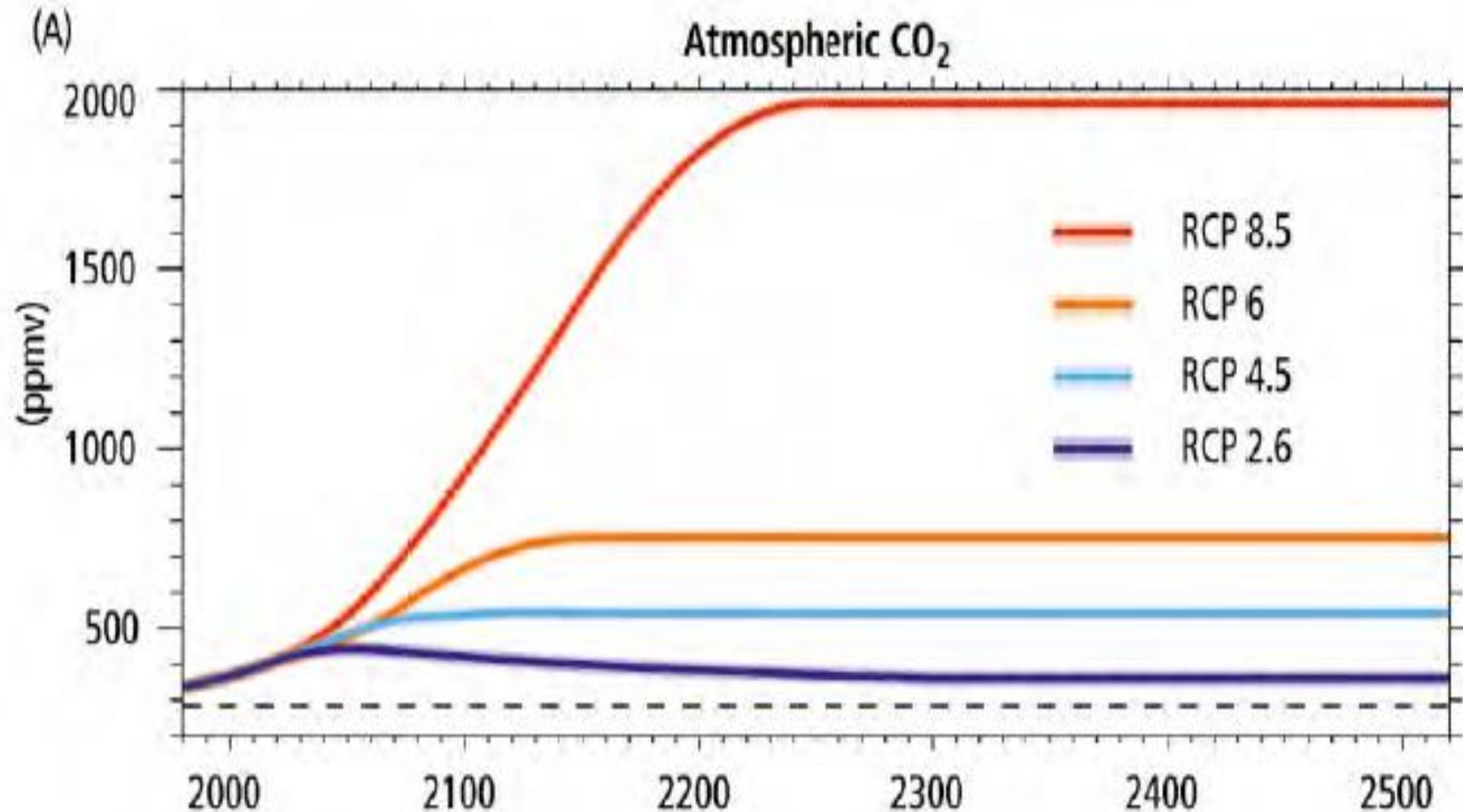


Effects are not homogeneous in regions



Source: IPCC 5th Assessment Synthesis Report November 2014

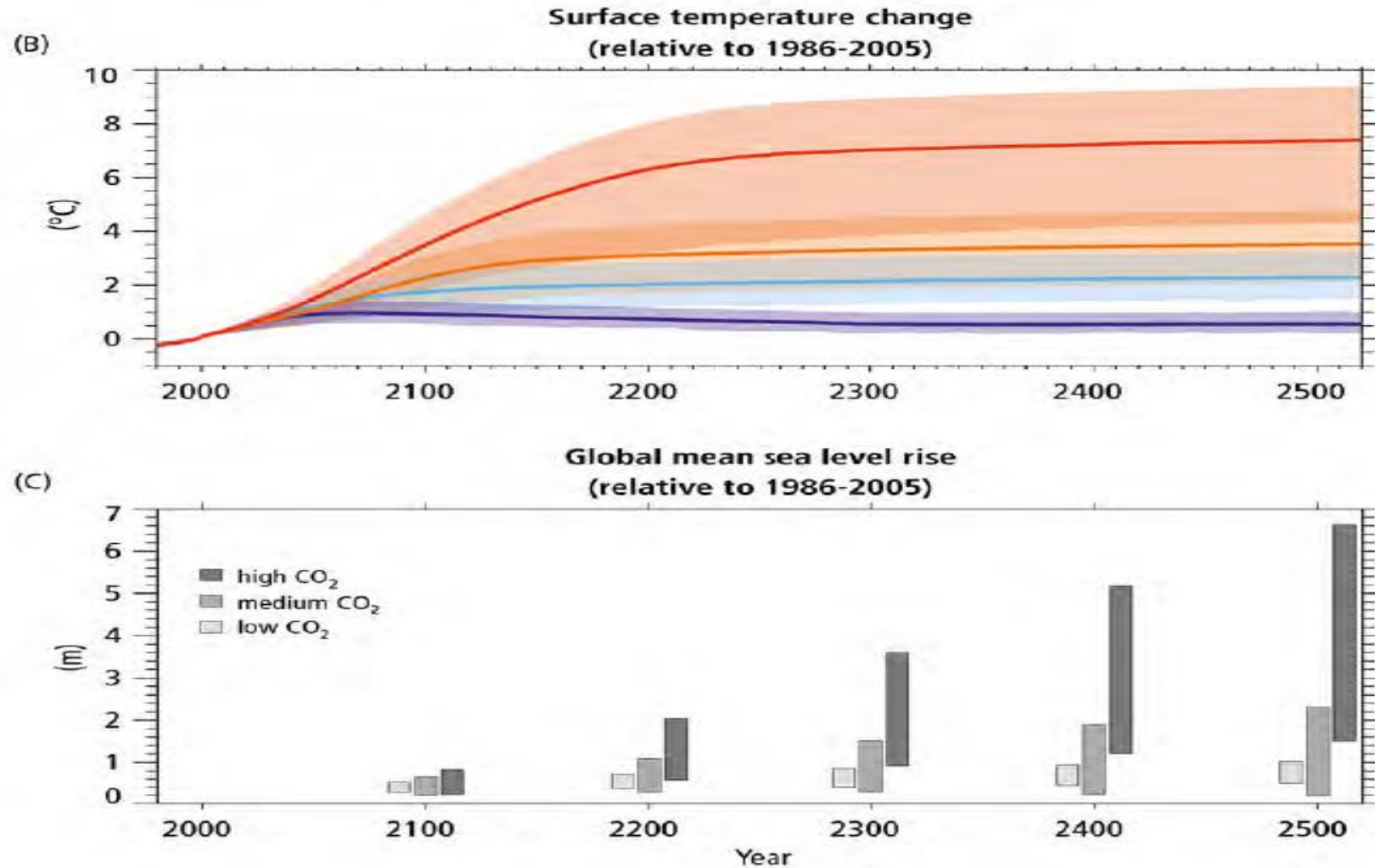
CO₂ content Long term scenarios IPCC



Source: IPCC 5th Assessment Synthesis Report November 2014
RCP: Representative Concentration Pathway as per Radiative Forcing



CO₂ content Long term scenarios IPCC



Source: IPCC 5th Assessment Synthesis Report November 2014

Conclusions from IPCC

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

Source: IPCC 5th Assessment Synthesis Report November 2014

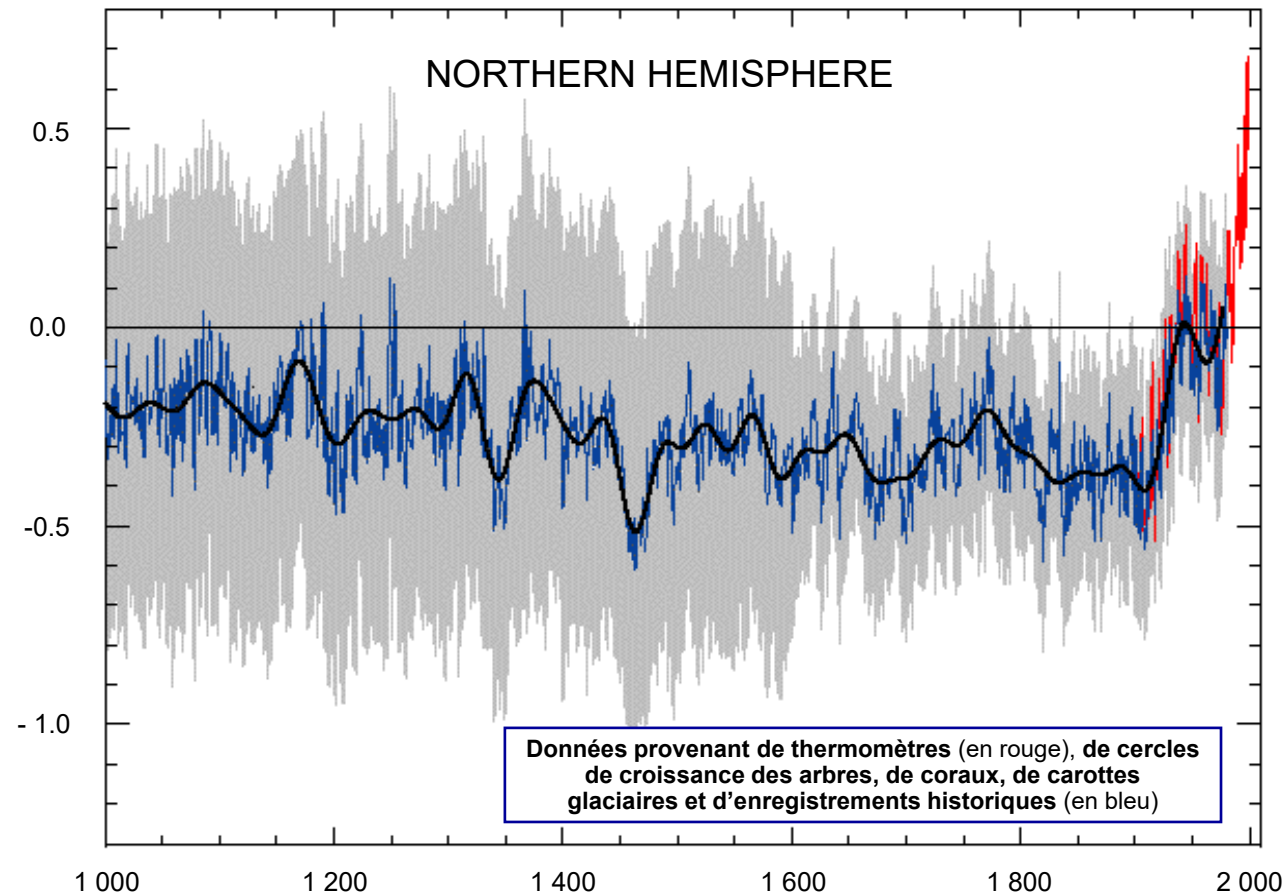


Temperature & CO₂ concentration



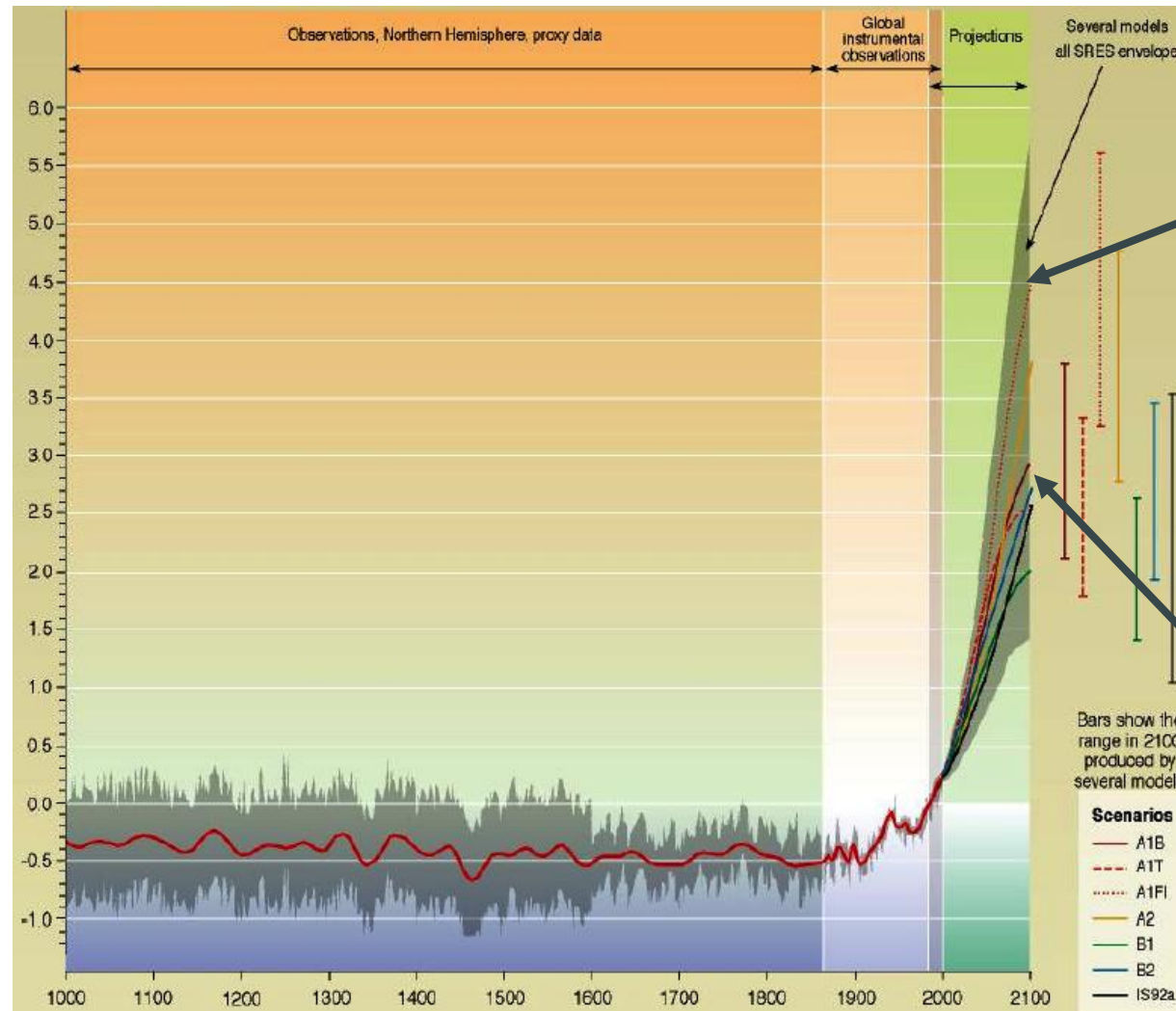
Climate Change: the Earth's evolving temperature

- ◆ Variation in global temperatures over 1000 years (in °C)
The zero reference is the period 1961-1990



Temperature evolution - Projections are heavily scenario-dependant

(This graph has been the subject of controversy, but is useful for the purpose of illustration)

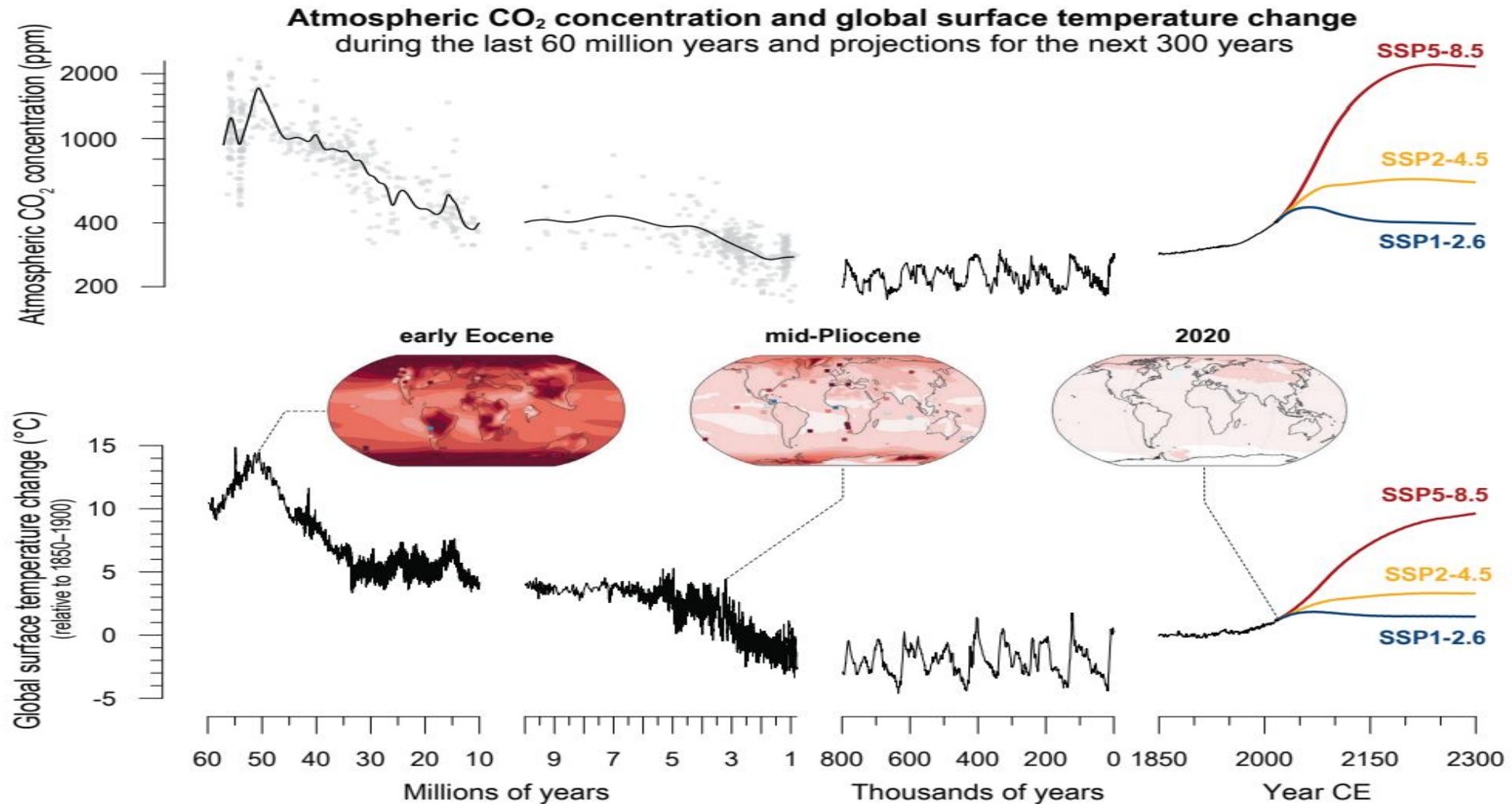


10 billion
humans
raise their
average
emissions
to those of
a Pole of
2000

World
emissions
remain
constant

Source: The « Hockey stick graph », Mann,
Bradley, Hughes 1999

Climate Change – CO₂ concentration & the Earth temperature History of long-term evolution



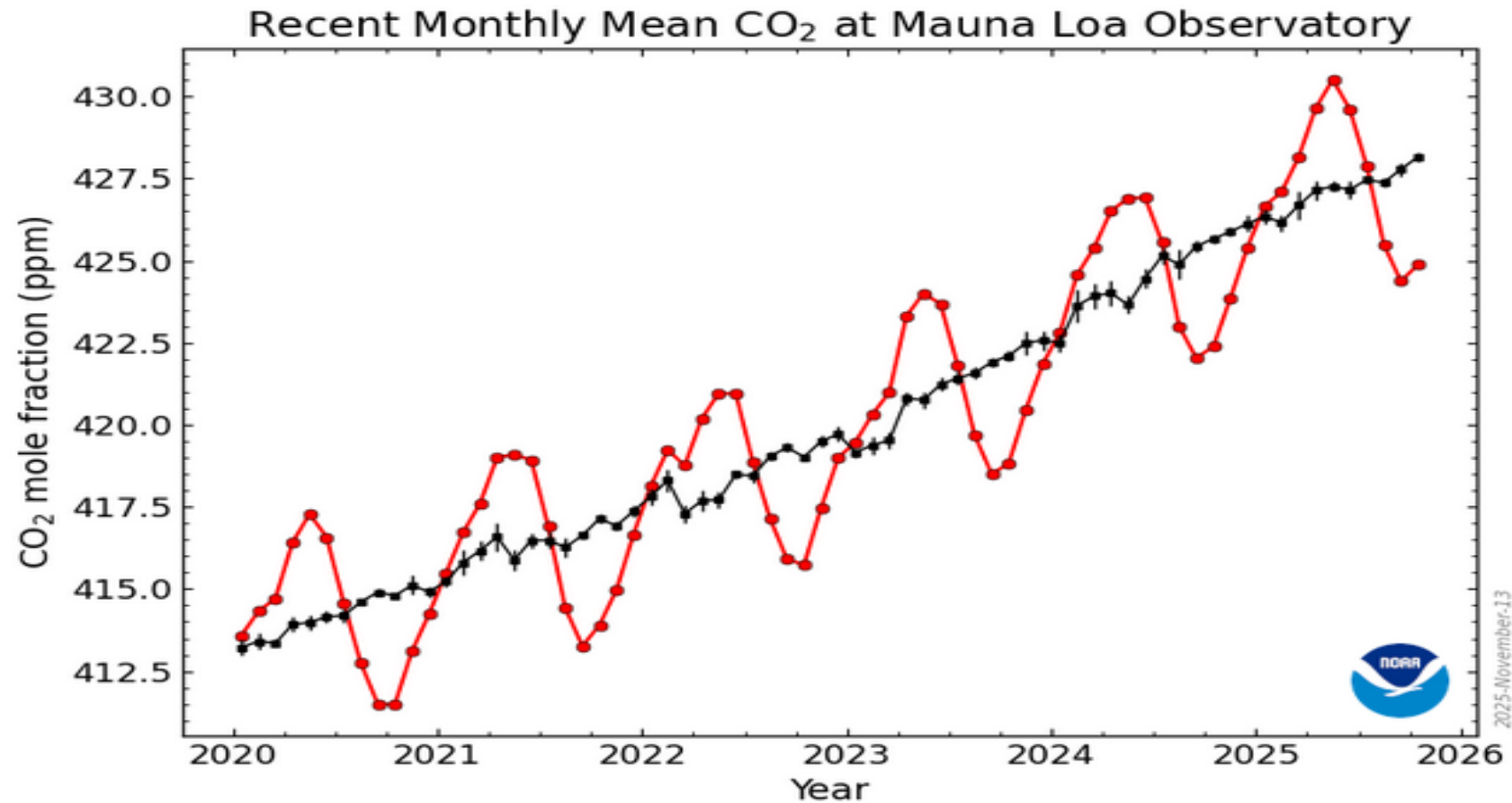
CO₂ concentration in the atmosphere

- Pre industrial revolution # 280 ppm
- 1958 # 320 ppm
- 2019 # 414 ppm
- May 2026 # 432 ppm (+54% vs 1800)



CO₂ concentration in the atmosphere

Measures taken at Mauna Loa observatory – Hawai - Evolution 2020 – 2025

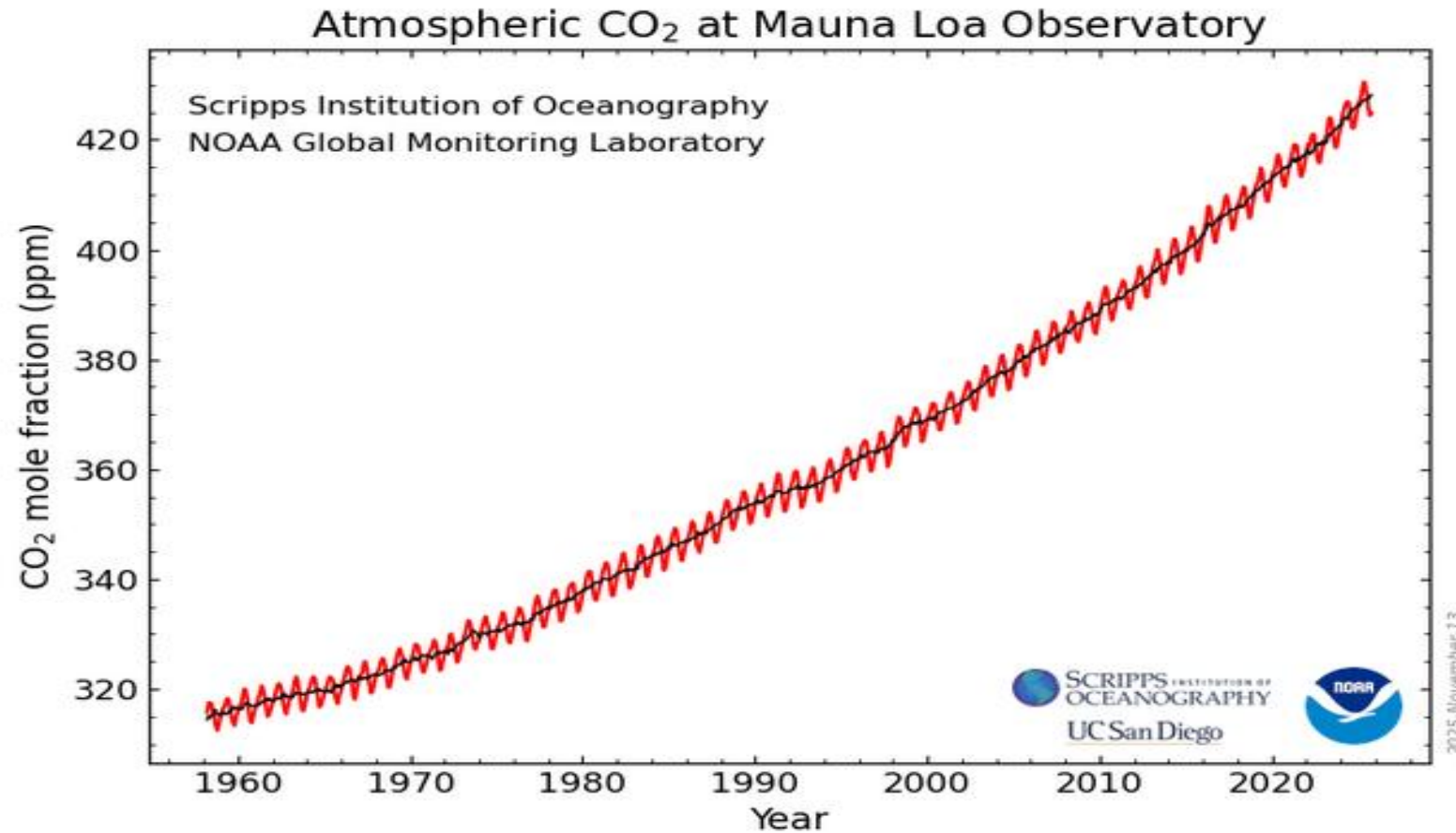


The graphs show monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. The carbon dioxide data on Mauna Loa constitute the longest record of direct measurements of CO₂ in the atmosphere. They were started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958 at a facility of the National Oceanic and Atmospheric Administration [Keeling, 1976]. NOAA started its own CO₂ measurements in May of 1974, and they have run in parallel with those made by Scripps since then [Thoning, 1989].



CO₂ concentration in the atmosphere

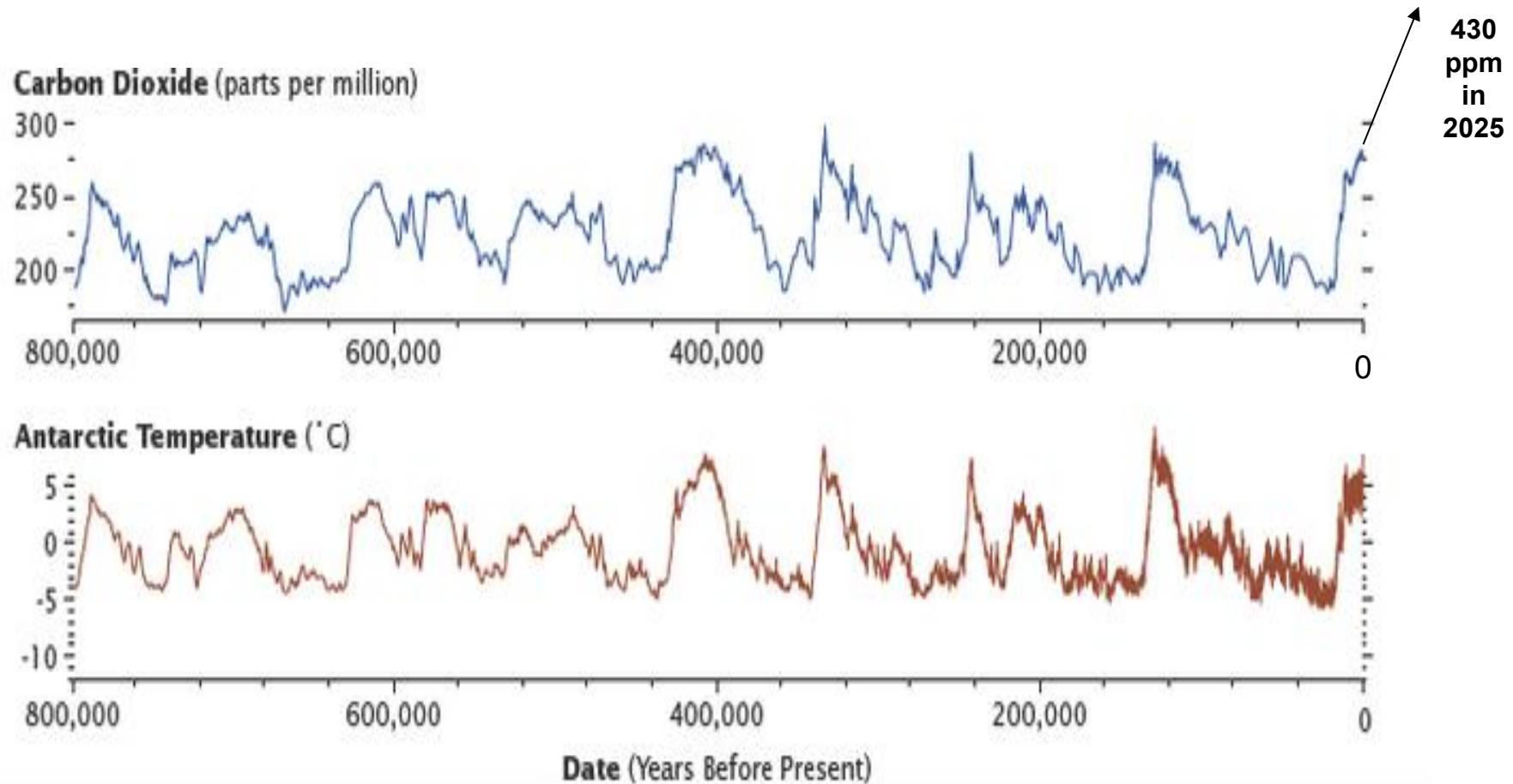
Measures taken at Mauna Loa observatory – Hawai - Evolution 1960 – 2025



The graphs show monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. The carbon dioxide data on Mauna Loa constitute the longest record of direct measurements of CO₂ in the atmosphere. They were started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958 at a facility of the National Oceanic and Atmospheric Administration [Keeling, 1976]. NOAA started its own CO₂ measurements in May of 1974, and they have run in parallel with those made by Scripps since then [Thoning, 1989].



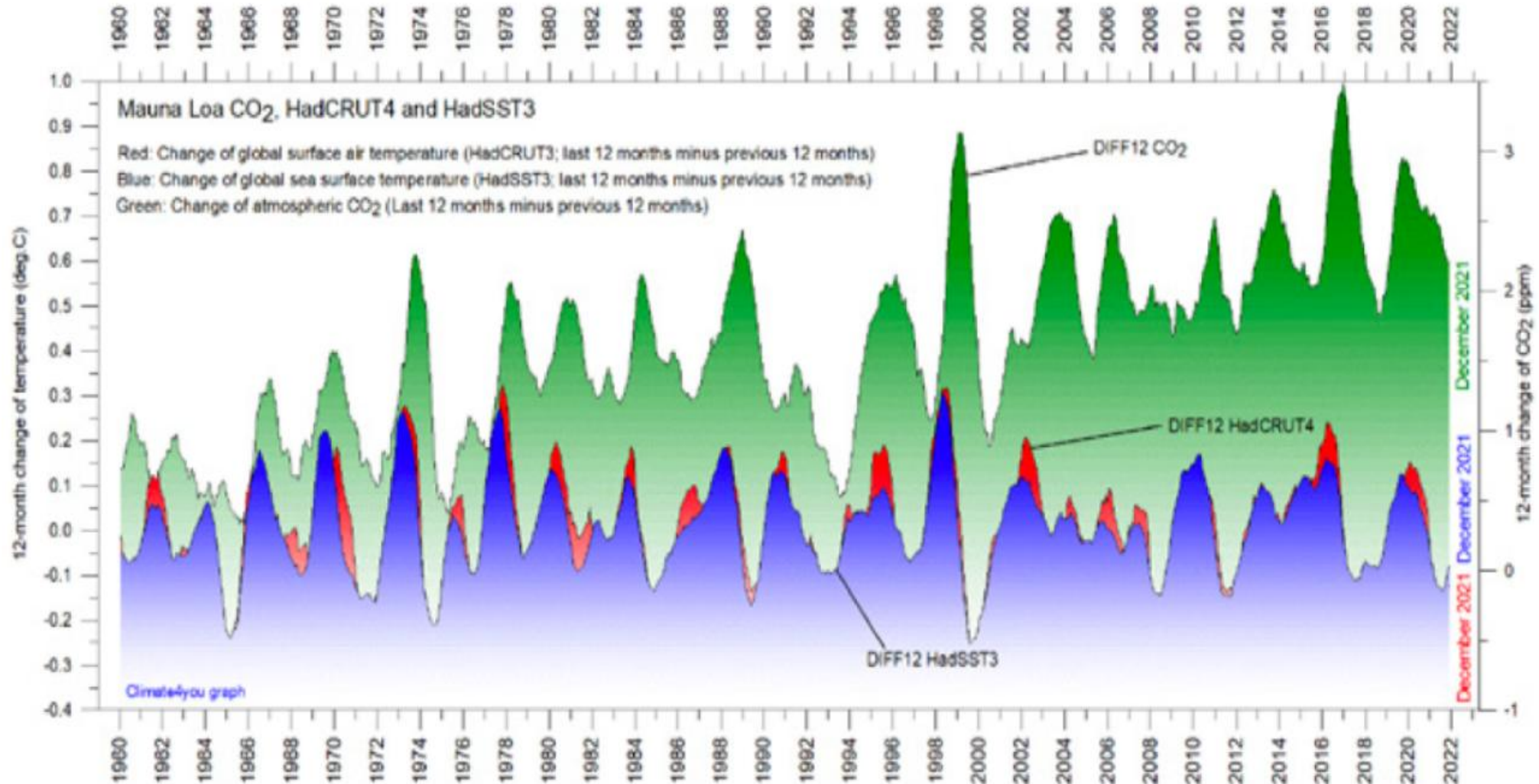
CO₂ Concentration in the Antarctic (Dôme C) and Evolution of Temperature up to 800 000 years BC



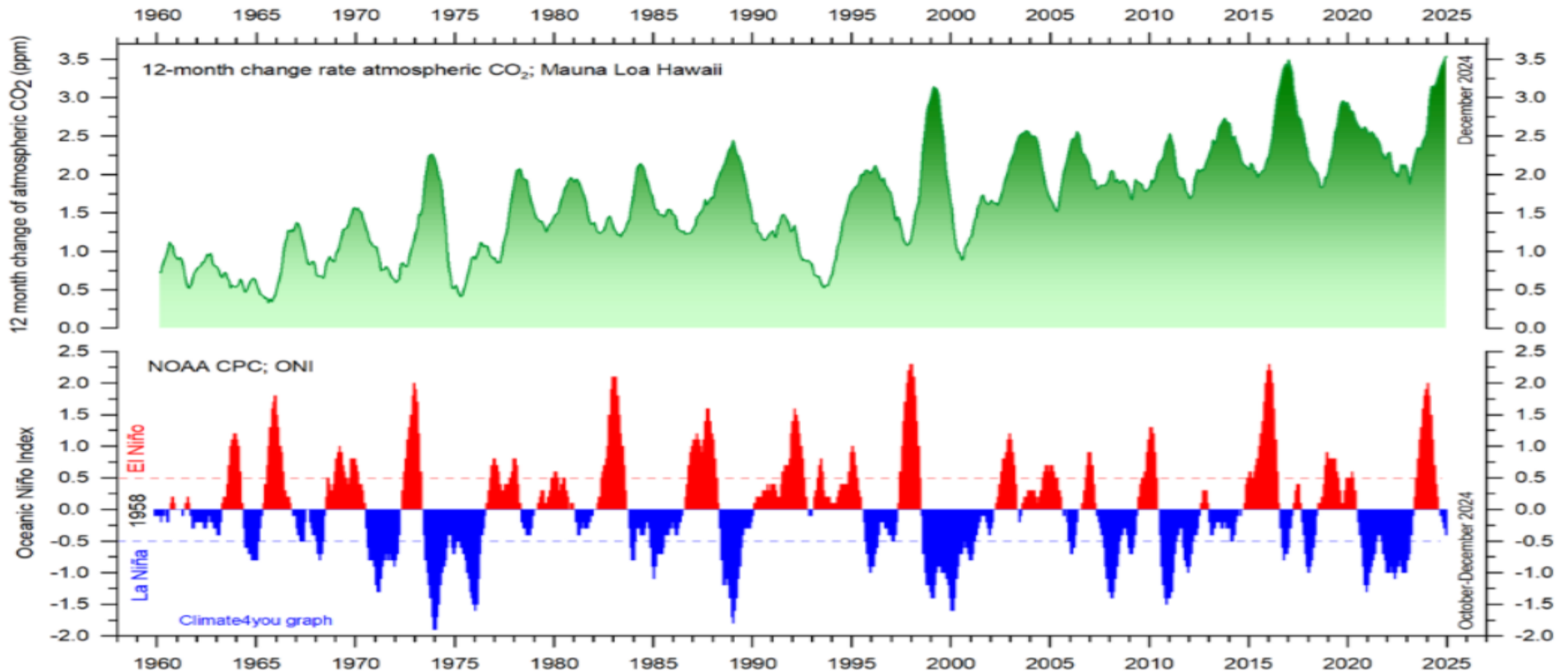
Source: EPICA Dôme C (European Project for Ice Coring in Antarctica) and NOAA



Correlation CO₂ Concentration and Temperature records 12 months changes - 1960 - 2023



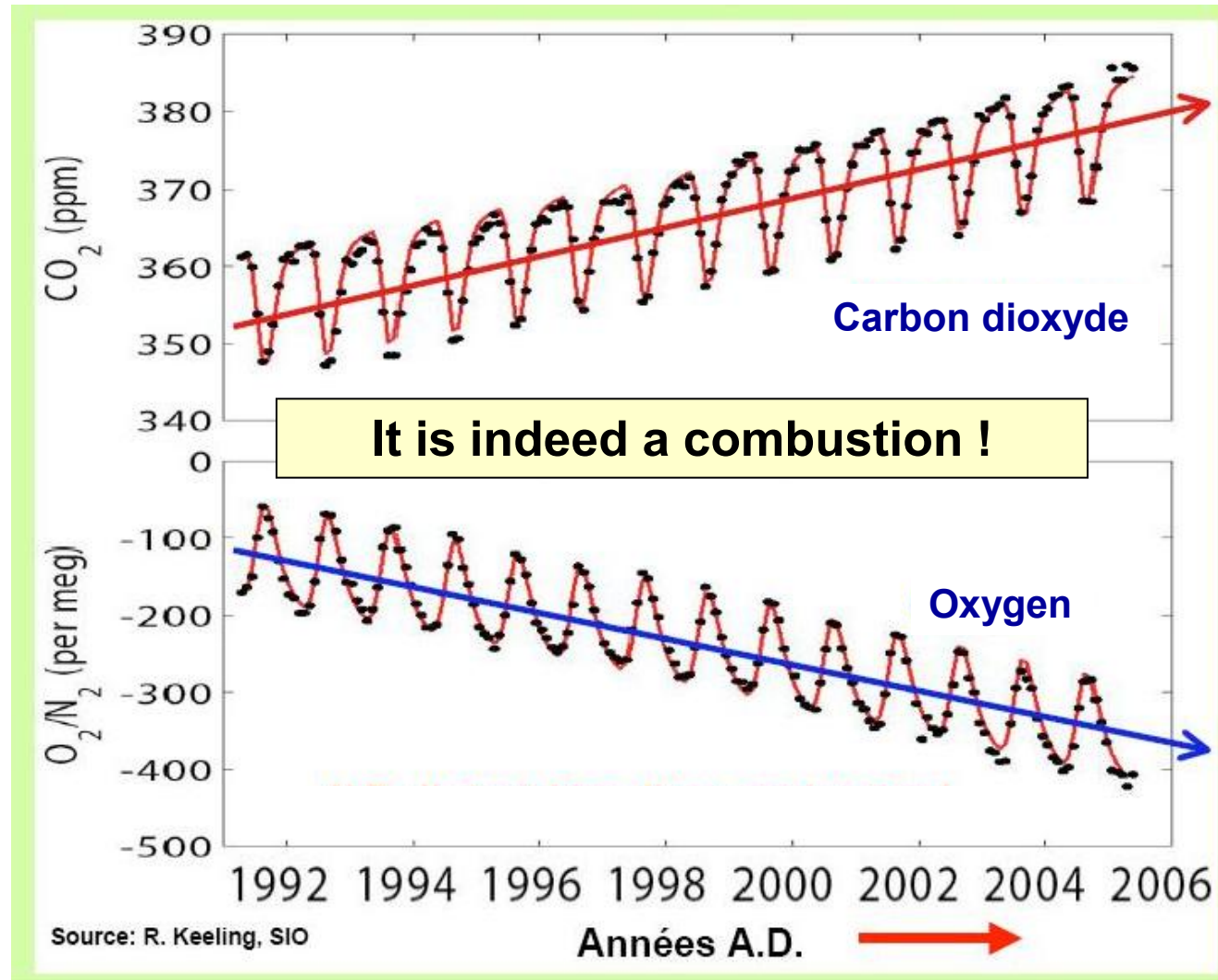
Correlation growth rate of CO₂ Concentration and Oceanic Nino Index 1960 - 2024



Source: Mauna Loa & NOAA. The Oceanic Nino Index (OCI) is NOAA's primary indicator for monitoring the ocean part of the seasonal climate pattern. The ONI tracks the running 3 months average sea surface temperature in the east-central Pacific and whether they are warmer or cooler than average

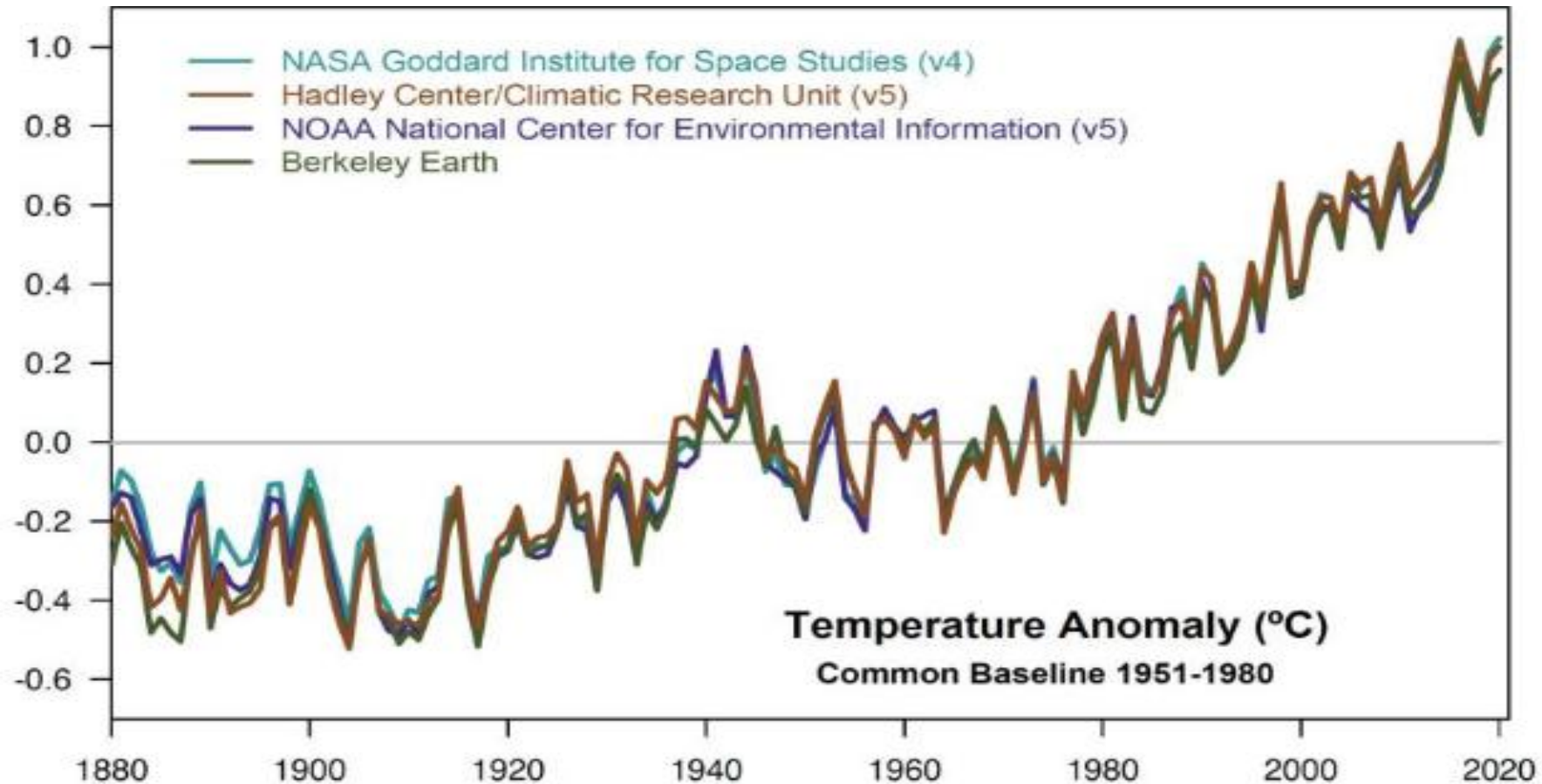


Human activities modify Greenhouse Effect

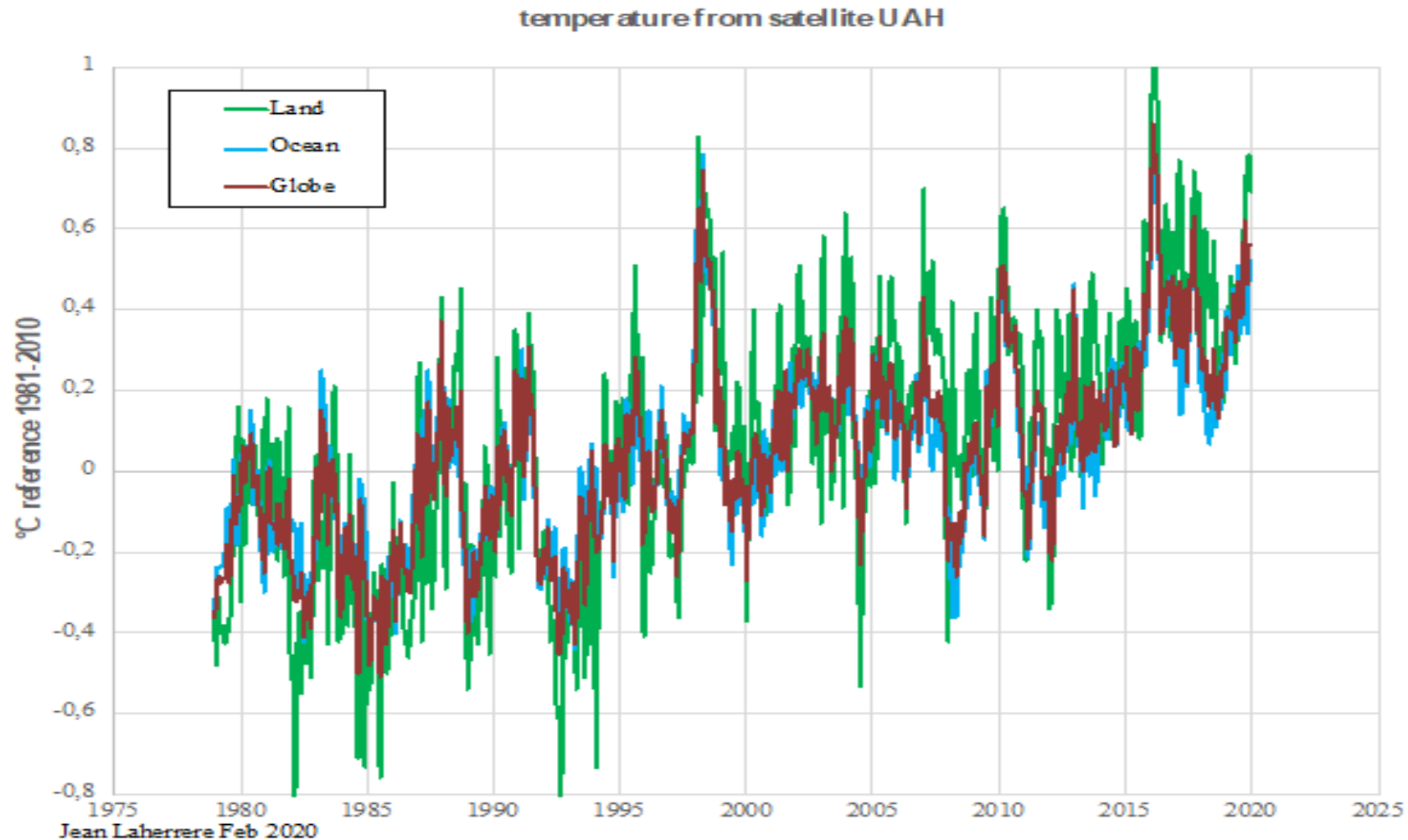


Climate Change: the Earth's evolving temperature

- ◆ Variation in global temperatures over 120 years (in °C)
The zero reference is the period 1951-1990

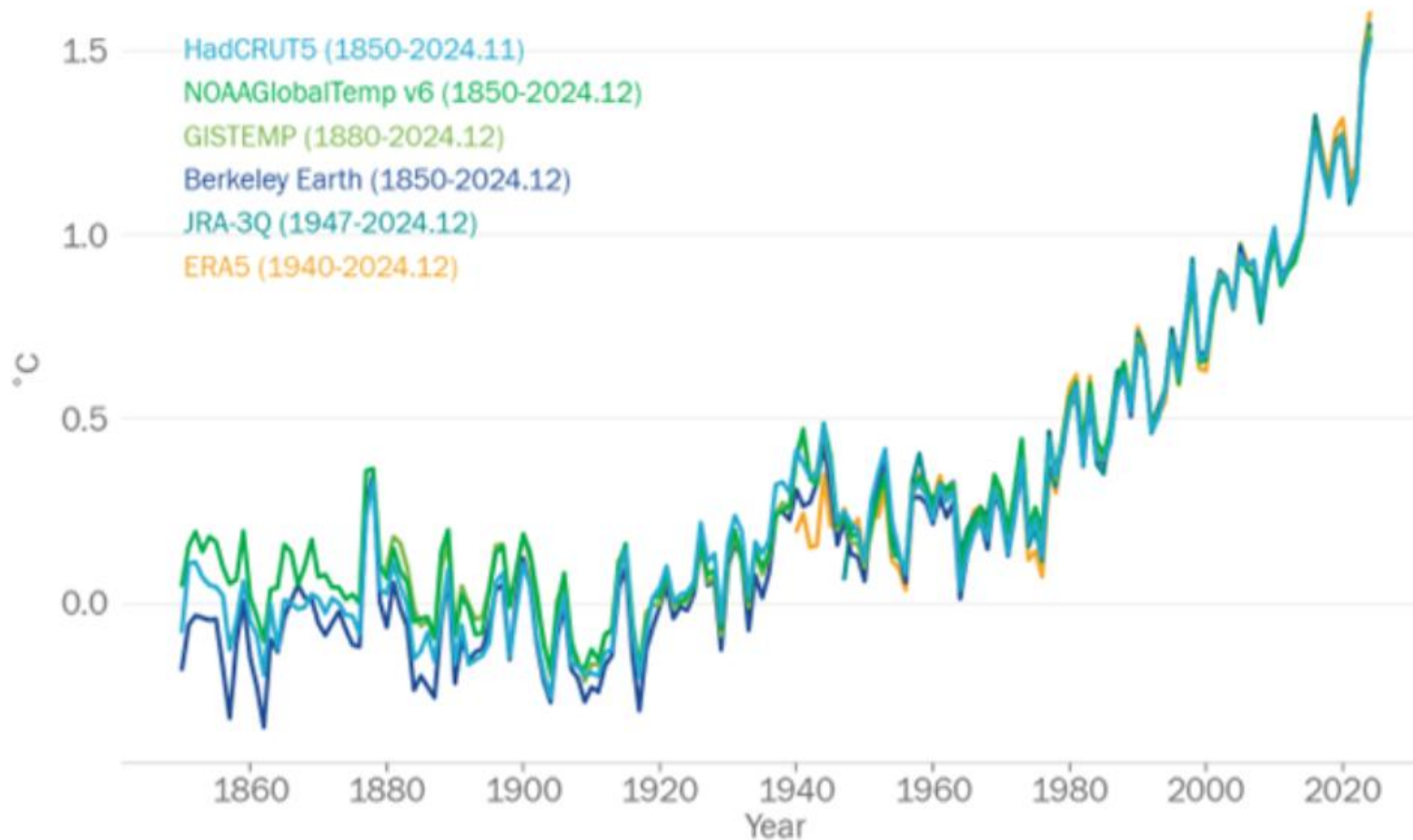


Temperature Evolution by NASA monitoring system based on US Climate Reference Network 0 reference period: 1981 - 2010



Climate Change – The Earth temperature

Global mean temperature 1850-2024
Difference from 1850-1900 average



The global average surface temperature was 1.55 °C (with a margin of uncertainty of ± 0.13 °C) above the 1850-1900 average, according to WMO's consolidated analysis of the six datasets.

This means that we have likely just experienced the first calendar year with a global mean temperature of more than 1.5°C above the 1850-1900 average.



Climate Change – The Earth temperature

Impact on Greenland Ice Sheet

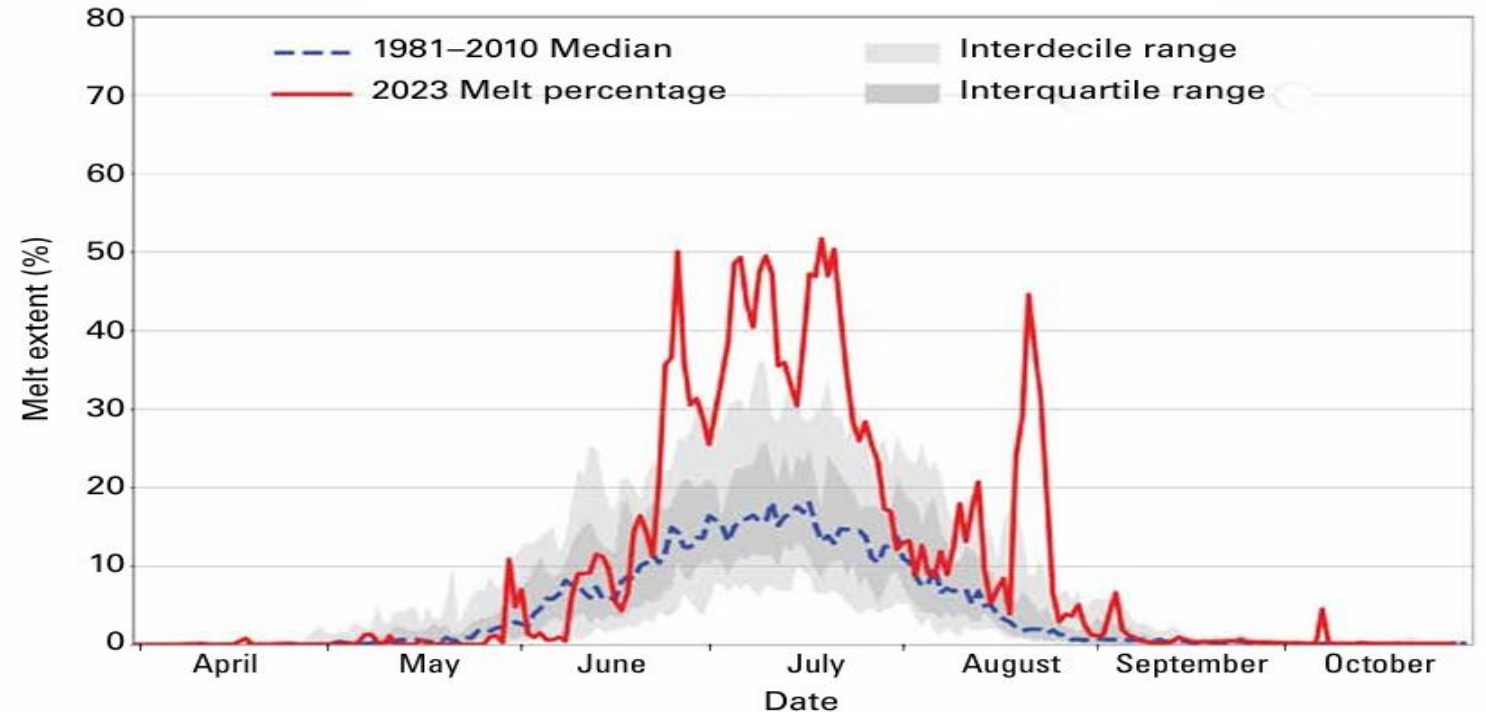
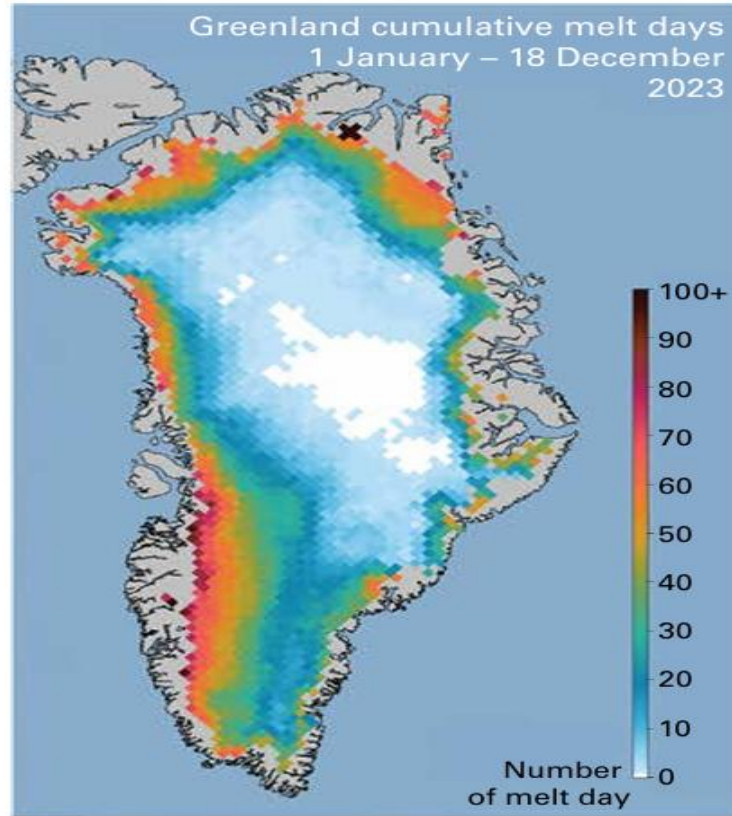


Figure 14. Greenland Ice Sheet melt conditions through 2023: (left) Cumulative melt days for Greenland in 2023. White areas indicate no melting occurred. (right) Percentage of the ice sheet experiencing melting conditions each day.

Source: Images and analysis courtesy of Thomas Mote, University of Georgia, and the U.S. National Snow and Ice Data Center..



What do we mean by Representative Concentration Pathways (RCP) and Shared Socio-economic Pathways (SSP)?



What is a Representative Concentration Pathway (RCP)?

- A Representative Concentration Pathway (RCP) is a Greenhouse Gas trajectory adopted by the International Panel for Climate Change (IPCC)
- Four pathways were used for Climate Modeling and Research for the IPCC 5th Assessment Report in 2014 (AR5).
- **The pathways describe different climate futures, all of which are considered possible** and are labelled after a possible range of Radiative Forcing values in the year 2100 (RCP 1,9/2,6 W/m², RCP 4,5 W/m², RCP 7,0 W/m², RCP 8,5 W/m²)



What is a Shared Socioeconomic Pathway (SSP)?

- **SSPs are *possible futures* that climate researchers in the IPCC consider in their 6th Assessment Report (AR6 WG1 - August 2021)**
- **Five pathways are shown : SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, covering a broad range of greenhouse gas and air pollutant futures.**
- **SSPx-y meaning :**
 - **x refers to SSP describing the socio-economic trends underlying the scenario**
 - **y refers to the approximate target level of radiative forcing (in W/m^2) resulting from the scenario in the year 2100**

Reminder : current level of radiative forcing $\sim 2,8 \text{ W/m}^2$



Shared Socio-Economic Pathways (SSP) vs Representative Concentration Pathway (RCP)

- **SSP: a range of new pathways that examine how global society, demographics and economics might change over the next century.** They have been developed in the IPCC 6th Assessment Report (AR6) in 2020/2021.
- Five pathways have been used and can be combined with the RCP effects deriving from the Climate Modelling.
- The pathways describe different climate futures, all of which are considered possible and are labelled after a possible range of societies development and Radiative Forcing values in the year 2100 (RCP 1,9/2,6 W/m², RCP 4,5 W/m², RCP 7,0 W/m², RCP 8,5 W/m²)

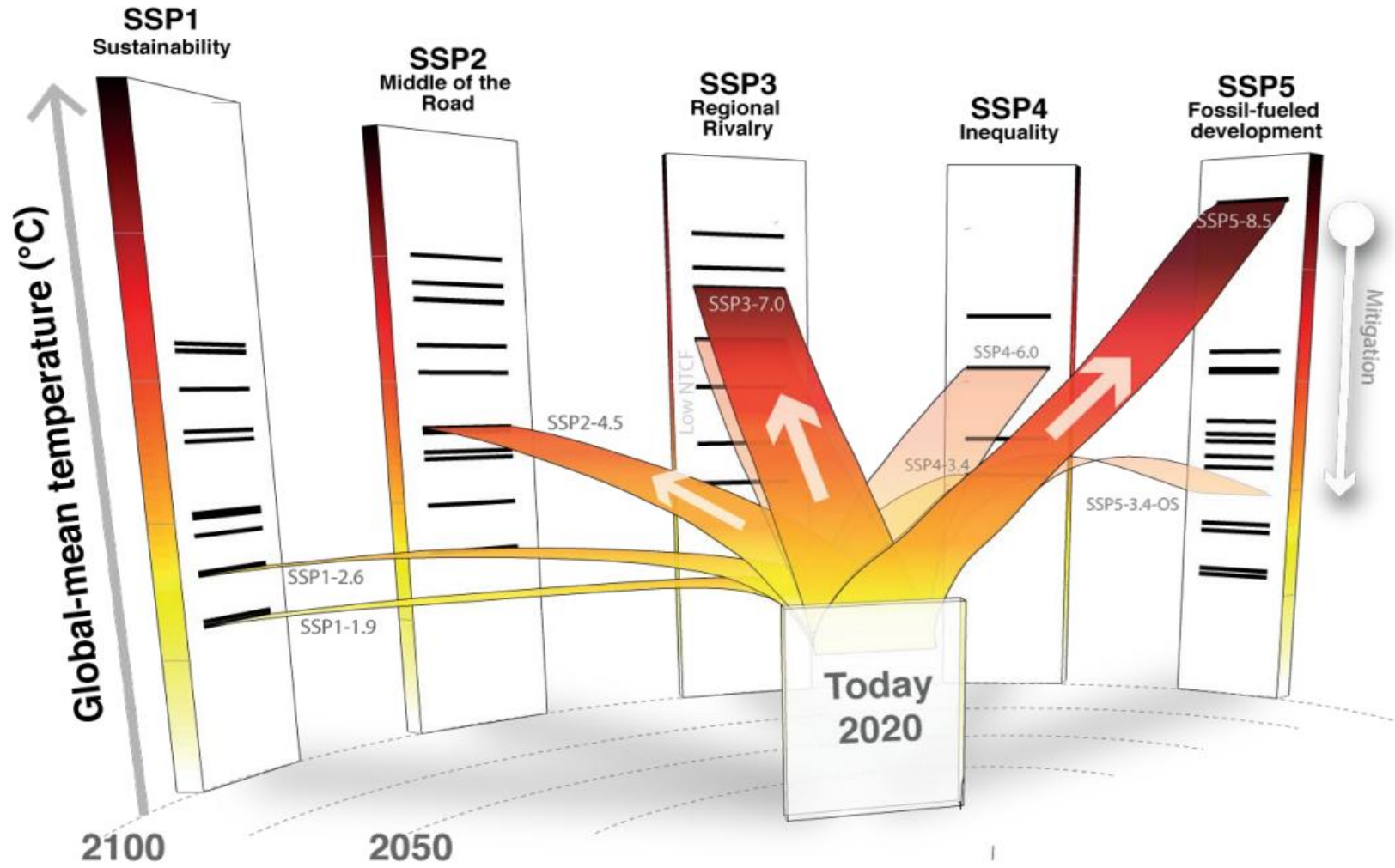


The Five SSP narratives

- **SSP1: Sustainability - Taking the Green Road - Low challenges to mitigation (resource efficiency) and adaptation (rapid development)**
- **SSP2: Middle of the Road - Medium challenges to mitigation and adaptation**
- **SSP3: Regional Rivalry – A Rocky Road - High challenges to mitigation (regionalized energy/ land policies) and adaptation (slow development)**
- **SSP4: Inequality – A Road Divided - Low challenges to mitigation (global high tech economy), high challenges to adaptation (regional low tech economies)**
- **SSP5: Fossil-fueled Development – Taking the Highway - High challenges to mitigation (resource/fossil fuel intensive), low challenges to adaptation (rapid development)**



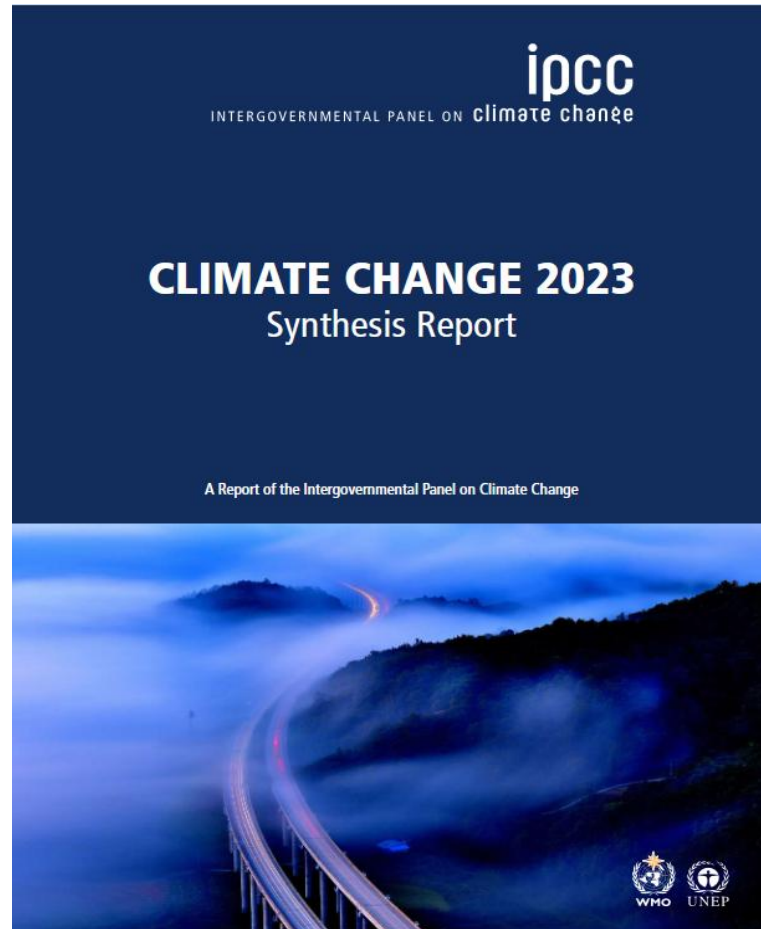
The Five SSPs



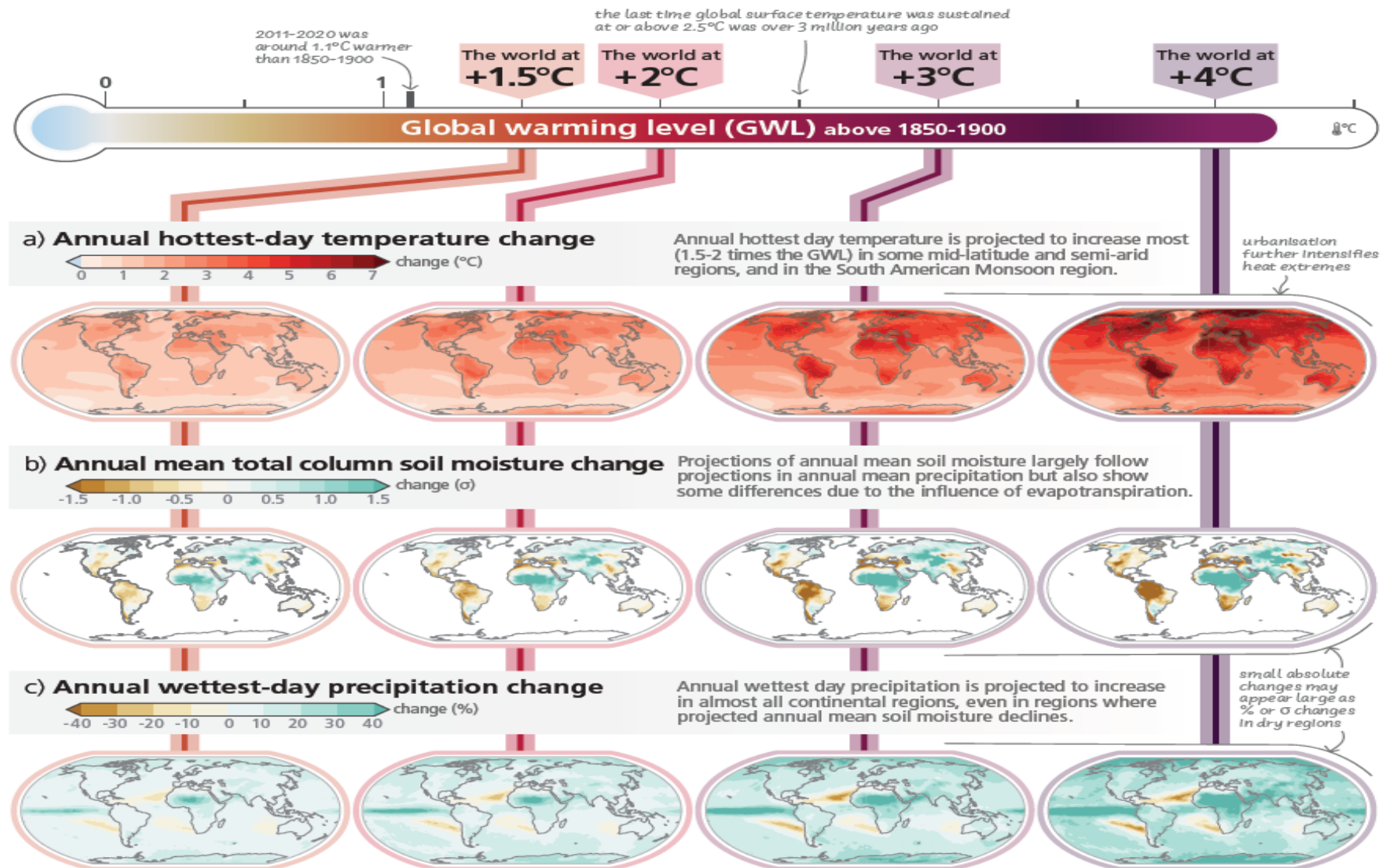
The evolutive IPCC Assessment Reports from 2023 to 2016 (No update for 2025)



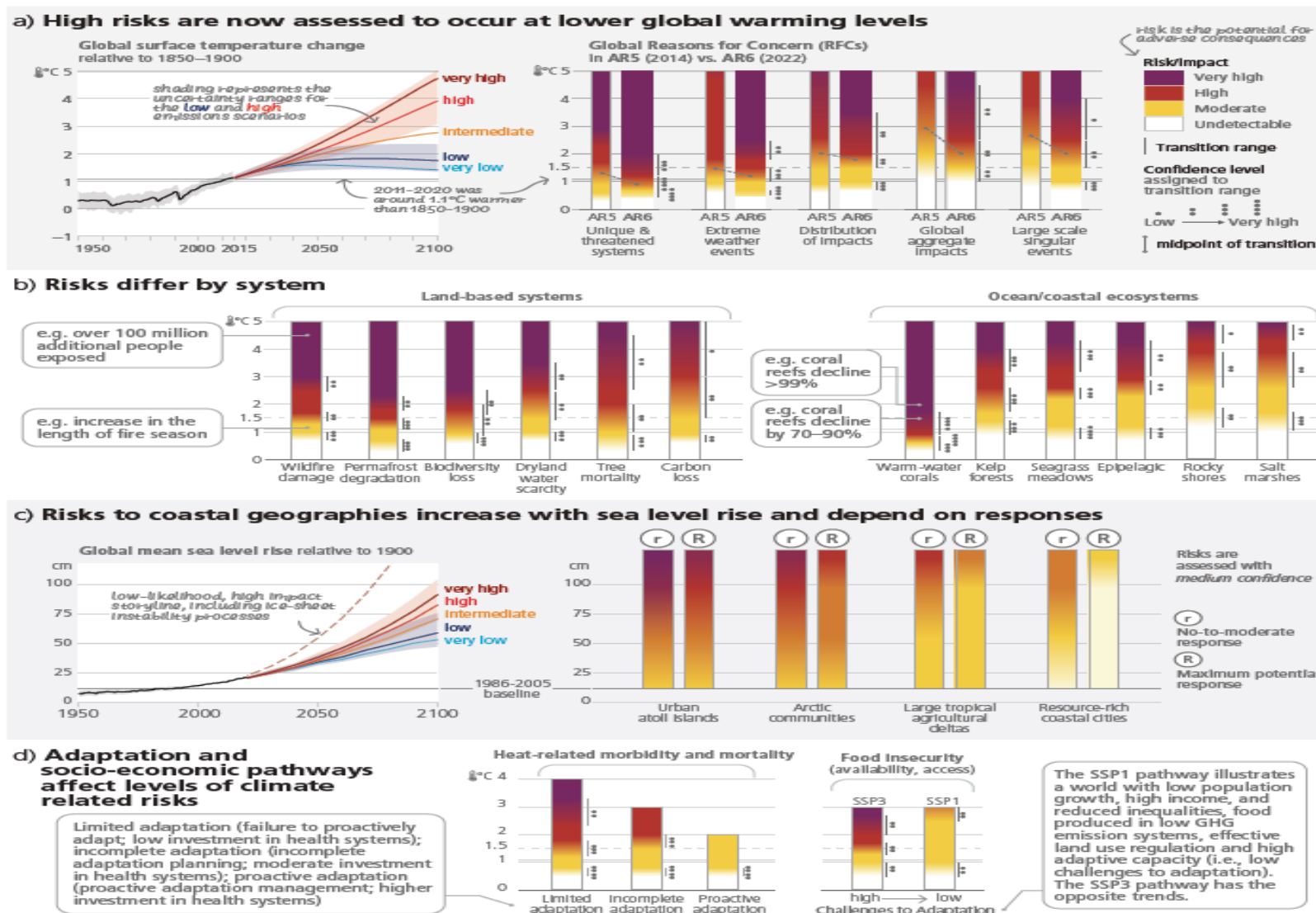
IPCC Report March 2023 Climate Change 2023 Synthesis Report (WG I,II & III) Summary for Policymakers



Global Warming Level and its consequences



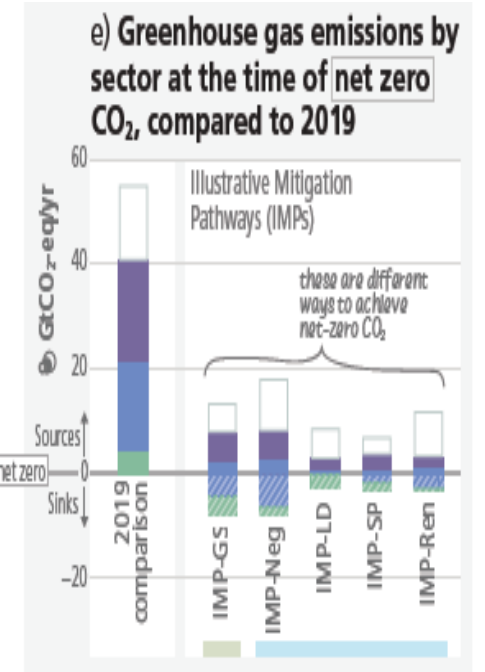
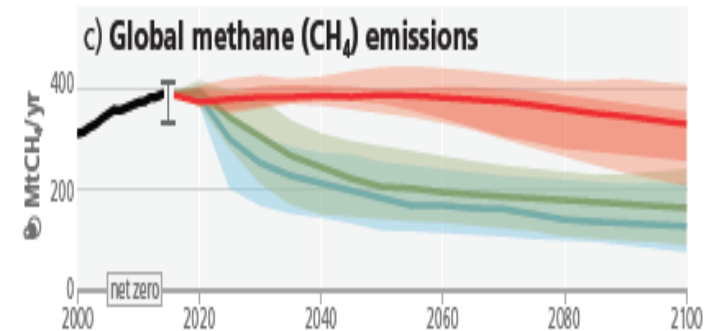
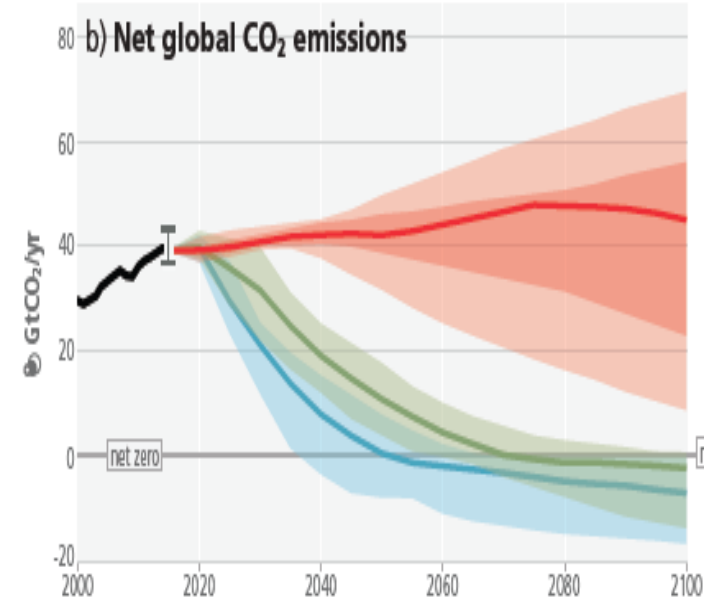
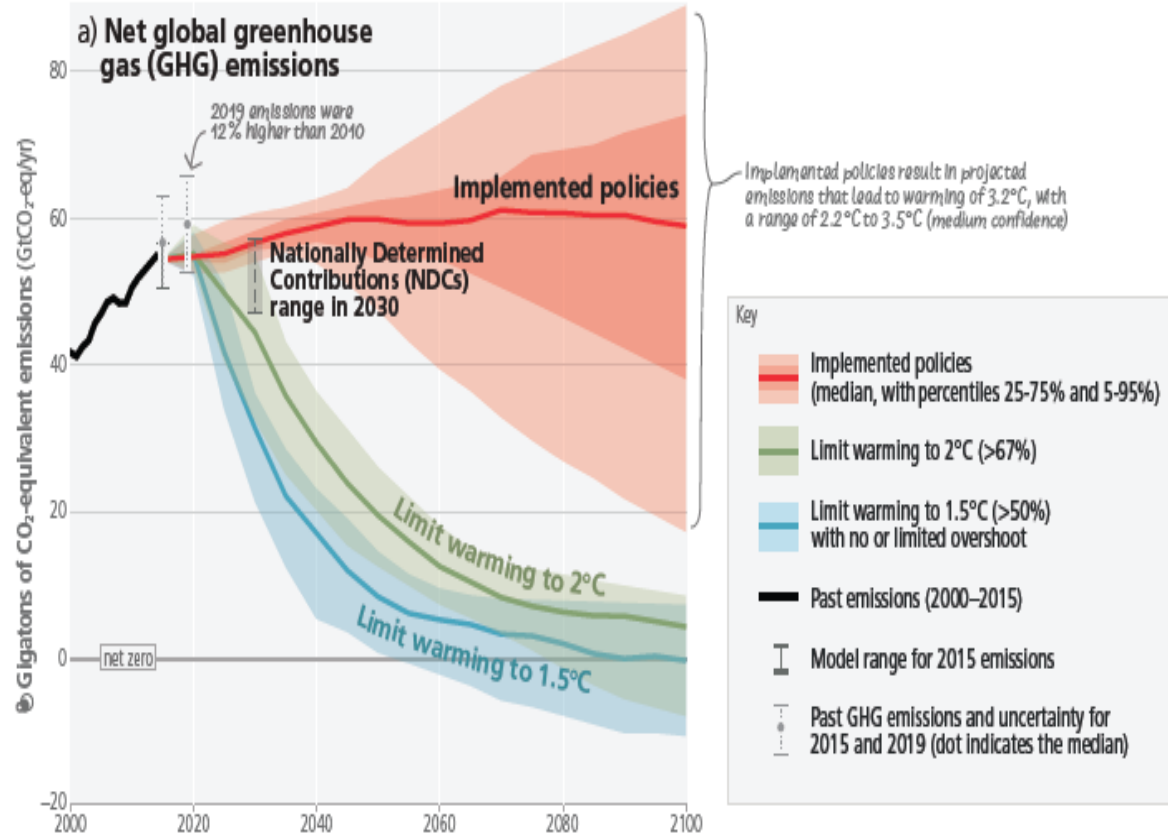
Risks are increasing with every increment of warming



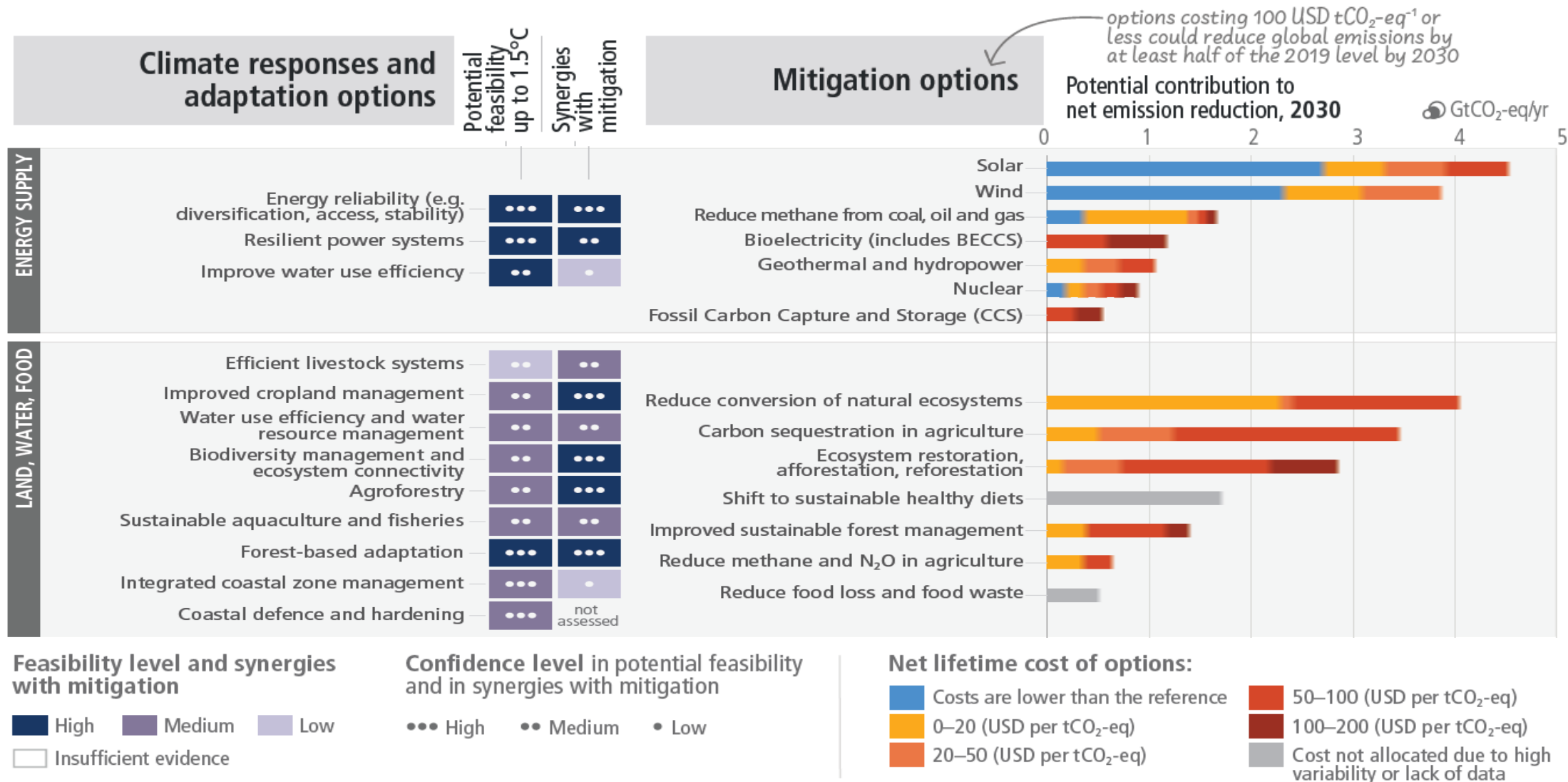
Global emissions vs Scenarios

Need for rapid, deep, immediate actions

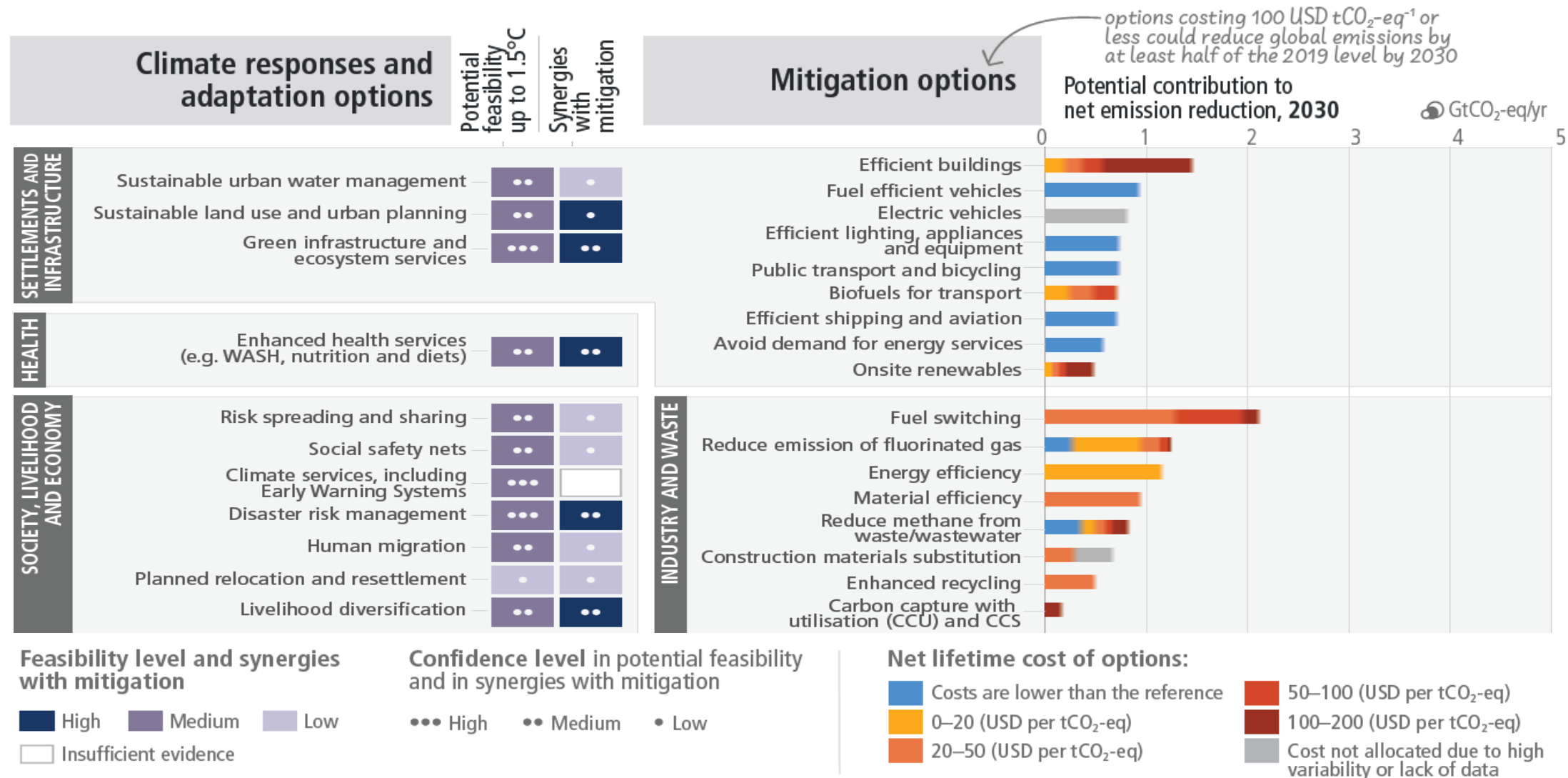
Net zero CO₂ and net zero GHG emissions can be achieved through strong reductions across all sectors



Potential contributions to Emissions reduction by sector and by costs (1)

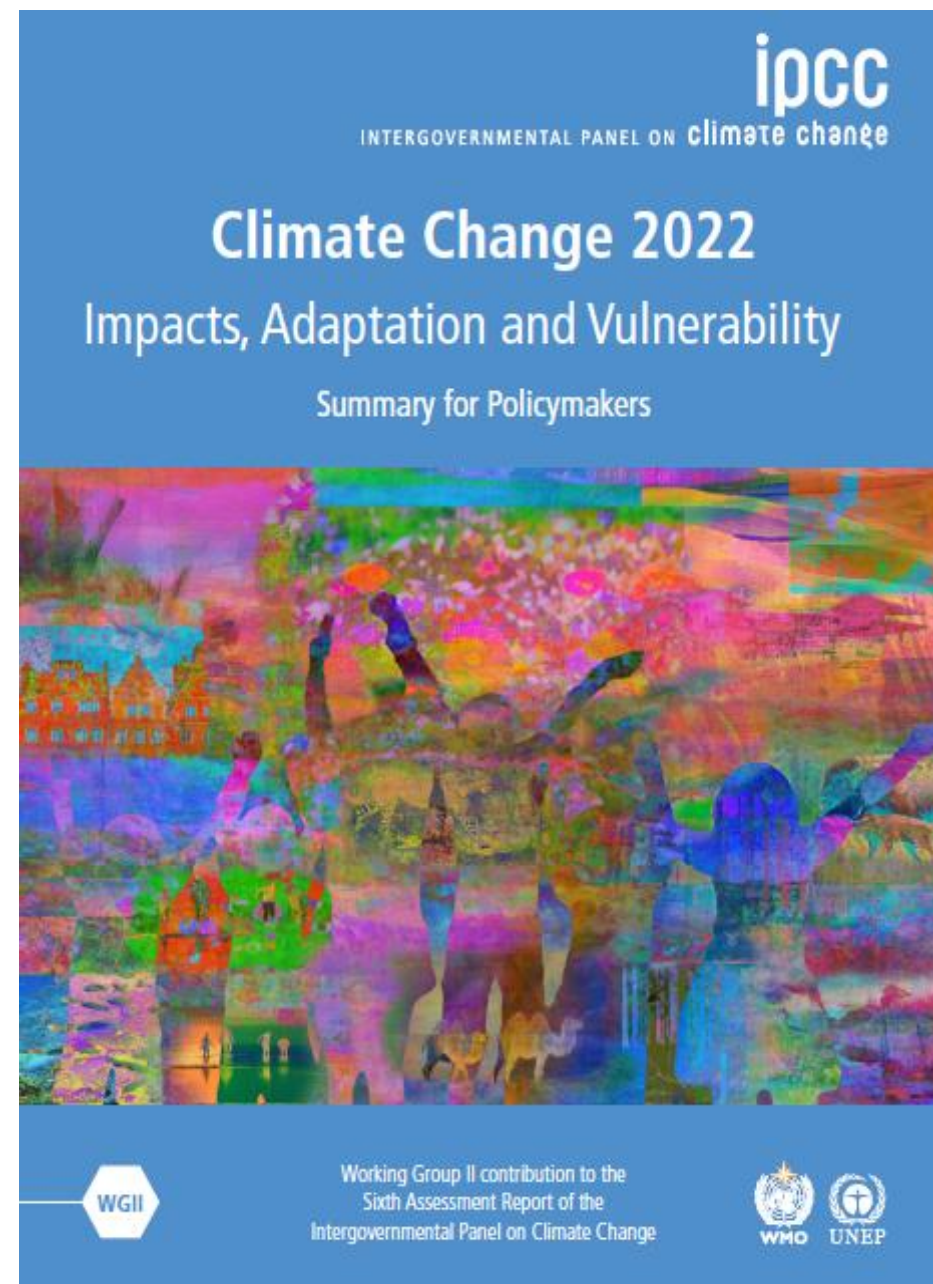


Potential contributions to Emissions reduction by sector and by costs (2)



IPCC Report March 2022 6th Assessment Report





Source: IPCC Report March 2022 WG II

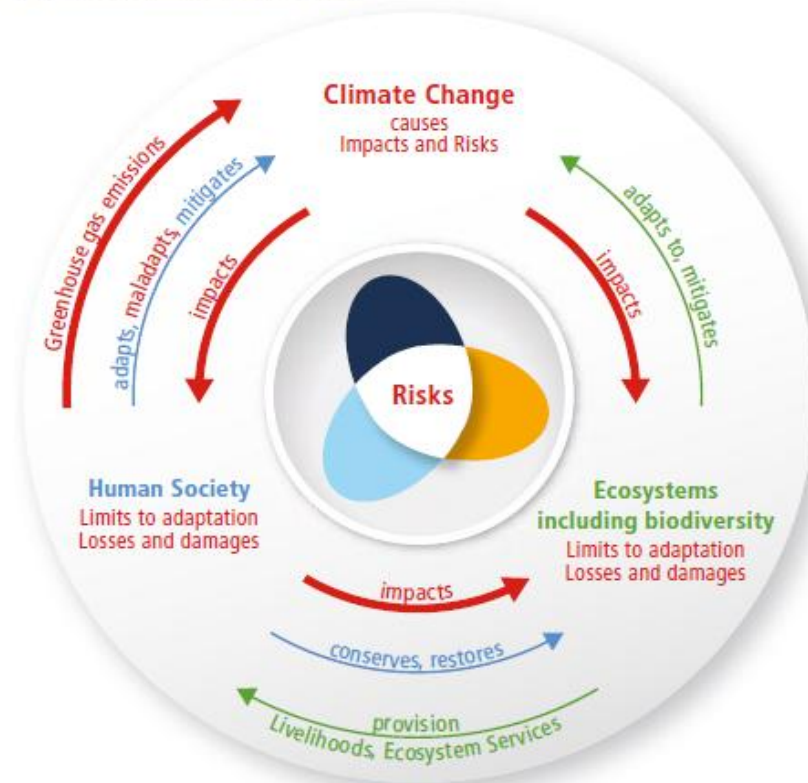


IPCC Report 2022

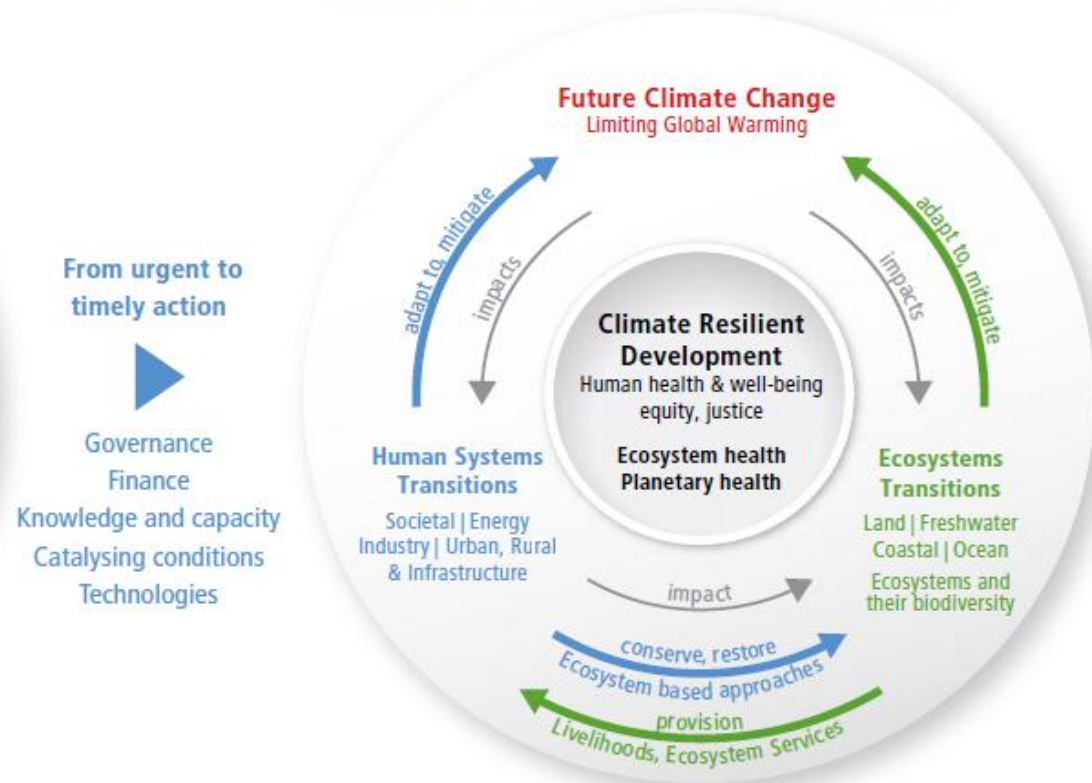
Climate Change – Limiting Global Warming

From climate risk to climate resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems

(a) Main interactions and trends



(b) Options to reduce climate risks and establish resilience



The risk propeller shows that risk emerges from the overlap of:

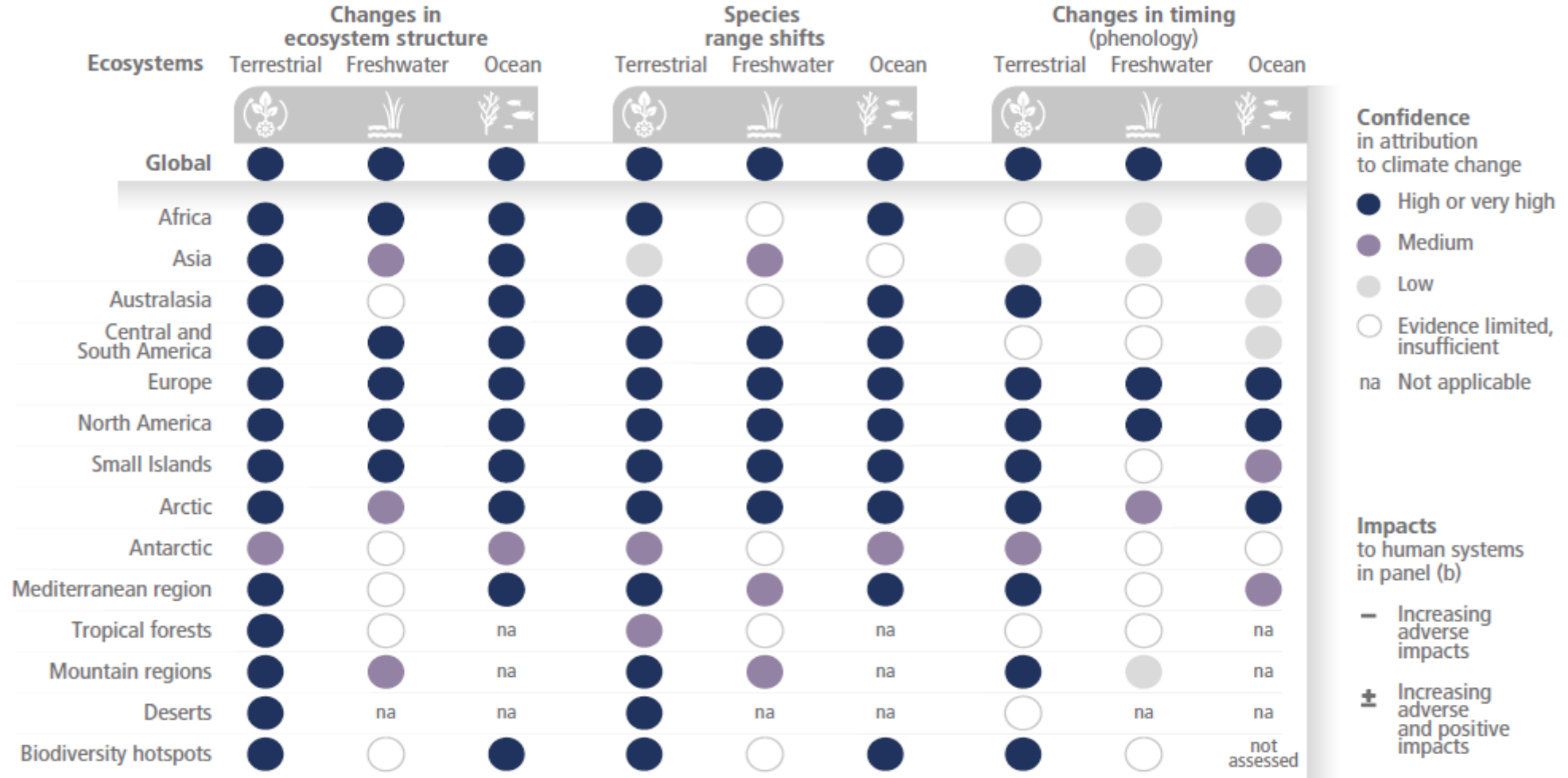


Source: IPCC Report March 2022 WG II

IPCC Report 2022

Impacts of Climate Change

(a) Observed impacts of climate change on ecosystems



IPCC Report 2022

Impacts of Climate Change

(b) Observed impacts of climate change on human systems

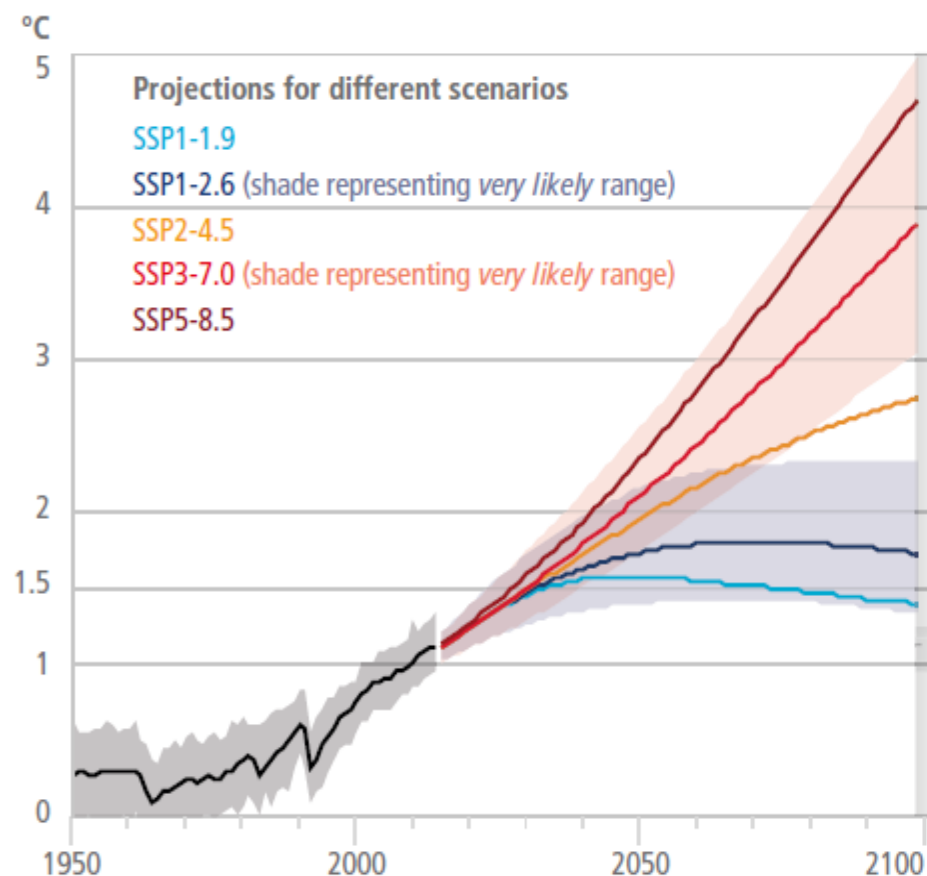
Human systems	Impacts on water scarcity and food production				Impacts on health and wellbeing				Impacts on cities, settlements and infrastructure			
	Water scarcity	Agriculture/crop production	Animal and livestock health and productivity	Fisheries yields and aquaculture production	Infectious diseases	Heat, malnutrition and other	Mental health	Displacement	Inland flooding and associated damages	Flood/storm induced damages in coastal areas	Damages to infrastructure	Damages to key economic sectors
Global	±	-	○	-	-	-	-	-	-	-	-	-
Africa	-	-	-	-	-	-	○	-	-	-	-	-
Asia	±	±	-	-	-	-	-	-	-	-	-	-
Australasia	±	-	±	-	-	-	-	not assessed	-	-	-	-
Central and South America	±	-	±	-	-	-	not assessed	-	-	-	-	-
Europe	±	±	-	±	-	-	-	-	-	-	-	-
North America	±	±	-	±	-	-	-	-	-	-	-	-
Small Islands	-	-	-	-	-	-	○	-	-	-	-	-
Arctic	±	±	-	-	-	-	-	-	-	-	-	±
Cities by the sea	○	○	○	-	○	-	not assessed	-	○	-	-	-
Mediterranean region	-	-	-	-	-	-	not assessed	-	±	-	○	-
Mountain regions	±	±	-	○	-	-	○	-	-	na	-	-

Source: IPCC Report March 2022 WG II

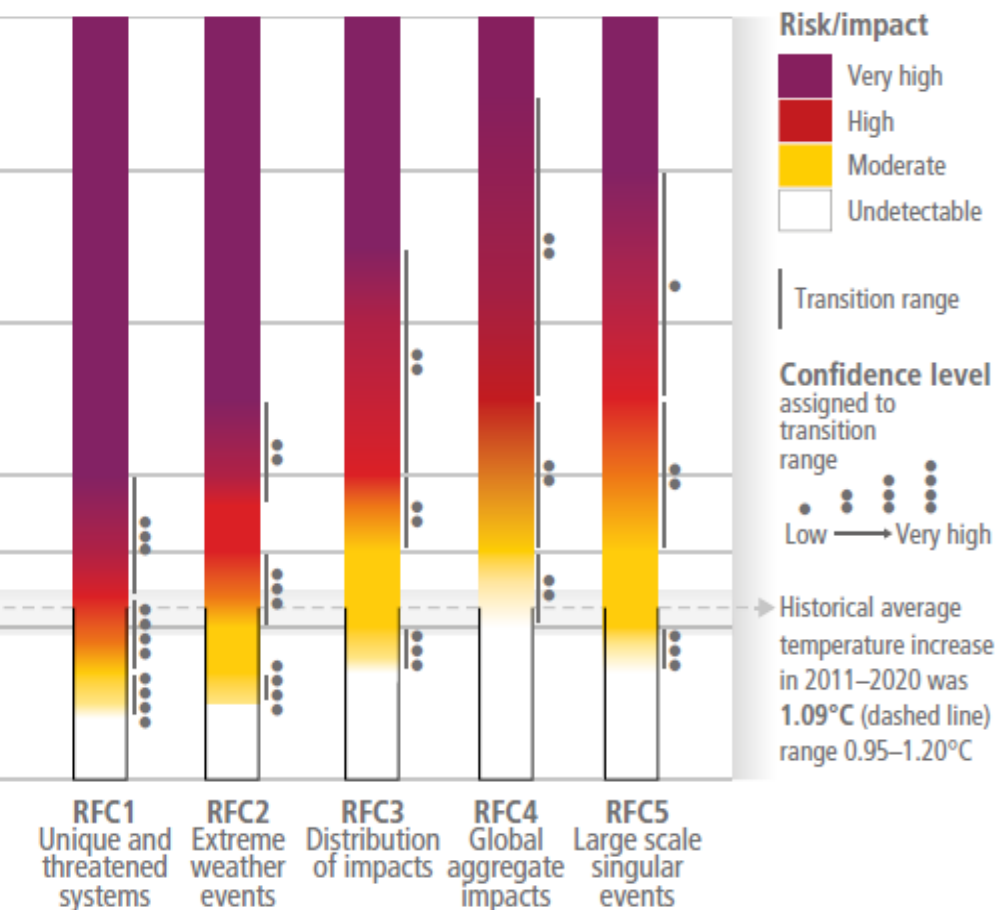


IPCC Report 2022 – Risks & Threats (1)

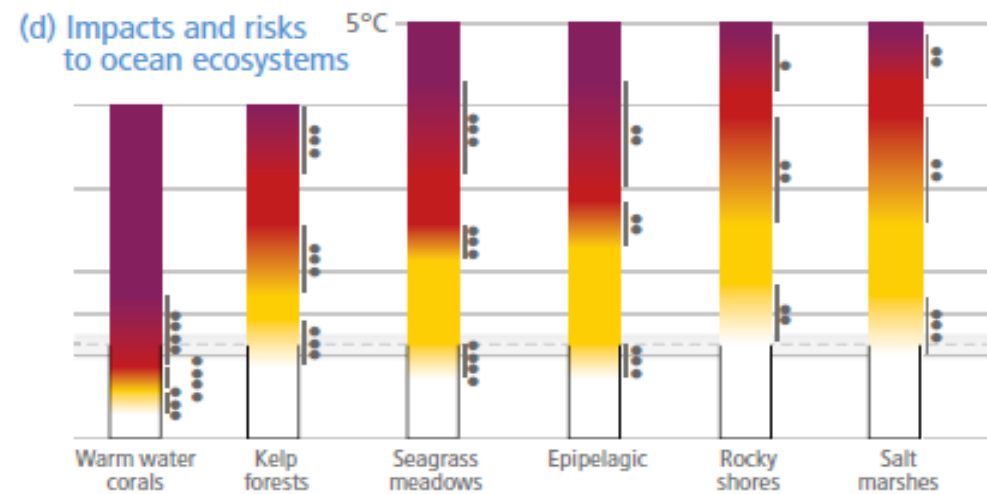
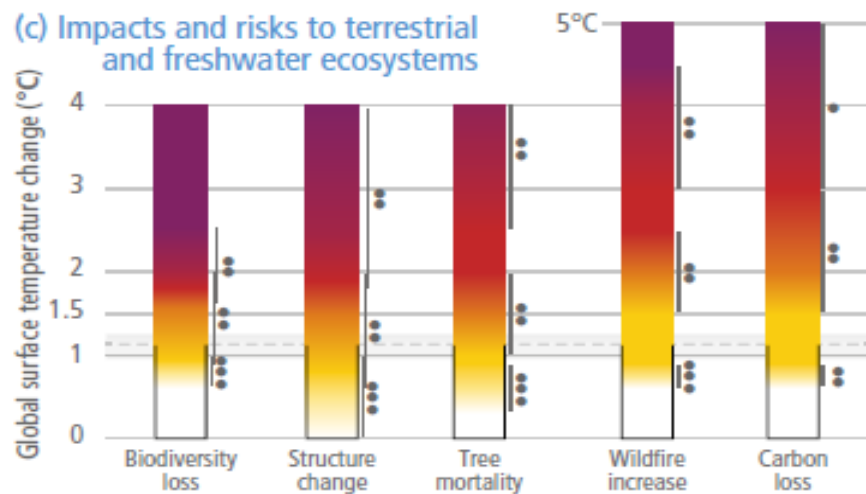
(a) Global surface temperature change
Increase relative to the period 1850–1900



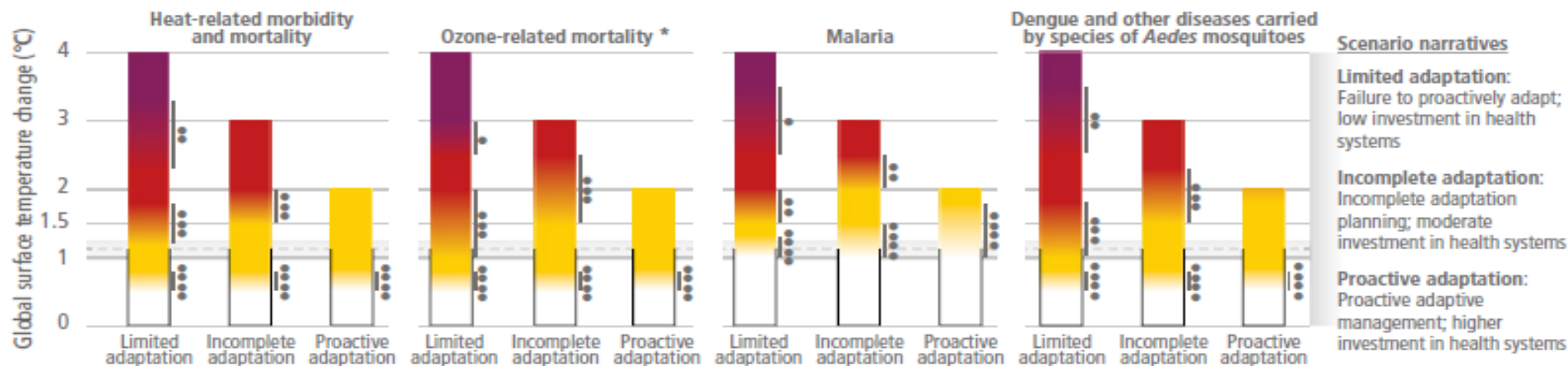
(b) Reasons for Concern (RFC)
Impact and risk assessments assuming low to no adaptation



IPCC Report 2022 – Risks & Threats (2)



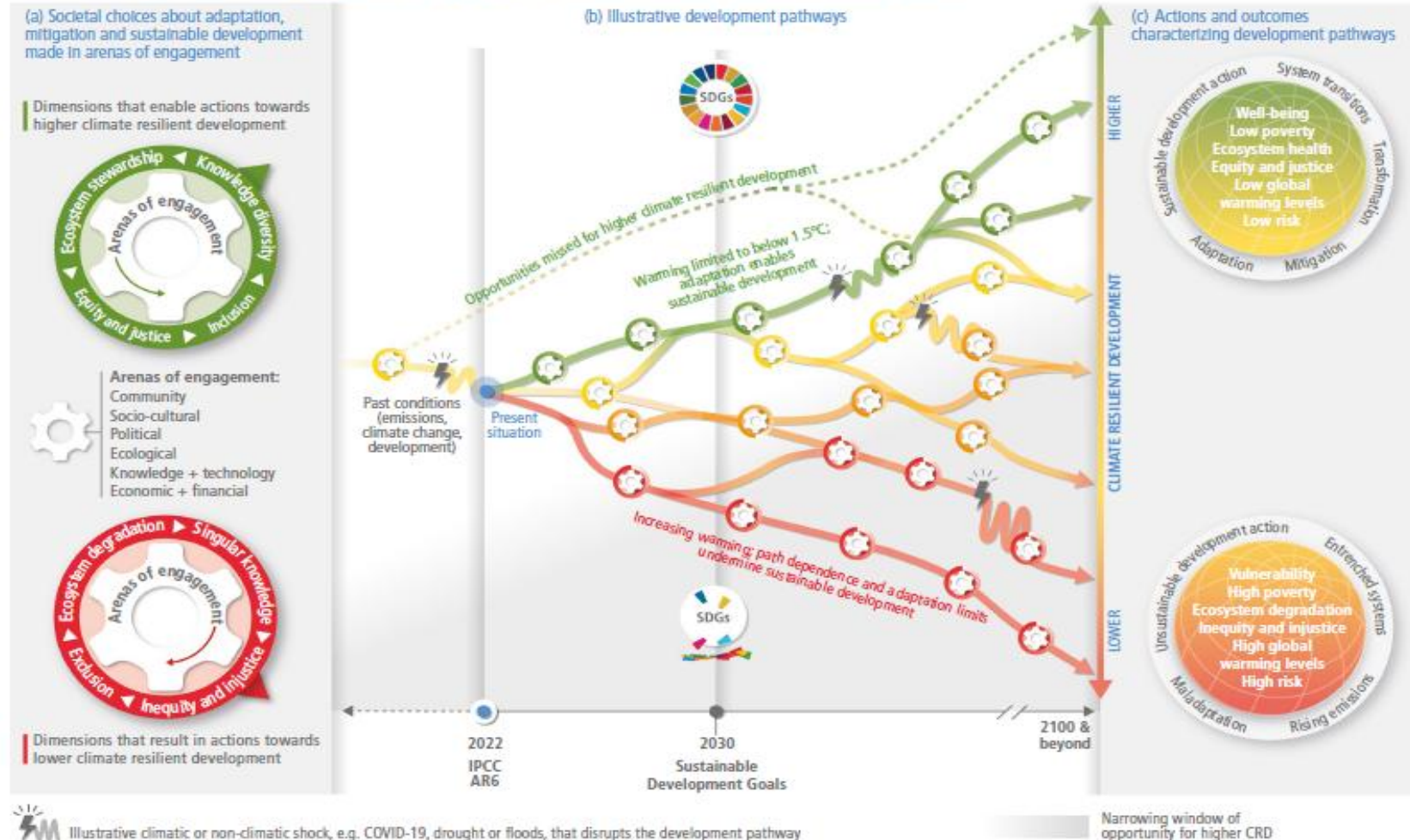
(e) Climate sensitive health outcomes under three adaptation scenarios



* Mortality projections include demographic trends but do not include future efforts to improve air quality that reduce ozone concentrations.

IPCC Report 2022 – Climate Resilient Development The Challenge

There is a rapidly narrowing window of opportunity to enable climate resilient development



Source: IPCC Report March 2022 WG II



ipcc

INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2022

Mitigation of Climate Change

Summary for Policymakers

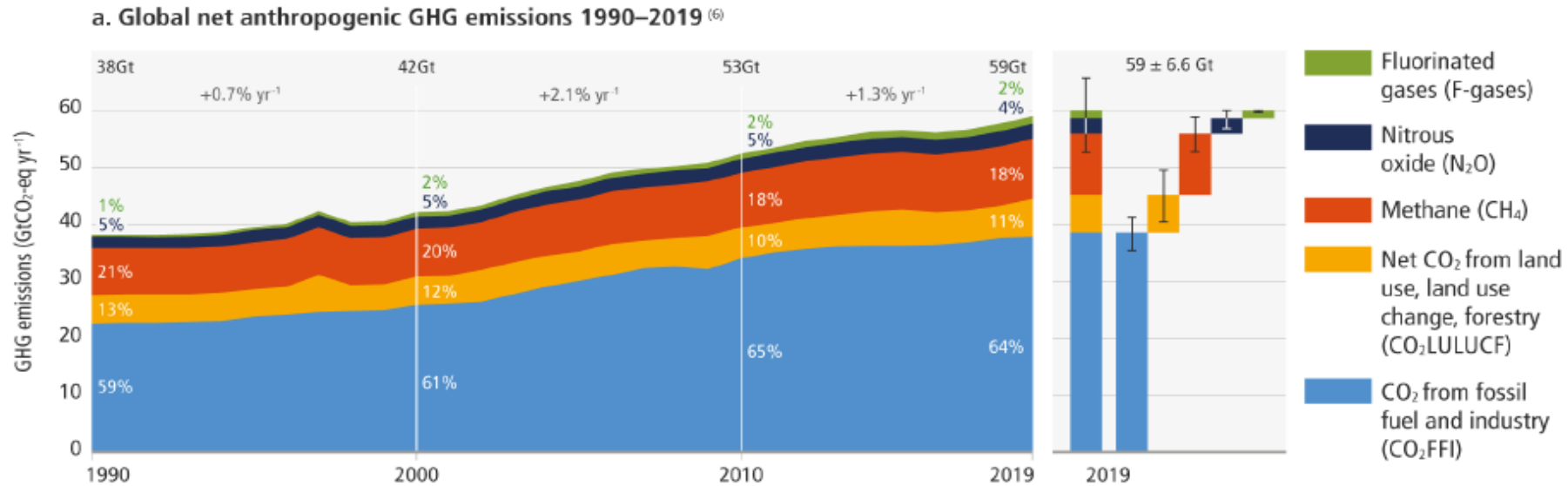


WGIII

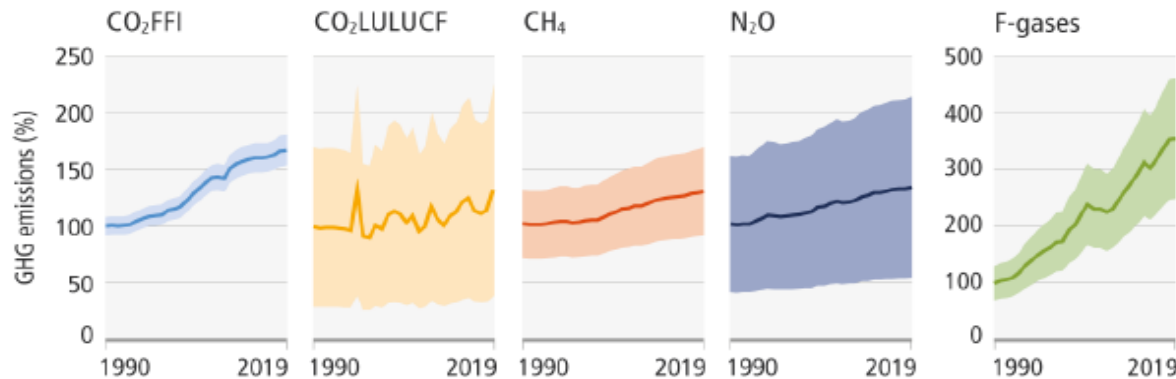
Working Group III contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change



Global anthropogenic GHG emissions 1990 - 2019



b. Global anthropogenic GHG emissions and uncertainties by gas – relative to 1990

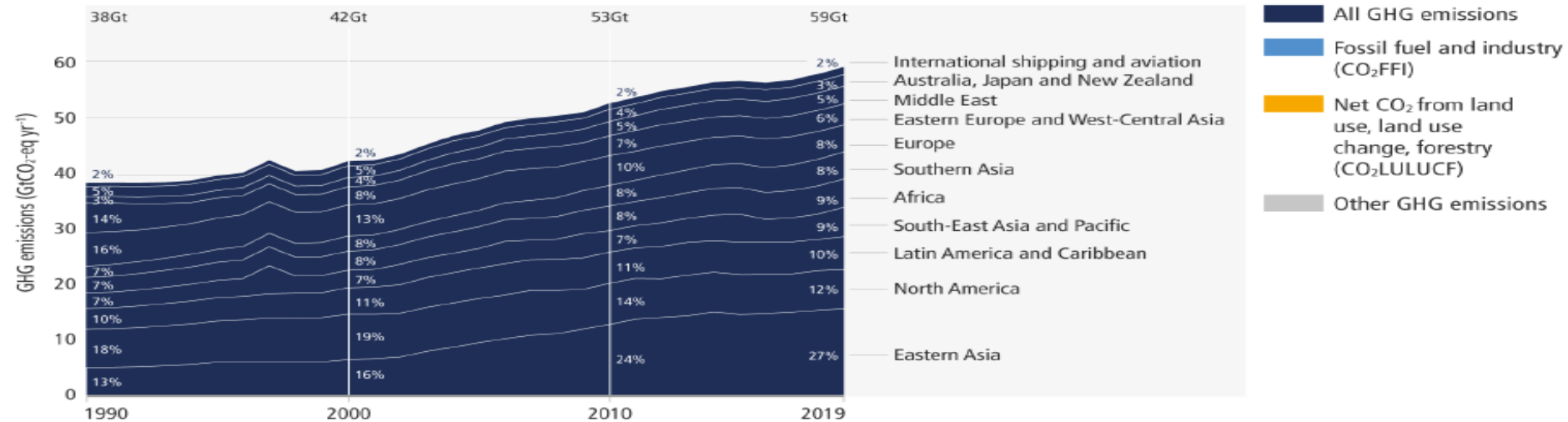


The solid line indicates central estimate of emissions trends. The shaded area indicates the uncertainty range.

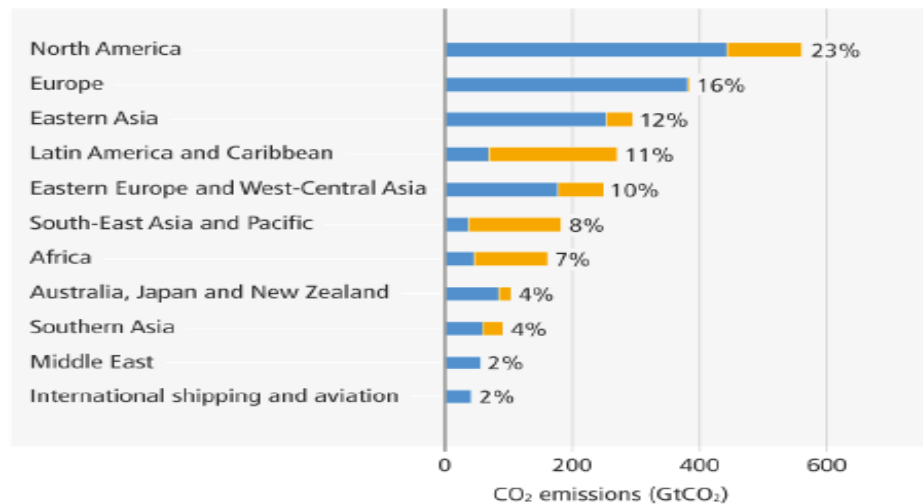
	2019 emissions (GtCO ₂ -eq)	1990–2019 increase (GtCO ₂ -eq)	Emissions in 2019, relative to 1990 (%)
CO ₂ FFI	38±3	15	167
CO ₂ LULUCF	6.6±4.6	1.6	133
CH ₄	11±3.2	2.4	129
N ₂ O	2.7±1.6	0.65	133
F-gases	1.4±0.41	0.97	354
Total	59±6.6	21	154

Global anthropogenic GHG emissions 1990 - 2019

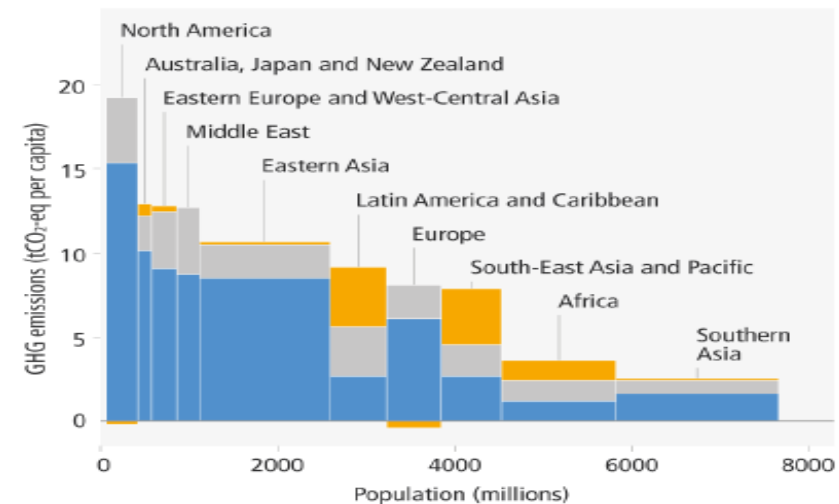
a. Global net anthropogenic GHG emissions by region (1990–2019)



b. Historical cumulative net anthropogenic CO₂ emissions per region (1850–2019)



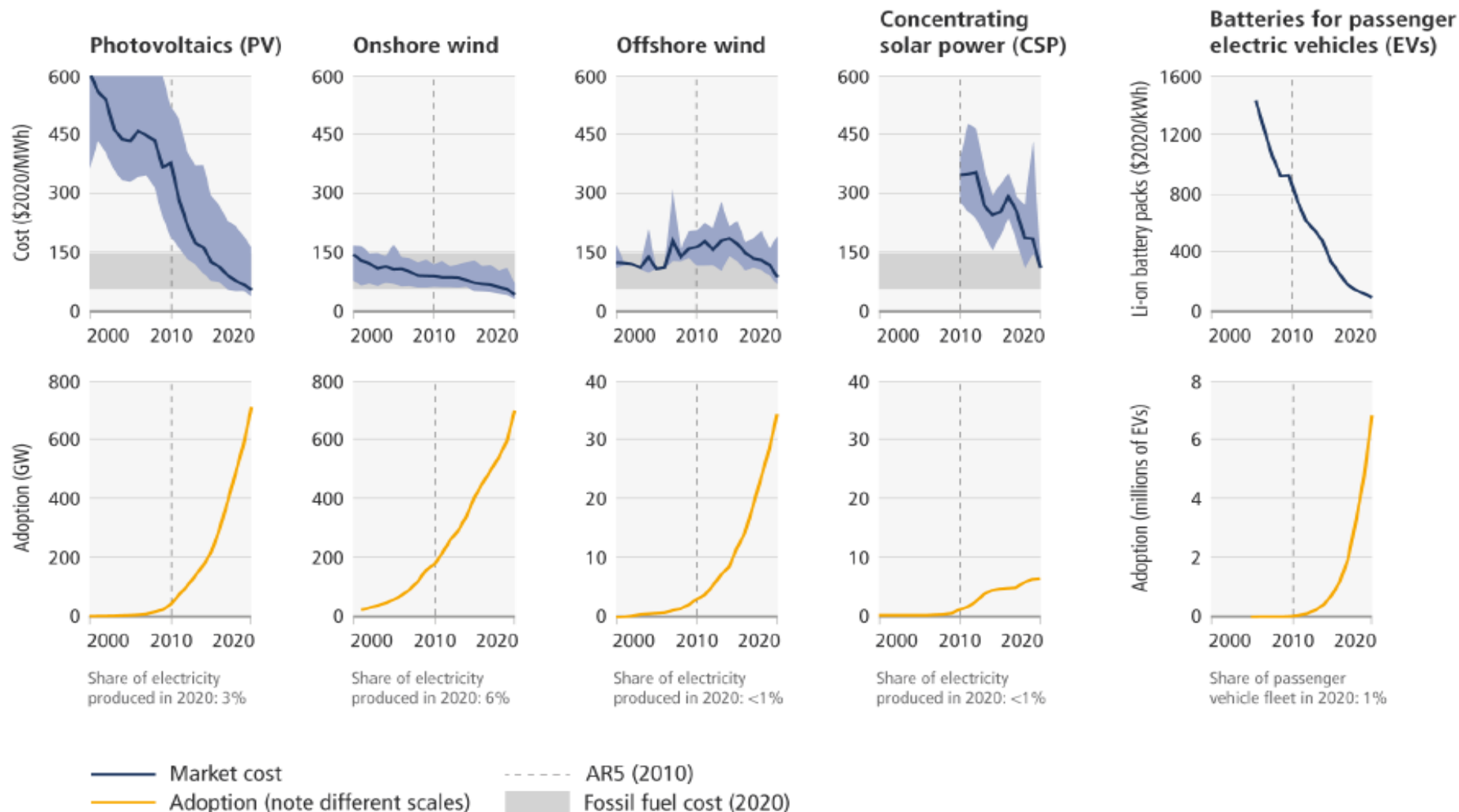
c. Net anthropogenic GHG emissions per capita and for total population, per region (2019)



Source: IPCC Report March 2022 WG III



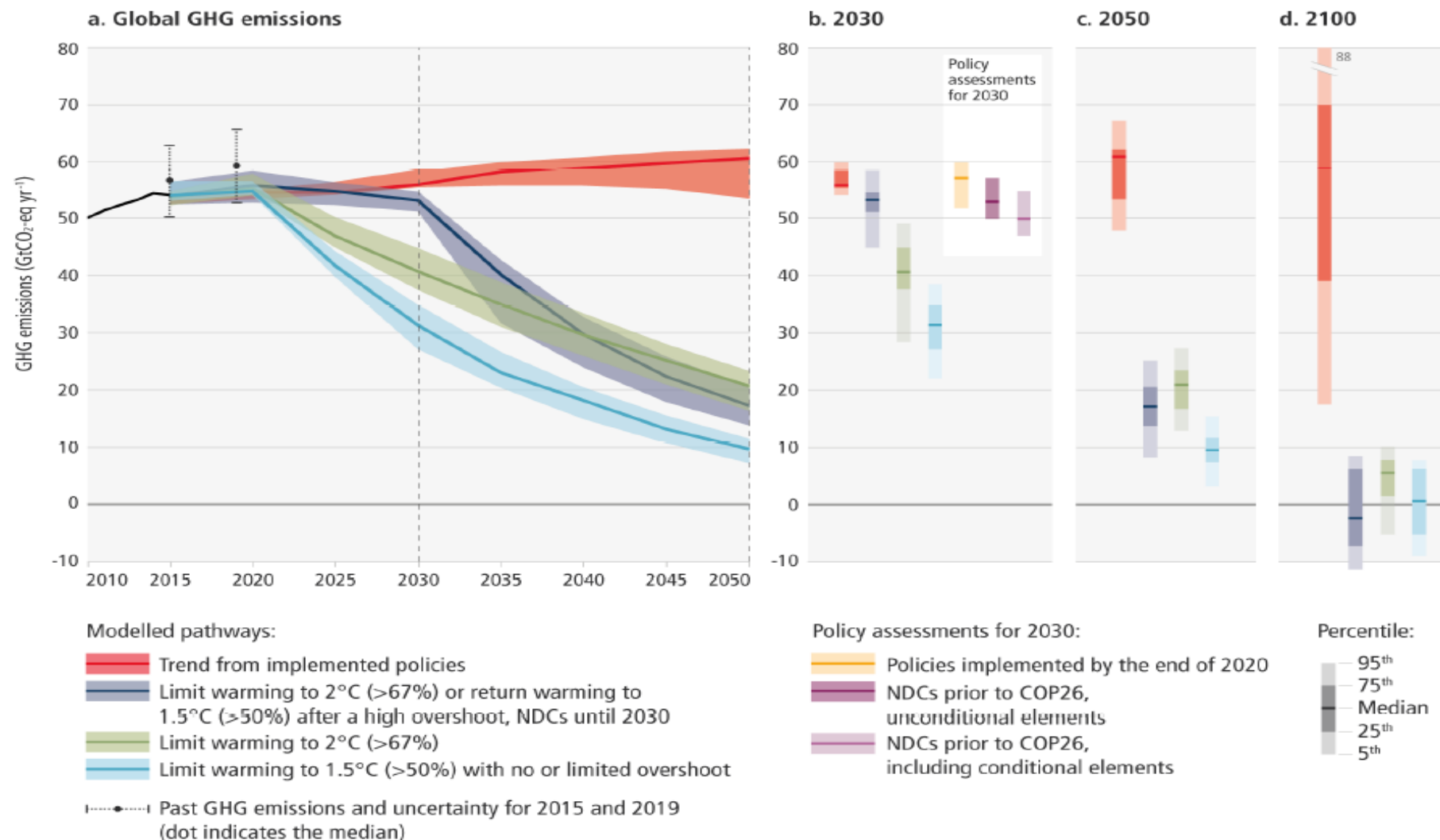
Costs reductions & Contributions increase of Renewable Energy 2000 - 2020



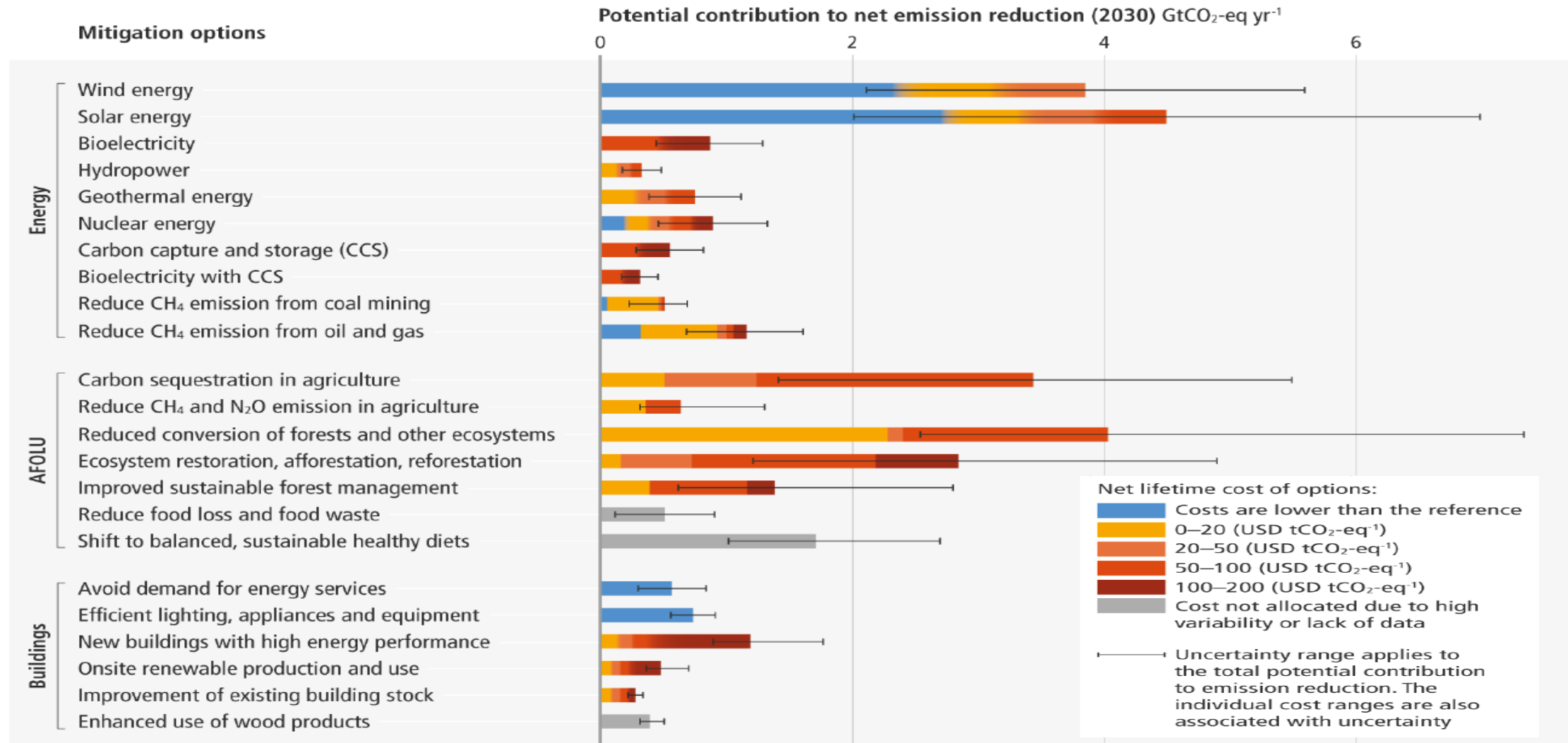
Source: IPCC Report March 2022 WG III



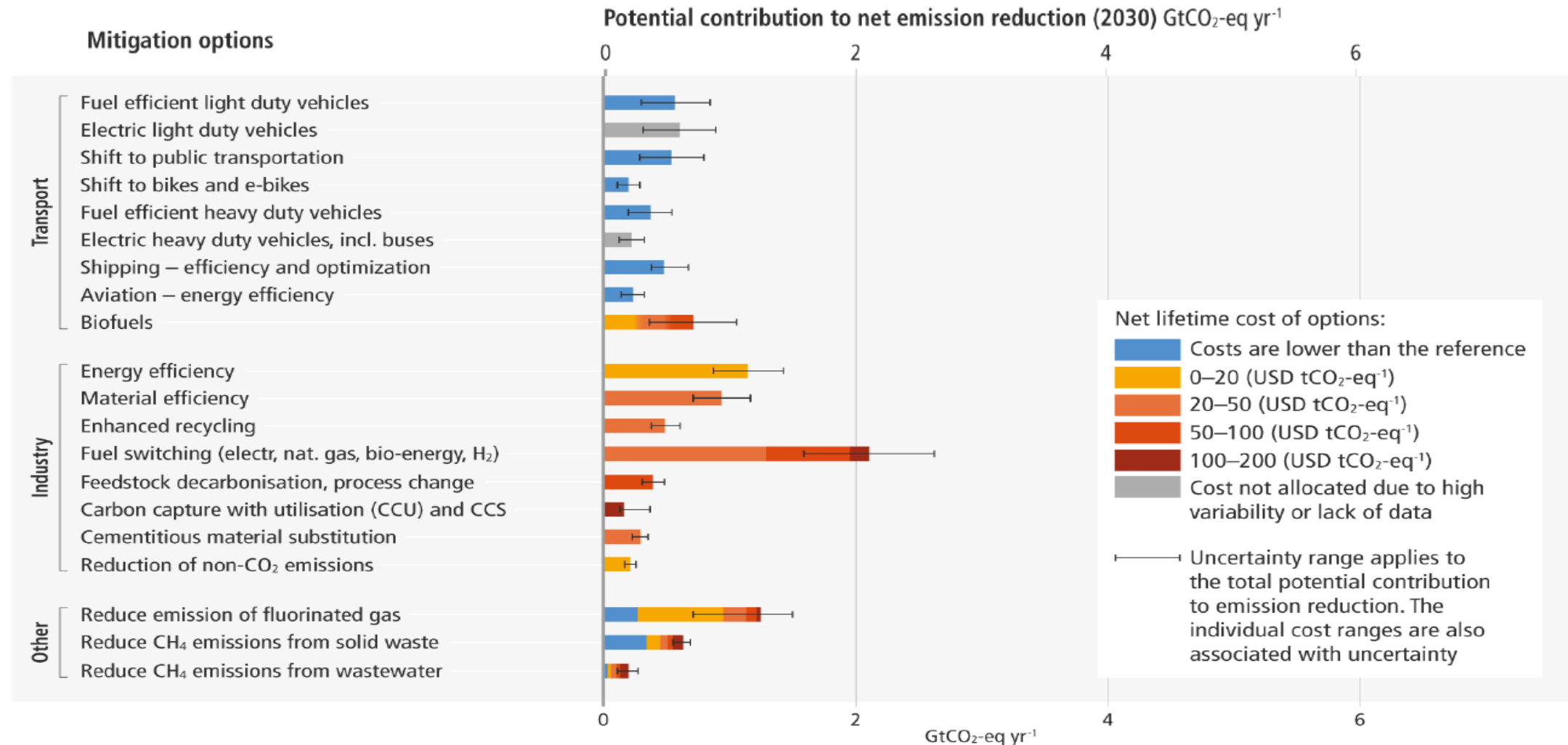
IPCC various Scenarios 2010 - 2050



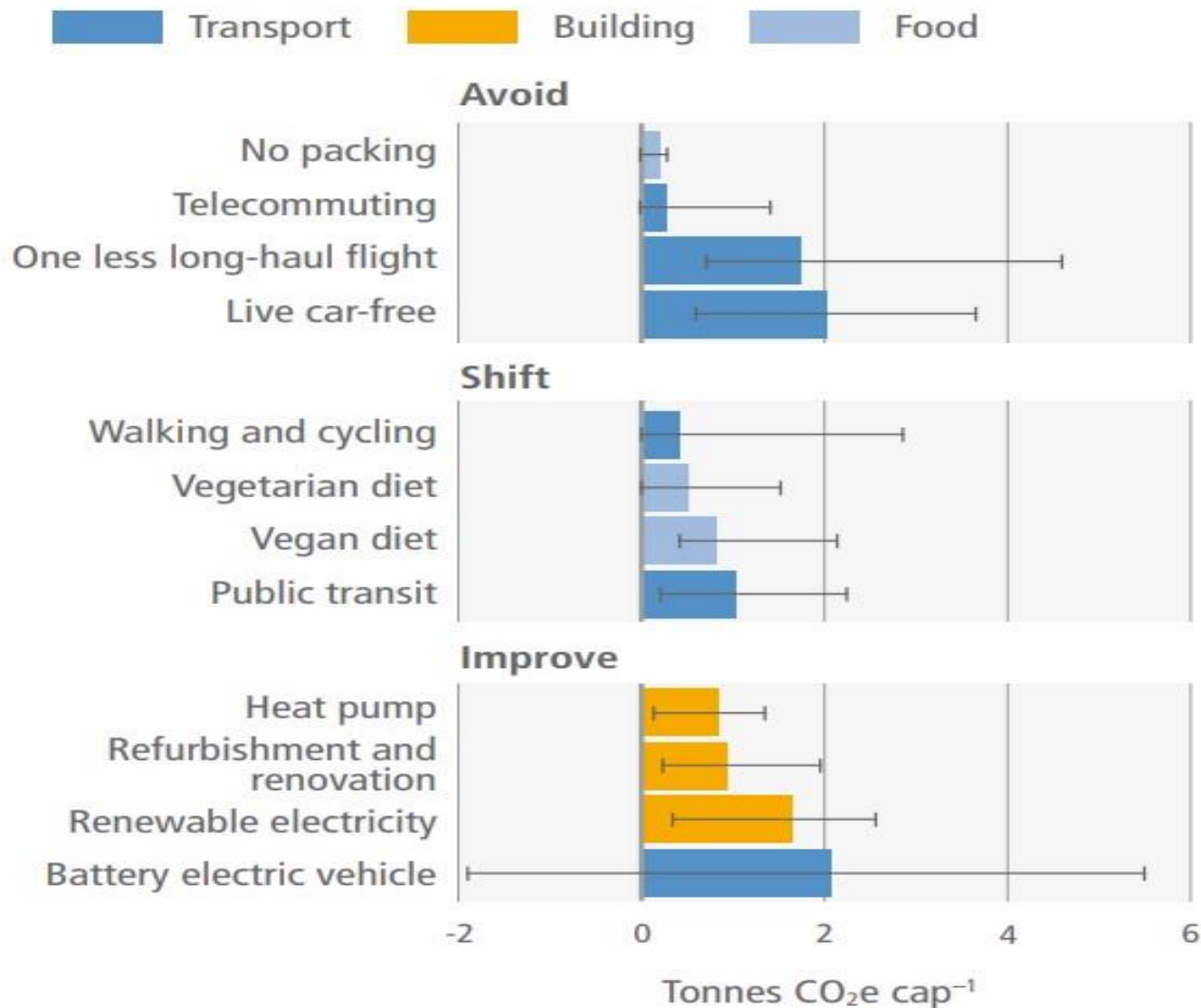
Potential contributions to Emissions reduction by sector and by costs (1)



Potential contributions to Emissions reduction by sector and by costs (2)



Mitigation of Climate Change : Behaviour



Low-carbon lifestyle transition can be classified into :

- Avoid
- Shift
- Improve

options; individual potential to reduce emissions is highest in mobility systems

Source:
IPCC AR6 WGIII –Technical Summary April 2022



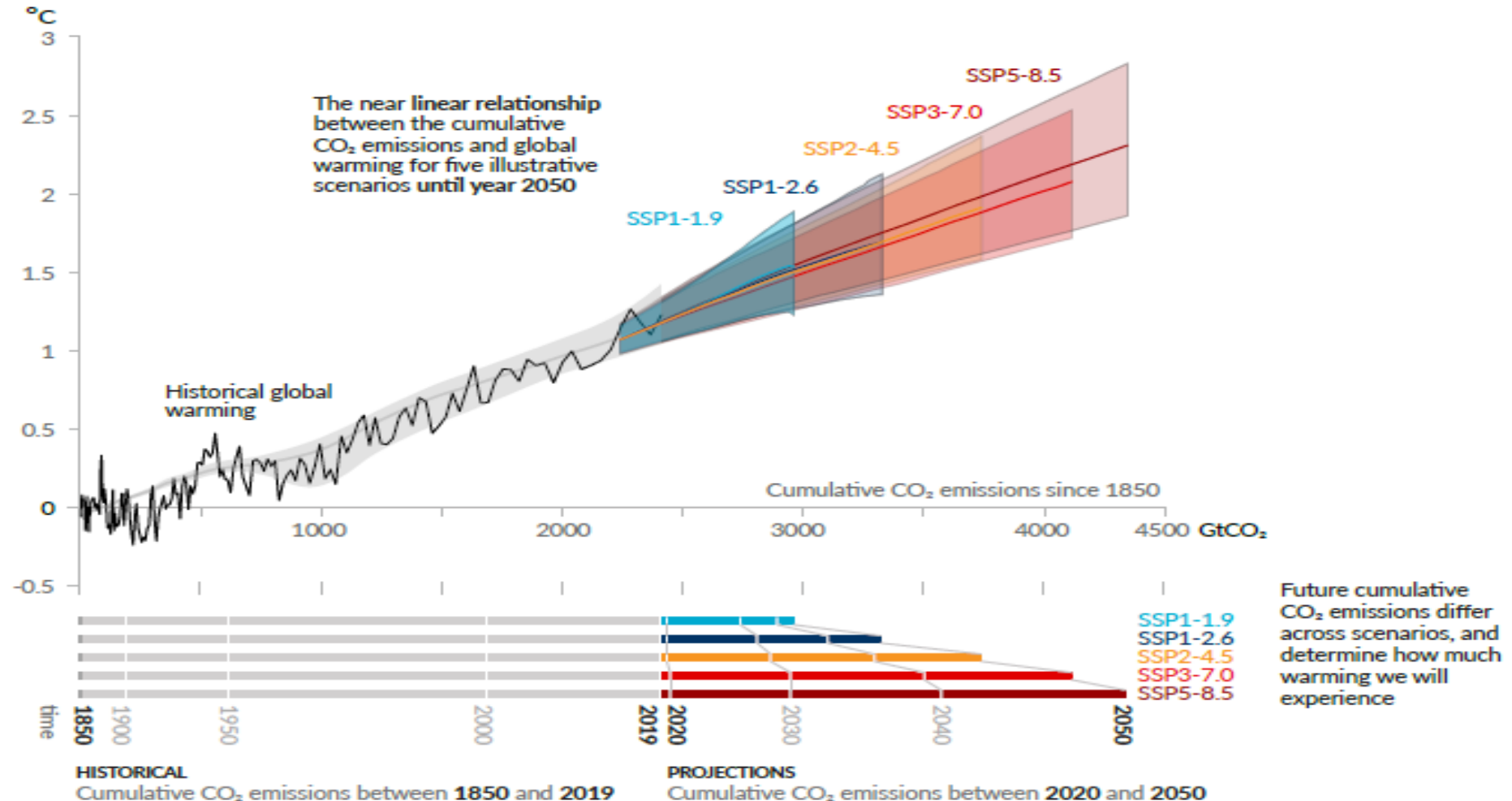
IPCC Report August 2021 – AR6 (Available for COP 26 Meeting)



IPCC Report August 2021

Confirmation of a forthcoming climate disaster

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



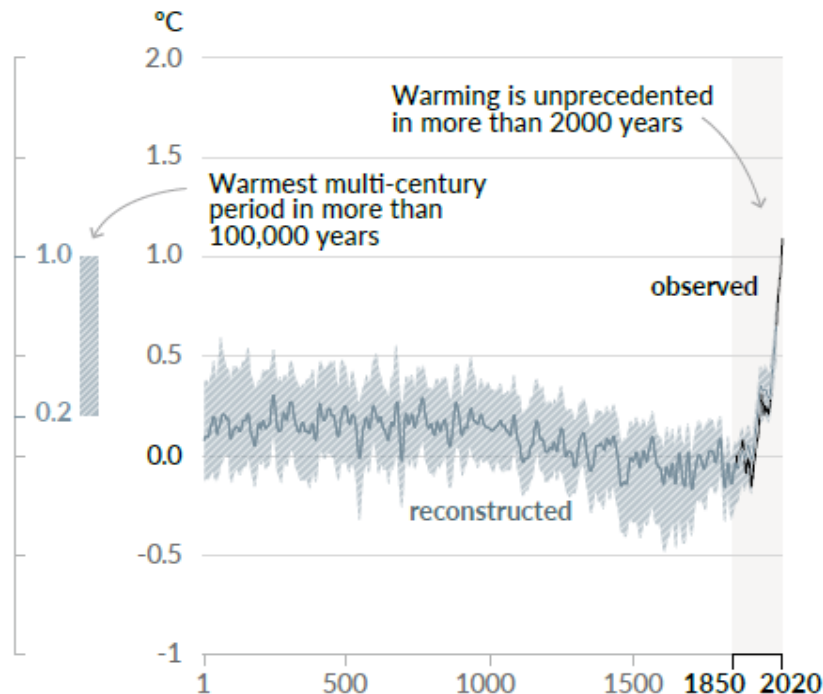
IPCC Report August 2021

Confirmation of a forthcoming climate disaster

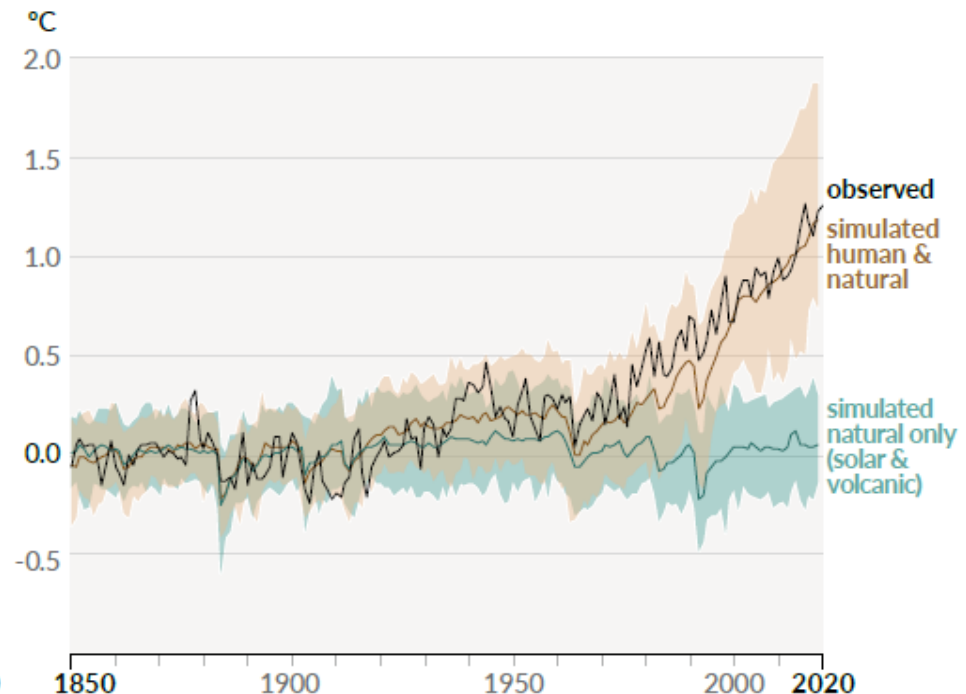
Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)



b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)



Source: IPCC Report August 2021

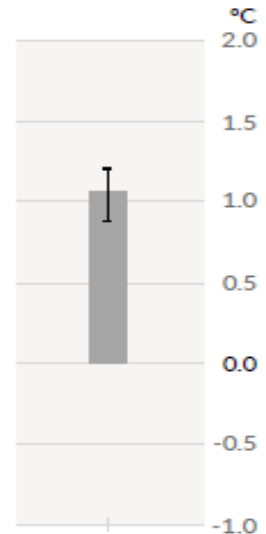


IPCC Report August 2021

Confirmation of a forthcoming climate disaster

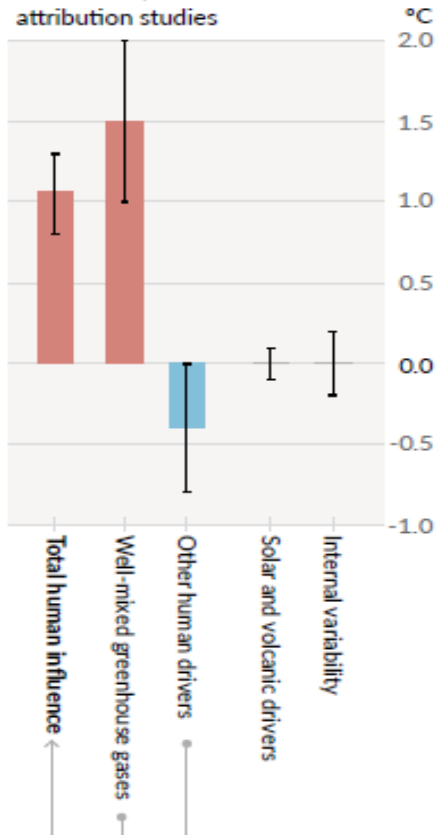
Observed warming

a) Observed warming 2010-2019 relative to 1850-1900

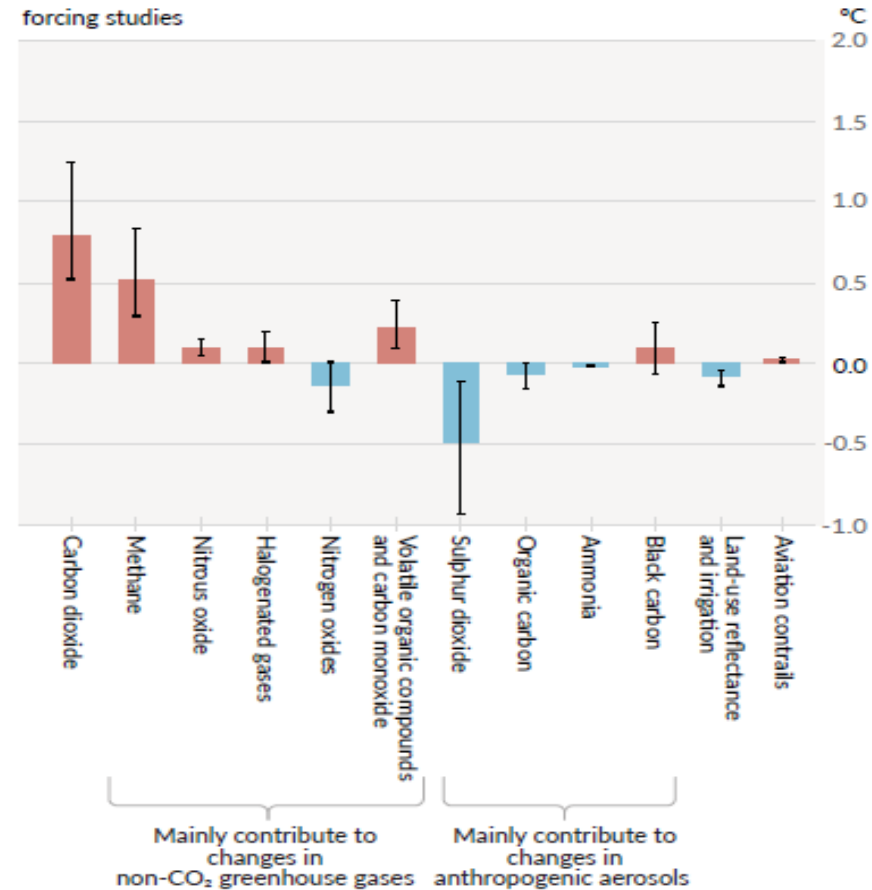


Contributions to warming based on two complementary approaches

b) Aggregated contributions to 2010-2019 warming relative to 1850-1900, assessed from attribution studies



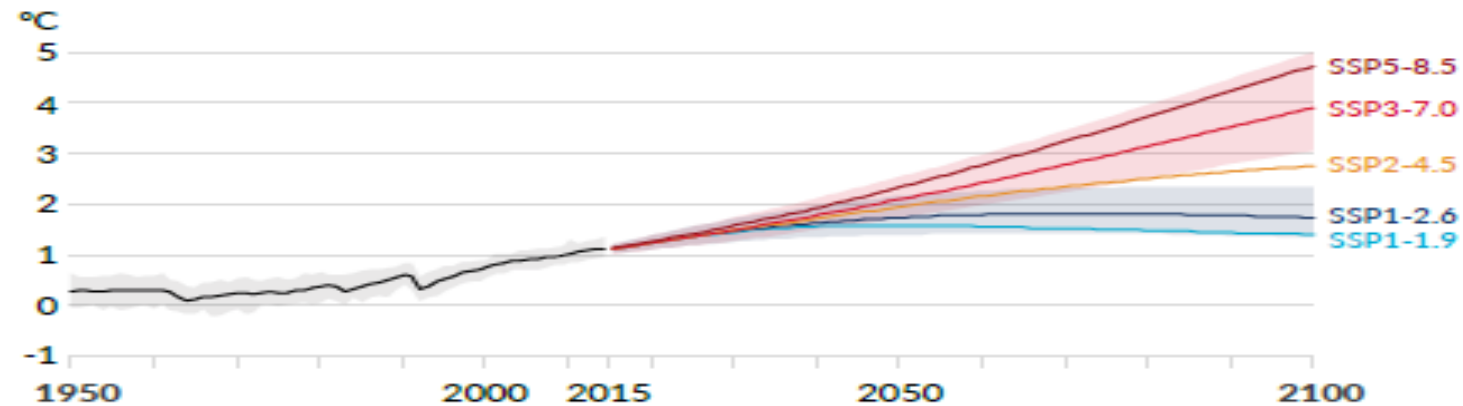
c) Contributions to 2010-2019 warming relative to 1850-1900, assessed from radiative forcing studies



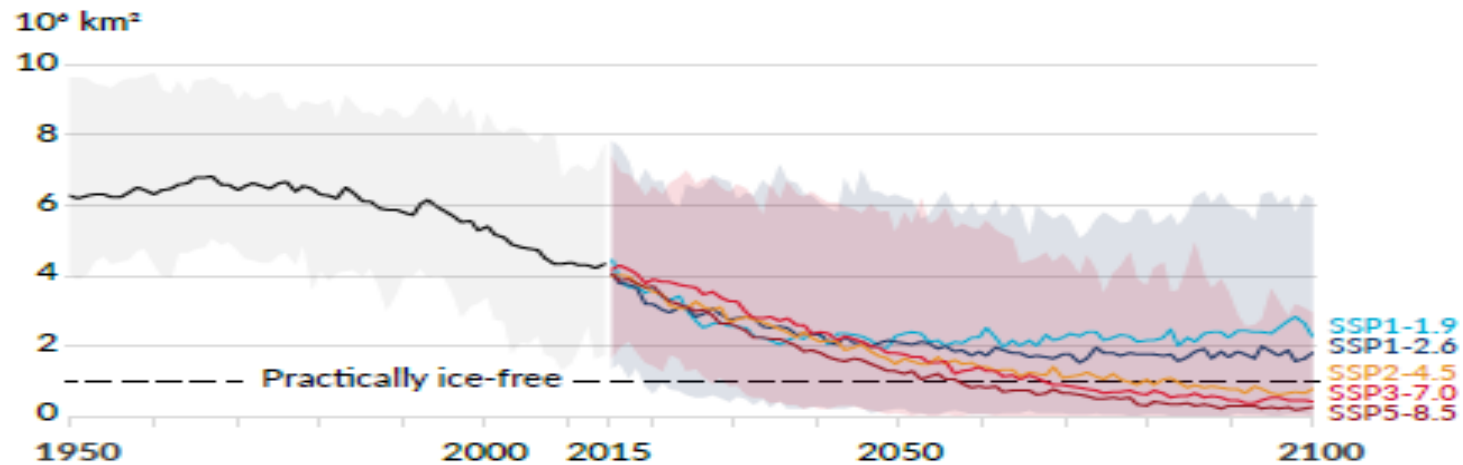
IPCC Report August 2021

Confirmation of a forthcoming climate disaster

a) Global surface temperature change relative to 1850-1900



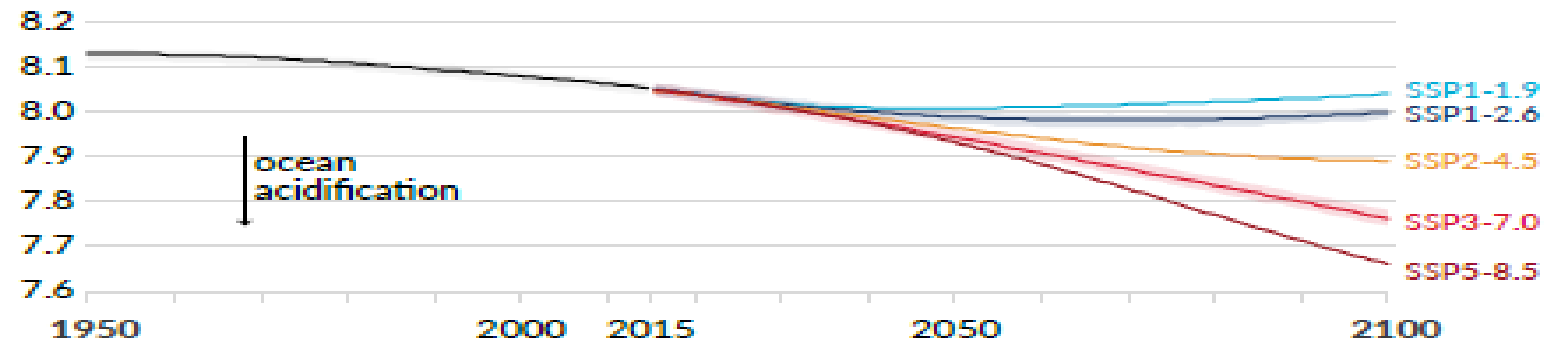
b) September Arctic sea ice area



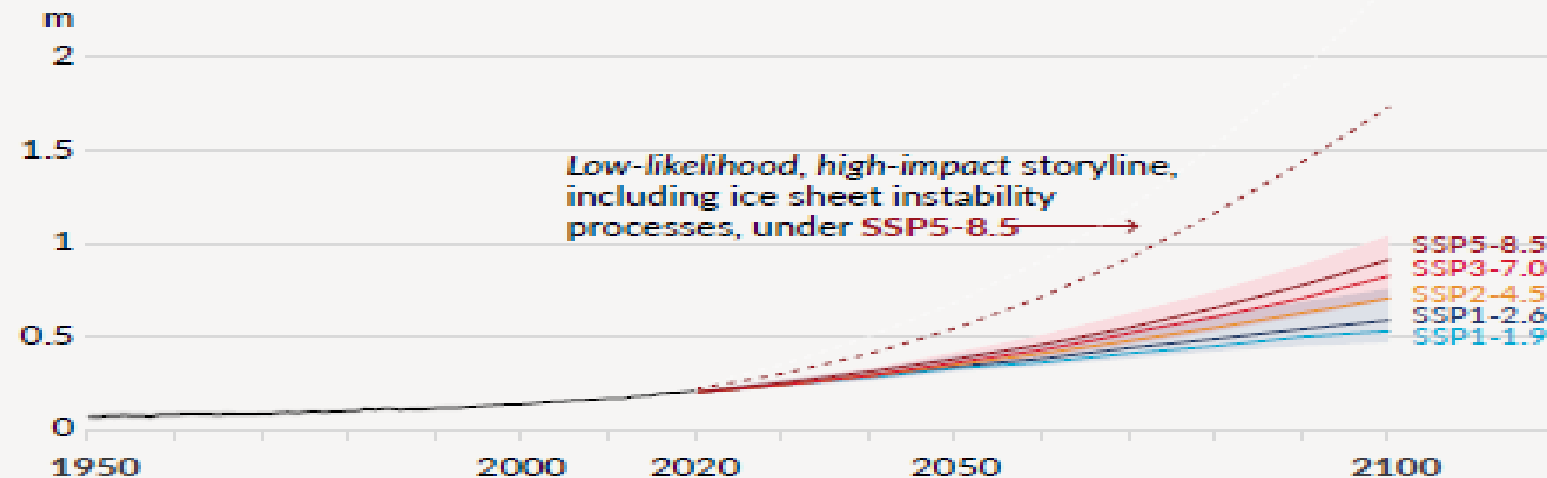
IPCC Report August 2021

Confirmation of a forthcoming climate disaster

c) Global ocean surface pH (a measure of acidity)



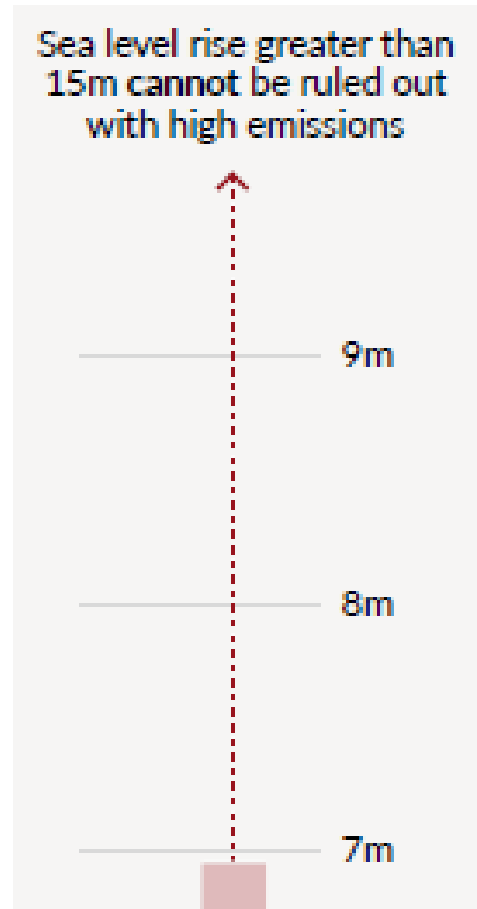
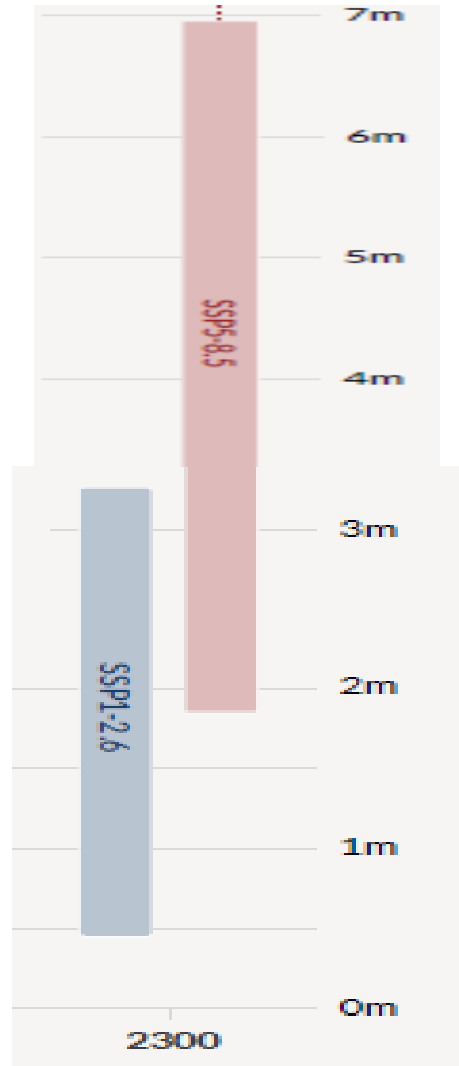
d) Global mean sea level change relative to 1900



IPCC Report August 2021

Confirmation of a forthcoming climate disaster

e) Global mean sea level change in 2300 relative to 1900

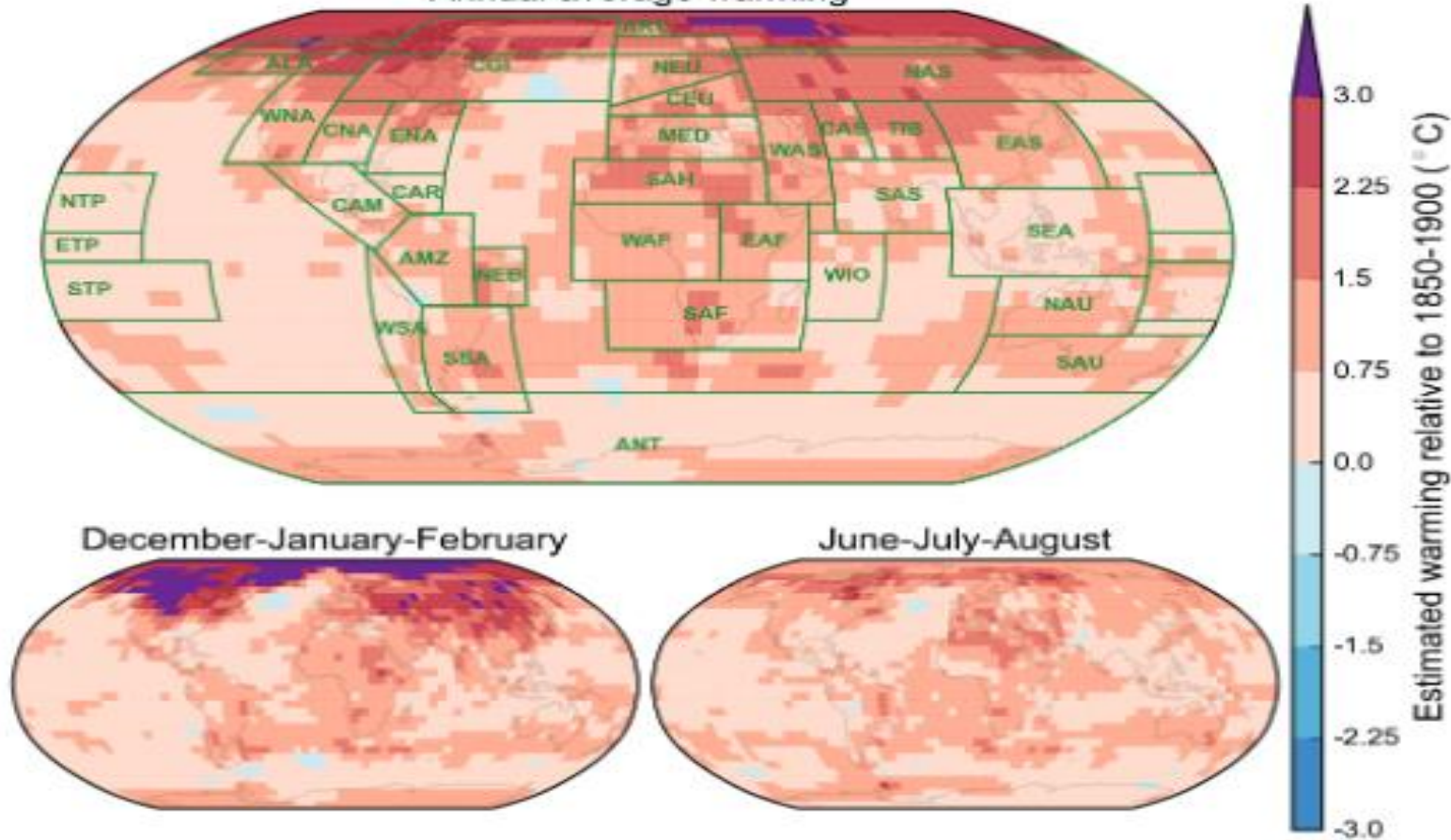


IPCC Report 2019



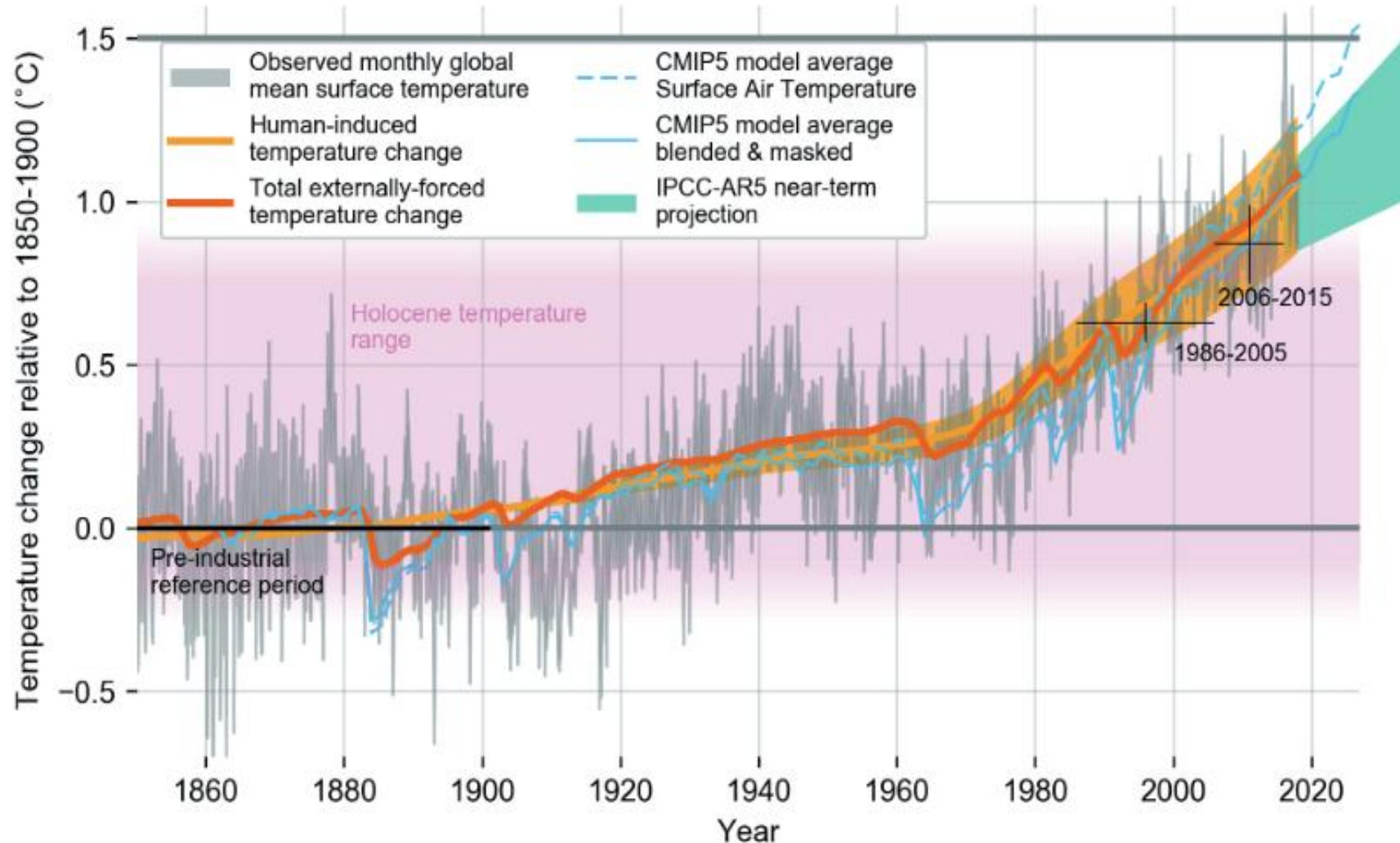
Climate Change: the Earth's temperature – Decades 2006 - 2015

Regional warming in the decade 2006-2015 relative to preindustrial
Annual average warming



Source: IPCC Report 2019

Climate Change: the Earth's evolving temperature from pre – industrial period

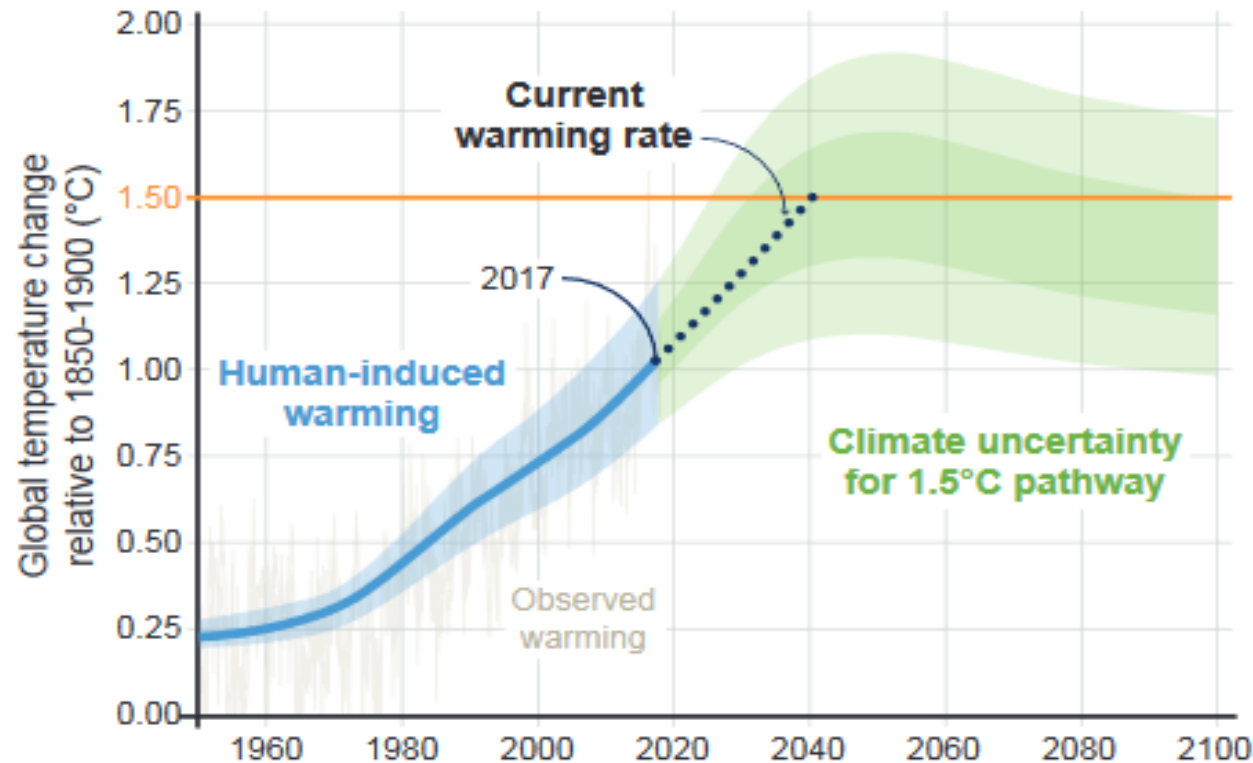


Source: IPCC Report 2019



Climate Change: the Earth's evolving temperature. The Trend vs Objective.....

Human-induced warming reached approximately 1°C above pre-industrial levels in 2017

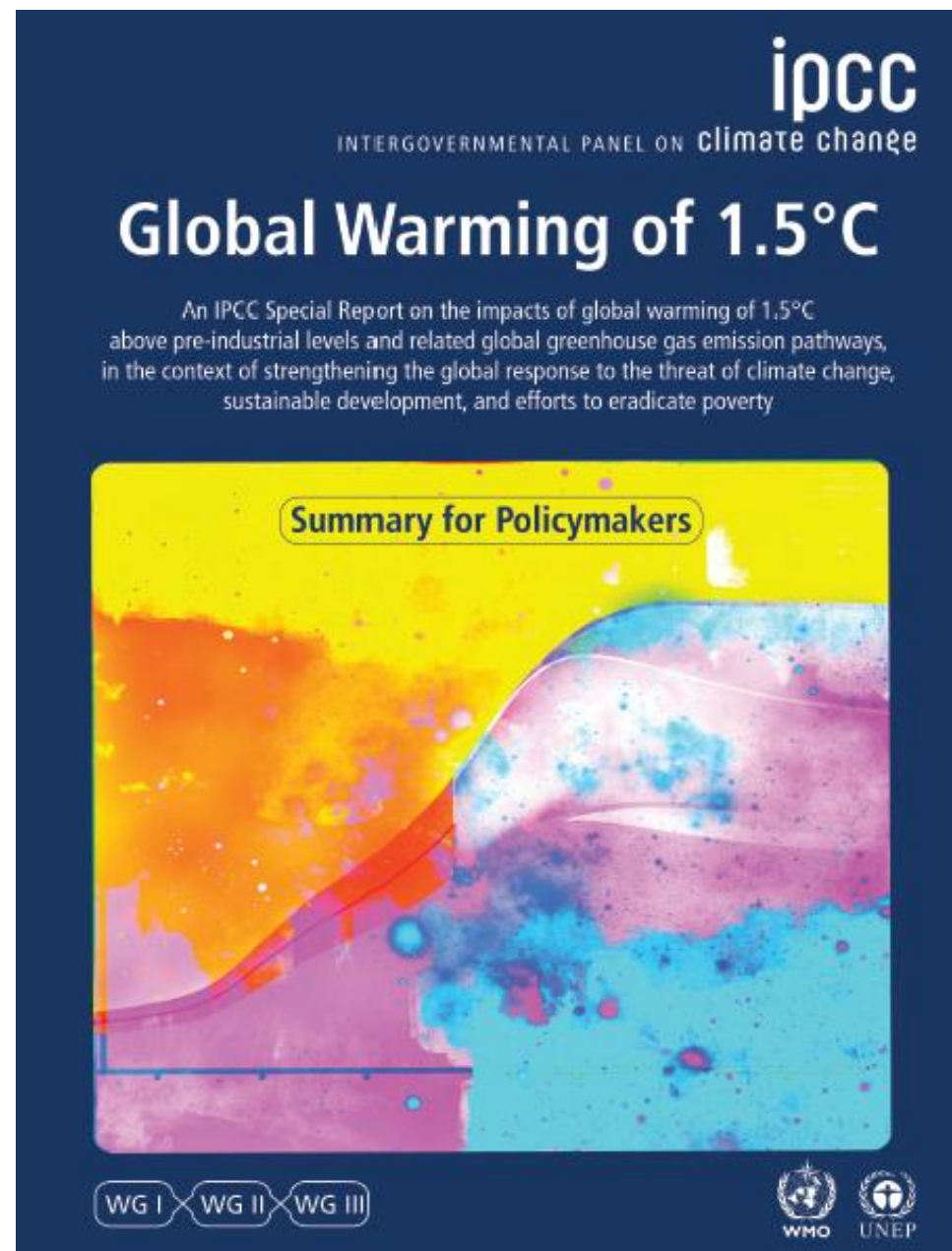


Source: IPCC Report 2019



IPCC Report October 2018 (Available for COP 24 Meeting)



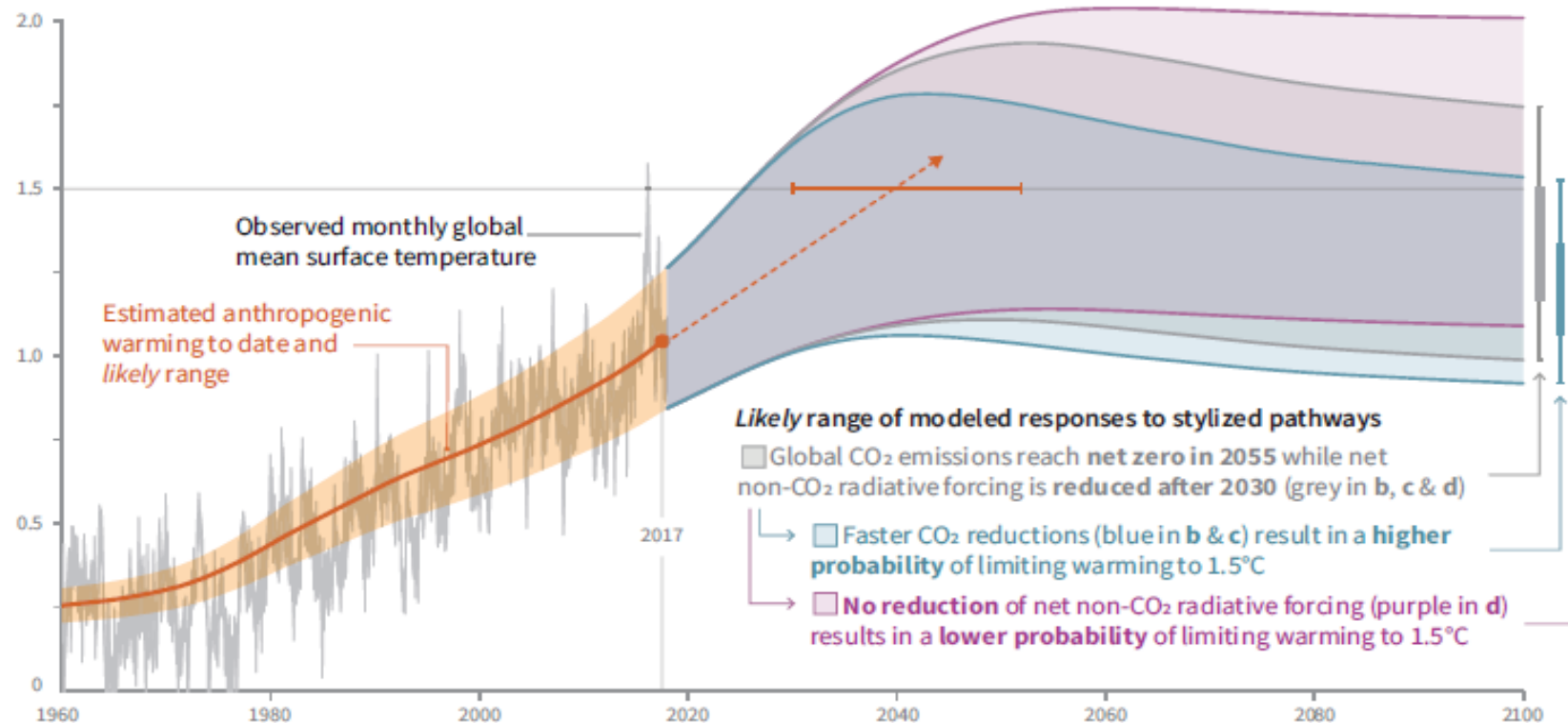


IPCC Report 2018

Cumulative emissions of CO₂ and future non-CO₂ radiative forcing determine the probability of limiting warming to 1.5°C

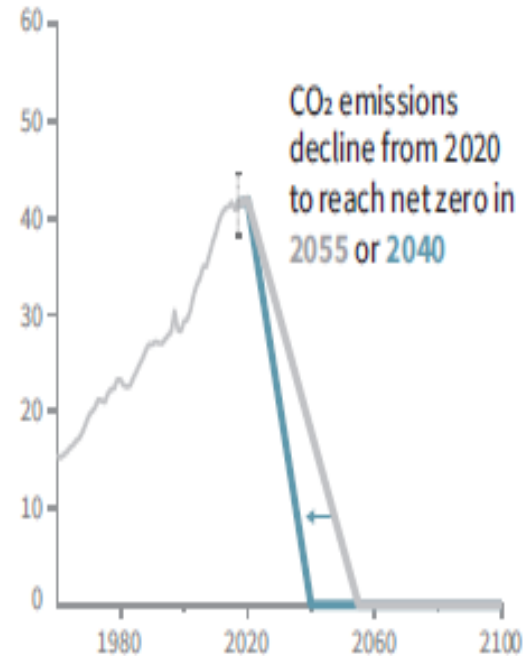
a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways

Global warming relative to 1850-1900 (°C)



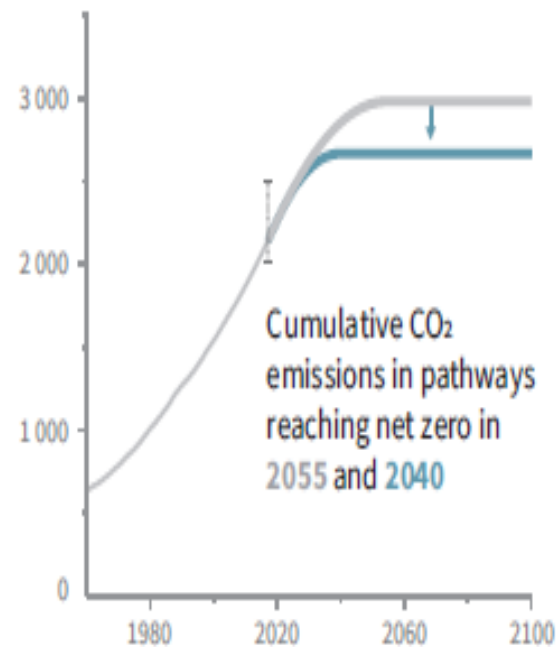
IPCC Report 2018

b) Stylized net global CO₂ emission pathways
Billion tonnes CO₂ per year (GtCO₂/yr)



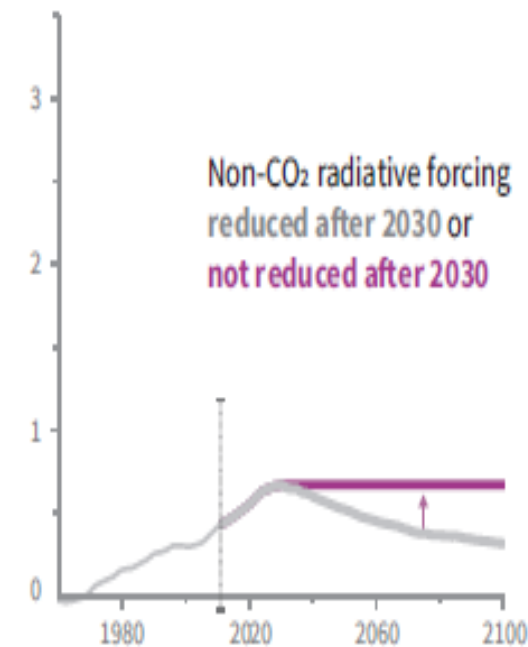
Faster immediate CO₂ emission reductions limit cumulative CO₂ emissions shown in panel (c).

c) Cumulative net CO₂ emissions
Billion tonnes CO₂ (GtCO₂)



Maximum temperature rise is determined by cumulative net CO₂ emissions and net non-CO₂ radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

d) Non-CO₂ radiative forcing pathways
Watts per square metre (W/m²)

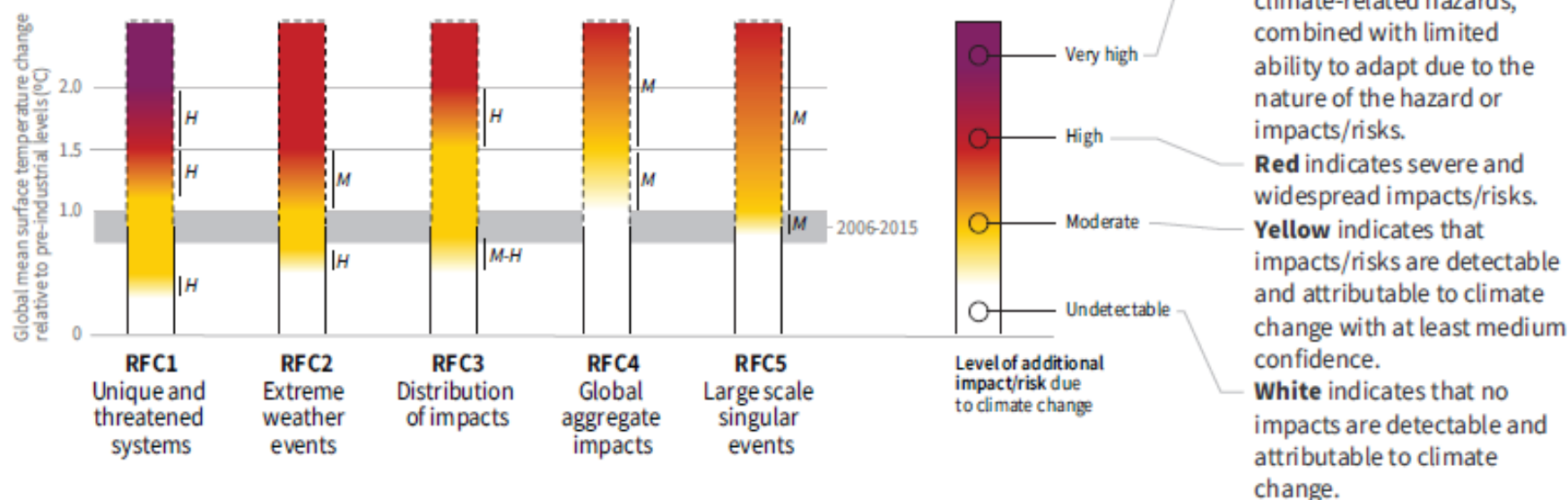


IPCC Report 2018 – Risks & Threats (1)

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

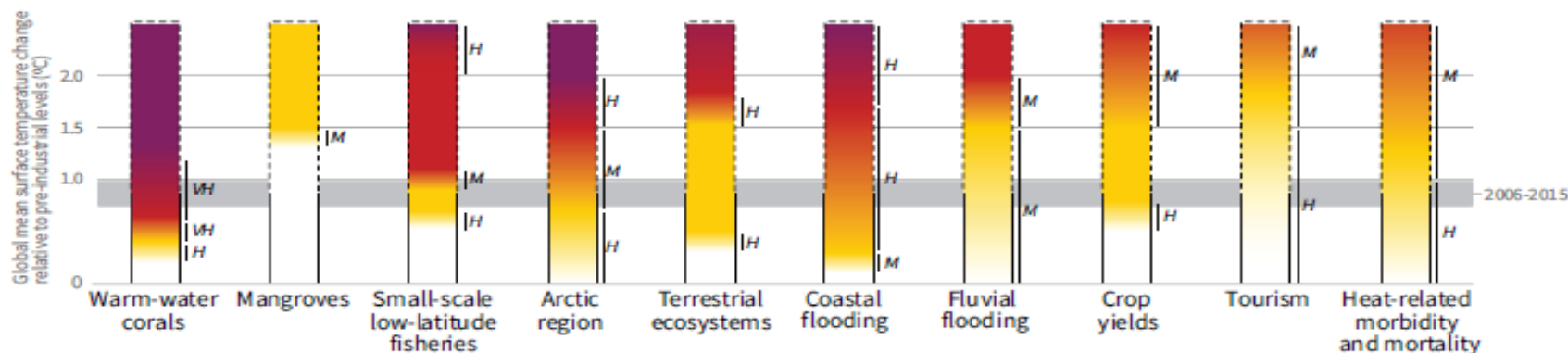
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



IPCC Report 2018 – Risks & Threats (2)

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: L=Low, M=Medium, H=High and VH=Very high

Figure SPM.2 | Five integrative reasons for concern (RFCs) provide a framework for summarizing key impacts and risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of global warming for people, economies and ecosystems. Impacts and/or risks for each RFC are based on assessment of the new literature that has appeared. As in AR5, this literature was used to make expert judgments to assess the levels of global warming at which levels of impact and/or risk are undetectable, moderate, high or very high. The selection of impacts and risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. (3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1, 5.5.3, 5.6.1, Box 3.4)

RFC1 Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots.

RFC2 Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding.

RFC3 Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.

RFC4 Global aggregate impacts: global monetary damage, global-scale degradation and loss of ecosystems and biodiversity.

RFC5 Large-scale singular events: are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets.

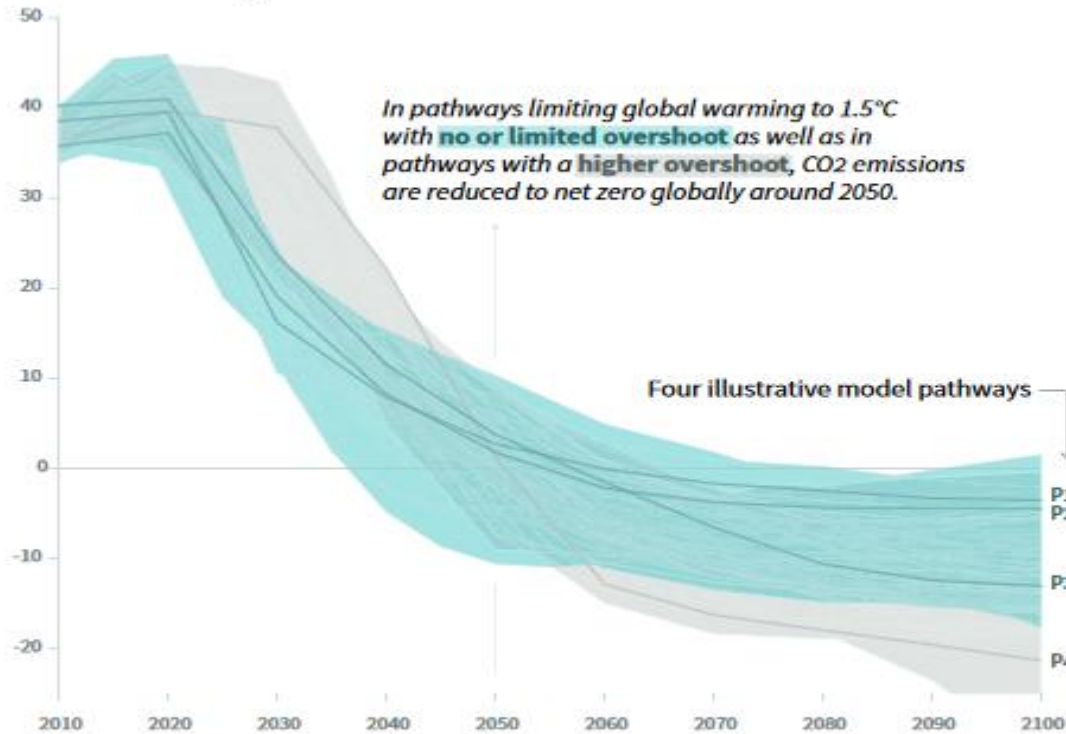


IPCC Report 2018

Various Scenarios for Total Net Emissions

Global total net CO₂ emissions

Billion tonnes of CO₂/yr



Timing of net zero CO₂
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Pathways limiting global warming to 1.5°C with **no or limited overshoot**

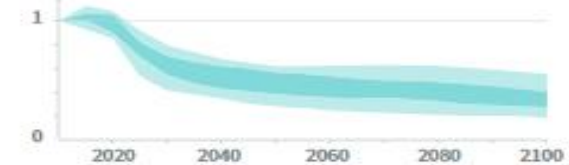
Pathways with **higher overshoot**

Pathways limiting global warming below 2°C
(Not shown above)

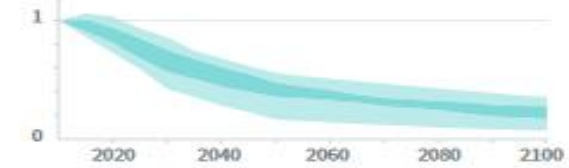
Non-CO₂ emissions relative to 2010

Emissions of non-CO₂ forcers are also reduced or limited in pathways limiting global warming to 1.5°C with **no or limited overshoot**, but they do not reach zero globally.

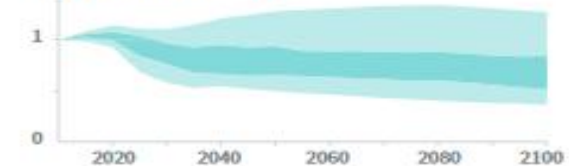
Methane emissions



Black carbon emissions



Nitrous oxide emissions

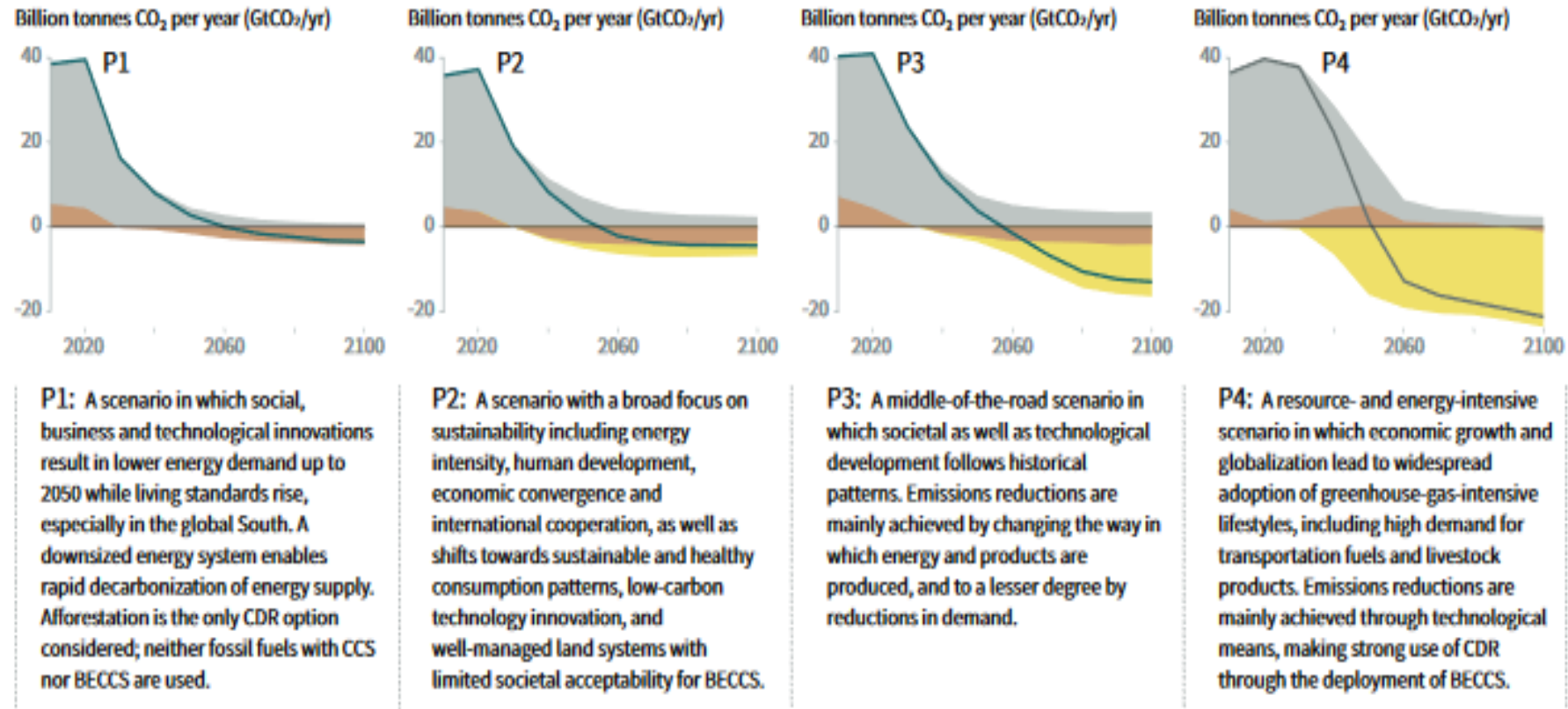


IPCC Report 2018

Various Scenarios for Total Net Emissions

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways

● Fossil fuel and industry ● AFOLU ● BECCS



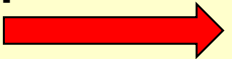
Nota: CDR: Carbon Dioxide Removal, BECCS: Bioenergy with Carbon Capture and Storage



The Feedbacks effects



CO2 emissions, Temperature increase & Feedbacks effects

- The CO2 content in the atmosphere is not the only parameter which increases the Earth temperature. The increase of the Earth temperature generates additional processes which amplify the consequences: **the positive feedbacks**. If the amount of CO2 in the atmosphere doubled compared to pre-industrial levels, the Earth's temperature would eventually balance out of about 1,5°C warmer. The feedbacks effects increase substantially this figure. Feedbacks can be positive or negative. **The combined effects of all feedbacks is significantly positive** (IPCC), they are incorporated in the IPCC analysis, taking into account some uncertainty around the magnitude of these feedbacks. Among these feedbacks effects:
 - As temperature rises, more water evaporates. Water vapour is a greenhouse gas, and has an effect on clouds formation  positive feedback.
 - Melting away of sea ice and snow cover on land (high albedo) leads to less reflection of sun energy  positive feedback.
 - Arctic declining sea ice is causing the arctic to warm  positive feedback.
 - Melting permafrost in arctic and siberian region generates release of organic carbon  positive feedback.



Climate issues - the feedback effects

CO₂ content in the atmosphere

is not the only parameter which increases the Earth temperature.

The increase of earth temperature generates **additional processes** which amplify the consequences.



In IPCC analysis, so-called positive feedbacks with some uncertainty around the magnitude

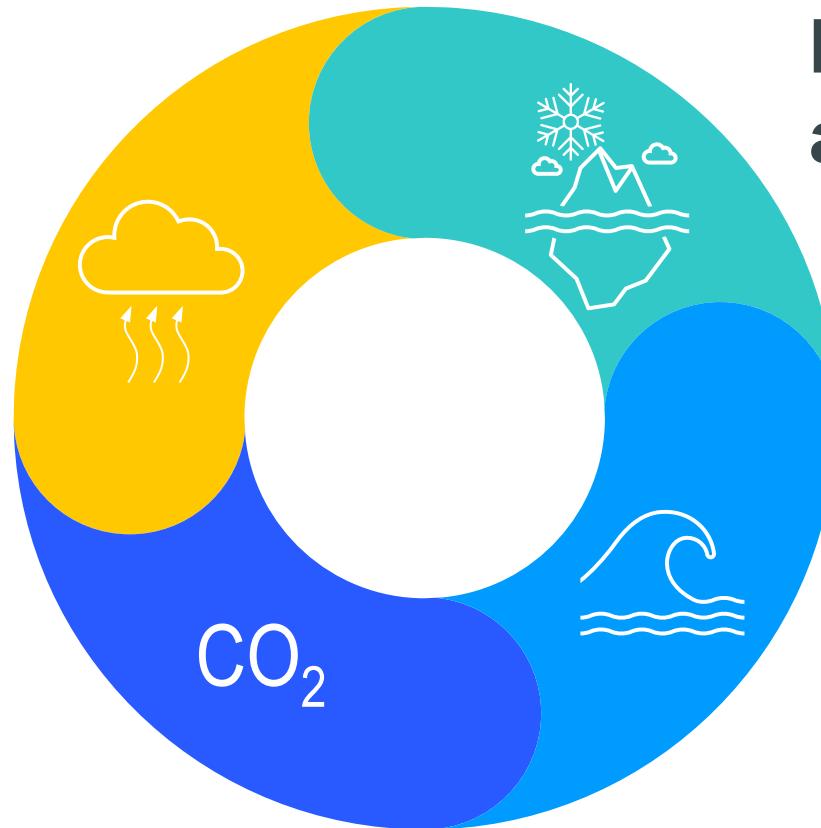


Climate issues - the feedback effects

Feedbacks effects

Water evaporation
effect on clouds formation

Melting of permafrost
in arctic and Siberian region
releases of organic carbon



**Melting away of sea ice
and snow covering land**
Lower albedo → less
reflection of sun energy

Arctic declining sea ice
causing the arctic to warm

Nota: Albedo is the fraction of sunlight that is diffusely reflected by a body
= Reflected Energy/Incident Energy

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Climate issues - the feedback effects – Myhre formula

A minor variation of CO₂ content in the atmosphere has important consequences in term of greenhouse effect, increase of Radiative Forcing (RF) and consequently increase of Temperature (T). The additional Feedbacks effects substantially amplify this phenomena.

This can be proven by the Myhre formula. **Gunnar Myrhe is a Norwegian scientist, ex-IPCC member**

$\Delta RF \text{ (Wm}^{-2}\text{)} = 5,35 \ln C(t)/C(t_0)$ with $C(t) = \text{CO}_2$ concentration, $\ln = \text{Natural logarithm}$.

Energy emitted per surface unit depends only upon temperature: $RF = \sigma T^4$, σ : Stefan-Boltzmann constant.

➡ $\Delta T = \frac{1}{4} * T / RF * \Delta RF = \frac{1}{4} * (273^\circ\text{C} - 18^\circ\text{C}) / 235 \text{ Wm}^{-2} * RF = 0,27 * \Delta RF$ (Earth/Atmosphere thermodynamical balance is effective with Energy input/output # 235 W/m² and Temperature # -18°C)

➡ $\Delta T \text{ (}^\circ\text{C)} = 1,44 \ln C(t)/C(t_0)$ with $C(t) = \text{CO}_2$ concentration, $\ln = \text{Natural logarithm}$.

This experimental formula gives the temperature increase according to the CO₂ concentration in atmosphere (Reference : beginning of industrial age - $C(t_0) = 280 \text{ ppm}$)

For $C(t) = 425 \text{ ppm}$,

$\Delta RF \# 2,3 \text{ Wm}^{-2}$

$\Delta T \# 0,6^\circ\text{C}$ and not $1,4^\circ\text{C}$. Additional Feedbacks effects account for more than 50%.



Human activities are estimated to have caused today approximately 1,3/1,4°C of global warming above pre-industrial level.

Warming greater than the global annual average is being experienced in many land regions and seasons.

Warming is generally higher over land than over the ocean.

Global warming is likely to reach 1,5°C between 2030 and 2050 if it continues to increase at the current rate. It is expected to reach 3,4 to 3,9°C at the end of the century if no progress is made.

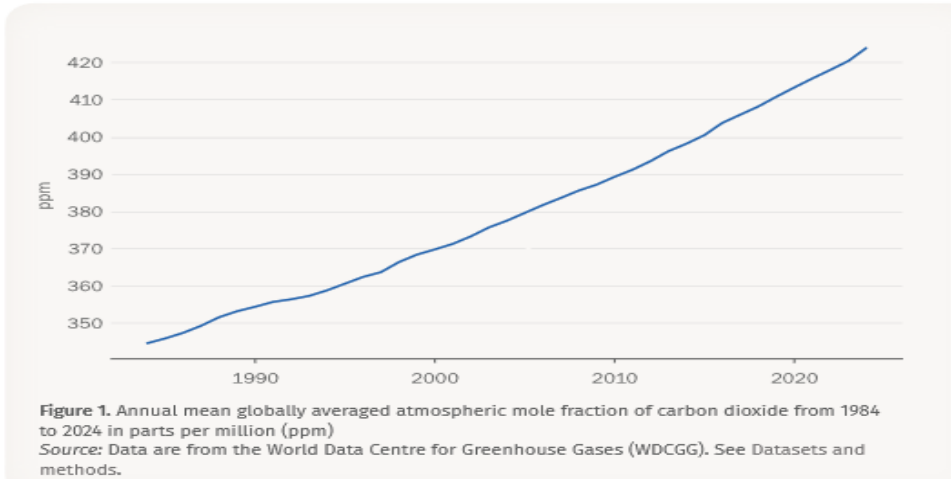


World Meteorological Organization (WMO) 2026 Report State of the Global Climate 2025

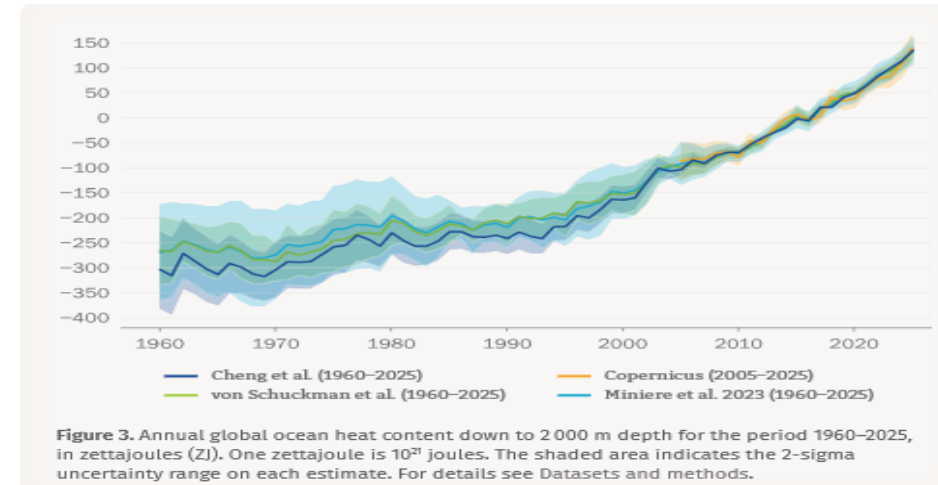


CO₂ concentration, Ocean Heat Content & Mean Ocean PH evolution – WMO 2026

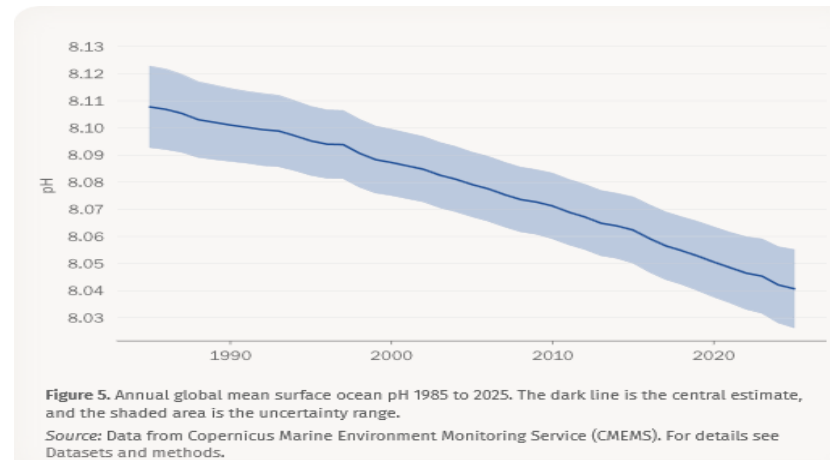
CO2 Concentration (ppm)



Global Ocean Heat content (ZJ)



Global Mean surface ocean PH



Source: World Meteorological Organization (WMO)
State of Global Climate 2026

Climate Change – The Earth temperature - WMO 2026

Key messages

The annually averaged global mean near-surface temperature in 2025 was $1.43\text{ °C} \pm 0.13\text{ °C}$ above the 1850–1900 average used to represent pre-industrial conditions.

The year 2025 was the second or third warmest year in the 176-year observational record, depending on which of nine datasets is used. The year 2024 remains the warmest year in all the datasets, at $1.55\text{ °C} \pm 0.13\text{ °C}$ above the 1850–1900 average.

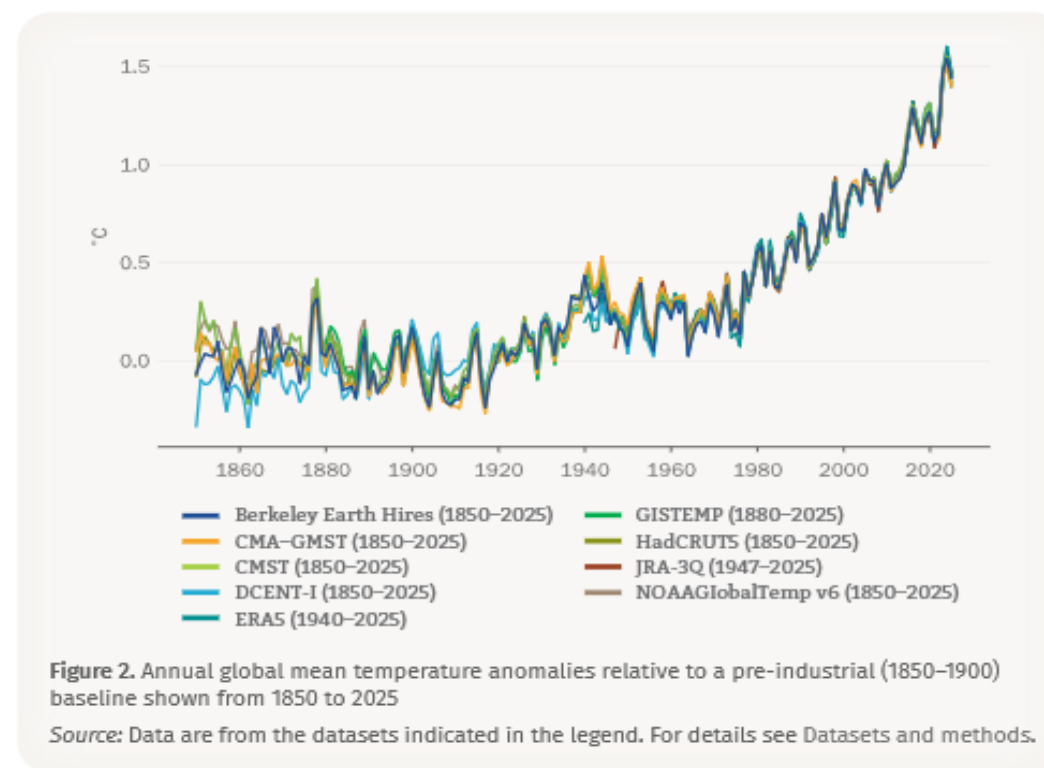
For global mean temperature, the past eleven years, 2015–2025, were the eleven warmest years on record.

State of the indicator

Based on a synthesis of nine global temperature datasets (see [Datasets and methods](#)), the annually averaged global mean near-surface temperature in 2025 was $1.43\text{ °C} \pm 0.13\text{ °C}$ (90% uncertainty range) above the 1850–1900 average. Depending on the dataset used, 2025 was the second (two datasets) or third (seven datasets) warmest in the 176-year observational record (Figure 2). The warmest year was 2024 with an anomaly of $1.55\text{ °C} \pm 0.13\text{ °C}$. The past eleven years, 2015–2025, were the eleven warmest years on record and the past three years 2023–2025, the three warmest in all nine datasets.

The annual global mean temperature of 2025 was lower than the record high of 2024, consistent with the shift from a strong El Niño at the start of 2024 to weak La Niña conditions at the start and end of 2025. Despite this, 2025 continued a run of exceptionally high global temperatures and January 2025 was the warmest January on record.

In 2025, the global mean land temperature was the second or third highest on record at 0.80 °C above the 1991–2020 average. The global mean sea-surface temperature (SST) – the temperature in the upper few metres of the ocean – was the third highest on record at 0.39 °C above the 1991–2020 average. Despite La Niña conditions, around 90% of the ocean surface area experienced at least one marine heatwave during 2025 and only 18% experienced a marine cold wave. Ocean heat content, referring to the upper 2 000 metres of the ocean, was the highest on record (see [Ocean heat content](#)). SST is more variable than ocean heat content because it represents the temperature of a much thinner layer (a few metres for SST as compared to 2 000 m for ocean heat content) which can thus change temperature more quickly.



Source: World Meteorological Organization (WMO)
State of Global Climate 2026

Climate Change - Global Sea Level Rise - WMO 2026

Key messages

In 2025, global mean sea level was comparable to the record-high levels observed in 2024 in the satellite altimetry record.

The year-to-year increase from 2024 to 2025 was smaller than 2023 to 2024, consistent with short-term variability associated with La Niña conditions.

The rate of global mean sea-level rise since 2012 is higher than the rate of global mean sea-level rise in the earlier part of the satellite record, 1993–2011.

State of the indicator

Satellite altimetry records showed a rapid increase in global mean sea level of about 5 mm over 2023 and 2024 (Figure 4) associated with a strong El Niño that ended in early 2024.¹³ In 2025, global mean sea level continued at levels comparable to 2024, reflecting the transition from El Niño to weak La Niña conditions (see [Climate driver: El Niño–Southern Oscillation](#)). The year-to-year increase from 2024 to 2025 was therefore smaller than from 2023 to 2024.

At the end of 2025, the global mean sea level was around 11 cm higher than it was in January 1993, the start of the satellite record. The mean rate of sea-level rise has increased with time. From 1993 to 2011, sea level rose at an average rate of 2.65 ± 0.3 mm per year. During the period 2012 to 2025, the rate was 4.75 ± 0.3 mm year.¹⁴

Sea level has risen since 1993 in all oceanic regions, except for an area of the Southern Ocean in the Pacific sector. Some areas have risen faster than the global mean, including the tropical and south-western Pacific, as well as north of 30°N in the Pacific. Areas where sea-level rise was slower than the global mean include the eastern Pacific, south Indian Ocean and north Atlantic south of Greenland. The rate of sea-level rise over the past 33 years in the Indian Ocean, north of 30°S, and in the tropical and eastern Atlantic Ocean, has been similar to the global mean.



Figure 4. Global mean sea level change (change from January 1993 in mm) shown for 1993–2025. The seasonal cycle has been removed from the data. The shaded area indicates the uncertainty. Source: Data from Aviso, Centre national d'études spatiales (CNES). For details see Datasets and methods.

Source: World Meteorological Organization (WMO)
State of Global Climate 2026



Climate Change – The Earth Energy Imbalance - WMO 2026

Key messages

The Earth's energy imbalance is a key climate indicator that measures how fast the heat trapped by anthropogenic emissions of greenhouse gases is accumulating in the climate system. The heat warms the ocean, continents and atmosphere, and melts ice.

The Earth's energy imbalance combines information about changes in all parts of the climate system in a comprehensive and holistic way, allowing a better quantification and prediction of changes in the climate system.

Since 1960, the Earth's energy imbalance has been increasing, particularly in the past 20 years compared to the previous 66 years.

Indicator background

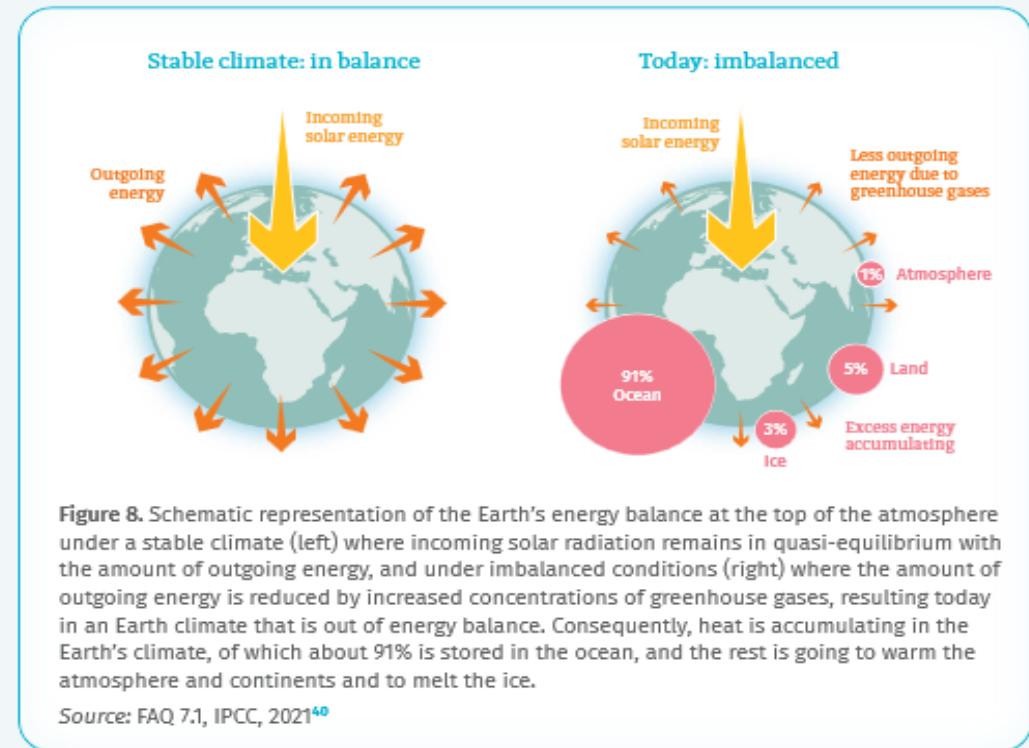
The Earth's energy imbalance (EEI) is the difference between the amount of energy the Earth receives from the Sun (incoming solar radiation minus reflected solar radiation) and the amount of energy the Earth radiates back into space (outgoing long-wave radiation) (Figure 8). If the amount of incoming radiation exceeds the amount of outgoing radiation (for example, due to the greenhouse effect), the EEI is "positive", meaning the Earth is gaining energy, mostly in the form of heat. If more energy escapes the Earth than is received (for example, after large volcanic eruptions), the EEI is "negative", meaning the Earth is losing energy and cooling.

Due to increasing concentrations of greenhouse gases, the EEI has become increasingly positive over time, and the accumulation of surplus energy has led to warming of the climate.³⁰ Approximately 91% of the surplus energy has been absorbed by the ocean, 5% by the continents, 3% by the cryosphere and 1% by the atmosphere.

The EEI measures the rate of the heat accumulation and thus allows us to monitor the rate of global warming.^{31,32,33} It provides a comprehensive picture of warming, combining changes in all components of the climate system. It is therefore a crucial metric for assessing the state of the global climate system as well as testing our understanding and monitoring of it.³⁰

The EEI can be measured in two ways:

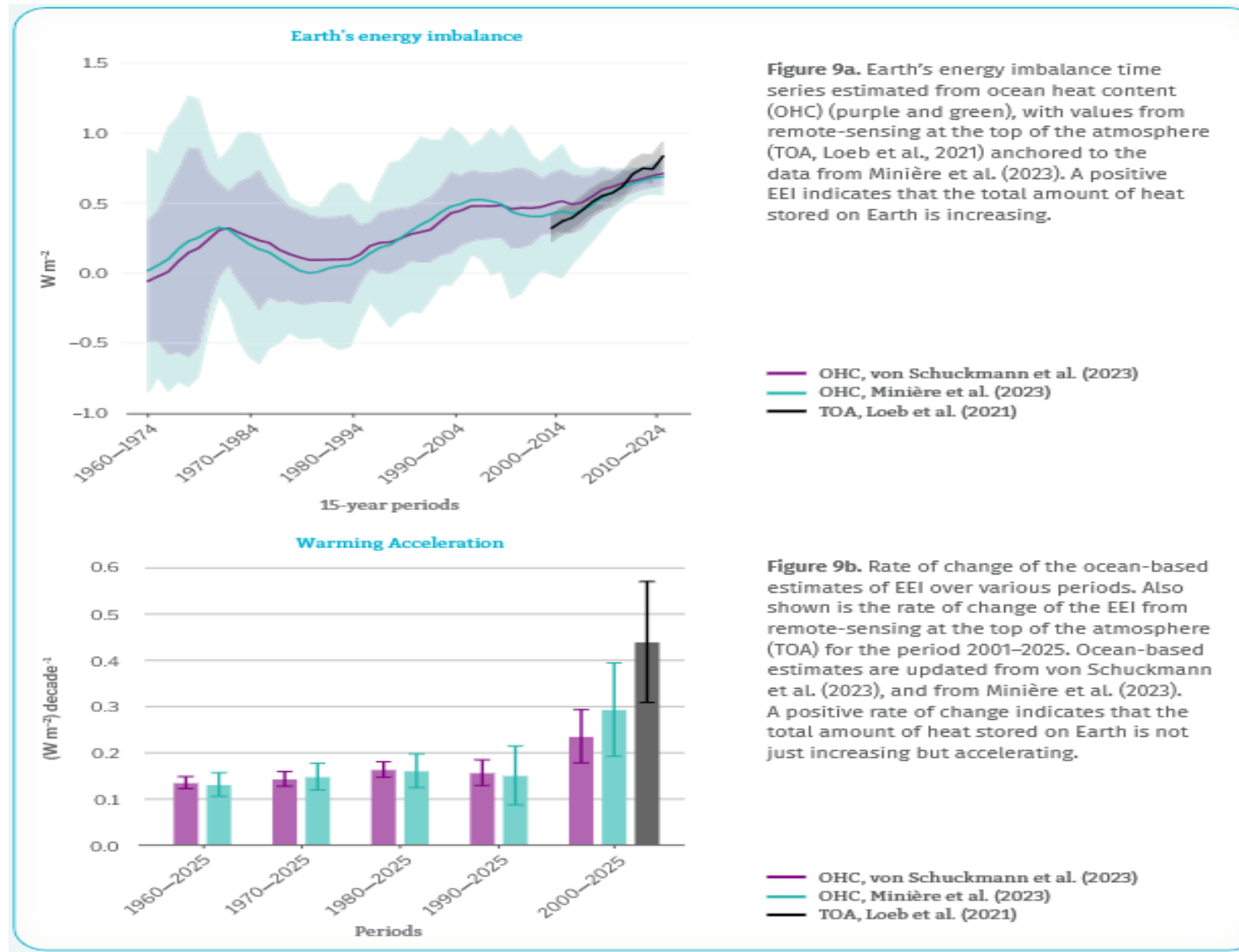
1. The Earth heat inventory (1960–present). This method combines separate estimates of heat stored in the ocean, land and atmosphere, as well as the energy needed to melt ice. This hybrid approach integrates the Global Climate Observing System (satellite and in situ) data, reanalyses and climate models.³⁷



Source: World Meteorological Organization (WMO)
State of Global Climate 2026

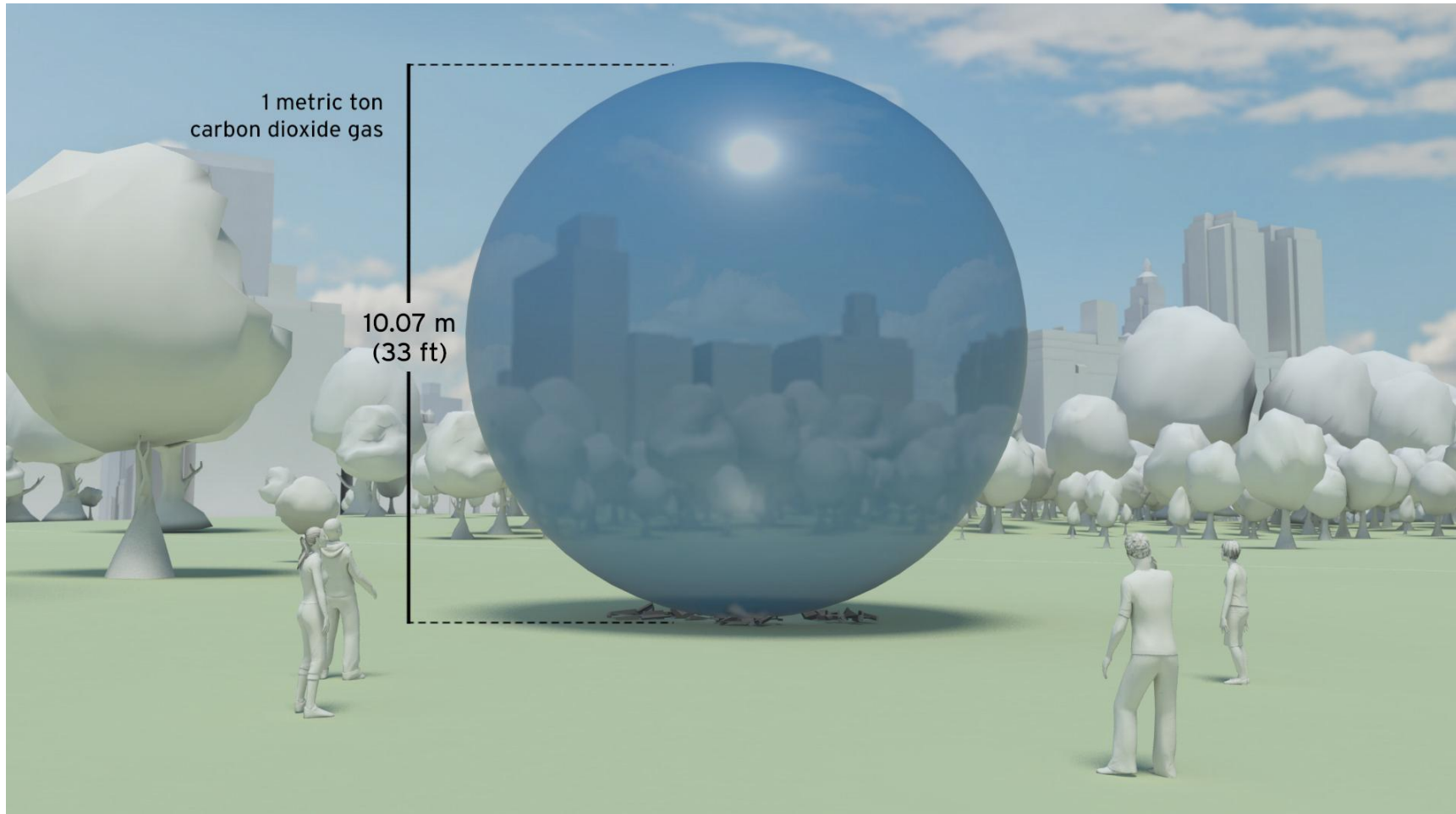


Climate Change – The Earth Energy Imbalance - WMO 2026



Source: World Meteorological Organization (WMO)
State of Global Climate 2026

1 t of CO₂



**Emissions amounting to # 35 Gt CO₂ mean
95 Mt added per day to the atmosphere!**



The Impact of Forest and Land Uses

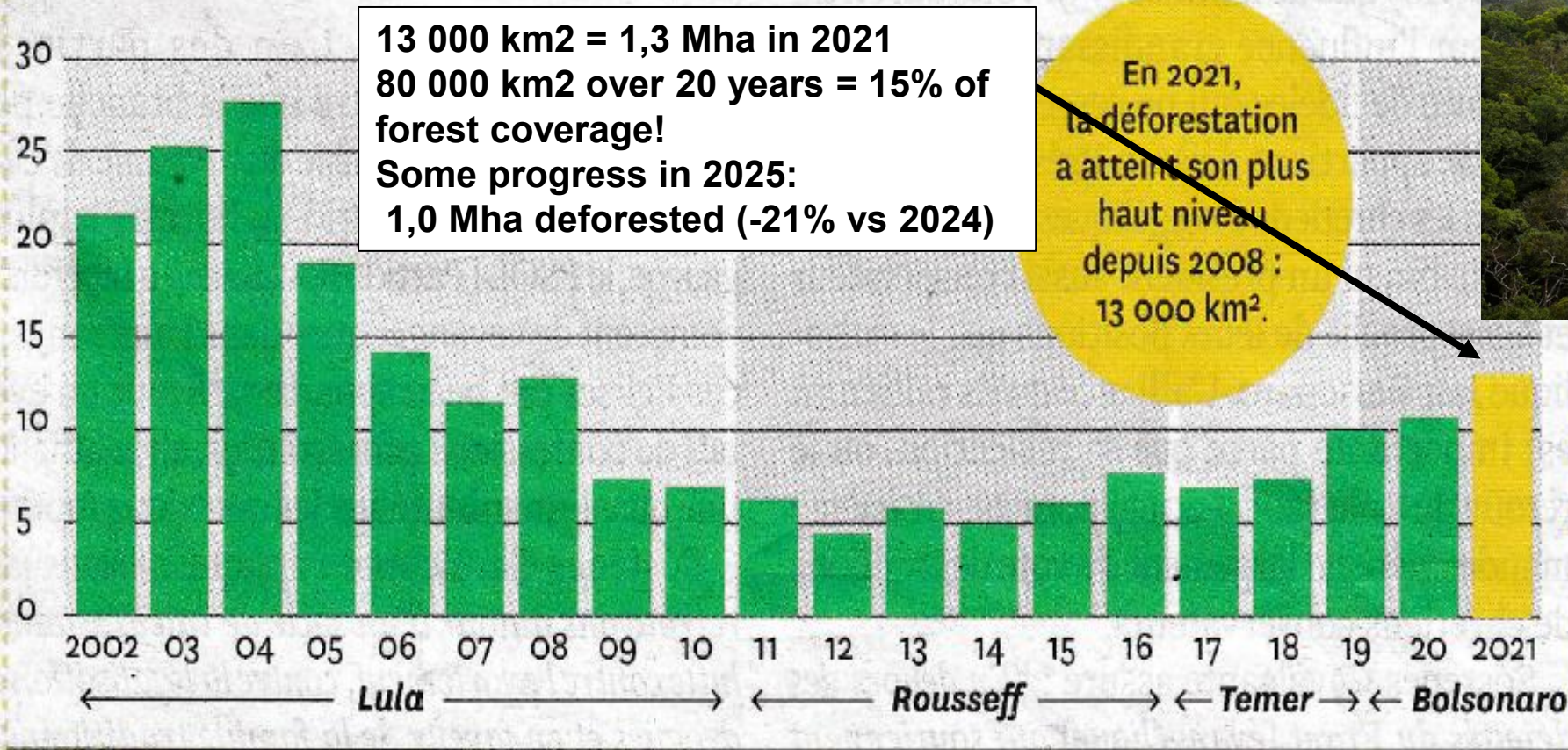


The Impact of Deforestation – Amazonia

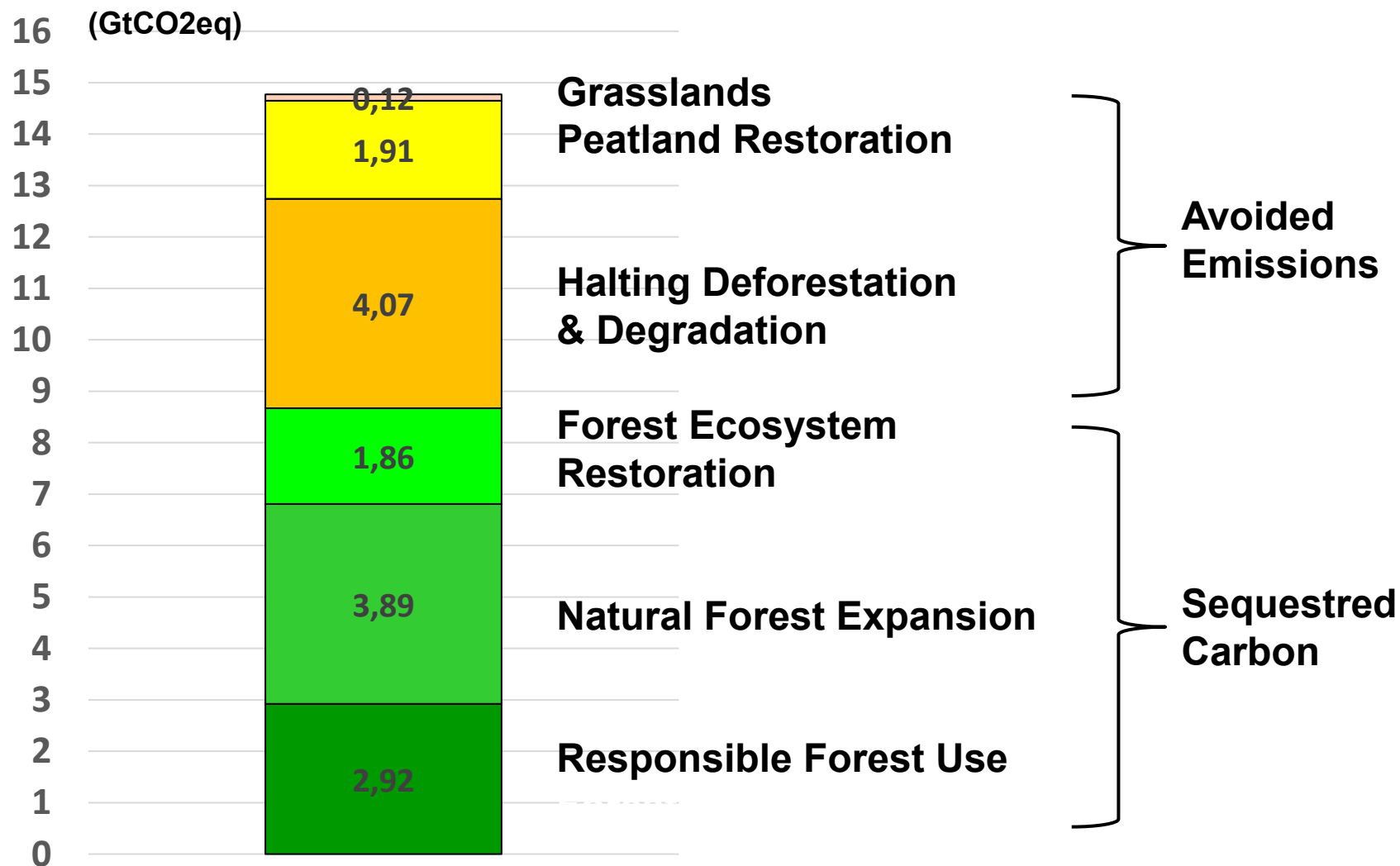
Forest coverage # 550 Mha

La déforestation de l'Amazonie s'accélère de nouveau

Perte de couvert forestier, en milliers de km², par an

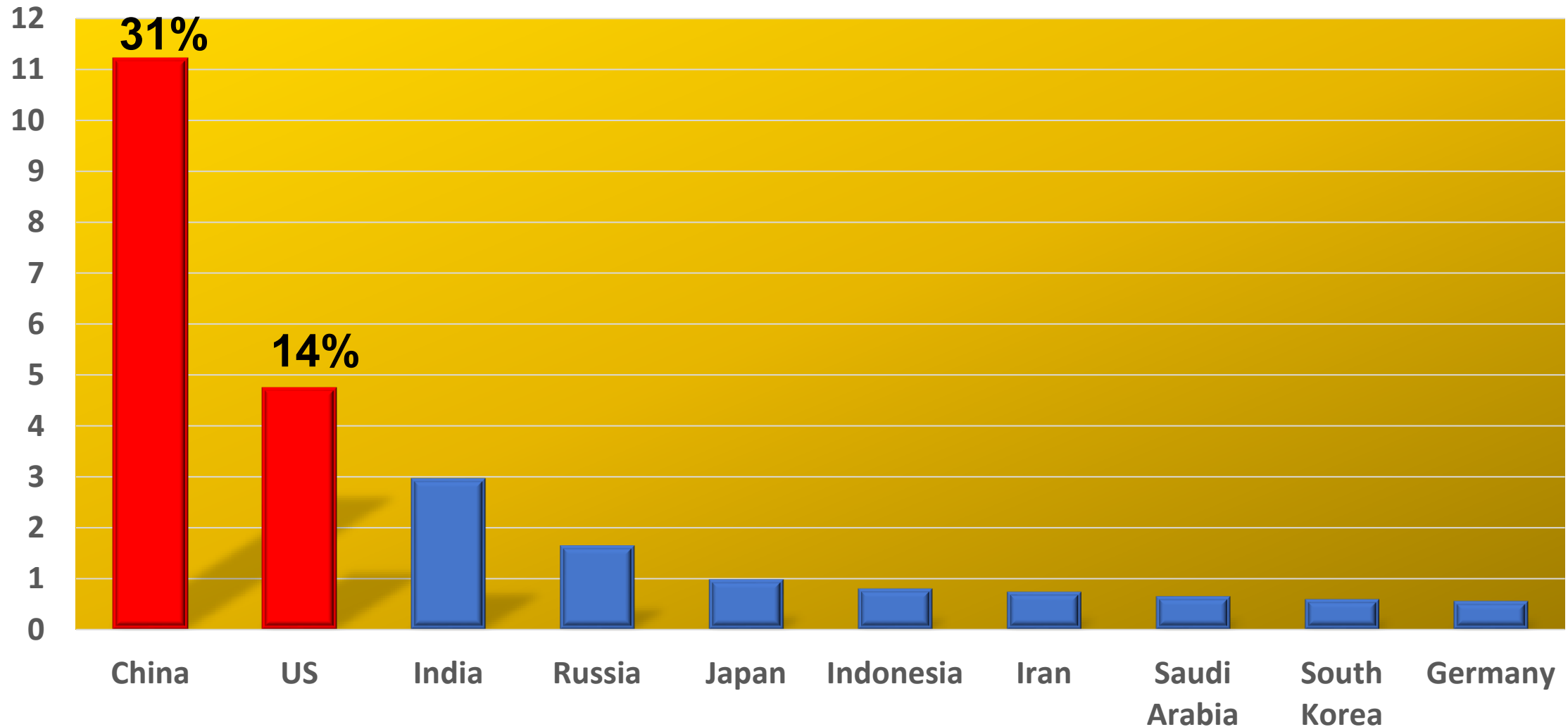


Forest – Related Climate Mitigation Options # 15 GtCO₂eq/year Potential Savings by 2050



10 first countries by CO₂ Energy Emissions – Year 2025

(GtCO₂)

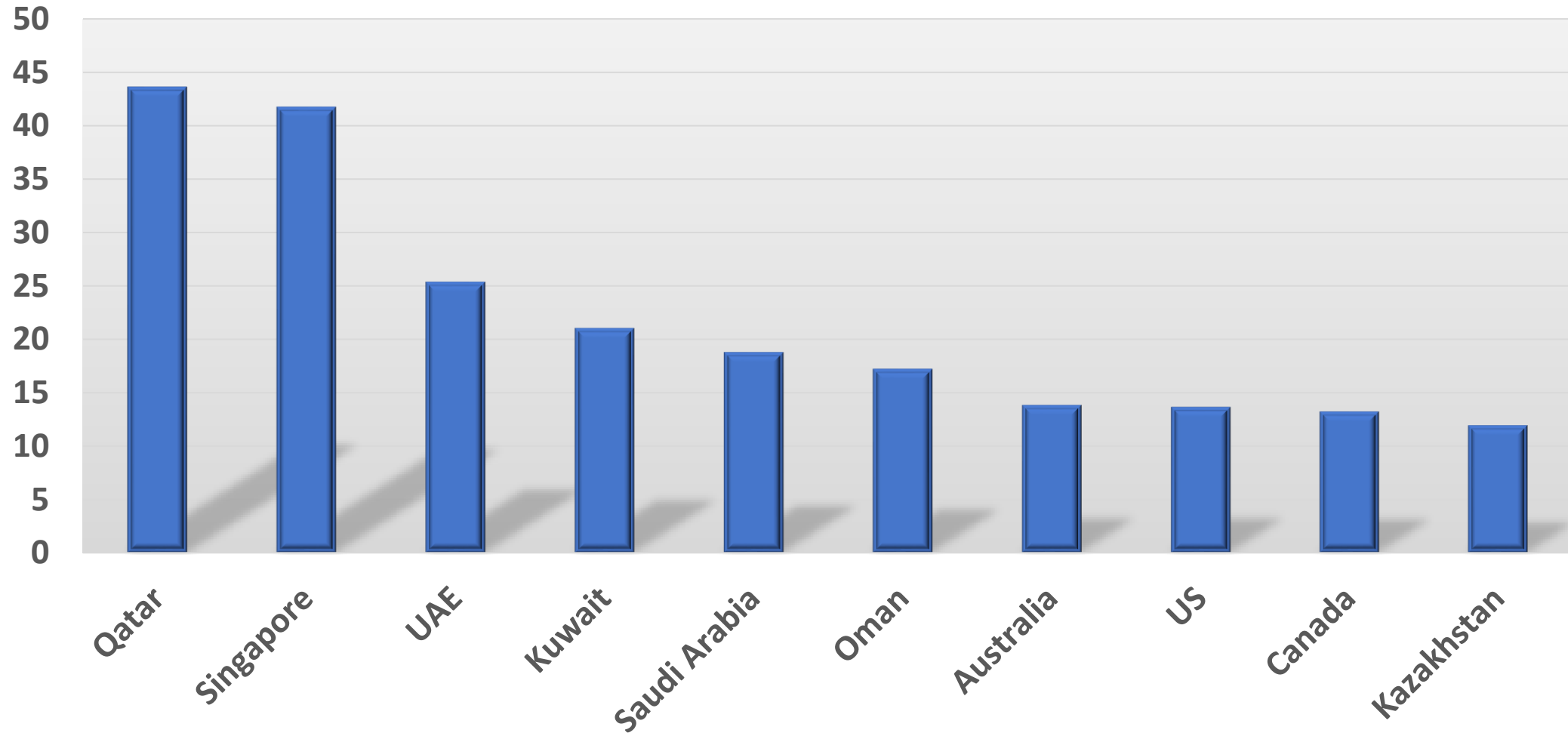


Source: Data from EI Stat. Review 2026



Among the 10 first countries by CO₂Energy /capita emissions Year 2025

tCO₂/capita

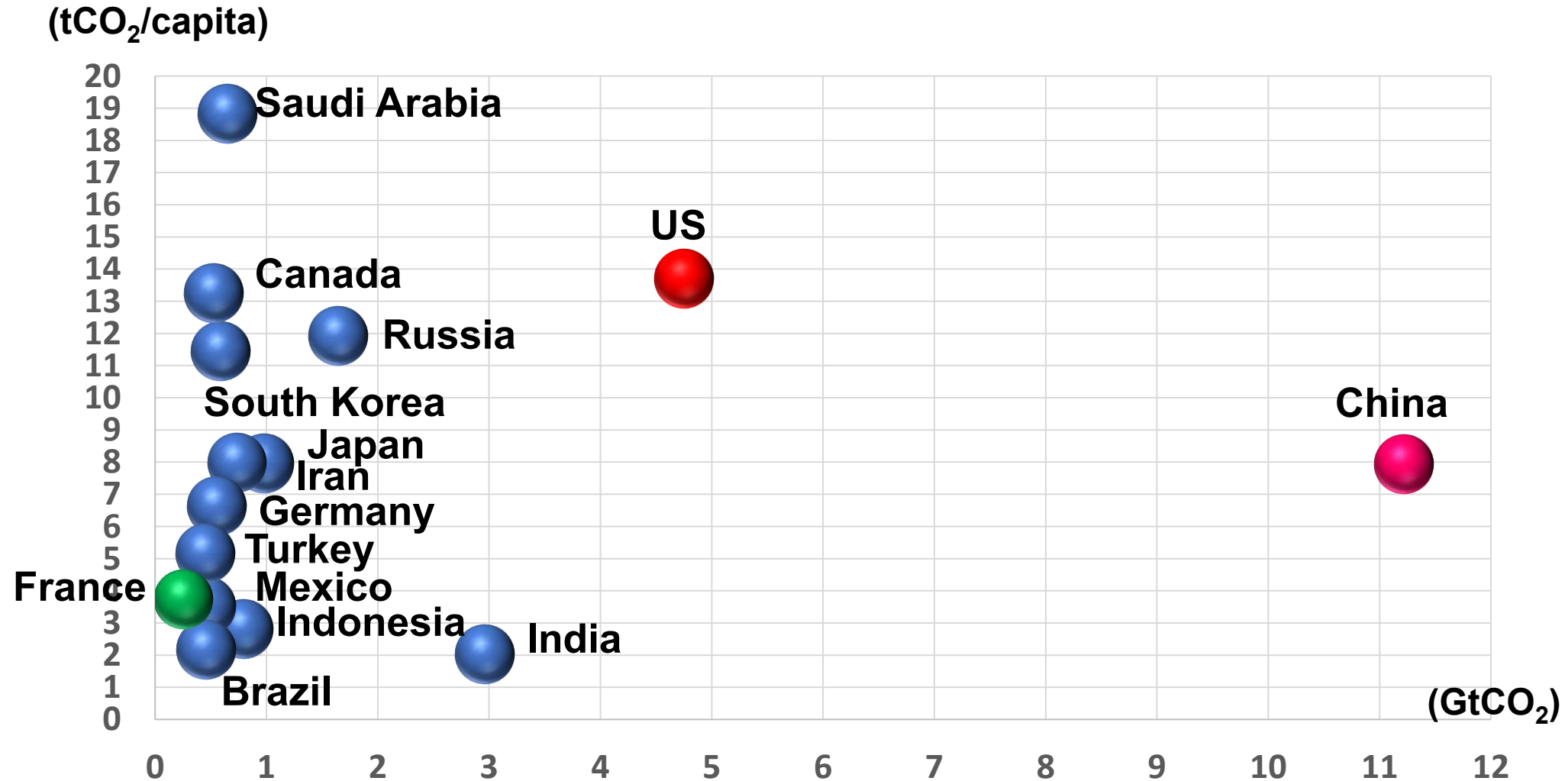


Source: Data from El Stat. Review 2026

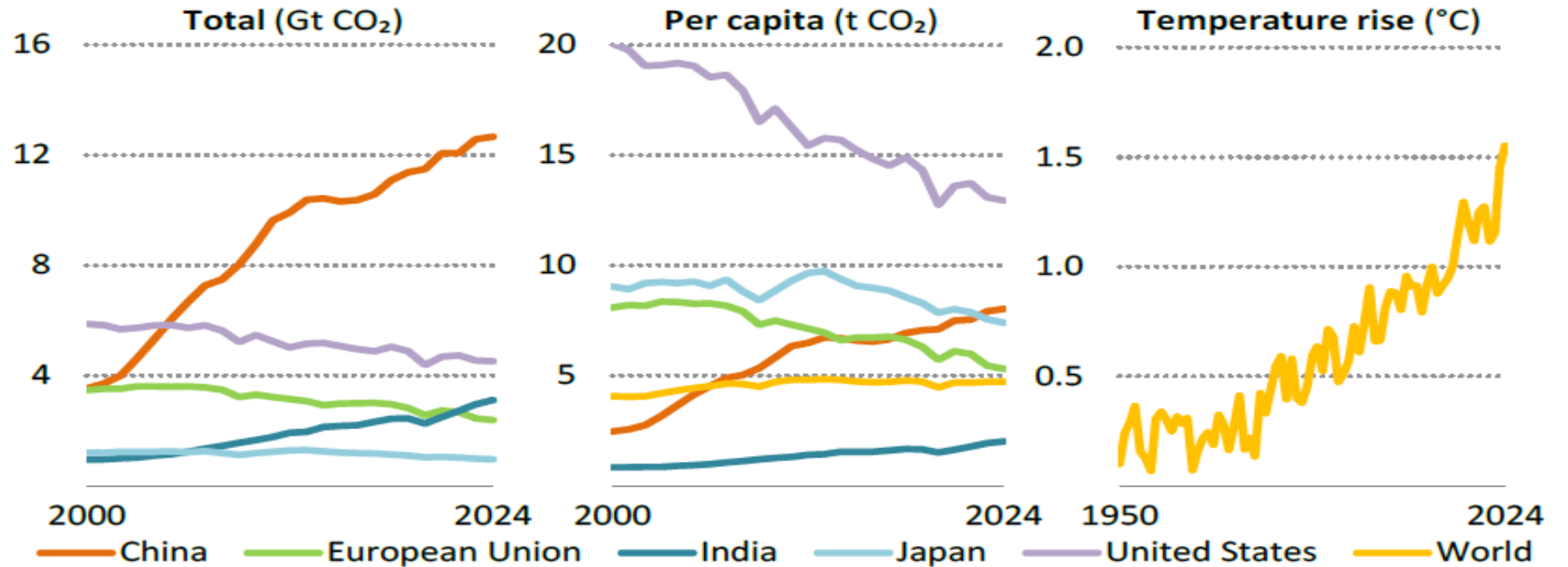


CO₂ Energy Emissions – Year 2025

Ranking is different for tCO₂ & tCO₂ per capita



CO₂ Energy Emissions* & Temperature rise



IEA. CC BY 4.0.

Energy-related emissions reached another all-time high in 2024, which was the hottest year ever recorded, with temperatures of over 1.5 °C above pre-industrial levels

Notes: Gt CO₂ = gigatonnes of carbon dioxide; t CO₂ = tonnes of carbon dioxide; °C = degree Celsius. Temperature rise is the average of HadCRUT5, Berkeley Earth, NOAA GlobalTemp v6, GISTEMP, ERA5, and JRA-3Q datasets adjusted by the World Meteorological Organisation so that each dataset is relative to the period 1850-1900.

Sources: IEA analysis and WMO (2025).

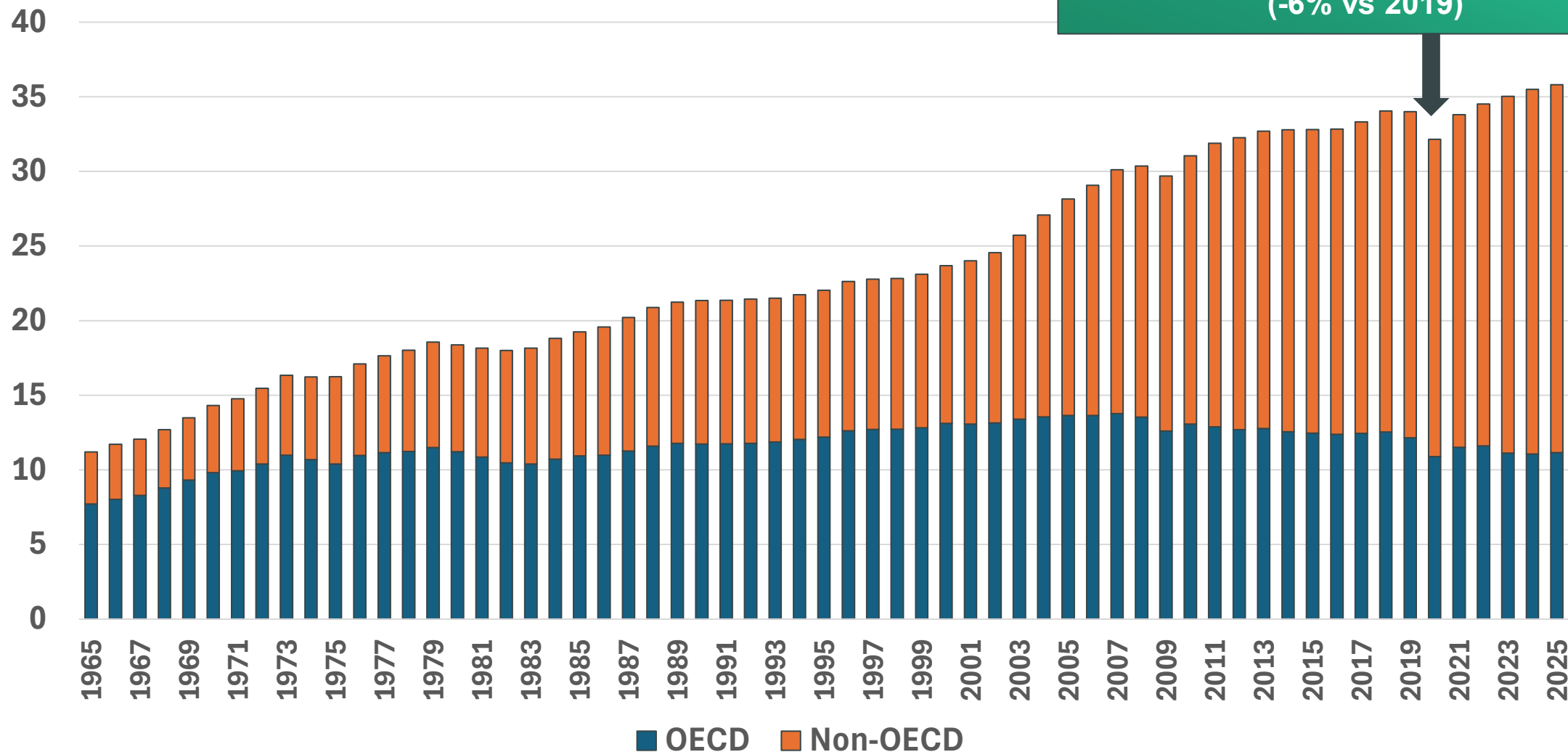
Source: IEA WEO 2025. Figures may slightly differ according to sources

* Includes Industrial Process & Flaring



Energy-related CO₂ Emissions – increasing for Non-OECD

(GtCO₂)



Impact of the coronavirus pandemic
(-6% vs 2019)



2

Economic consequence for energy and industries



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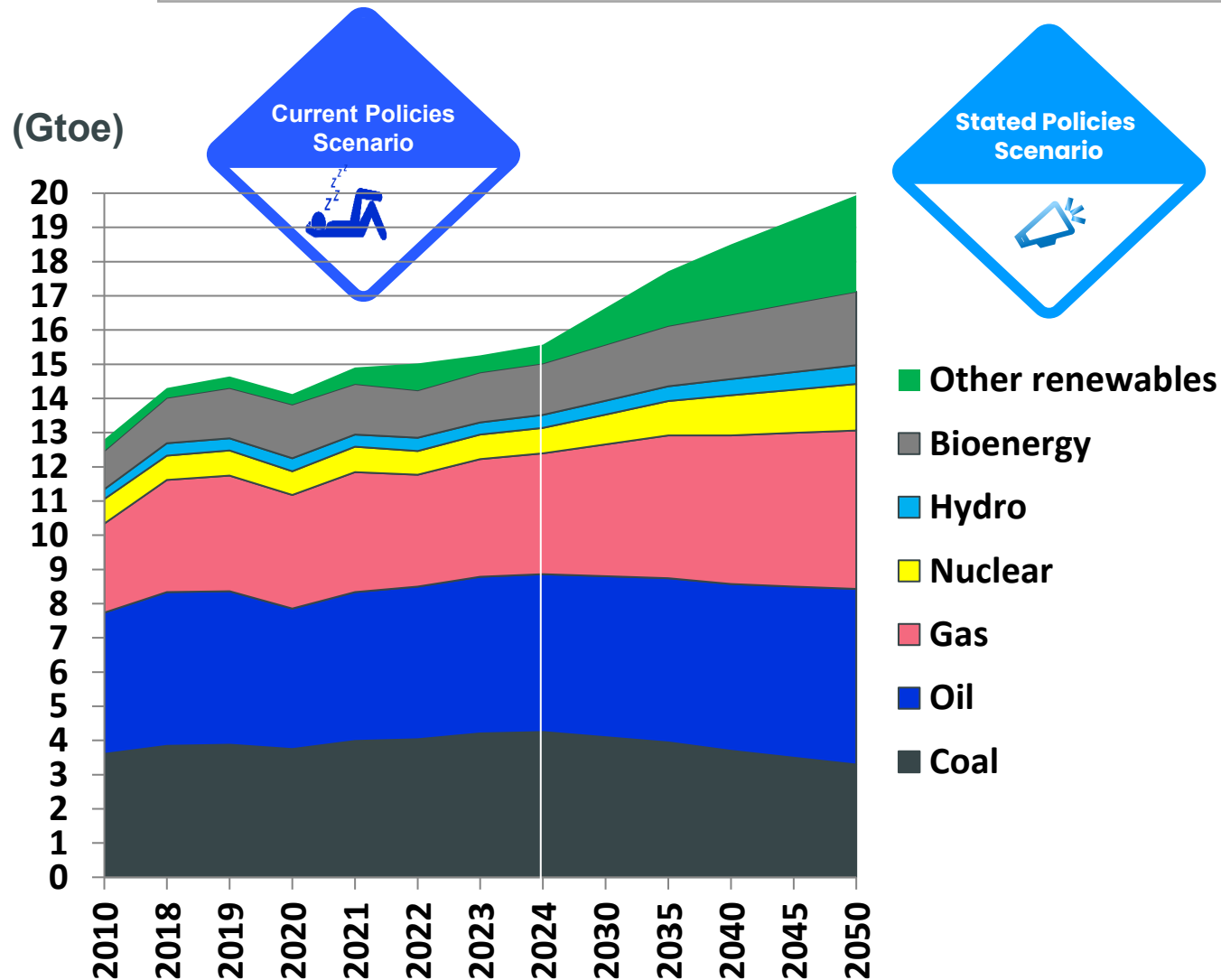
1. What is science telling us about climate change ?
2. Economic consequences for energy and industries
3. The Kaya Equation
4. Agenda for Climate Change Negotiations
5. CO2 Markets, Pricing and Trading
6. Carbon Capture and Storage technologies
7. What implications for oil companies:
the case of TotalEnergies



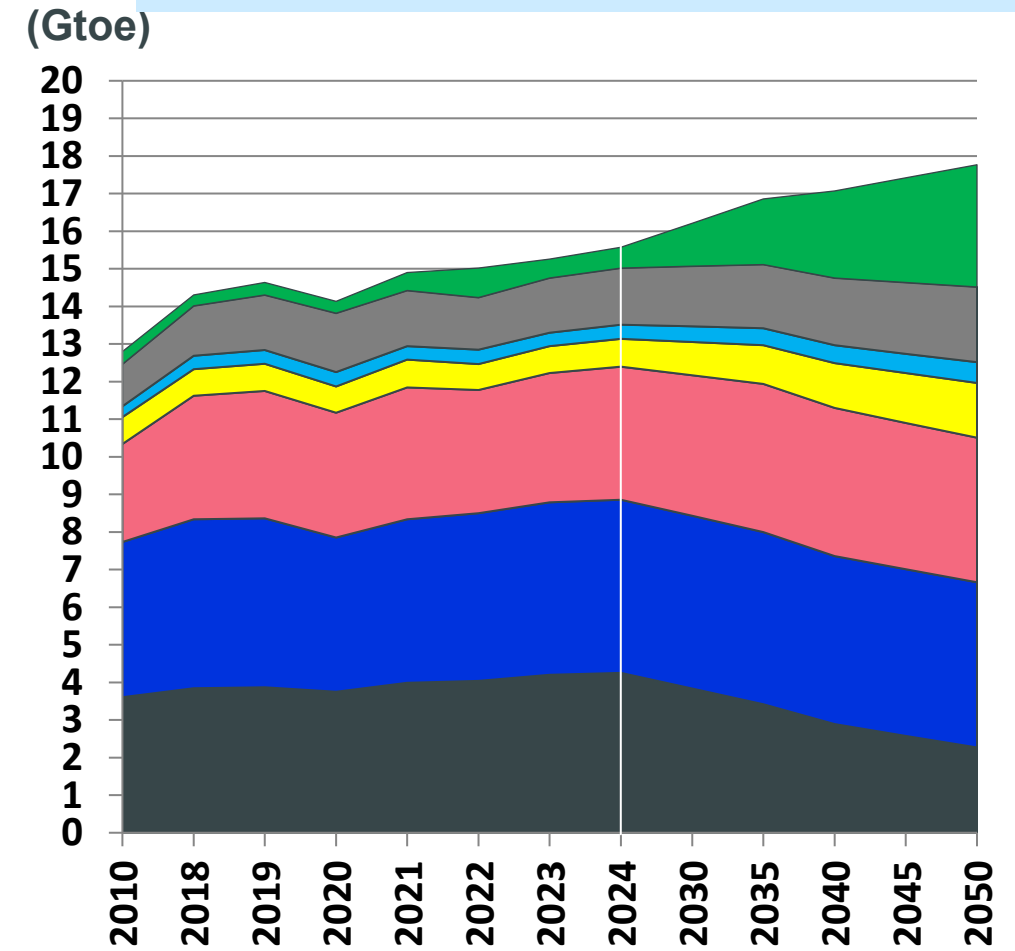
**International Energy Agency (IEA) Perspectives
World Energy Outlook (WEO) 2025
See Book 2**



Primary Energy Demand IEA 2025 CPS and STEPS Scenarios (Gtoe)

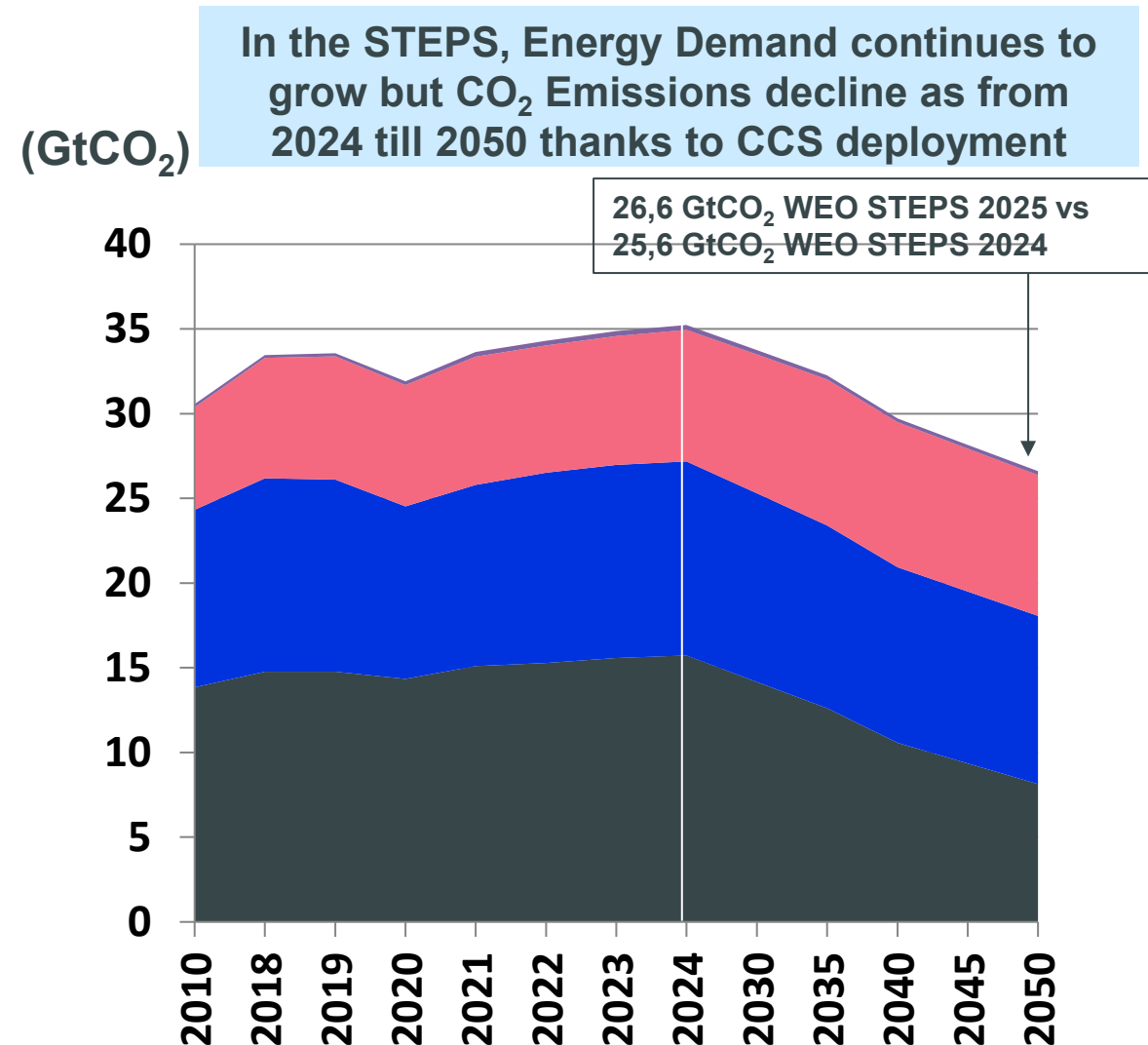
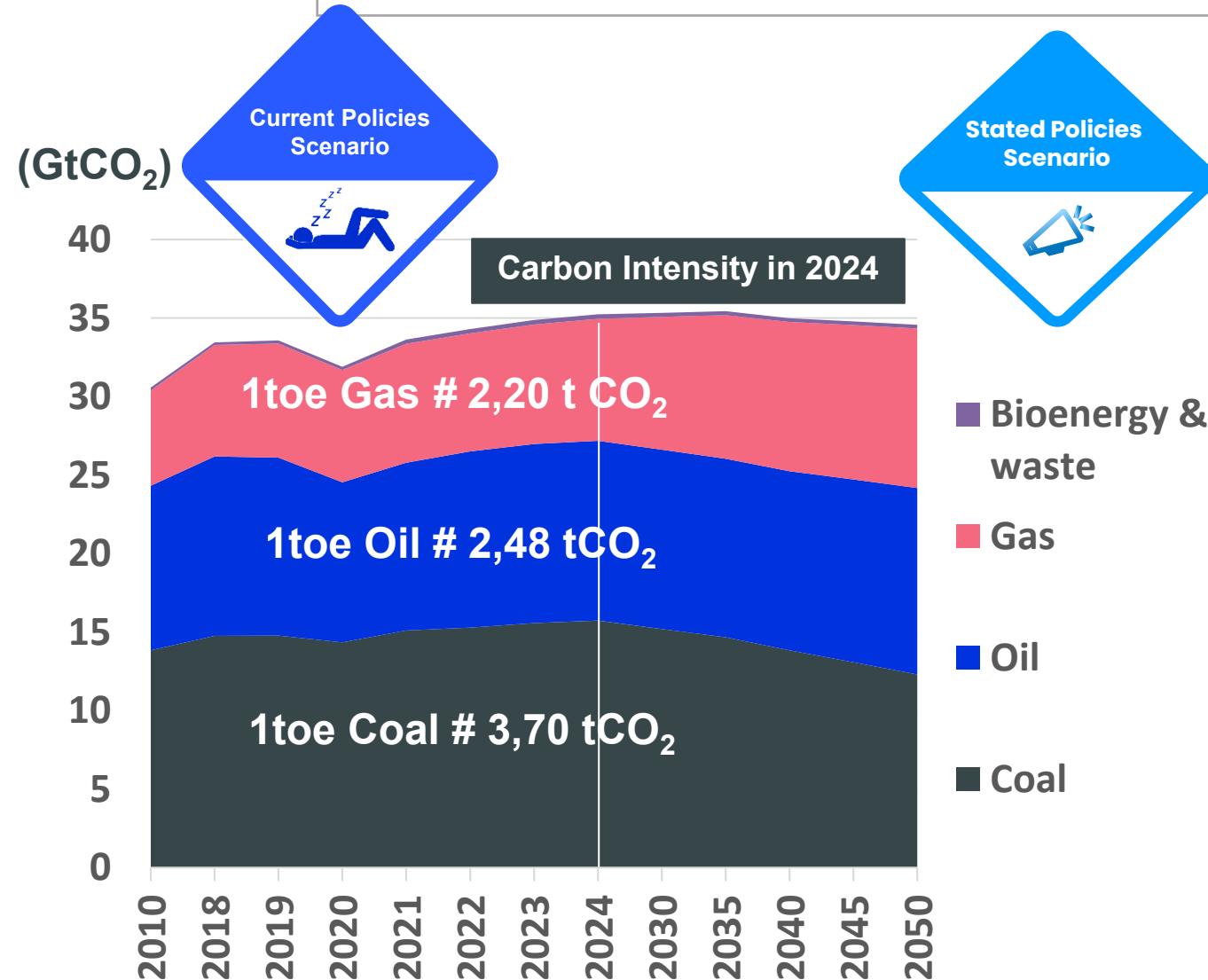


In the STEPS, Energy Demand continues to grow after 2024

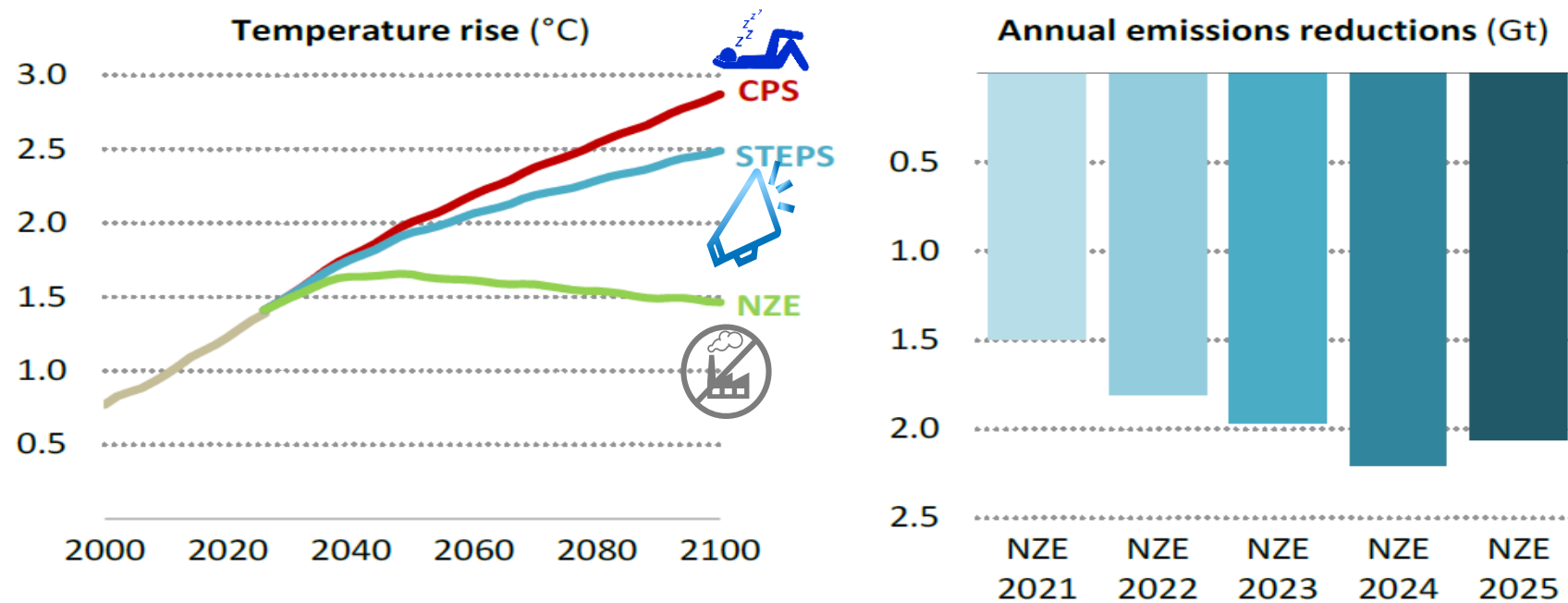


Source: Ch.Guérutte/Data from IEA WEO 2025
1 EJ = 10^{18} J = 23,88 Mtoe

CO₂ Energy Emissions (Combustion activities) IEA 2025 CPS and STEPS Scenarios (GtCO₂)



Three IEA Scenarios vs their consequences in term of temperature rise in 2100



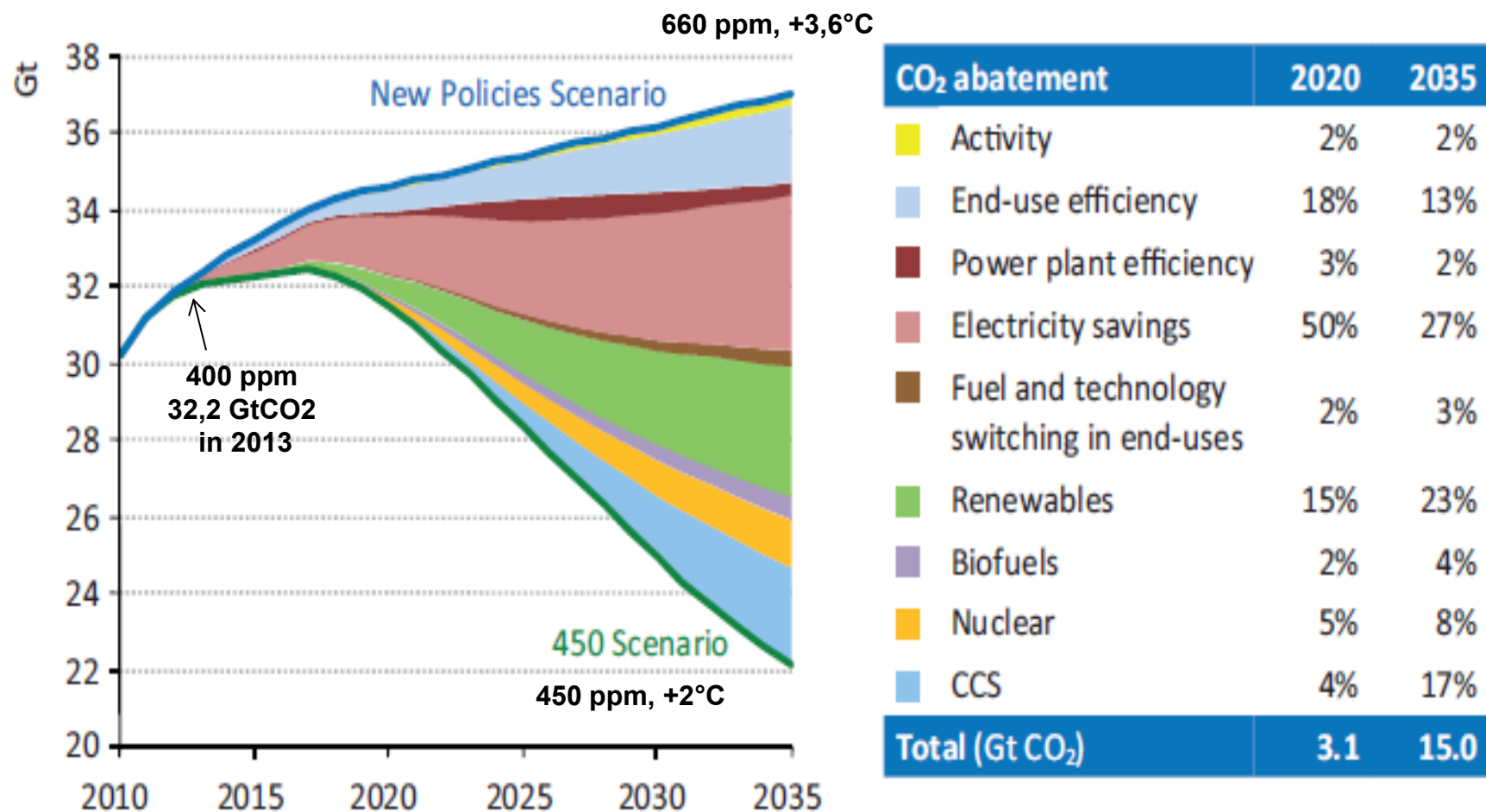
IEA. CC BY 4.0.

The average temperature rise reaches 2.9 °C in 2100 in the CPS, 2.5 °C in the STEPS, and in the NZE Scenario it peaks at around 1.65 °C in 2050 and falls below 1.5 °C in 2100

Notes: Gt = gigatonnes. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario; NZE 20xx = NZE Scenario in the *World Energy Outlook* of the specified year. The figure shows median long-term average global temperature anomaly relative to 1850-1900 and matches the Intergovernmental Panel on Climate Change Sixth Assessment Report definition of warming of 0.85 °C between 1995-2014.



Reminder: IEA WEO 2012 - CO₂ Emissions Abatement 450 Scenario vs Central Scenario

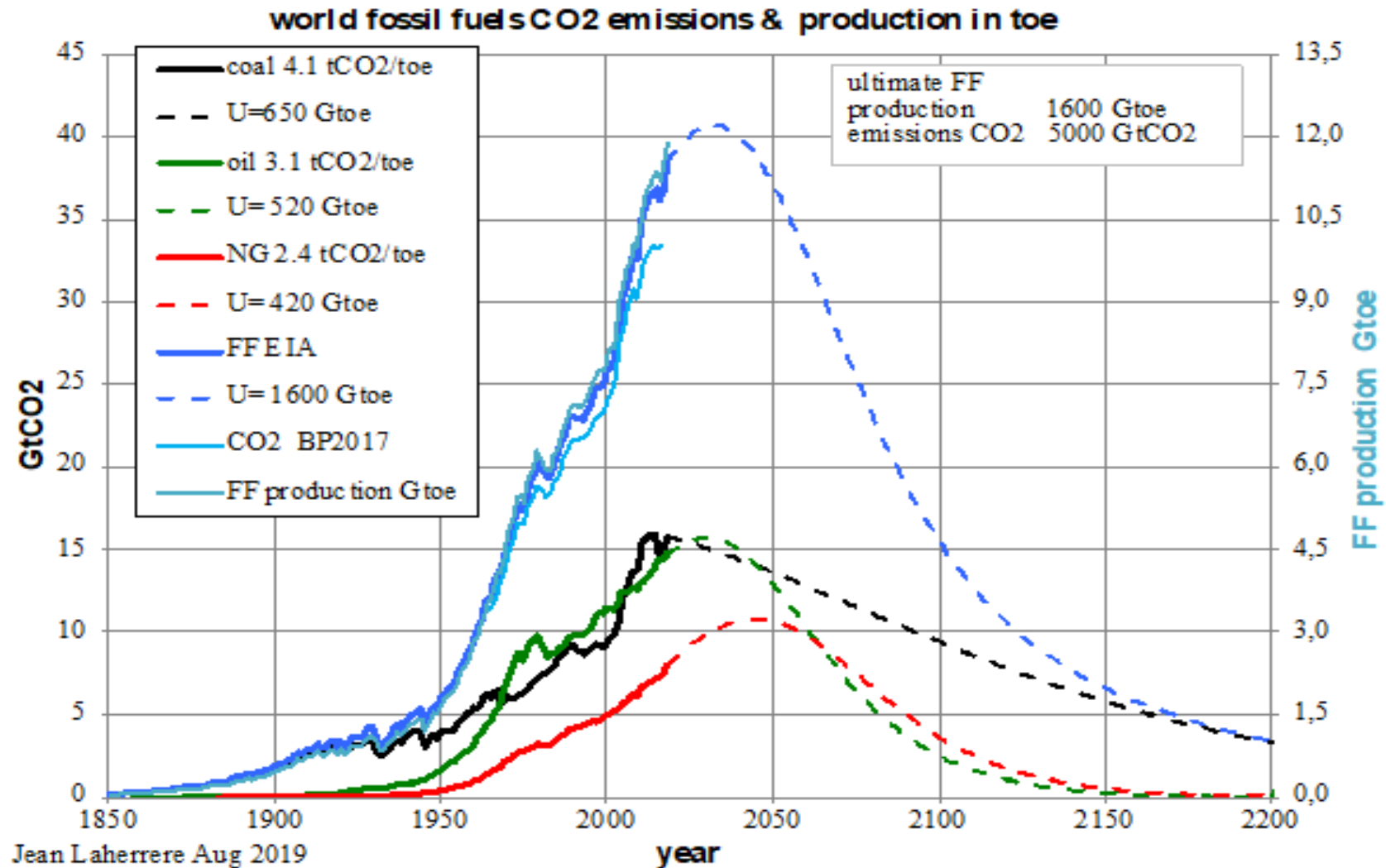


Source: IEA 2012 World Energy Outlook

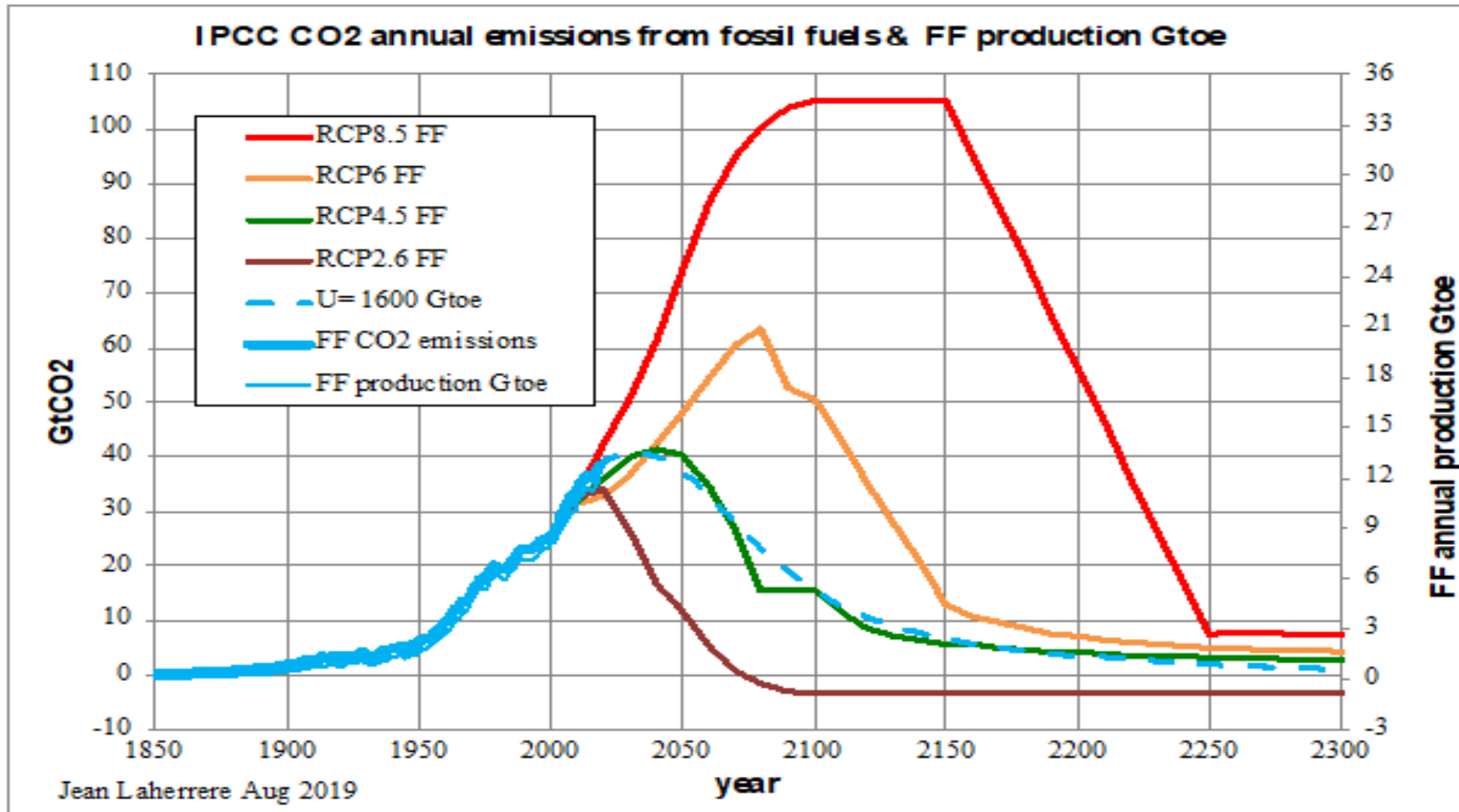


Energy related CO₂ Emissions

A Long Term vision till Year 2200

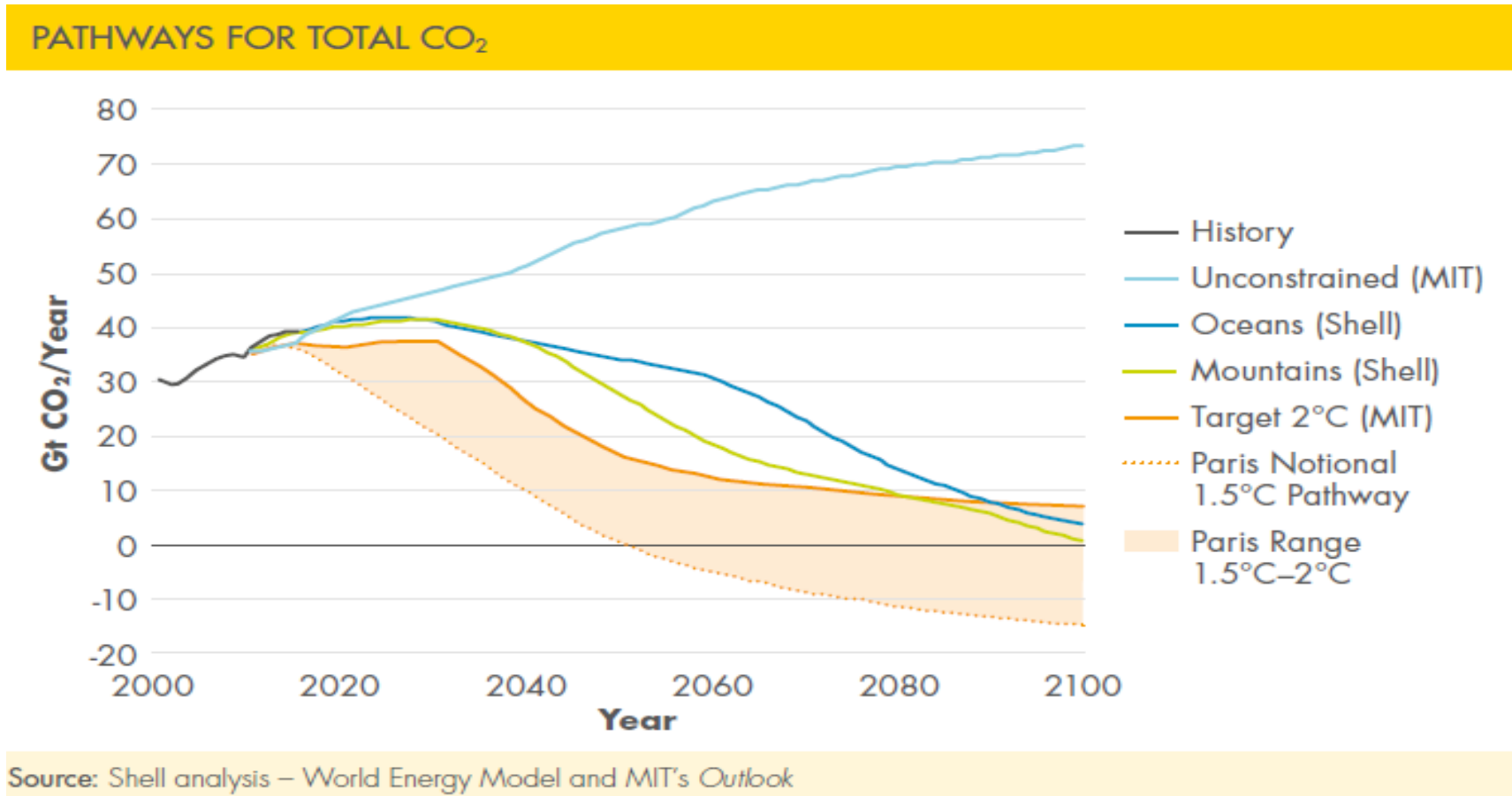


Energy related CO₂ Emissions with different RCP Scenarios and Fossil Fuels (FF) Production A Long Term vision till Year 2300



Reminder - Energy related CO₂ Emissions

A view by Shell 2017

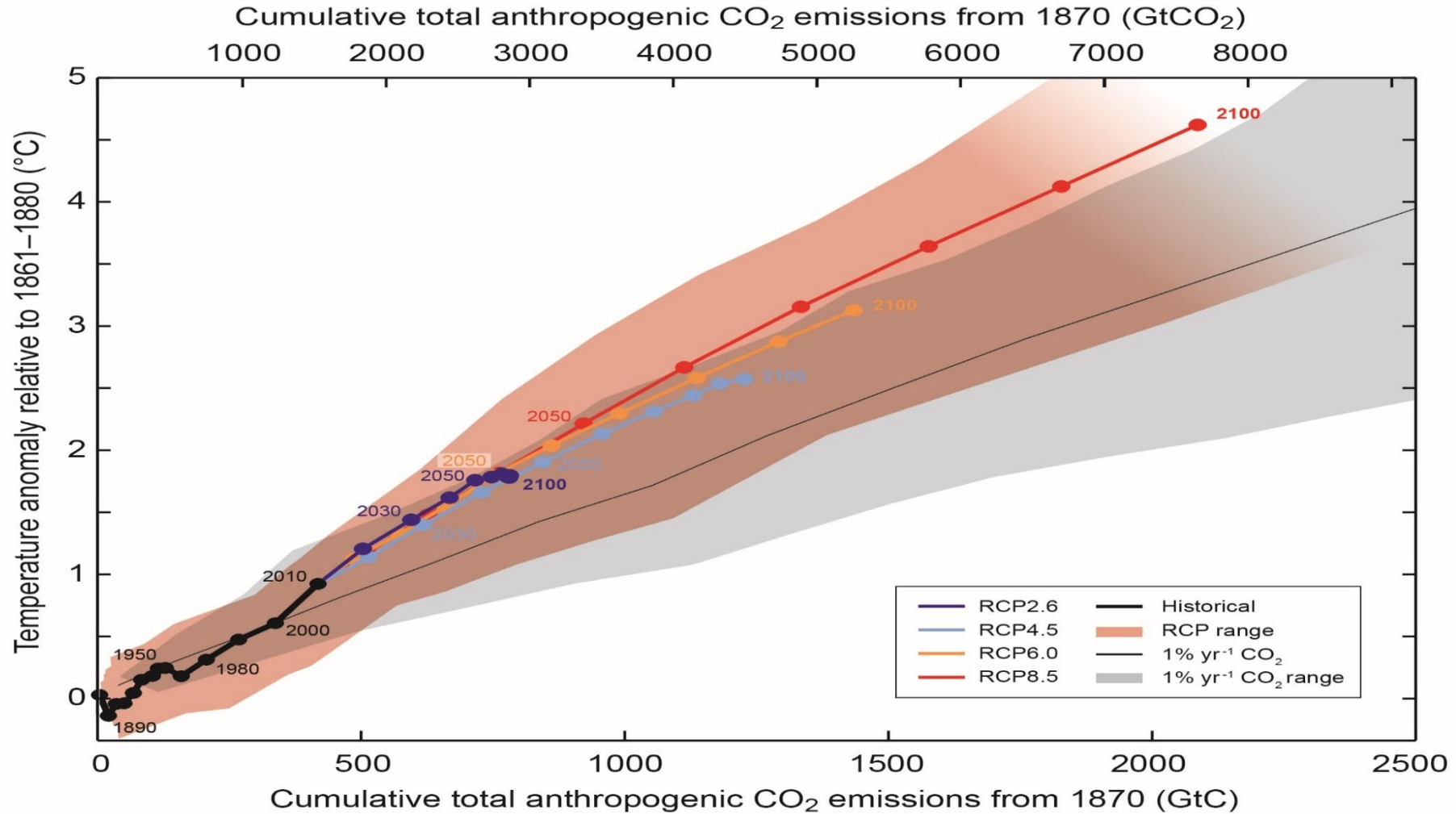


Source: Shell scenarios 2017

Nota: Oceans and Mountains correspond to two different scenarios developed by Shell regarding the evolution of the world economy.



Cumulative CO₂ Emissions Various scenarios vs Radiative Forcing

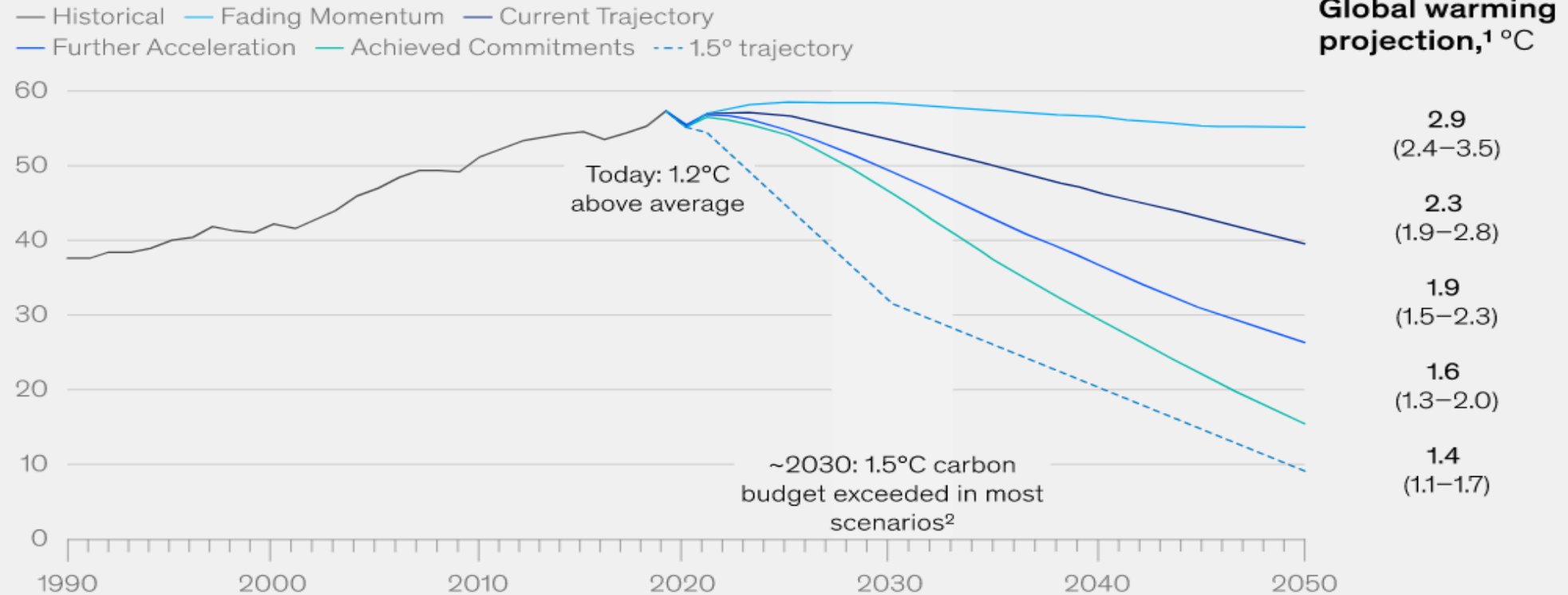


Source: IPCC Report 2019
RCP: Representative Concentration
Pathway as per Radiative Forcing



GHG Emissions Scenarios by McKinsey

Global net CO₂ equivalent emissions, GtCO₂e per year



¹Warming estimate is an indication of global rise in temperature by 2100 versus pre-industrial levels (range 17th to 83rd percentile), based on IPCC assessments given the respective emission levels and assuming continuation of trends after 2050 but no net-negative emissions.

²250 Gt of cumulative CO₂ emissions from 2023 for a 50% chance of limiting global warming to 1.5°C.

Source: Indicators of Global Climate Change 2023; McKinsey Energy Solutions' Global Energy Perspective 2023

McKinsey & Company



History of CO₂ Emissions & Remaining Budget Need to reverse the trend, drastically!

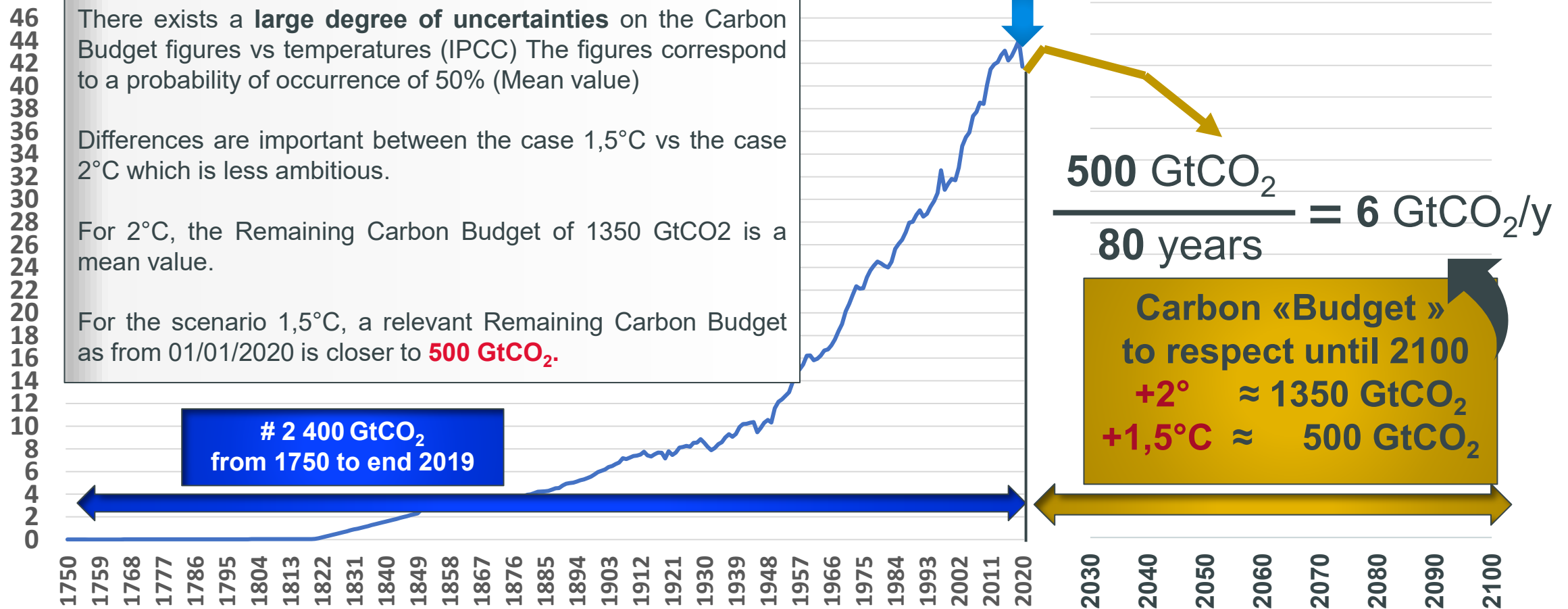


History of CO₂ Emissions & Remaining Budget at 01/01/2020

(Fossil Fuels combustion, Cement, Flaring, Land Use)

(GtCO₂)

Protocol on climate in Dec. 2015 – COP 21 Paris Agreement, involving all countries, effective 2020



Source: Ch.Guéritte/Data from Global Carbon Budget 2023

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TPA Toolbox Energy Book 3 - GHG

History of CO₂ Emissions & Remaining Budget at 01/01/2025

The Remaining Carbon Budget is melting every year

Protocol on climate in Dec. 2015 – COP 21 Paris Agreement, involving all countries, effective 2020

(GtCO₂)

There exists a **large degree of uncertainties** on the Carbon Budget figures vs temperatures (IPCC) The figures correspond to a probability of occurrence of 50% (Mean value)

Differences are important between the case 1,5°C vs the case 2°C which is less ambitious.

For 2°C, the Remaining Carbon Budget of 1100 GtCO₂ is a mean value.

For the scenario 1,5°C, a relevant Remaining Carbon Budget as from 01/01/2025 is closer to **170 GtCO₂**.

2 890 GtCO₂
from 1750 to end 2024

170 GtCO₂ : Extinction in 4 years!

Carbon «Budget»
to respect until 2100
+2° ≈ 1100 GtCO₂
+1,5°C ≈ 170 GtCO₂

1750 1758 1766 1774 1782 1790 1798 1806 1814 1822 1830 1838 1846 1854 1862 1870 1878 1886 1894 1902 1910 1918 1926 1934 1942 1950 1958 1966 1974 1982 1990 1998 2006 2014 2022

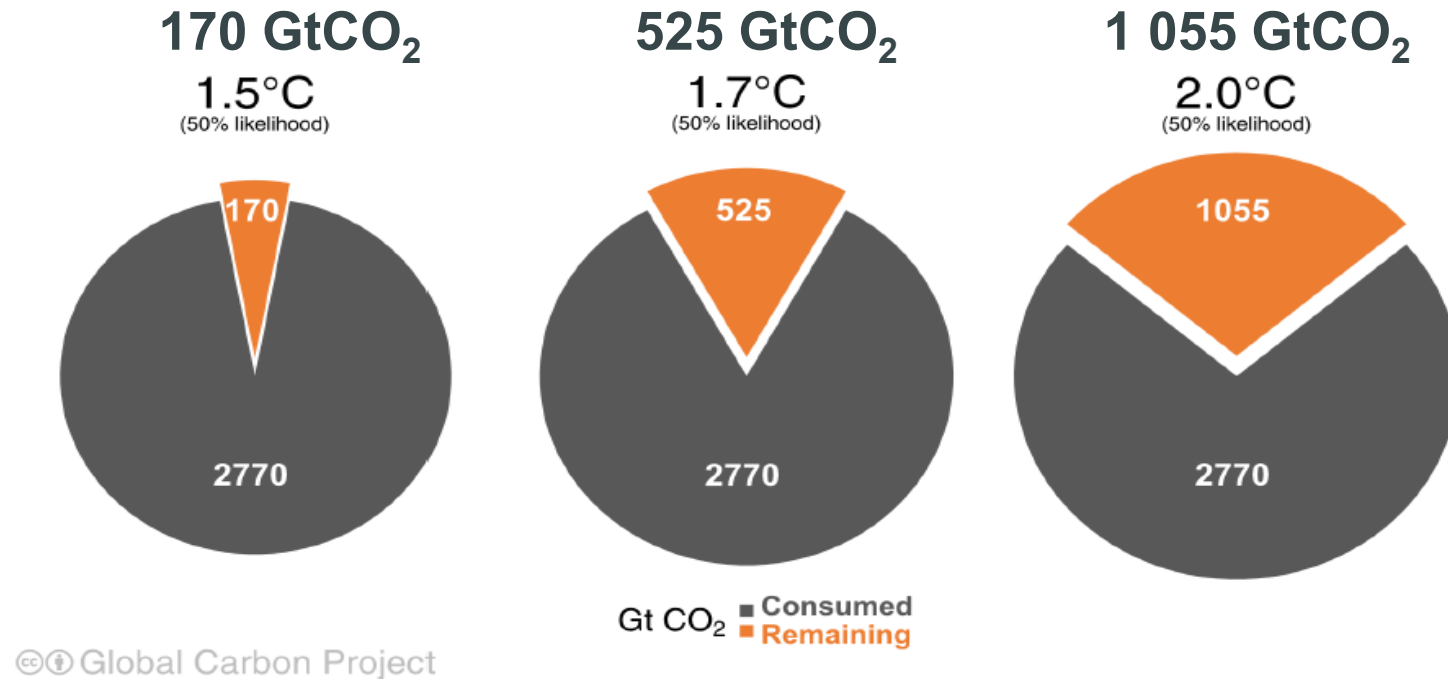
2030 2040 2050 2060 2070 2080 2090 2100



Cumulative Emissions and Carbon Budget (GtCO₂)

A view by Global Carbon Project 2025

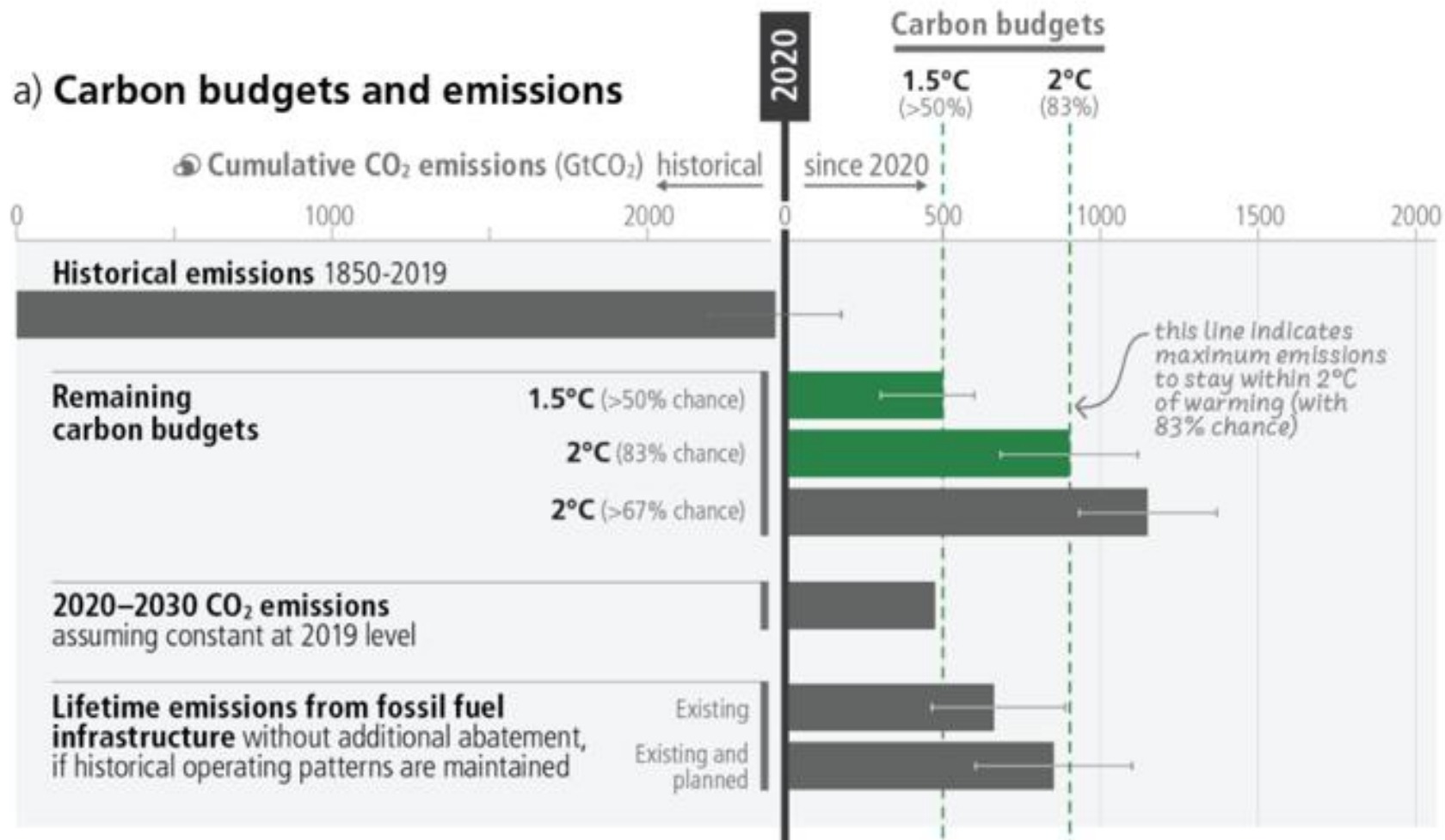
The remaining carbon budget to limit global warming to 1.5°C, 1.7°C and 2°C is 170 GtCO₂, 525 GtCO₂, and 1055 GtCO₂ respectively, equivalent to 4, 12 and 25 years from 2026. A total of 2770 GtCO₂ has been emitted since 1850.



The remaining carbon budgets are the average of two estimates (IPCC AR6 and Forster et al., 2025), both updated by removing the most recent emissions. Quantities are subject to additional uncertainties e.g., future mitigation choices of non-CO₂ emissions
Source: IPCC AR6 WG1; [Forster et al., 2023](#); [Friedlingstein et al 2025](#); [Global Carbon Project 2025](#)

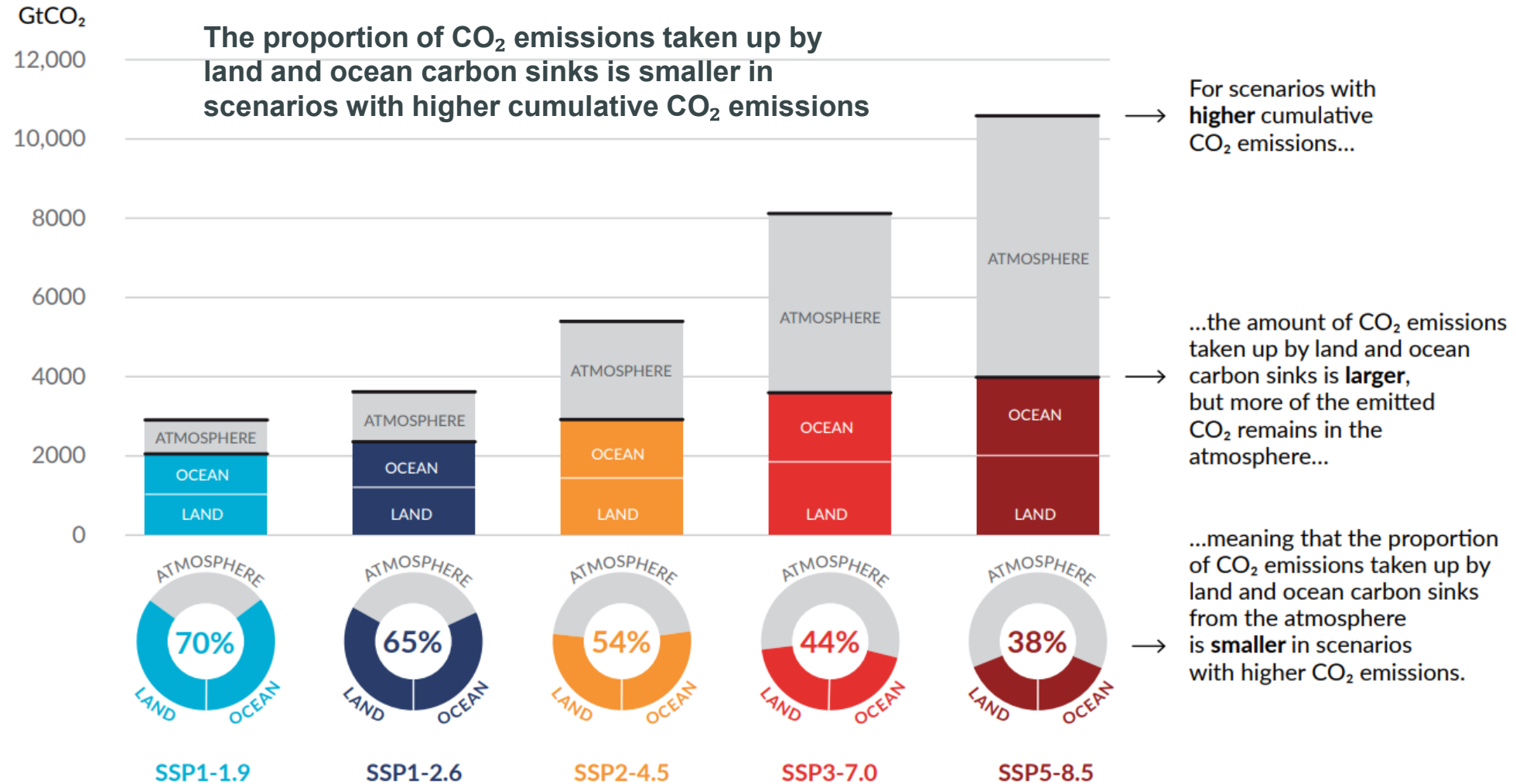


Carbon Budget & Emissions – IPCC 2023



Source : IPCC AR6 – Final long report – March 2023

More emissions → less absorption by land/oceans



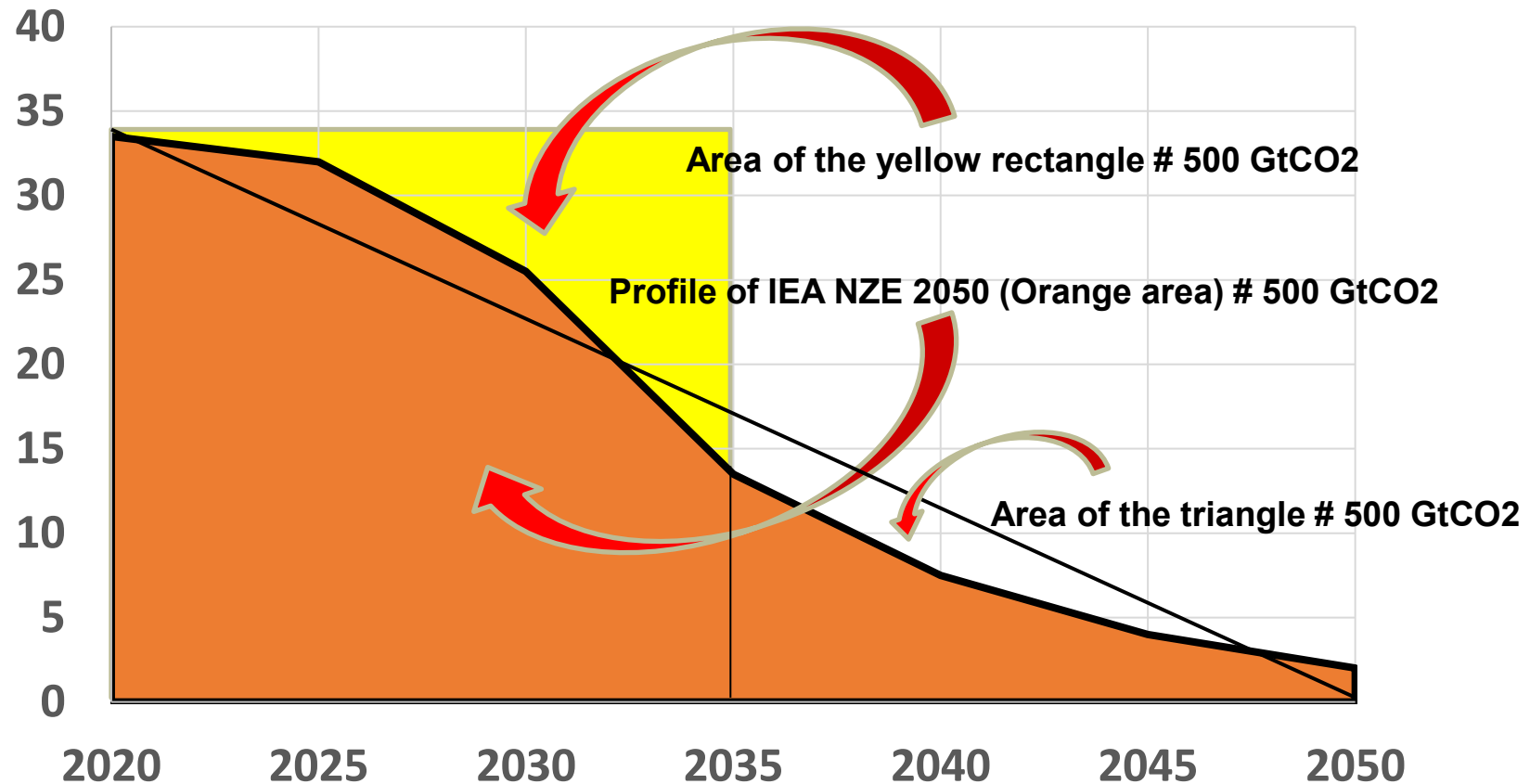
Source : IPCC AR6 – WG1 SPM – August 2021



CO₂ Emissions - Net Zero in 2050 - To achieve 1,5°C

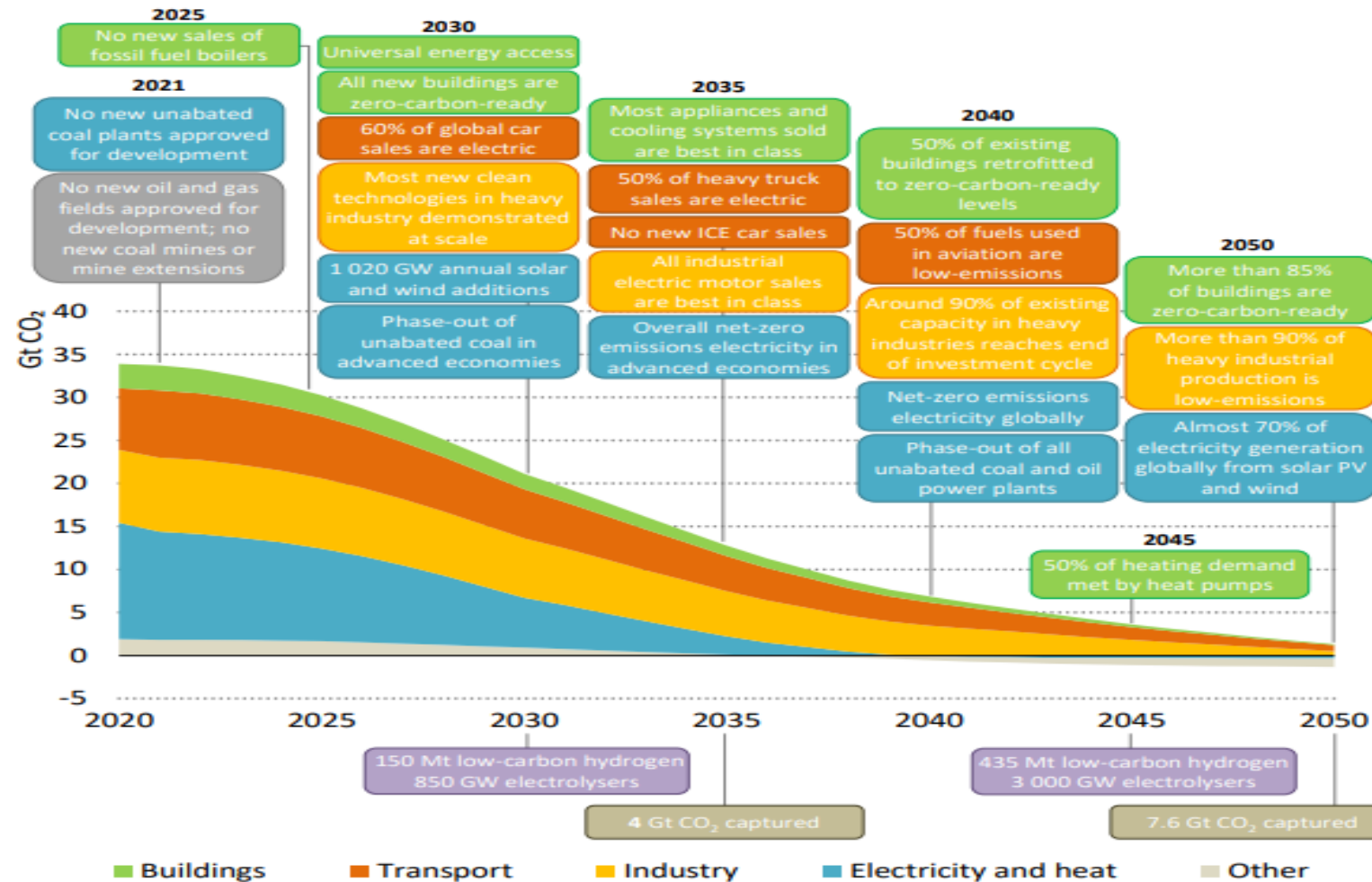
An illustration (Based on budget 01/01/2020)

(GtCO₂)



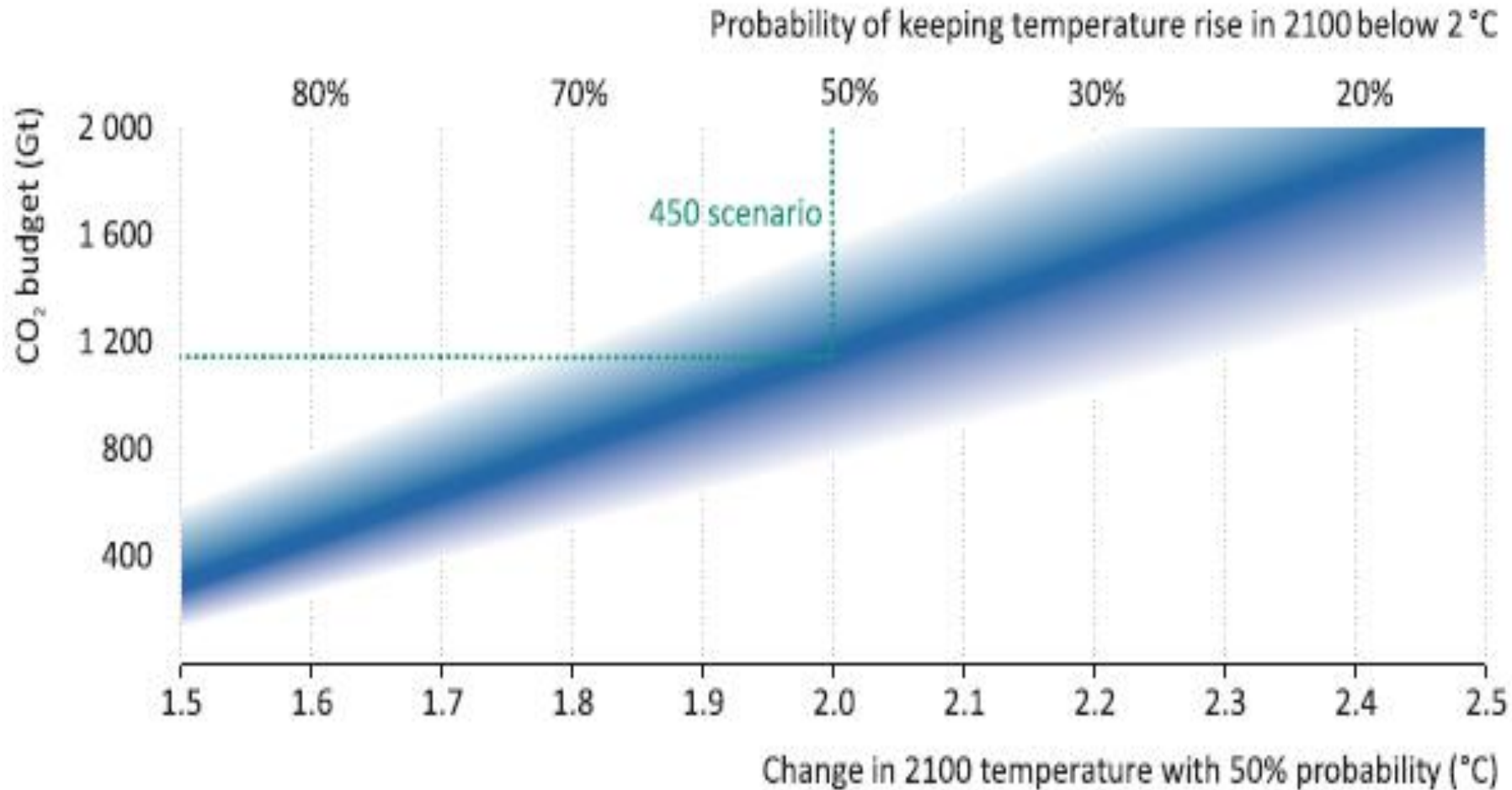
Total Final Energy Consumption by sectors

The new IEA 2021 Scenario NZE2050



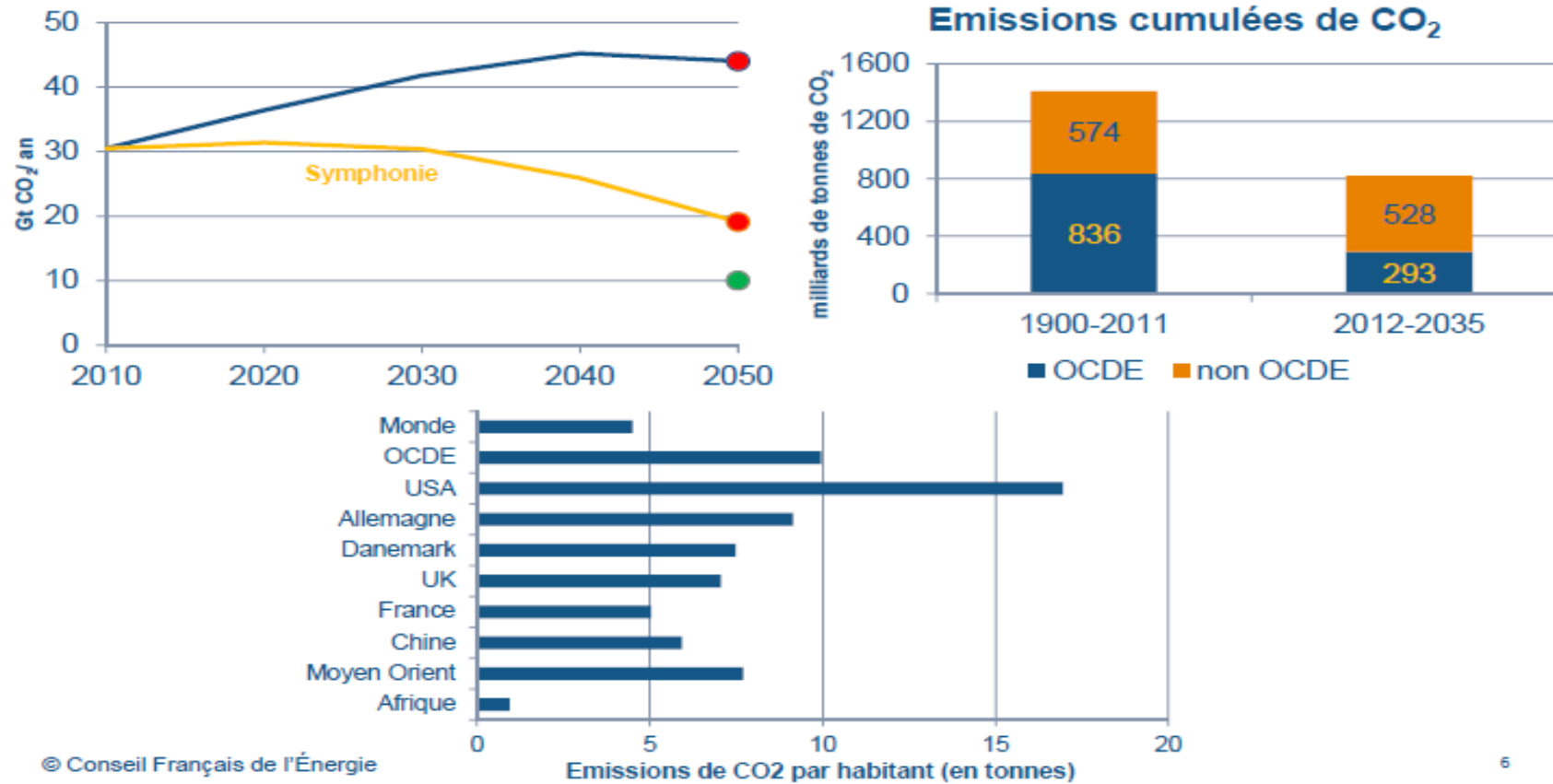
CO₂ Energy Budget: need to reverse the trend

CO₂ Budget 2015 - 2100

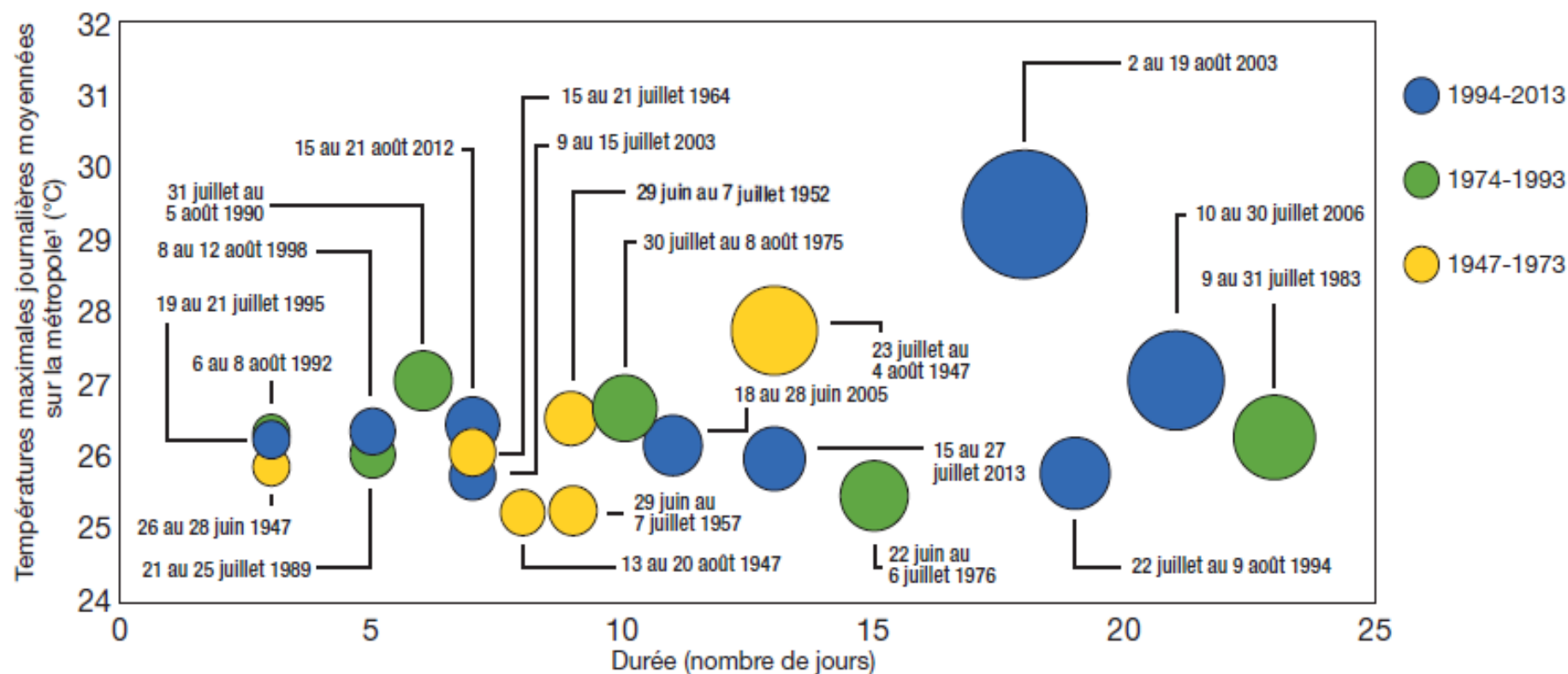


A view by the « Conseil Français de l'Energie » 2012/2013 Vision

L'urgence climatique



Heat Periods in France 1947 - 2013



Source: Ministère de l'Écologie, du Développement Durable et de l'Énergie – France 2015



For those who do not believe in Science...



Défis environnementaux : le réchauffement climatique



Banquise arctique

Janvier 2000

Décembre 2010



Janvier 2000



Décembre 2010

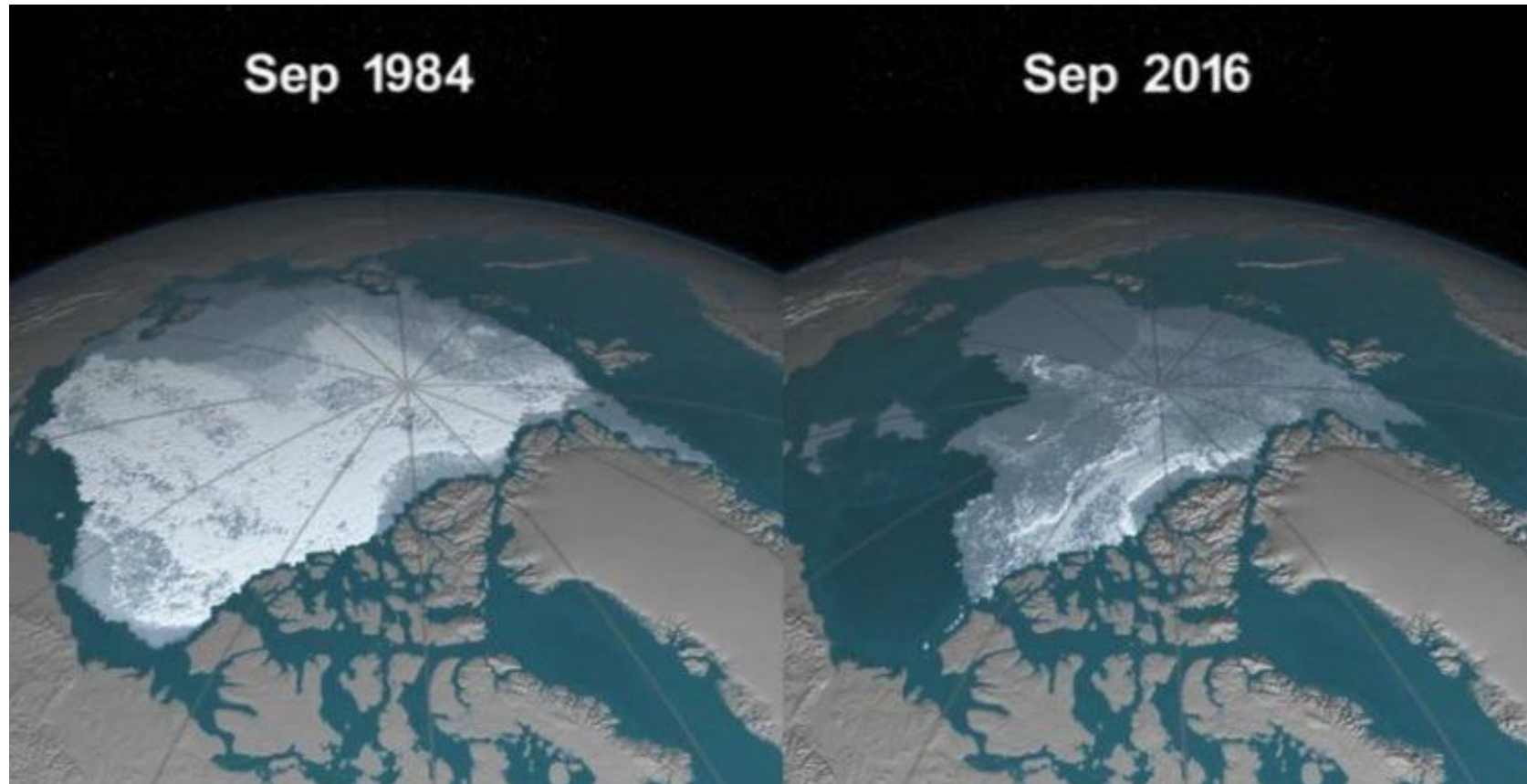
Source: ACIA, Impacts of a Warming Arctic, *Climate Impact Assessment Report*, Cambridge University Press,



Défis environnementaux : le réchauffement climatique



Banquise arctique



Source: NASA



Climate Change challenges - Greenland

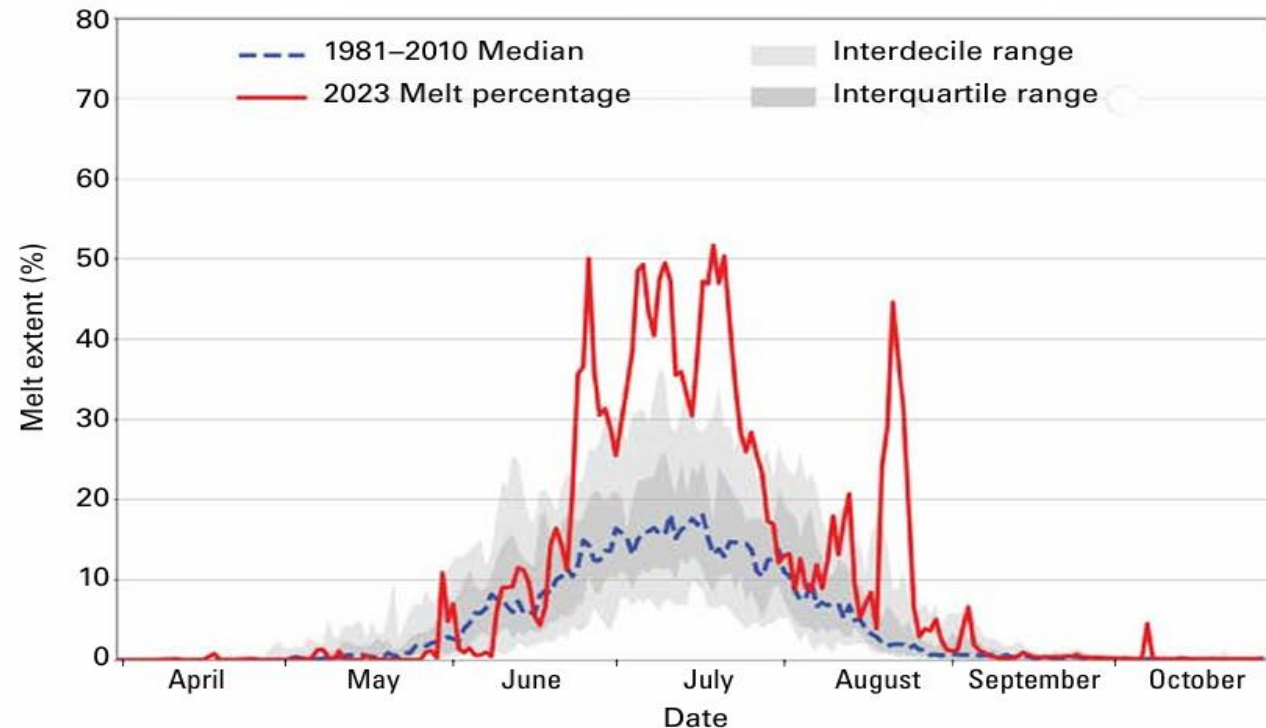
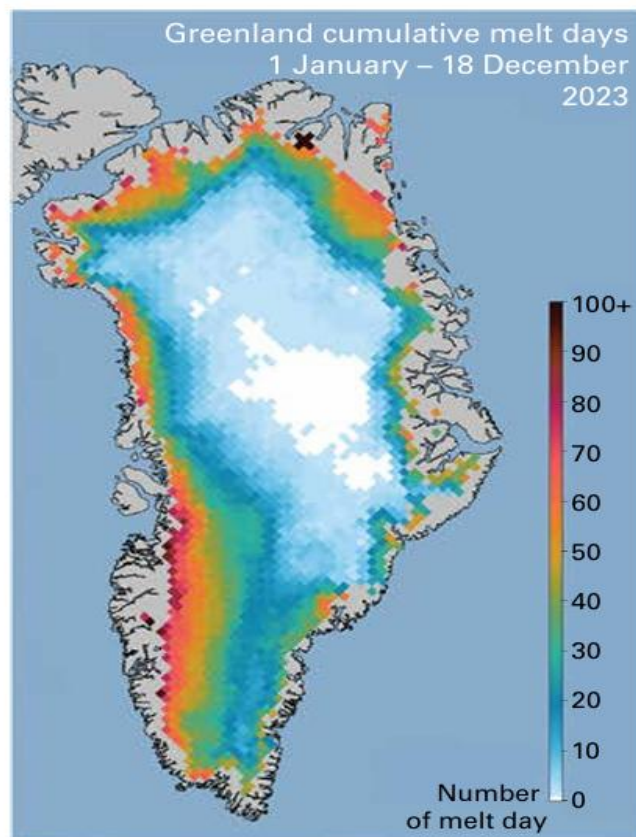


Figure 14. Greenland Ice Sheet melt conditions through 2023: (left) Cumulative melt days for Greenland in 2023. White areas indicate no melting occurred. (right) Percentage of the ice sheet experiencing melting conditions each day.

Source: Images and analysis courtesy of Thomas Mote, University of Georgia, and the U.S. National Snow and Ice Data Center..

Source: World Meteorological Organization (WMO)
State of Global Climate 2023

Potential melting of ice caps: Greenland only



Potential melting of ice caps: Groenland and Antarctic



Climate Change consequences - Sea Level rise

Sea Level Equivalent (SLE) - Compilation of various data

Cryospheric data		Mean/Rounded figures		ChG March 2018												Nota:	
Density	kg/m3																200 000 glaciers on earth
Density of ice	916,7																Antartica + Greenland = Inlandsis
Density of fresh water	1000,0																Source: IPCC, GRACE, ICESat., WGMS, etc.
Density of sea water	1027,0																
Characteristics	Surface		Aver. Thickness	Volume		Mass	Sea Level Equivalent (SLE)		Observed losses					SLE			
	Mkm2	%	m	Mkm3	%	1000 Gt	Calculat. m	IPCC m	Period	Gt/year	Cumul. Gt	%	Cum. mm	mm/year			
Earth	510,00	100,0%		1080000,00	100,0%	5,97 10 ⁹											
Out of which oceans	362,00	71,0%	3600,00	1320,00	0,1%	1360000											
Out of which land	148,00	29,0%		1078680,00	99,9%												
Quantity of free water				1360,00	100,0%												
Out of which salted water				1320,00	97,1%												
Out of which fresh water				40,00	2,9%												
Quantity of fresh water				40,00	100,0%												
Out of which surface waters				0,04	0,1%												
Out of which subsurface waters				6,96	17,4%												
Out of which ice				33,00	82,5%												
Land	148,00	100,0%		1078680,00													
SLE ice cap & glaciers + thermal expansion	14,47	9,8%	2300	33,00	100,0%	30251	81,4	65,8	2002 - 2011								2,8
Out of which ice cap antarctica	12,00	8,1%	2500	30,00	90,9%	27501	74,0	58,0	1992 - 2001	30	300	0,00%	0,8	0,1			
									2002 - 2011	147	1470	0,01%	4,0	0,4			
									1992 - 2012	180	2000	0,01%	5,4	0,5			
Out of which ice cap arctic (Greenland)	1,74	1,2%	1600	2,80	8,5%	2567	6,9	7,4	2003 - 2010	185	1500	0,06%	4,0	0,5			
									1992 - 2001	34	340	0,01%	0,9	0,1			
									2002 - 2011	215	2150	0,08%	5,8	0,6			
									1992 - 2012	270	3000	0,12%	8,1	0,7			
Out of which glaciers & small ice caps	0,73	0,5%	300	0,20	0,6%	183	0,5	0,4	2003 - 2009	260	1800	0,98%	4,8	0,7			
SLE due to thermal expansion										1992 - 2016				30,0	1,1		

Source: various – Compilation: Ch.Guérutte



Carbon Emissions for different Products

g CO₂eq per kWh_e

Nota:

The table shows the implied CO₂ emissions from electricity generation deriving from combustion of various fossil fuels.

The values represent the average amount of CO₂ per kWh of electricity produced in OECD between 2010 and 2014. They are indicative values, Actual values depend upon each specific case.

** These products represent a very minor part used for electricity generation.*

Product	gCO ₂ / kWh
Anthracite*	875
Coking coal*	820
Other bituminous coal	870
Sub-bituminous coal	940
Lignite	1030
Gas works gas*	335
Coke oven gas*	390
Blast furnace gas*	2425
Other recovered gases*	1590
Oil shale*	1155
Peat*	765
Natural gas	405
Crude oil*	590
Refinery gas*	450
Liquefied petroleum gases*	525
Kerosene*	625
Gas/diesel oil*	715
Fuel oil	670
Petroleum coke*	930
Municipal waste (non-renew.)*	1200

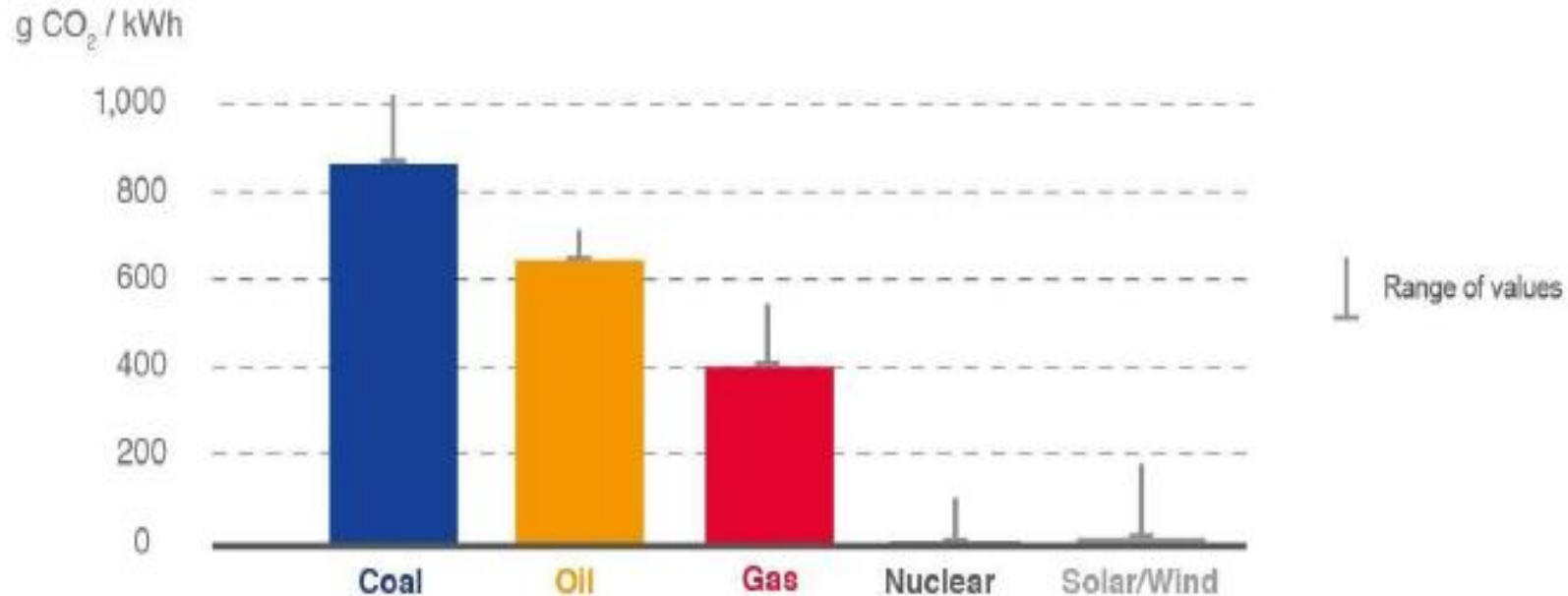
Source: IEA Report CO₂ emissions from fuel combustion 2016



CO2 Emissions: Gas emits half as much as Coal

IN POWER GENERATION, NATURAL GAS
EMITS ONLY HALF AS MUCH AS COAL

*Greenhouse gas emissions
from power generation, by technology*

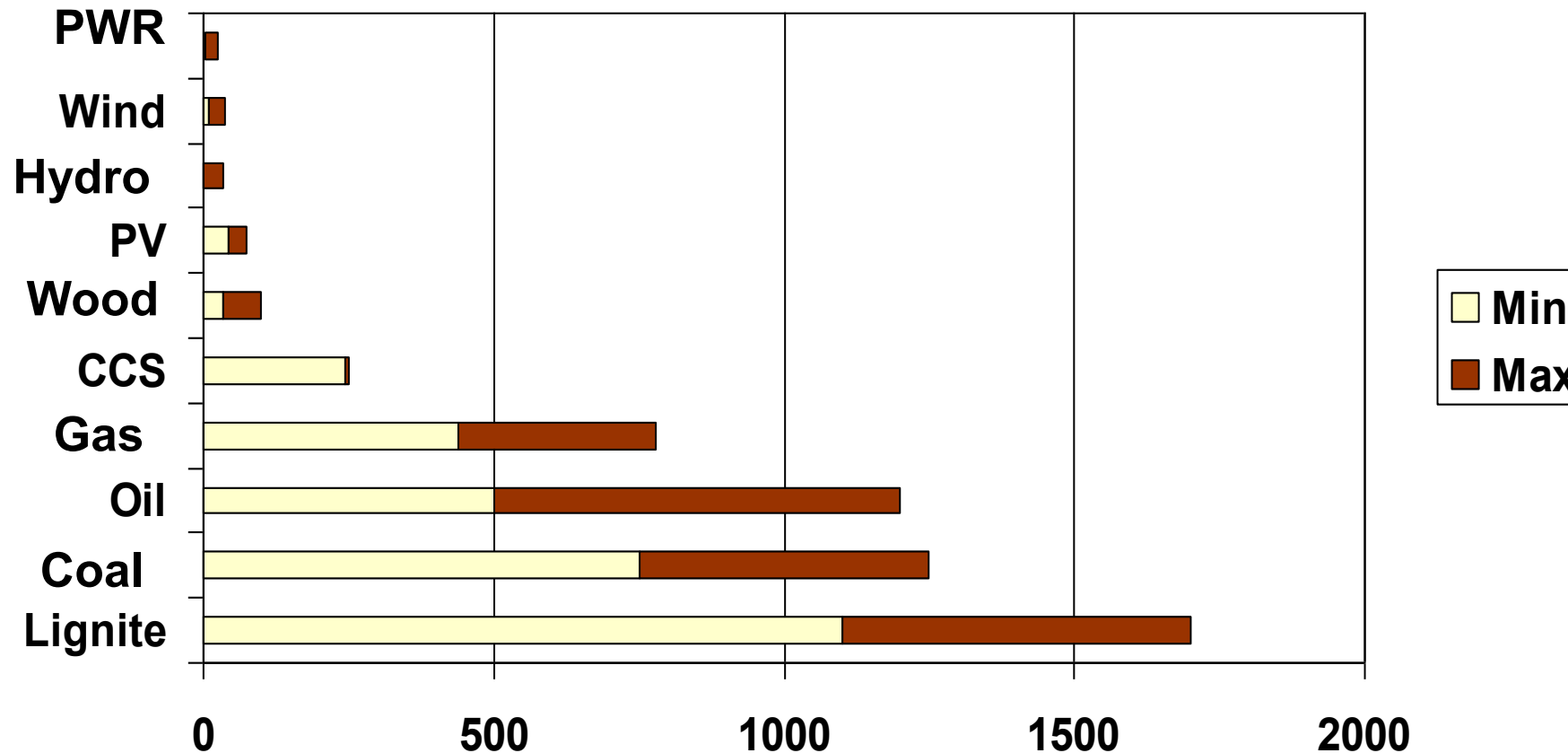


Source : IEA CO₂ Emissions From Fuel Combustion 2014
IPCC, Fifth Assessment Report (AR5), WG3 Annex II, Table A,
III.2, 2014.



Life Cycle GHG Emissions, g CO₂eq per kWh_e

D. Weisser IAEA May 2006



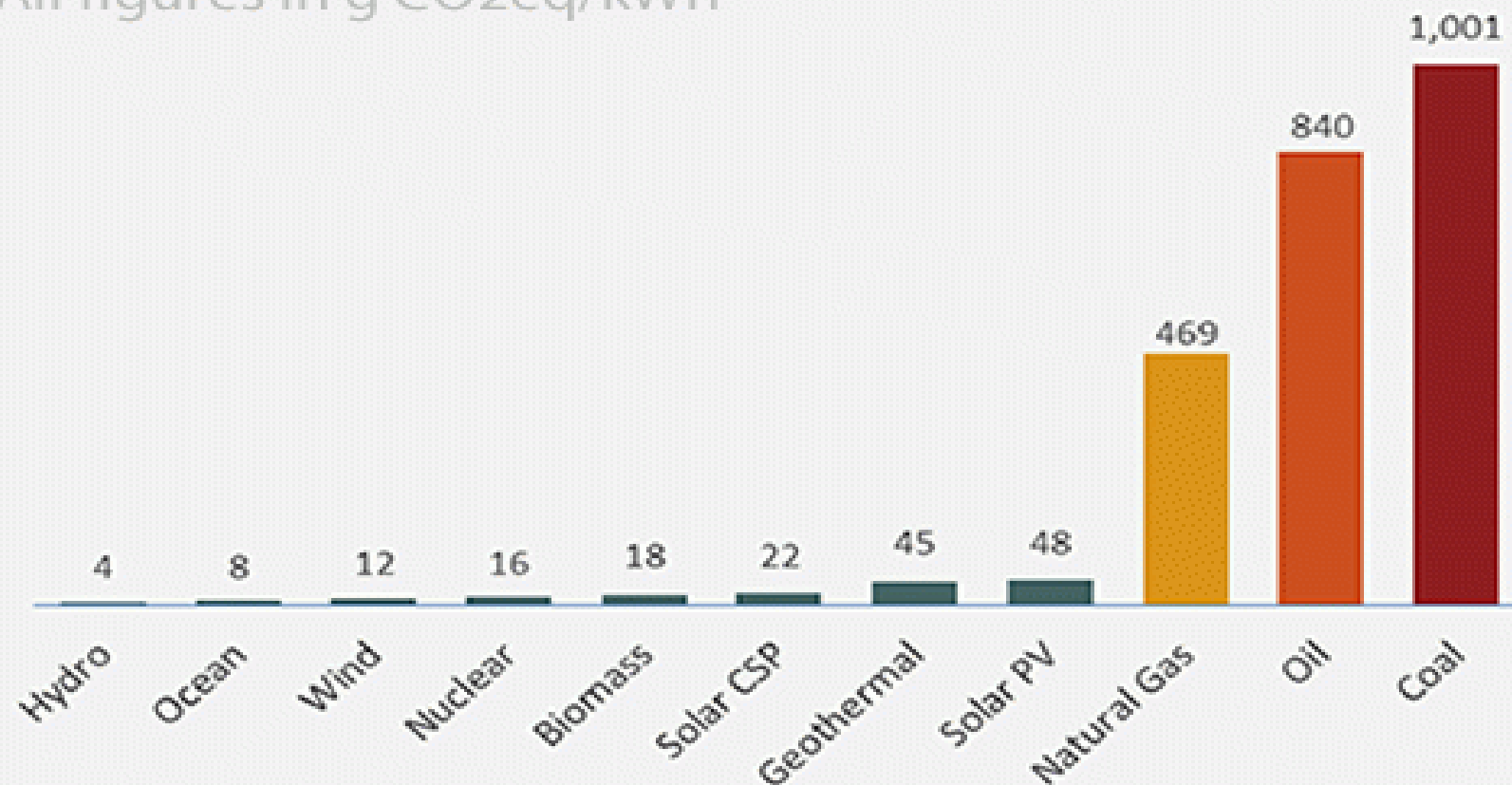
Ranges reflect differences in assessment technology, conversion efficiency, assessment boundary, etc.



Life Cycle GHG Emissions, g CO₂eq per kWh_e

The Carbon Intensity of Electricity Generation

All figures in g CO₂eq/kWh

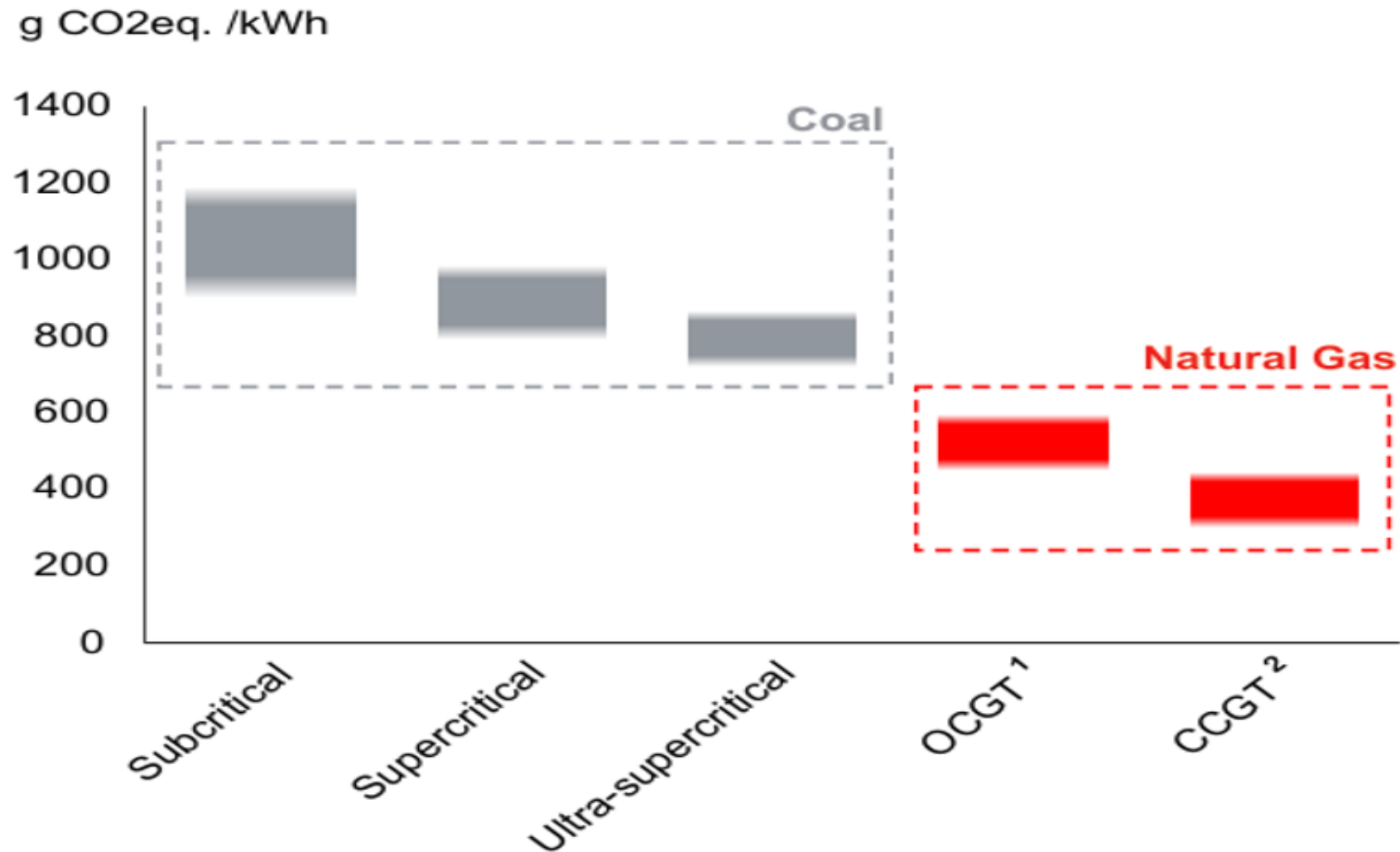


Note: Data is the 50th percentile for each technology from a meta study of more than 50 papers
Source: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation



Life Cycle GHG Emissions for different Technologies

Coal & Natural Gas – gCO₂eq./kWh_e

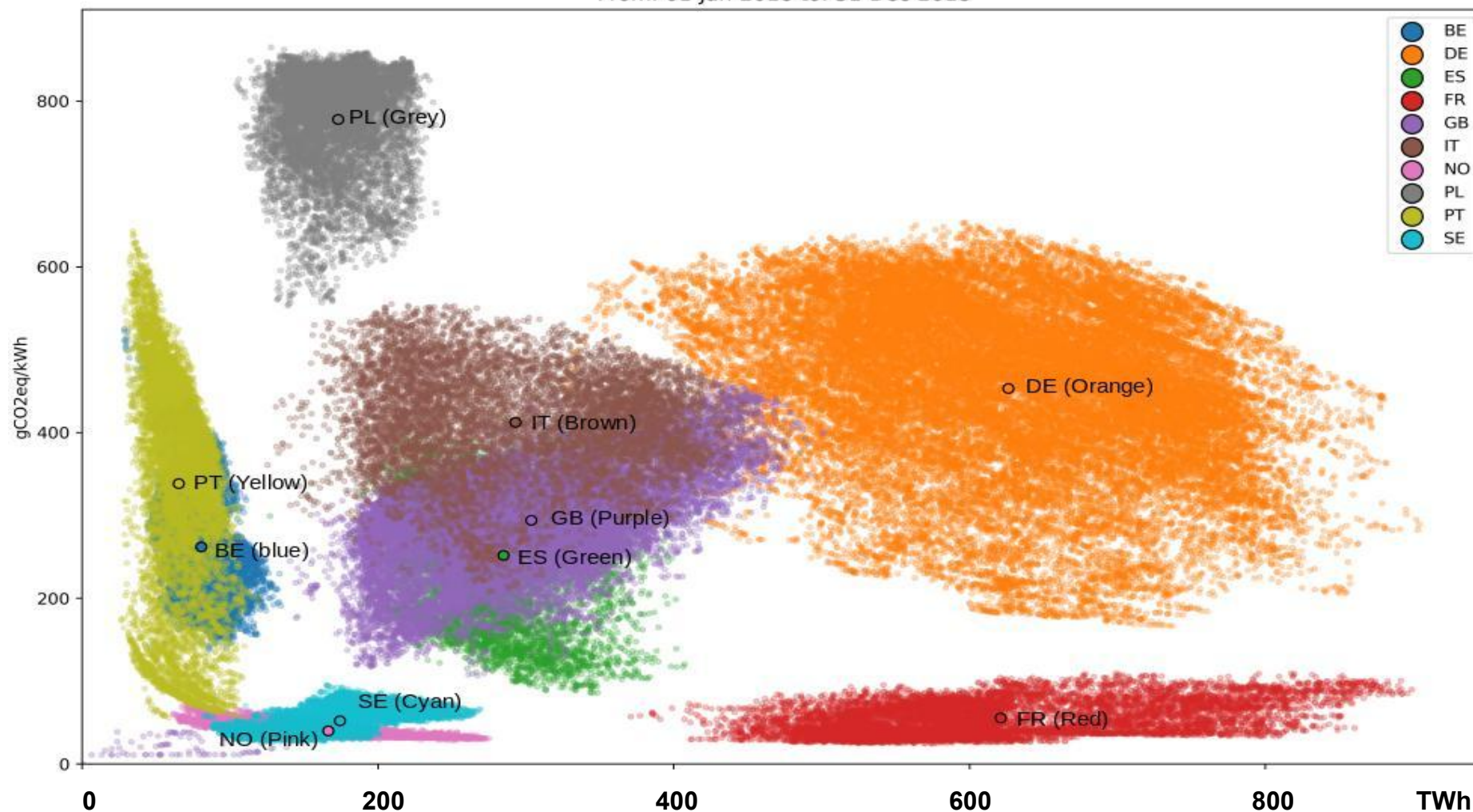


Carbon Intensity of Electricity Production (g CO₂eq per kWh_e)

Relative emission compared to power generation

Source: ENTSO-E, IPCC 2018

From: 01-Jan-2018 to: 31-Dec-2018



The main issue: Constraints on CO₂ and CH₄ Emissions

- ◆ The main culprits for global warming:
 - Water in the atmosphere (vapor or droplets)
 - CO₂: the focus of last 10 years
 - CH₄: an underestimated culprit (methodology issues)
- ◆ The potential constraint on emissions:
 - Taxation systems
 - Emission prices (CO₂ markets)
 - Emission Trading System (ETS) established by UE in 2005, but CO₂ prices evolve up and down timewise. No international Carbon price today.....
- ◆ The major issue:
 - What marginal and average costs in 2010 – 2020 – 2050 for CO₂ and CH₄ emissions ?
 - 20 to 50 \$/tCO₂ or 200 to 500 \$/t ? Are CCS estimated costs relevant ?
Additional energy costs for CCS facilities?



3

The Kaya Equation See Book 2 – Chapter 7



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1. What is science telling us about climate change ?
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7. What implications for oil companies:
the case of TotalEnergies





THE DILEMMA



The Kaya* Equation (One tool among others)

*Yoichi Kaya is a japanese energy economist



The Kaya Equation

$$CO_2 = \frac{CO_2}{Energy} * \frac{Energy}{GDP} * \frac{GDP}{Pop} * Pop$$

$$tCO_2 = \frac{tCO_2}{toe} * \frac{toe}{k\$} * \frac{k\$}{Pop} * Pop$$

$$CO_2 = \text{Carbon Intensity} \times \text{Energy Intensity} \times \text{Purchasing Power} \times \text{Population}$$

Nota: GDP is expressed in constant money



4

Agenda for Climate Change Negotiations



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Agenda for Climate Change negotiations

The Origin

United Framework Convention on Climate Change (UNFCCC)

- **Adopted during the « Earth Summit » in Rio de Janeiro in 1992.**
- **Put into force on 21 March 1994 by 197 states.**
- **Ultimate Objective: to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, through mitigation and adaptation. The parties should act to protect the climate system on the basis of common but differentiated responsibilities. Developed countries parties should take the lead in addressing climate change. Developing countries parties implementation of their commitments will depend on the effective implementation by developed countries parties of their commitments related to financial resources and transfer of technology. Full account will be taken that economic and social development and poverty eradication are the priorities of developing countries parties.**



Agenda for Climate Change negotiations

- **1992: Earth Summit – Rio de Janeiro. Intervention of Severn Cullis-Suzuki, 12 years old. Adoption of the UNFCCC.**
- **1995: COP 1 – Berlin. Preparation of the Kyoto Protocol.**
- **11 December 1997: COP 3 - Kyoto Protocol Signature. 37 developed countries, excl. USA**
- **16 February 2005: Kyoto Protocol Effective. Emissions reductions in two periods. 2008-2012 : Kyoto Protocol 1st commitments period. 2013-2020 : Kyoto Protocol 2nd commitments period**
- **2009: COP 15 - Copenhagen. Objective: to limit increase of temperature at 2°C. Developed and developing countries are parties of the agreement. No real commitments at stake.**
- **December 2010: COP 16 - Cancun Agreement. Creation of the Green Climate Fund (GCF). Creation of the Standing Committee of Finance (SCF). To finance the developing countries at the level of 100 G\$ per year as from 2020**
- **2012: Doha (Amendments)**



Agenda for Climate Change negotiations

- **2015: COP 21 – Paris. Agreement to be in force as of 2020, based on 5th GIEC report - 195 countries involved, including US and China. To limit temperature increase at a level of 2°C vs pre-industrial levels. Efforts to be made to limit at 1,5°C. To reinforce adaptation measures. To optimize the financial flows towards low carbon emissions developments. To keep a relevant balance between « mitigation » and « adaptation ». For each country, to define their « Nationally Determined Contribution ». Paris Agreement put into force on 4 November 2016, ratified by 55 parties representing at least 55% of total world GHG emissions. Any Party can exit the agreement 3 years after the date of ratification, with an effective date one year after. Date for effective exit: 4 november 2020. On 1st June 2017, D. Trump decided that USA will exit the Paris Agreement, for the reason of potential economic disadvantages for the country. A majority of Countries (186) have today ratified the Paris Agreement. Concrete actions proposed, but no real commitments and no sanctions if proposed programmes are not met. New more ambitious plans to be proposed every 5 years in order to meet carbon neutrality by 2050.**
- **2016: COP 22 - Marrakech. Consolidation of Paris Agreement.**
- **2017: On 1st June 2017, D. Trump decided that USA will exit the Paris Agreement, for the reason of potential economic disadvantages for the country.**



Agenda for Climate Change negotiations

- **2017: COP 23 - Bonn. Disappointment, measures taken not effective enough.**
- **2018: COP 24 – Katowice. Publication of alarming reports by IPCC. Coal demand slightly increased, CO2 emissions continue to grow. Brazil refuses to organize the next COP. It will be held in Chile, with the cooperation of Costa-Rica. The IPCC report on the 1,5°C scenario has not been favorably welcomed by certain countries. Globally, loss of ambition has been noted. On the reporting, decision to fix a rulebook, define clear rules for emissions accounting, financial flows follow-up, global stocktake. Next global stocktake in 2023. Has validated COP 21 application rules. No real operational measures proposed.**
- **December 2019: COP 25 – Madrid (Previously scheduled in Santiago de Chile). Disappointing Results**
- **1st to 12 November 2021: COP 26 – Glasgow. No strong new commitments. 4 countries, including India announced new objectives for Net Zero Emissions after 2050.**
- **November 2022: COP 27 – Sharm El Sheikh/Egypt. No progress on measures to mitigate the effects of the Climate Change. Discussions on financial transfers from developed countries to emerging countries**



Agenda for Climate Change negotiations

- **2023: COP 28 – Dubaï : 30 November - 12 December.** In particular, decisions on phasing out inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible. Recognizing that transitional fuels can play a role in facilitating the energy transition while ensuring energy security. Recalling that developed country Parties shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation.
- **2024: COP 29: Baku – Azerbaïdjan: November 2024.** Difficult negotiations atmosphere. Developed nations have agreed to help channel “at least” 300 G\$ a year into developing countries by 2035 to support their efforts to deal with climate change.
- **2025: COP 30: Belem - Brazil**



COP 30 – Belem – Brazil 10 – 22 November 2025



COP 30 in Belem - Main conclusions of final Report

Context:

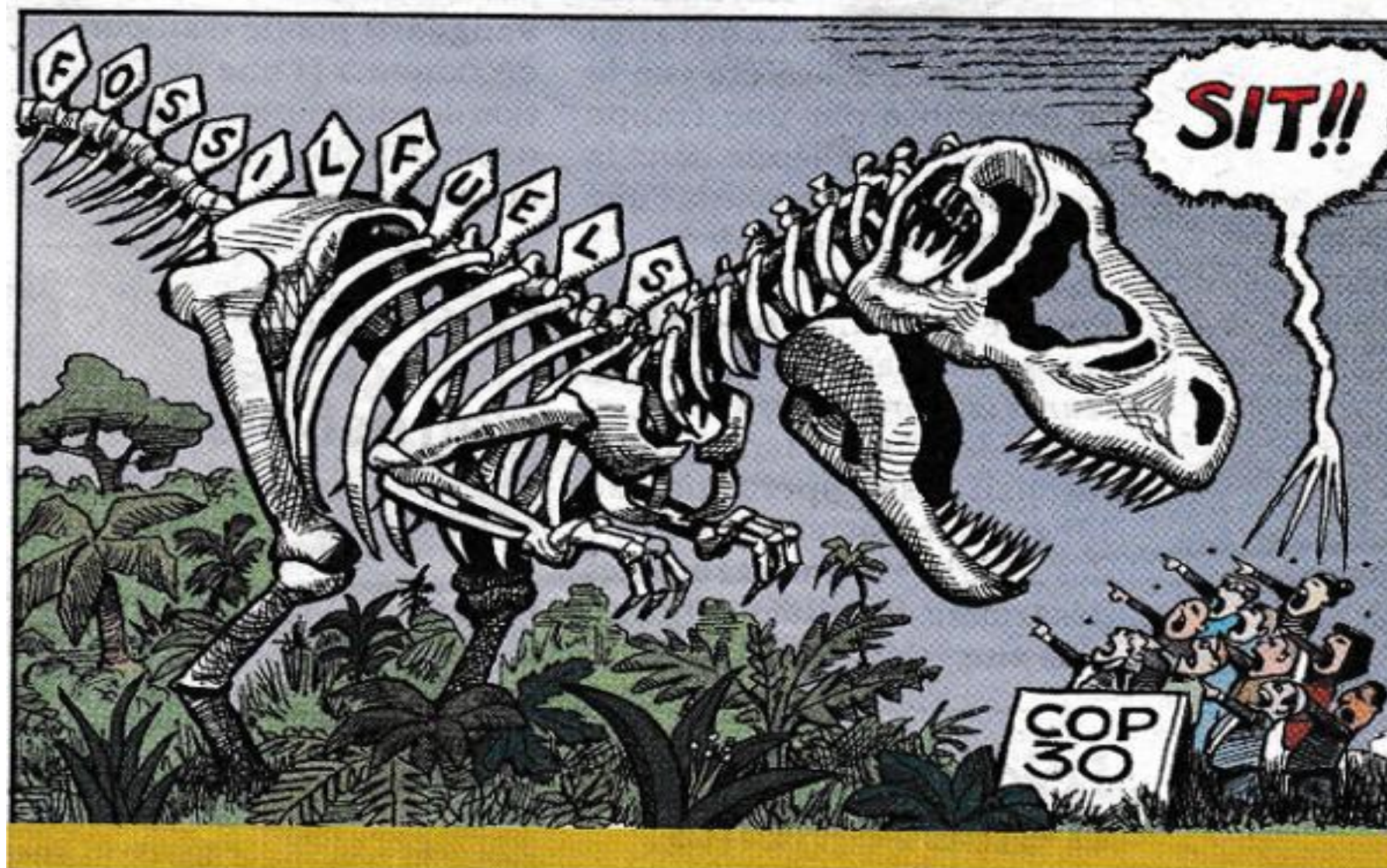
- **Trump's administration decided to quit the Paris Agreement.**
- **No US participation at COP 30.**
- **Many countries didn't provide their updated National Determined Contributions (NDC's)**

Conclusions:

- **Disappointing global results. Not ambitious enough.**
- **No mention to fossil energies, indirect reference to the COP 28 in Dubai.**
- **Adaptation: efforts to be made to triple the financial assistance to developing countries (objective: 120 G\$ per year)**
- **No commitments from developed countries to increase the global financial envelop (300 G\$ per year in 2035) to developing countries to combat climate change through Energy Transition and build-up related adaptation.**



COP 30 in Belem - Main conclusions of final Report



✓ Sur le dos du T. rex : Énergies fossiles.
"Assis!" Dessin de Kal paru
dans The Economist, Londres.

COP 29 – Baku

11 - 22 November 2024



COP 29 – Baku

11 - 22 November 2024

COP29 Presidency announces the full operationalisation of the **Loss and Damage Fund**

#BakuBreakthrough

Difficult negotiations atmosphere. Developed nations have agreed to help channel “at least” 300 G\$ a year into developing countries by 2035 to support their efforts to deal with climate change.



COP29
Baku
Azerbaijan



COP 29 - November 2024 BAKU



COP 29 - Main Achievements

200 countries in Baku, Azerbaijan, reached a breakthrough agreement that will:

- **Triple finance to developing countries**, from the previous goal of USD 100 billion annually, to USD 300 billion annually by 2035.
- **Scale up finance to developing countries, from public and private sources**, to the amount of USD 1.3 trillion per year by 2035.
- **Secure Carbon markets:** countries have agreed on the final building blocks that set out how carbon markets will operate under the Paris Agreement, making country-to-country trading and a carbon crediting mechanism fully operational.
- **Reach on transparent climate and adaptation reporting.**



COP 28 – Dubai

30 November – 12 December 2023



COP 28 – Dubai

30 November – 12 December 2023



COP 28 – Dubaï

30 November – 12 December 2023



COP 28 Dubai - 30 November – 12 December 2023

Final Decisions – Governments guidance for their Energy policy

- **Respecting** the commitments of the Paris Agreement **to limit temperature increase at 1,5°C vs pre-industrial levels.**
- **Concluding the first Global Stocktake** with reference to the objectives of the Paris Agreement.
- **Tripling renewable** energy capacity globally.
- **Doubling** the global average **annual rate of energy efficiency** improvements **by 2030.**
- **Accelerating** efforts towards **the phase-down of unabated coal power.** **Accelerating** efforts globally towards net zero emission energy systems, utilizing **zero- and low-carbon fuels well before or by around mid-century.**
- **Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner,** accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science.
- **Accelerating zero- and low-emission technologies,** including, inter alia, renewables, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production.



COP 28 Dubai - 30 November – 12 December 2023

Final Decisions – Governments guidance for their Energy policy

- **Accelerating** and substantially reducing non-carbon-dioxide emissions globally, including in particular methane emissions by 2030.
- **Accelerating** the reduction of emissions from road transport on a range of pathways, including through development of infrastructure and rapid deployment of zero and low-emission vehicles.
- **Phasing out inefficient fossil fuel subsidies** that do not address energy poverty or just transitions, as soon as possible.
- **Recognizing** that **transitional fuels can play a role** in facilitating the energy transition while ensuring energy security.
- **Recalling** that **developed country Parties shall provide financial resources to assist developing country Parties** with respect to **both mitigation and adaptation**.





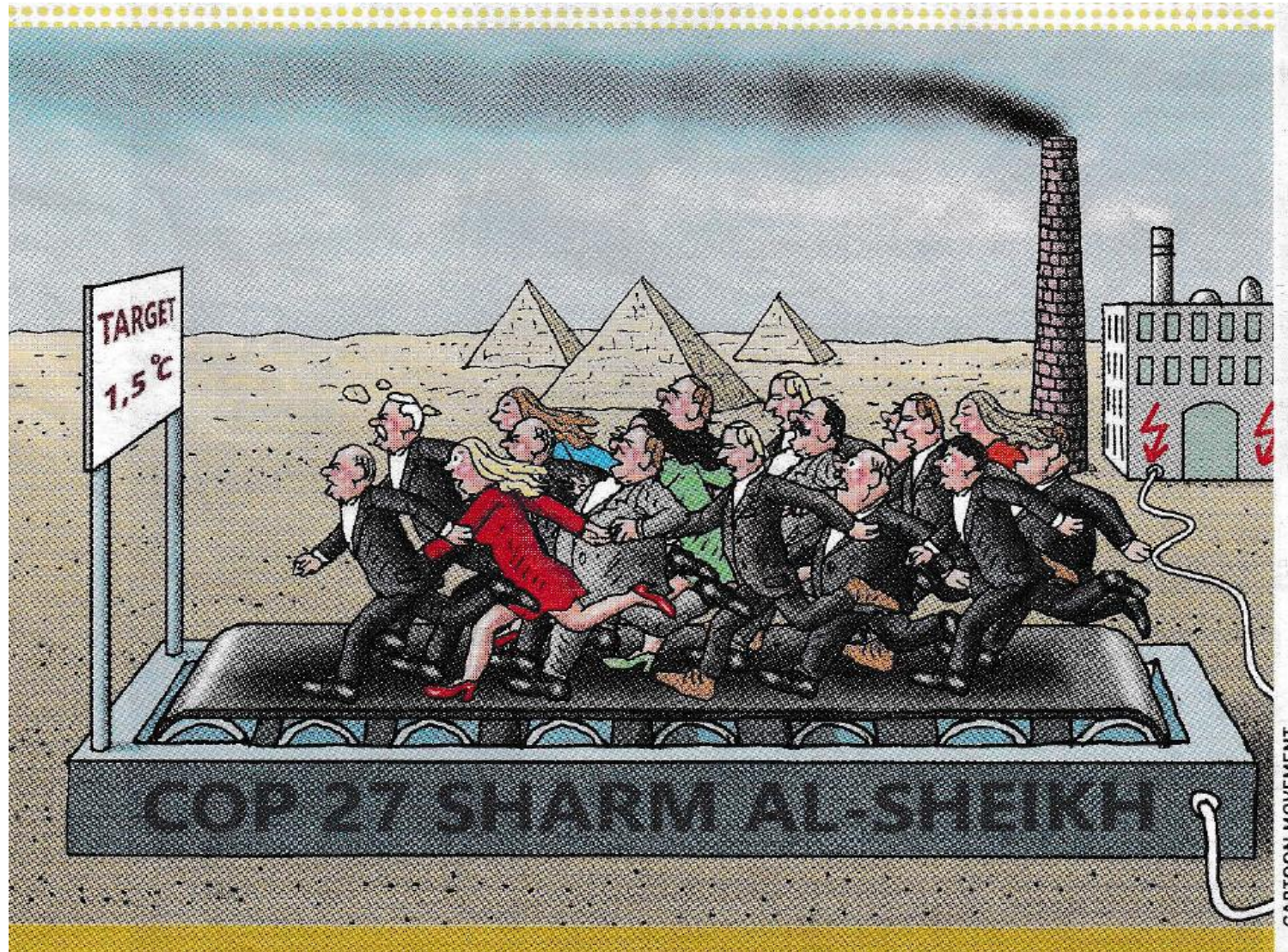
Conclusions of the COP27 Sharm El Sheikh

Main conclusions COP 27 Sharm El Sheikh

- **No progress on measures to mitigate the effects of Climate Change.**
- **Basic global agreement related to the financial compensations to be delivered from developed countries to poorest countries for the detrimental effects of Climate Change and for adaptation measures. Operational details to be worked out.**



Main conclusions COP 27 Sharm El Sheikh



Source: Courrier International November 2022²⁶²
Cartoon by Marian Kamensky - Austria

TPA Toolbox Energy Book 3 - GHG

COP 26



UN CLIMATE
CHANGE
CONFERENCE
UK 2020

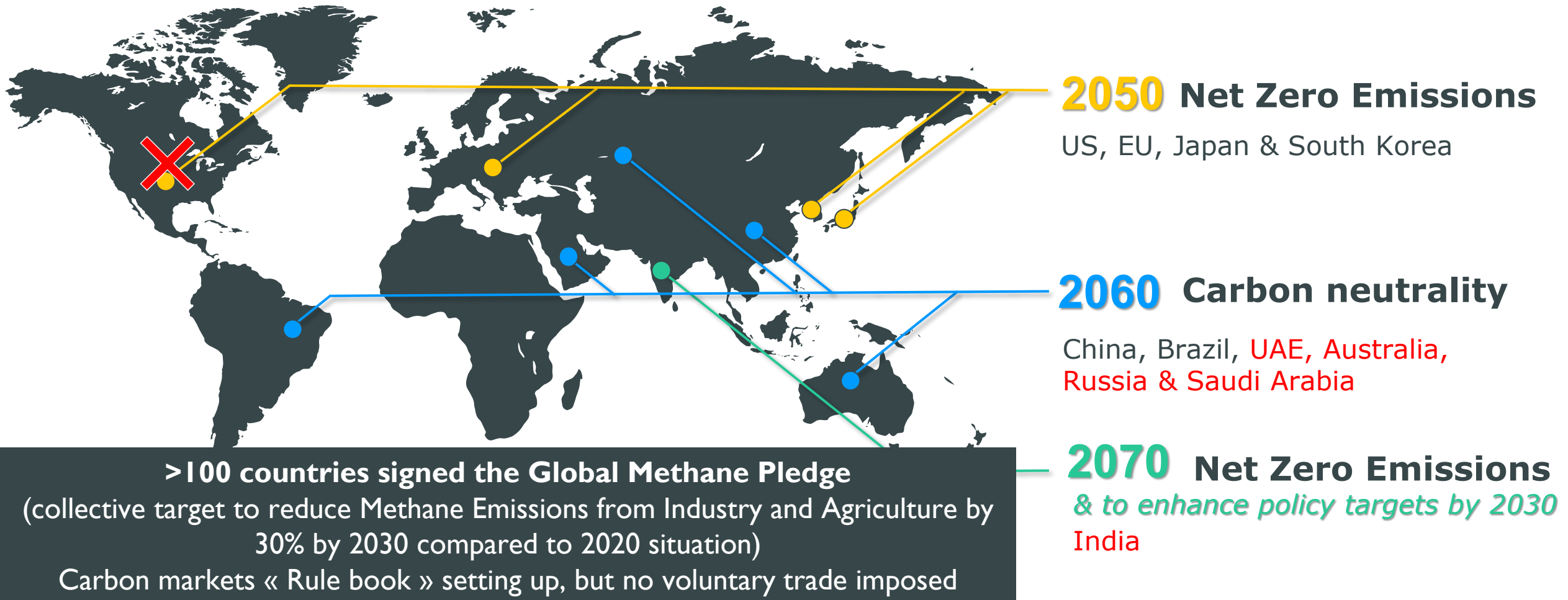
IN PARTNERSHIP WITH ITALY

1-12 November, 2021
Glasgow, Scotland

Conclusions of the COP 26 Glasgow



Reminder: Summary of global announced commitments as of mid-2021 following COP 26 – Glasgow, Nov. 2021



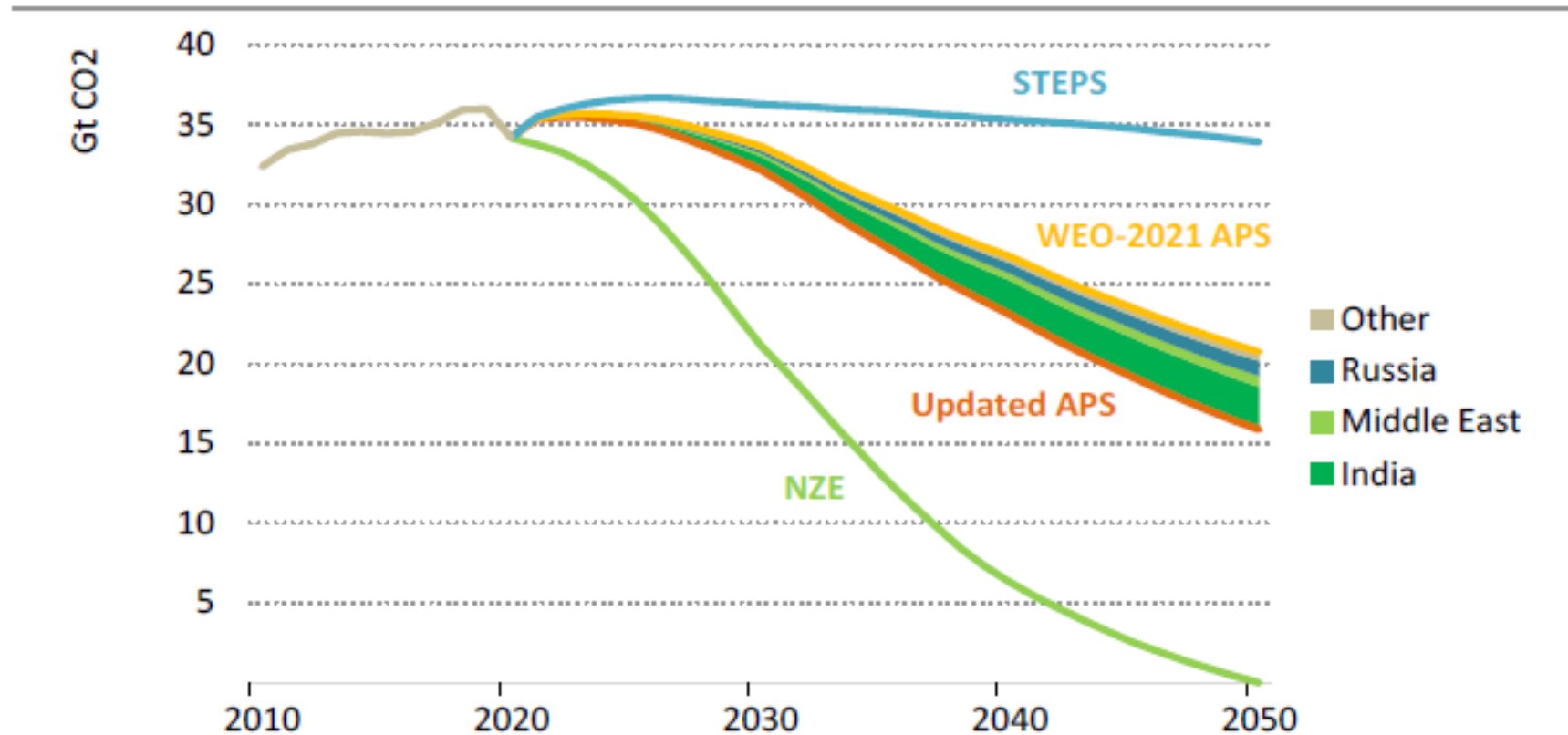
Following the COP 26 meeting, IEA has developed an additional scenario called Updated Announced Pledges Scenario (APS)



COP 26 – IEA Scenarios with Updated APS

CO2 Energy + Industrial Process Emissions

Some countries have proposed new commitments (notably India)



IEA. All rights reserved.

Note: Other = net zero pledge by Australia and commitment to the Global Coal to Clean Power Transition Statement by Indonesia. Middle East = net zero pledges by Saudi Arabia and the United Arab Emirates.

Source: Technical note on the emissions and temperature implications of COP26 pledges – November 2021

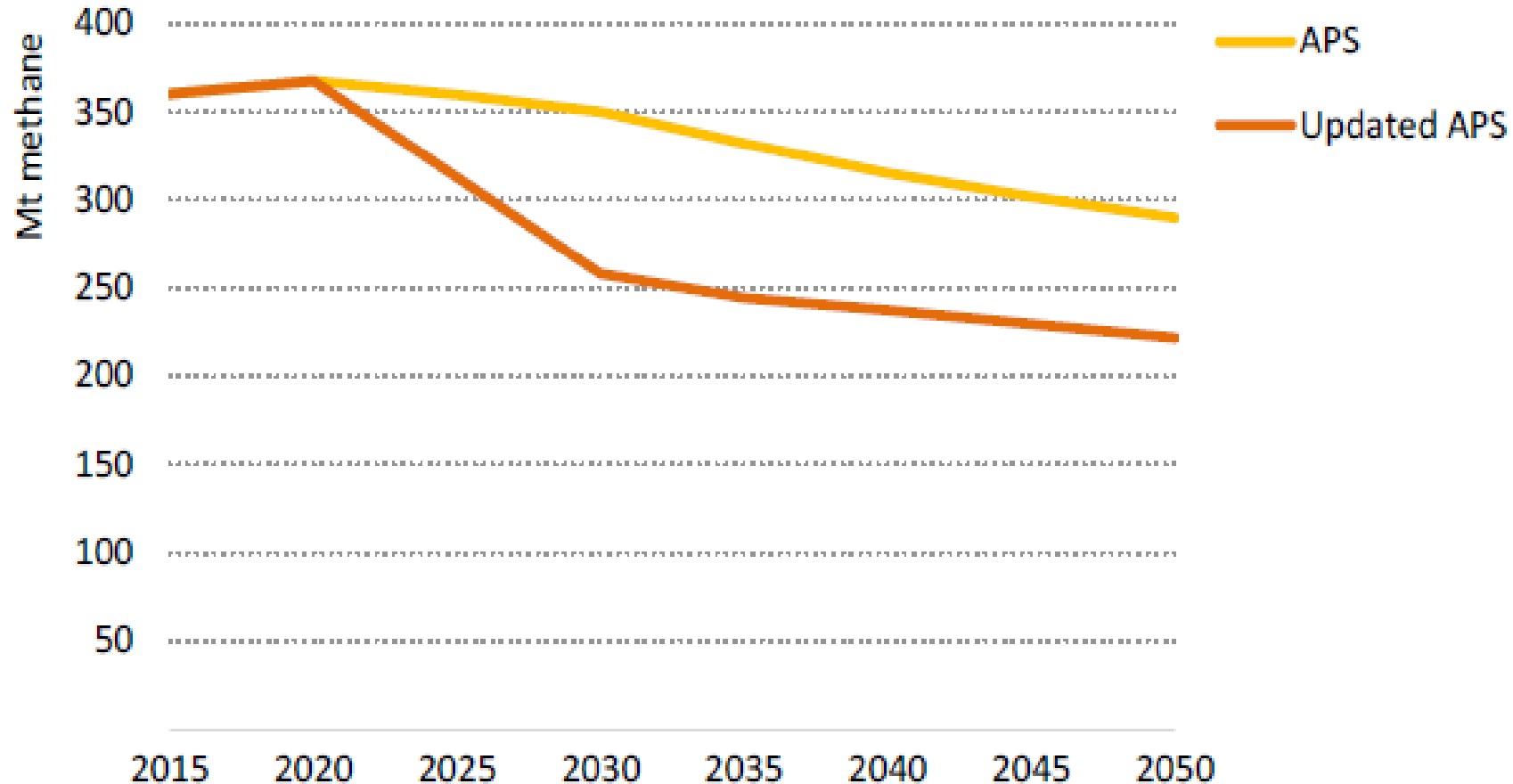
266

TPA Toolbox Energy Book 3 - GHG



COP 26 - Updated APS

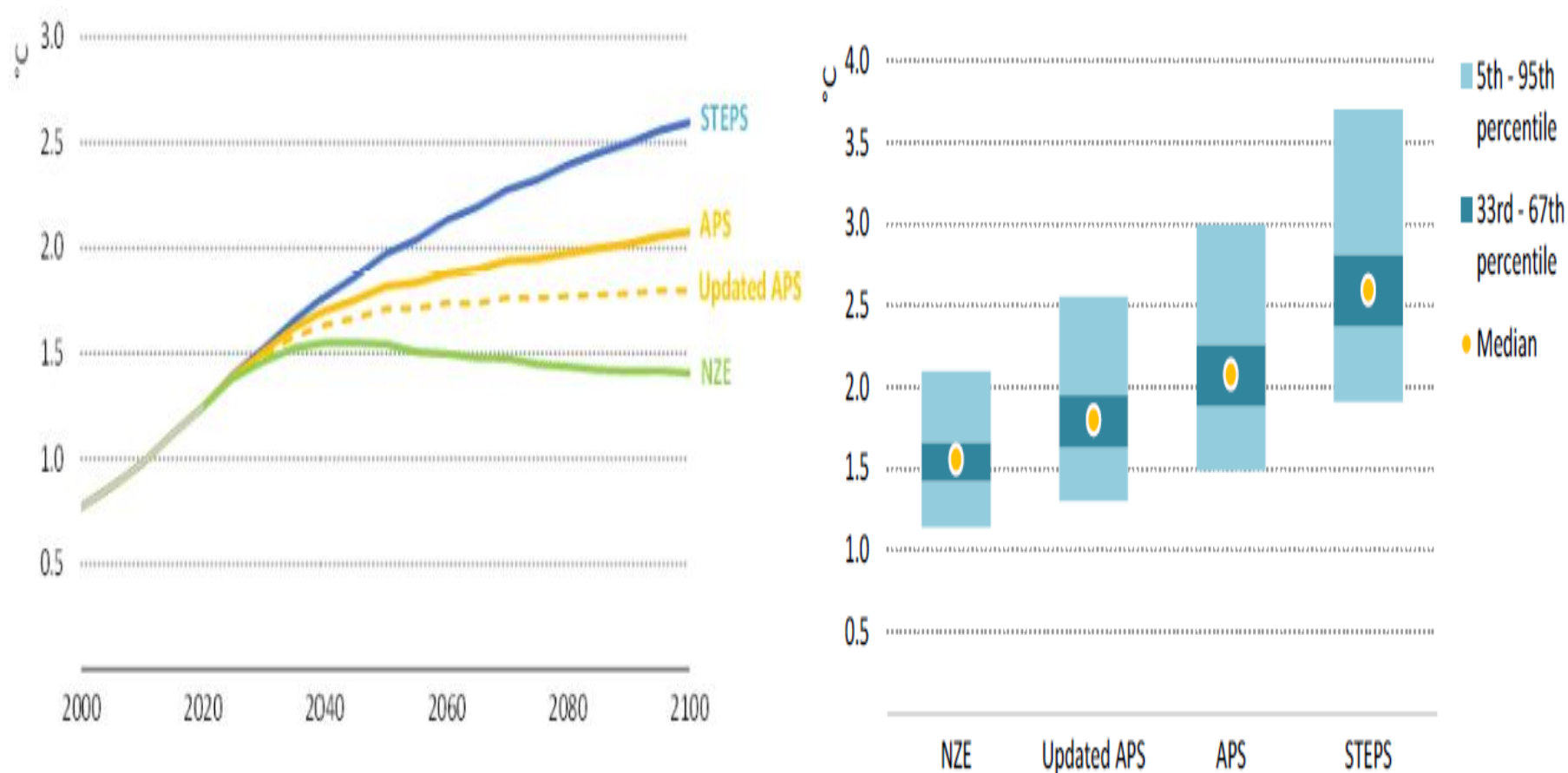
Global Methane Emissions from Energy, Agriculture and Waste have been revised



Source: Technical note on the emissions and temperature implications of COP26 pledges – November 2021¹⁶⁷



Temperature Increase vs IEA Scenarios (Compared with the pre-industrial levels)



Source: Technical note on the emissions and temperature implications of COP26 pledges – November 2021

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CO₂ + Industrial Process Emissions & relative Temperature Increase in 2100 vs IEA Scenarios (Compared with the pre-industrial levels)

Scenarios	CO ₂ Energy Emissions 2030 (GtCO ₂)	CO ₂ Energy Emissions 2050 (GtCO ₂)	Temperature Increase in 2100 (Mean Value)
STEPS	36	34	2,6 °C
APS	32	12	2,1 °C
<i>Updated APS 2021</i>	32	16	1,8 °C
<i>SDS 2021</i>	28	8	< 2,0 °C
NZE	23	0	1,5 °C

Source: Technical note on the emissions and temperature implications of COP26 pledges – November 2021 & IEA WEO 2022



Climate Change - Reconciliation

RCP's, CO₂ concentrations, Temperatures – IPCC Projections

RCP (W/m ²)	CO ₂ Concentration Range in 2100 (ppm CO ₂ eq.)	CO ₂ concentration Mean in 2100 (ppm CO ₂ eq.)	GHG Emissions Range in 2100 (GtCO ₂ eq.)	GHG Emissions Median in 2100 (GtCO ₂ eq.)	Temperature Change Mean over 2081-2100 (°C)	Temperature Change Max In 2100 (°C)
2,6	430-480	450	-7,0-7,0	0,0	0,3-1,6	1,6
4,5	580-720	650	5,0-30,0	20,0	1,0-2,5	3,0
6,0	720-1000	860	45,0-85,0	65,0	1,5-3,0	3,5
8,5	> 1000	> 1000	85,0-140,0	105,0	2,5-5,0	5,5

RCP: Representative Concentration Pathway as per Radiative Forcing due to human activities (W/m²)

Source: IPCC 5th Assessment Synthesis Report November 2014

Mini: 10th percentile – Max: 90th percentile



Agenda for Climate Change negotiations

2019

**Many demonstrations in various countries
in the world requesting urgent actions
from governments**



Reminder - Conclusions of COP 21 – Paris 12/12/2015

- **To limit the temperature increase below 2° C vs pre-industrial period, ideally to + 1,5 °C.**
- **To reach the peak of carbon emissions « as soon as possible ».**
- **To allocate a part of the « Green Funds » to the adaptation process (transfert of funds and technology from developed countries to developing countries)**
- **To accept a shared but differentiated responsibility for developed and developing countries, and not to put at risk the economic development of the last ones.**
- **To allocate 100 G\$ per year, as from 2020, to mitigate emissions and to finance projects for adaptation measures.**
- **To review every 5 years the commitments.**
- **Regarding carbon pricing, to consider useful to build-up mechanisms aiming at emissions reductions.**



Reminder - COP 21 – Paris 12/12/2015

Far too optimistic!

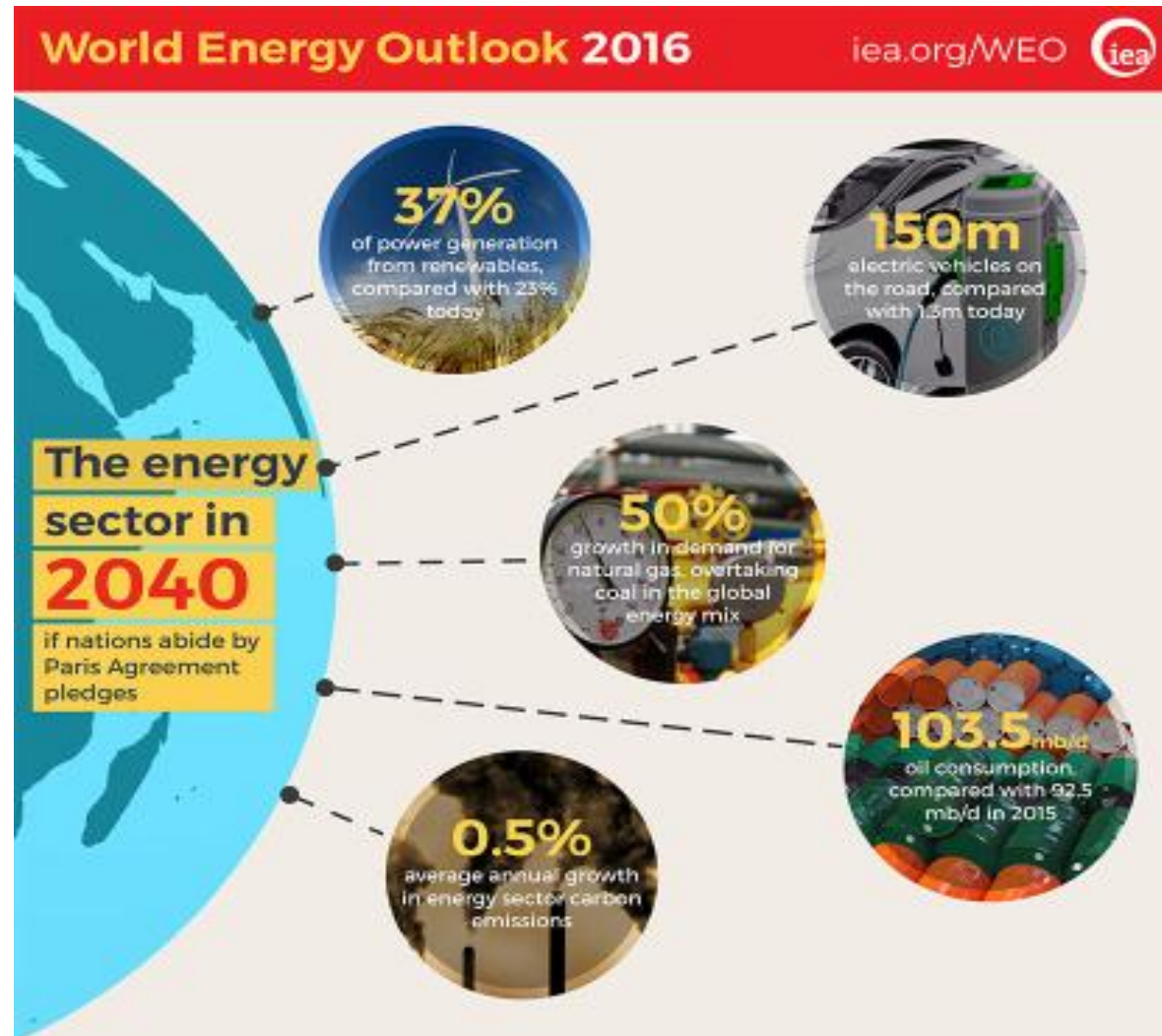


Conclusions of COP 21 – Paris 12/12/2015

**To be effective in 2020, the Paris Agreement must be ratified by at least 55 countries representing at least 55% of worldwide greenhouse gas emissions.
Done.**



COP 21 Pledges not ambitious enough!

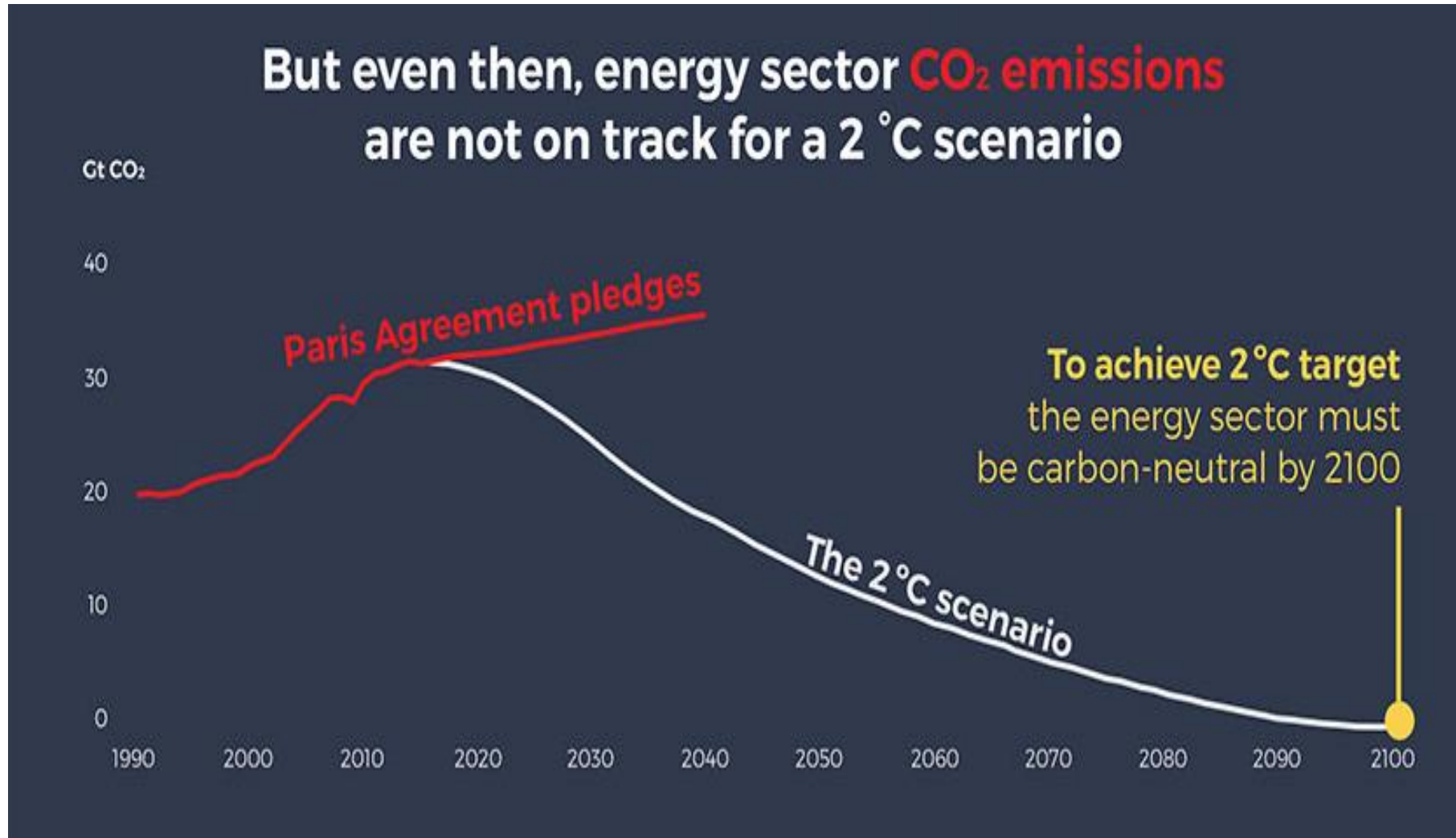


Source: IEA WEO 2016

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TPA Toolbox Energy Book 3 - GHG

COP 21 Pledges not ambitious enough!



Source: IEA WEO 2016

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CO2 Markets, Pricing and Trading



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the case of TotalEnergies



CO₂ Pricing is one essential element to mitigate the effects of Carbon emissions



Business Leadership Criteria

CARBON PRICING

Caring for Climate



THE CLIMATE GROUP



“Let us make sustainability the most powerful lobby...
Become advocates for an effective, well-functioning
carbon market... We must **place a true value on the
cost of carbon** to our economies and our future.
I urge you to work with Governments on this issue.”

— Ban Ki-Moon
United Nations Secretary-General



Source:



United Nations Global Compact

Published by Caring for Climate, an initiative of
the UN Global Compact, UNFCCC and UNEP.
Contact: caring4climate@un.org
Copyright © 2014



Business Leadership Criteria on Carbon Pricing

The Business Leadership Criteria on Carbon Pricing comprise three distinct but overlapping dimensions: integrating carbon pricing into long-term strategies and investment decisions, responsible policy advocacy, and communication on progress. All three dimensions of the criteria are aligned with limiting the increase in global mean temperature to 2° C above pre-industrial levels.

Consistent with the 2° C global target, companies are invited to indicate alignment with the following criteria:



Set an **internal carbon price** high enough to materially affect investment decisions to drive down greenhouse gas emissions;



Publicly advocate the importance of carbon pricing through policy mechanisms that take into account country specific economies and policy contexts; and



Communicate on progress over time on the two criteria above in public corporate reports.

Source:



United Nations Global Compact

Published by Caring for Climate, an initiative of the UN Global Compact, UNFCCC and UNEP.
Contact: caring4climate@un.org
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Carbon Pricing
Two main instruments:
Emission Trading Systems (ETS) & Carbon Tax (CT)



Emissions Trading System (ETS): How does it work?

- **Emissions Trading Systems are managed by a governing jurisdiction that sets a cap on the total level of GHG emissions.**
- **In order to get an efficient result on the long term, the cap must not be too relaxed, and need to be revised downwards, from time to time.**
- **The allowances to emit are either auctioned or allocated for free to eligible industrial entities, with the possibility to trade allowances. It is a Cap and Trade (CaT) system.**
- **The overall emission cap corresponds to the sum of distributed or auctioned allowances.**
- **The entities involved can buy or sell allowances.**
- **This creates a market which sets a price for CO₂**



Three Mechanisms to reduce emissions

- **Allocated Amount Units (AAU)** allocated to each enterprise in each country, which surplus can be traded through Emission Trading Systems (ETS)
- **Certified Emissions Reductions (CER)**, linked to Clean Development Mechanisms (CDM), derived from Projects financed by developed countries to reduce emissions in developing countries. These credits certified by UN can be traded.
- **Emissions Reduction Units (ERU)** related to joint projects aiming at reducing emissions. These credits can be traded.



Emissions Trading System (ETS): How does it work?

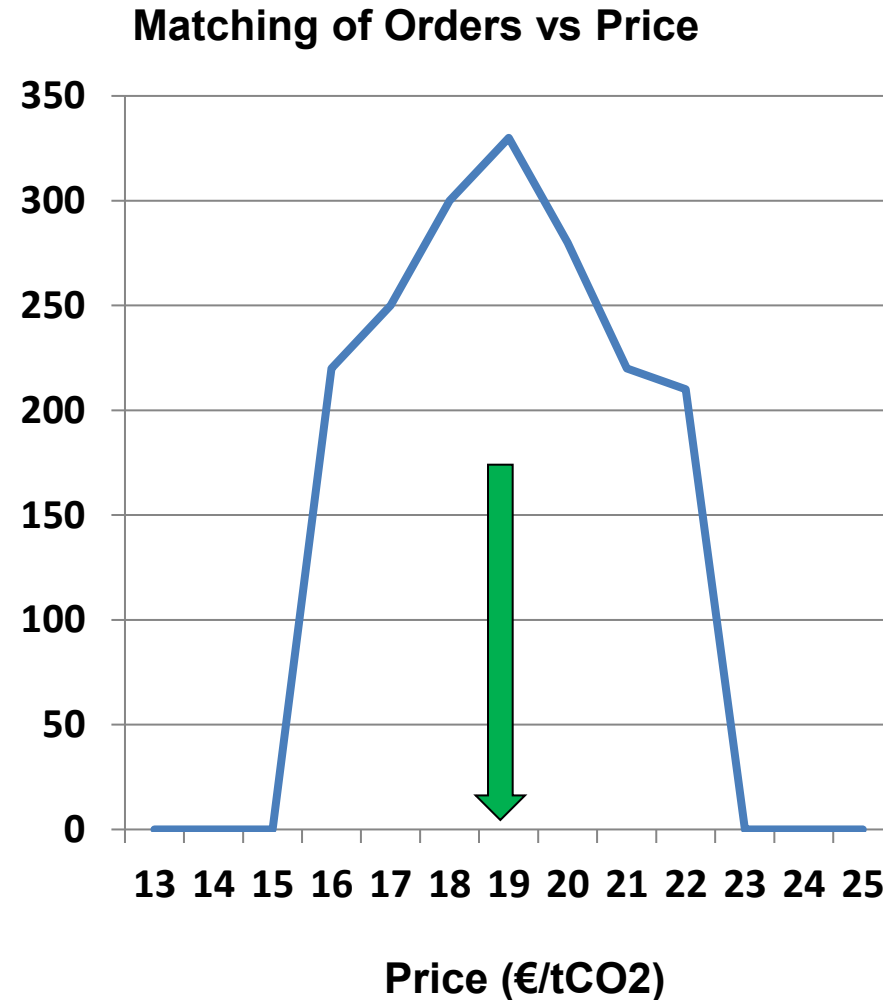
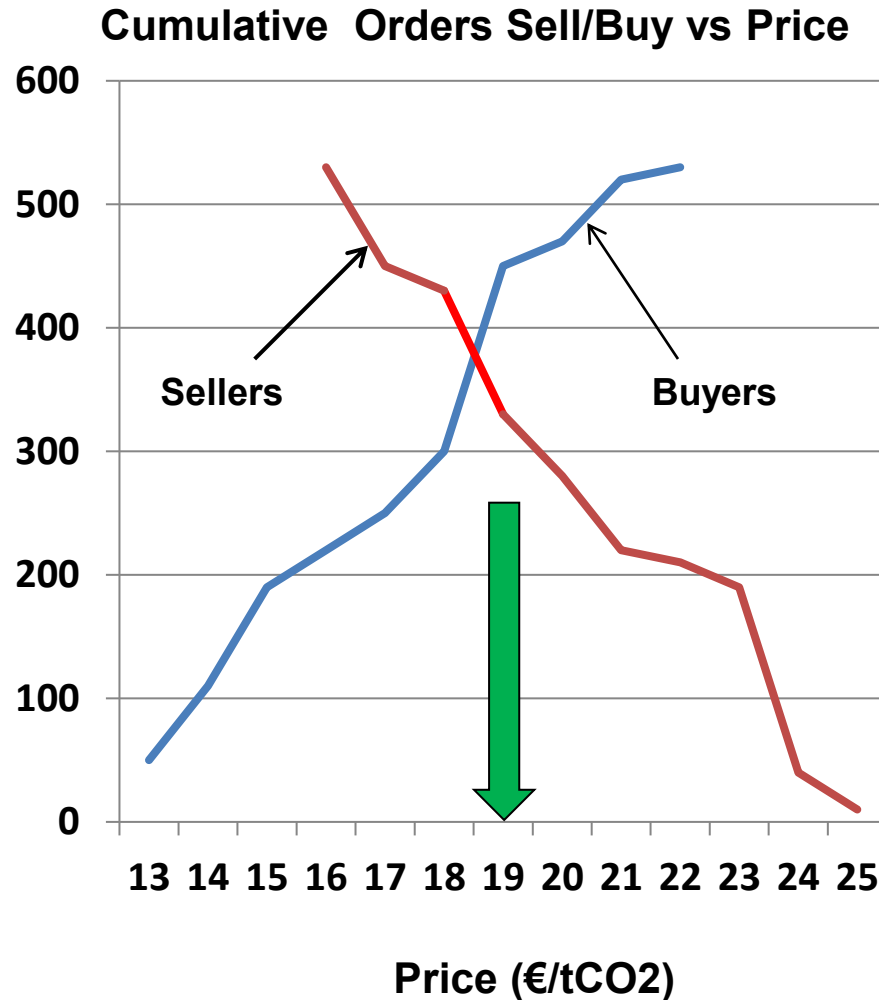
The Fixing Mechanism – One Example (1)

	Sellers of Surplus				Buyers of Deficits		
	Quantity	Price	Cumul.		Quantity	Price	Cumul.
	kt CO2	€/t CO2	kt CO2		kt CO2	€/t CO2	kt CO2
Company A	80	16	530	Company K	50	13	50
Company B	20	17	450	Company L	60	14	110
Company C	100	18	430	Company M	80	15	190
Company D	50	19	330	Company N	30	16	220
Company E	60	20	280	Company O	30	17	250
Company F	10	21	220	Company P	50	18	300
Company G	20	22	210	Company Q	150	19	450
Company H	150	23	190	Company R	20	20	470
Company I	30	24	40	Company S	50	21	520
Company J	10	25	10	Company T	10	22	530
Total	530		530		530		530



Emissions Trading System (ETS): How does it work?

The Fixing Mechanism – One Example (2)



Carbon Tax (CT): How does it work?

- **Carbon Taxes are directly applicable to level of GHG emissions, expressed as a value per tonne of CO₂.**
- **In order to be efficient and accepted on the long term, the Carbon Tax must be introduced and implemented incrementally to allow eligible users to adapt to rising energy prices.**
- **Carbon Tax doesn't guarantee the resulting overall level of CO₂ emissions.**
- **However, putting a price/penalty on each tonne of CO₂ emitted should motivate industrial companies to increase their energy efficiency and invest more in cleaner technologies..**



ETS vs CT

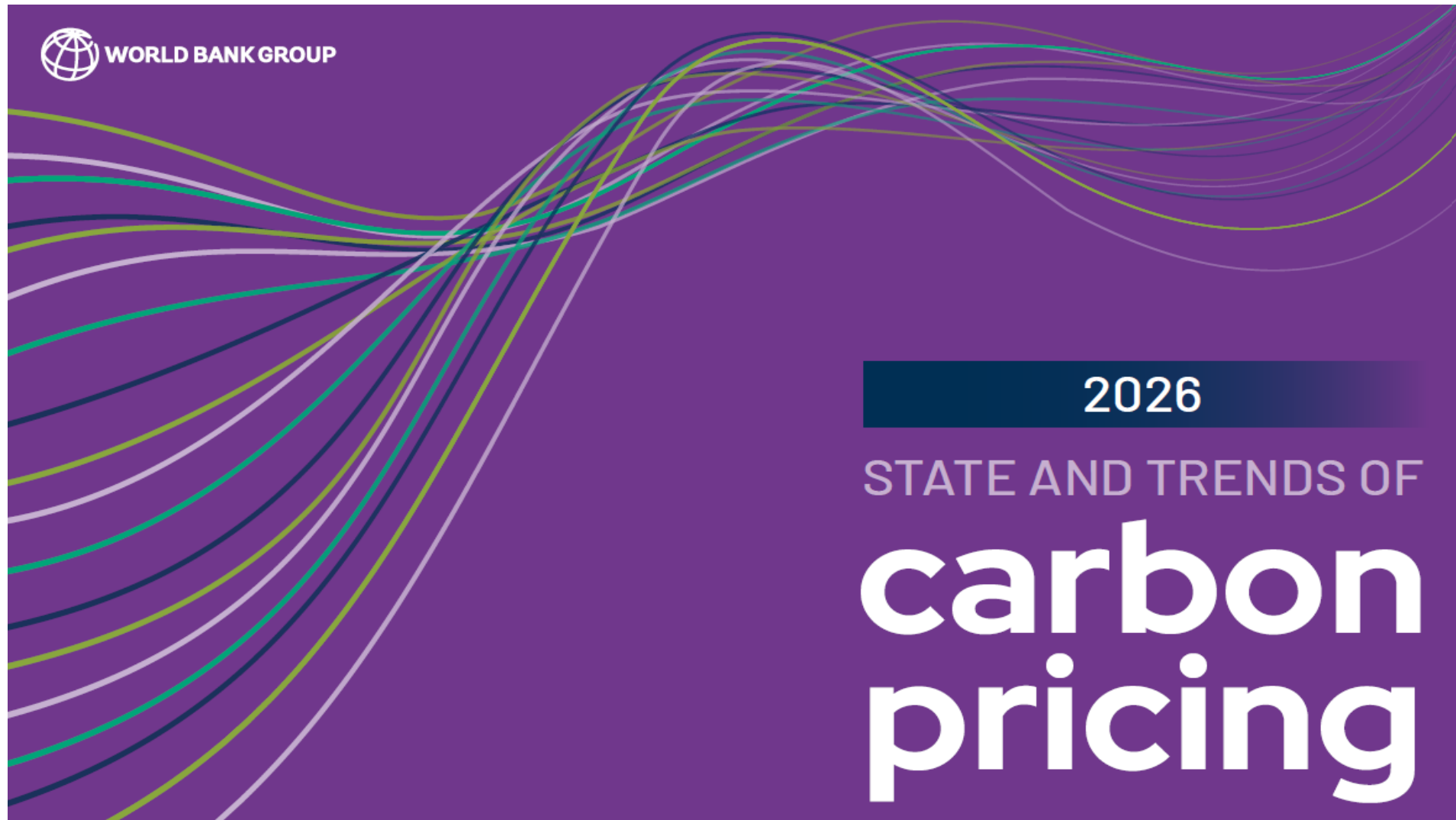
- **The two policy options have different targets and different impacts**
- **For different reasons, they tend to apply to different sectors. ETS usually target large energy - intensives activities and sectors. CT are applicable to more diffuse source of CO2 emissions such as road transport, air transport, etc.**
- **But, actually, both systems could apply to all emitting sectors.**



Carbon Pricing in 2026



Carbon Pricing in 2026



State & Trends of Carbon Pricing – World Bank 2026

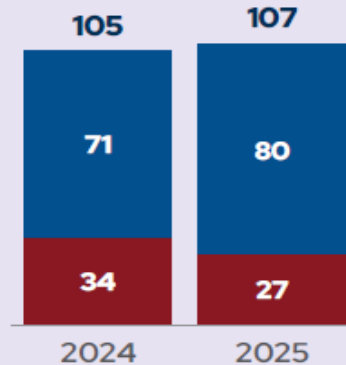
State and Trends of Carbon Pricing 2026

Carbon pricing

Average carbon prices have nearly doubled from 2016 to 2026
2026 US\$ t/CO₂e



ETS and carbon tax revenues continue to exceed US\$ 100 billion
2025 US\$



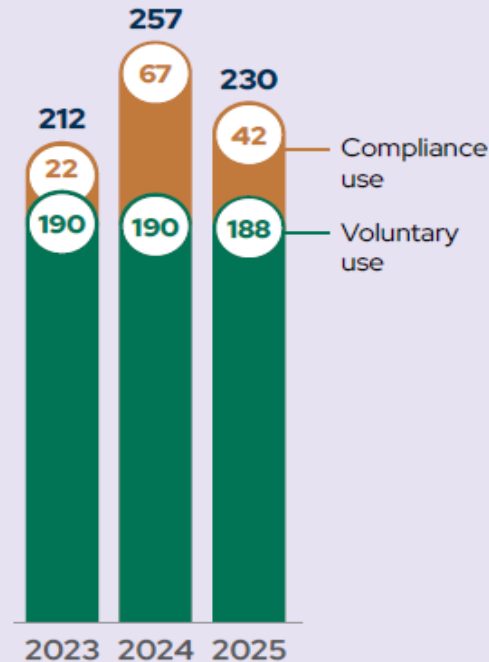
If policies under development are fully implemented by 2030, nearly

1/3

of global GHG emissions could be covered by an ETS or carbon tax

Carbon credit markets

Credit retirements around 10% lower than 2024 levels
Million tCO₂e



From 2024 to 2025 carbon credit issuances increased

8%

The first project received provisional issuance from

PACM

CORSIA-approved projects received a

US\$ 1.50-6/tCO₂e

price premium over similar credits that are not yet CORSIA-approved

Source: State and Trends of Carbon Pricing – World Bank May 2026

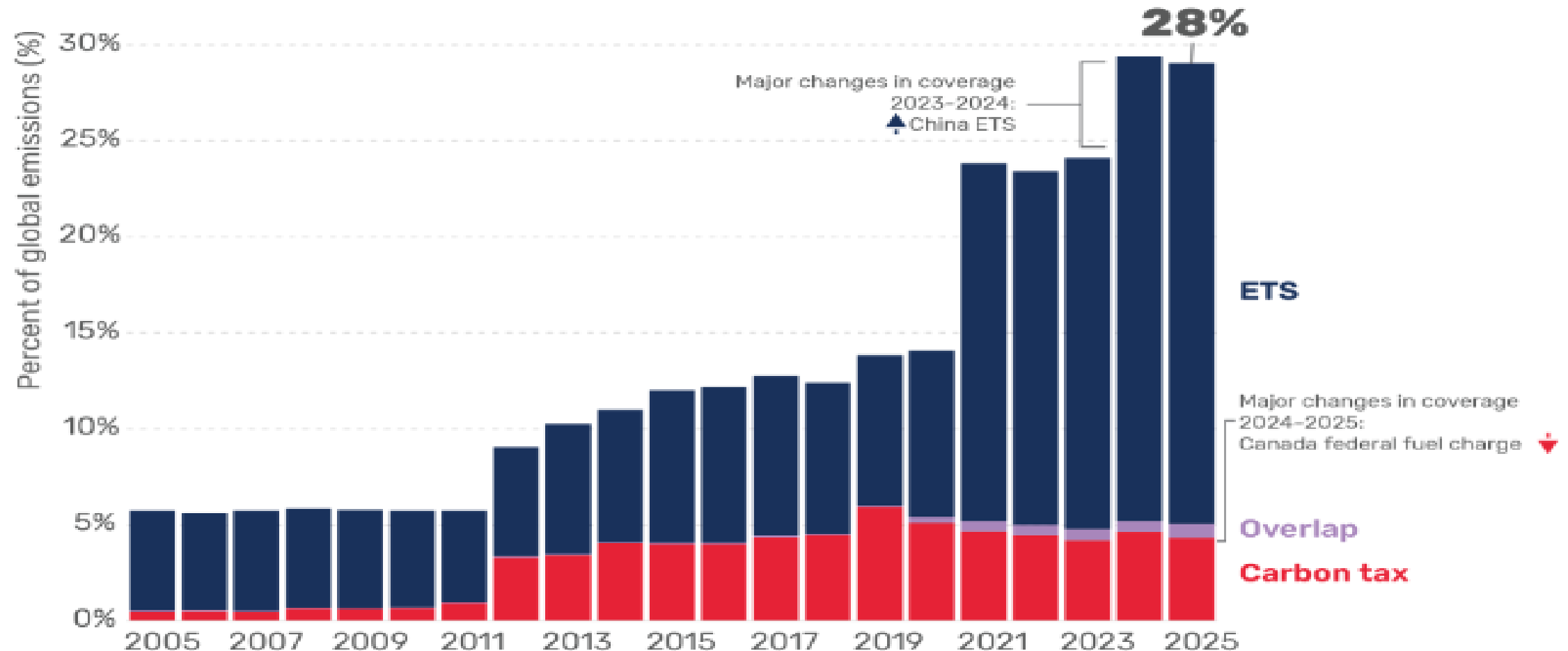
PACM: Paris Agreement Credit Mechanism –

CORSIA: Carbon Offsetting & Reduction Scheme for International Aviation

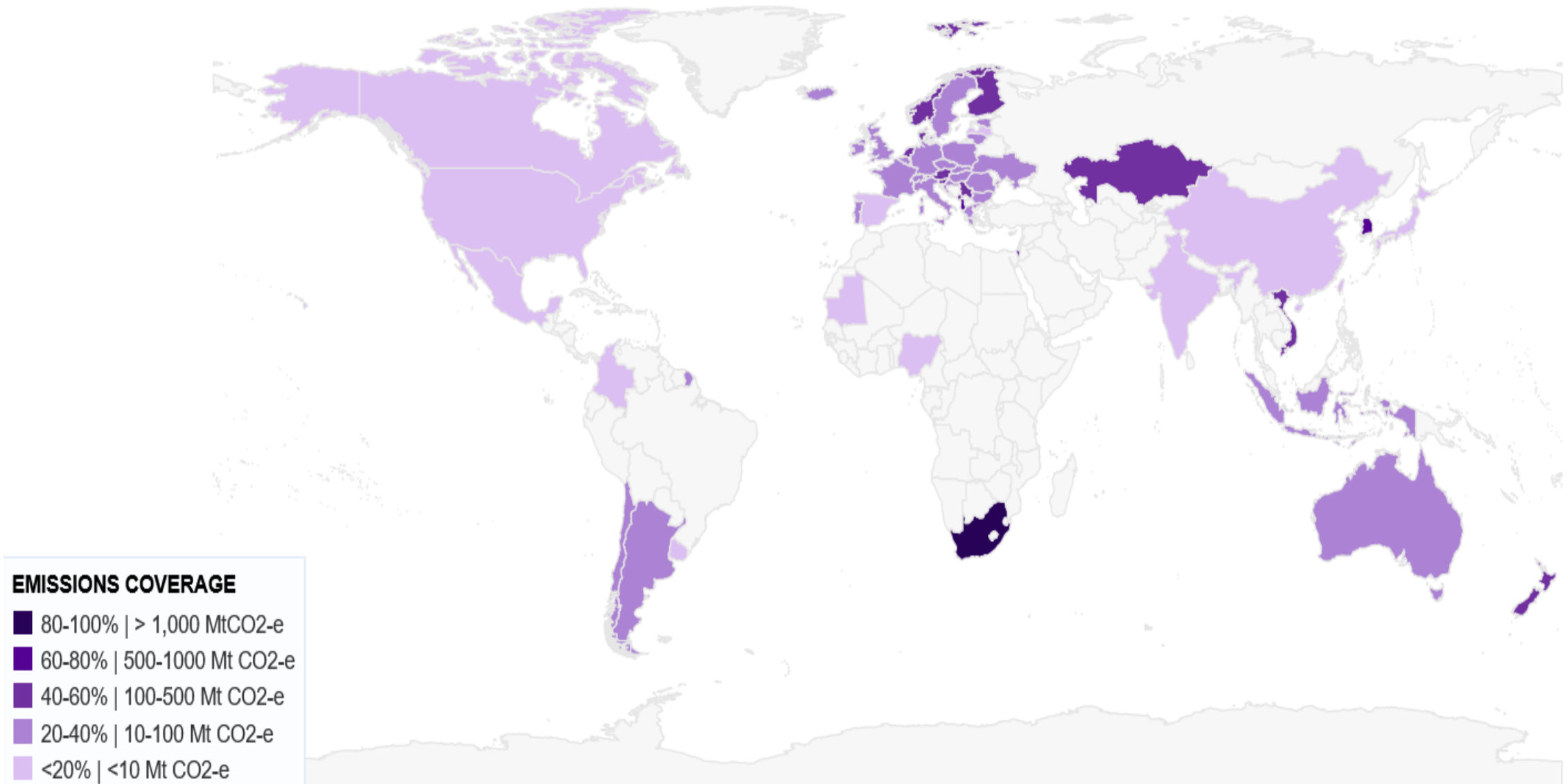


Global Emissions Coverage

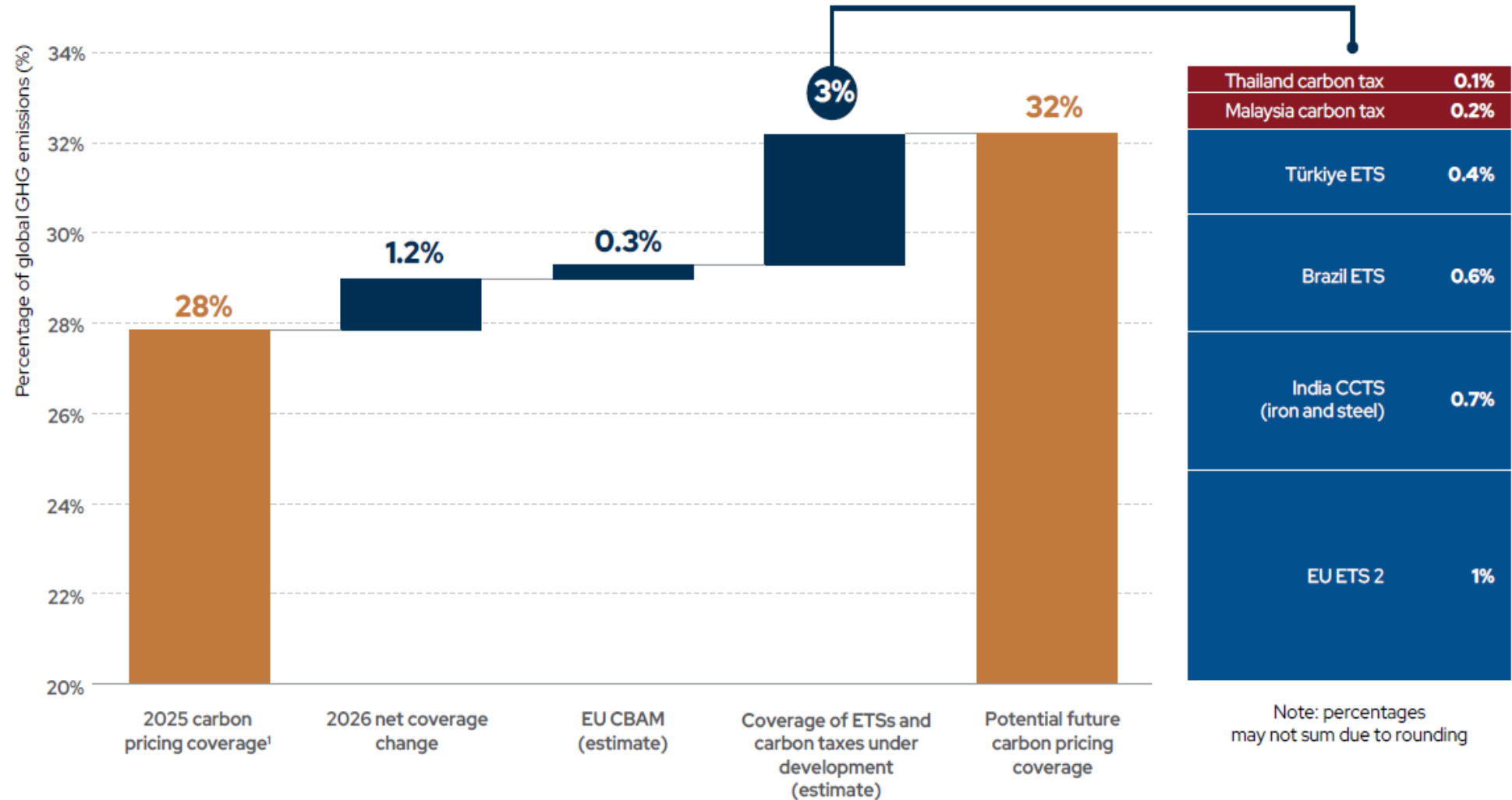
Share of global greenhouse gas emissions covered by an ETS or carbon tax, 2005–2025



Global Emissions Coverage



Global Emissions Coverage

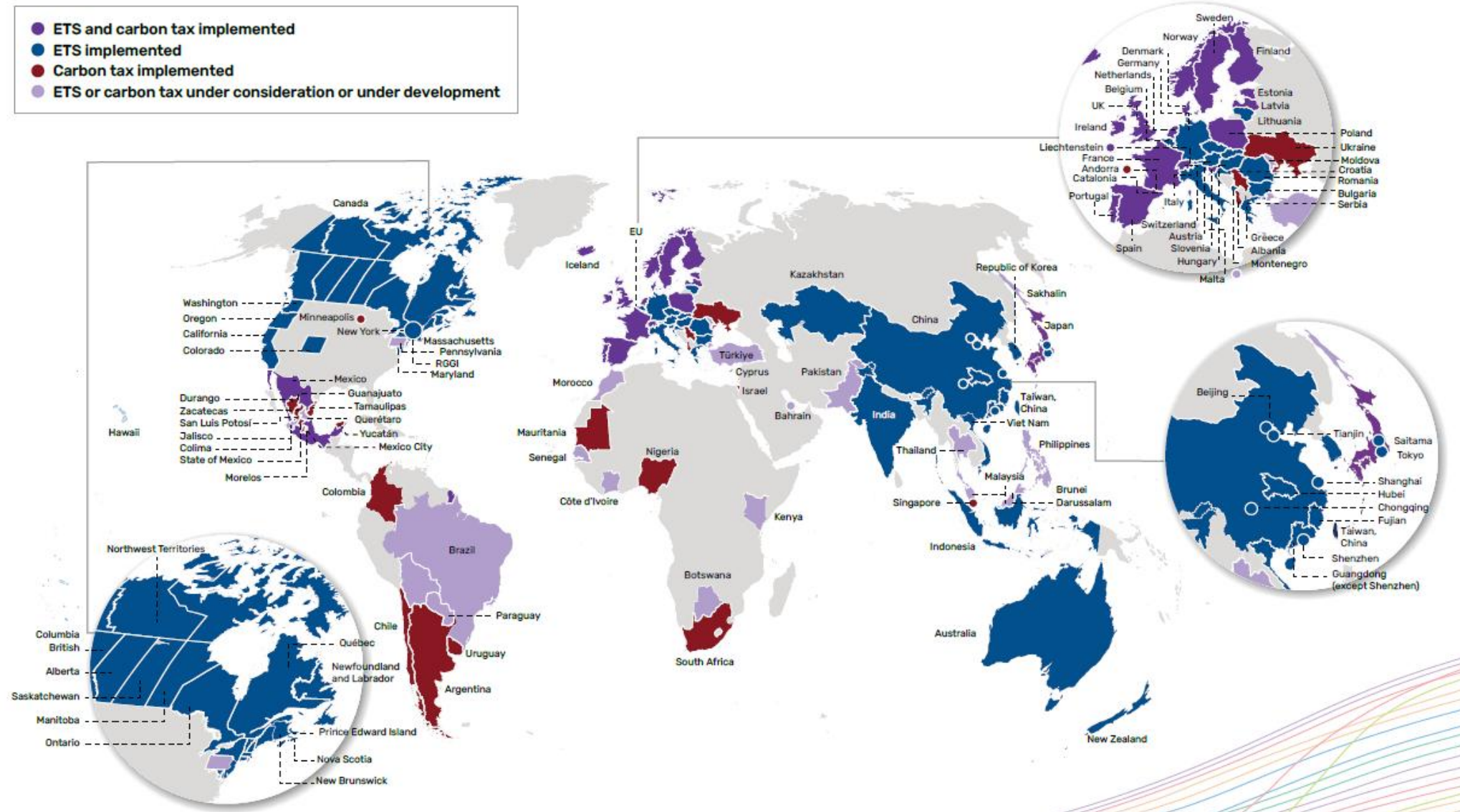


¹ Viet Nam's 0.5% ETS is implemented in 2026 but also applies to 2025 emissions

Note: Analysis does not account for potential overlaps between emissions covered by ETSs and carbon taxes and that are also subject to EU CBAM

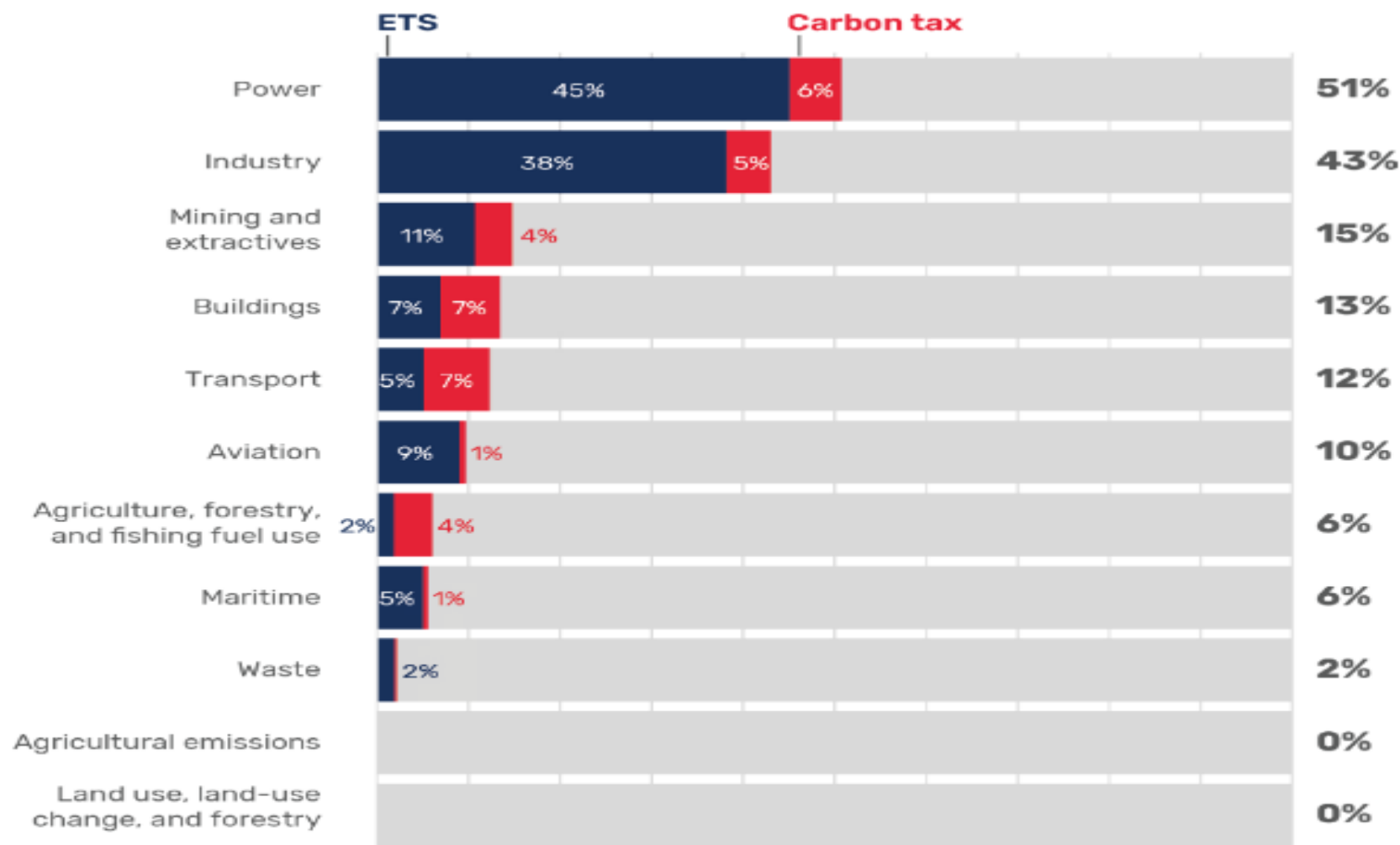


Global map of ETS & Carbon Taxes systems 2026



Economic sectors covered by a Carbon Pricing system

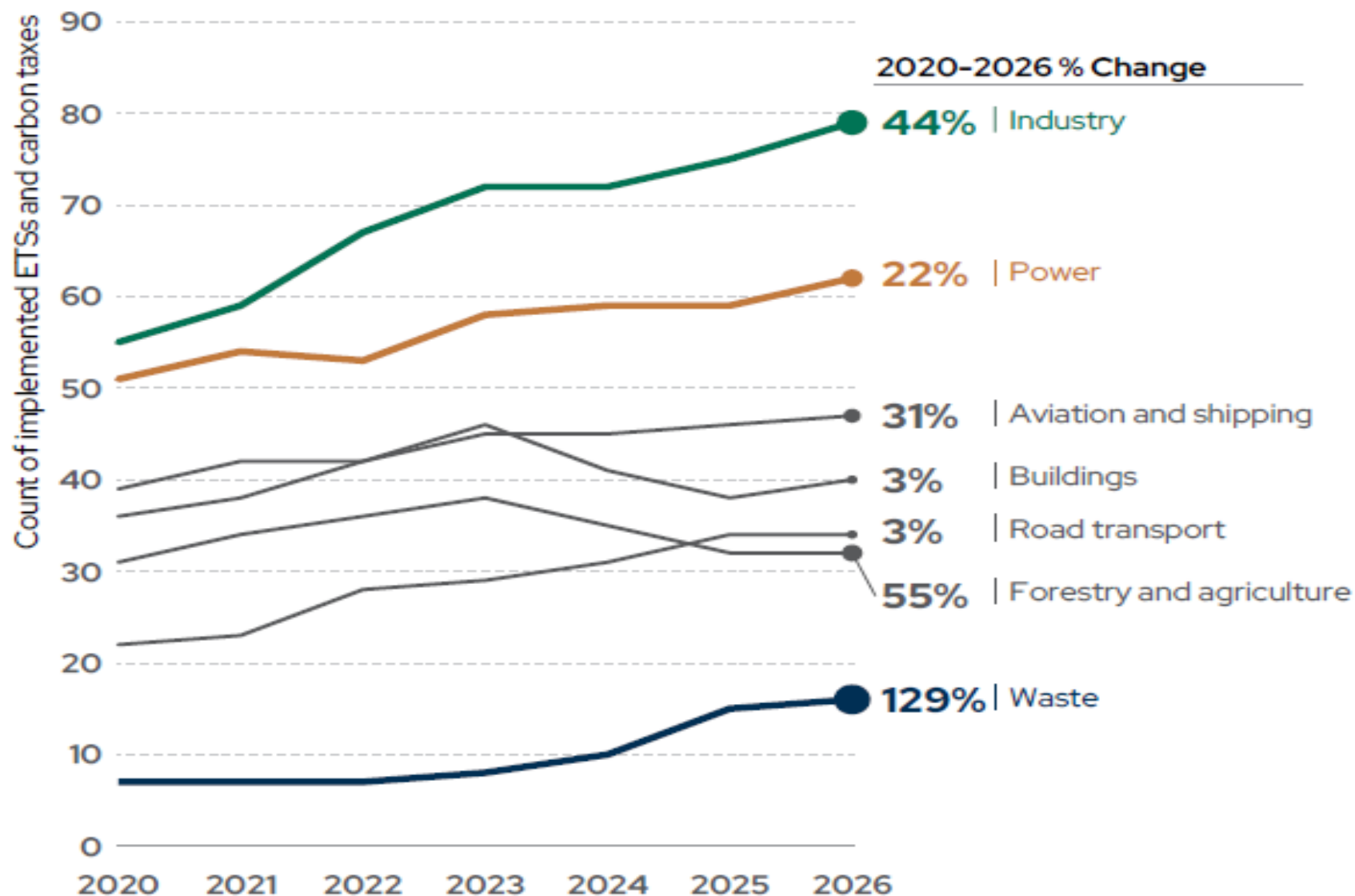
Share of economic sectors' global GHG emissions covered by an ETS or carbon tax



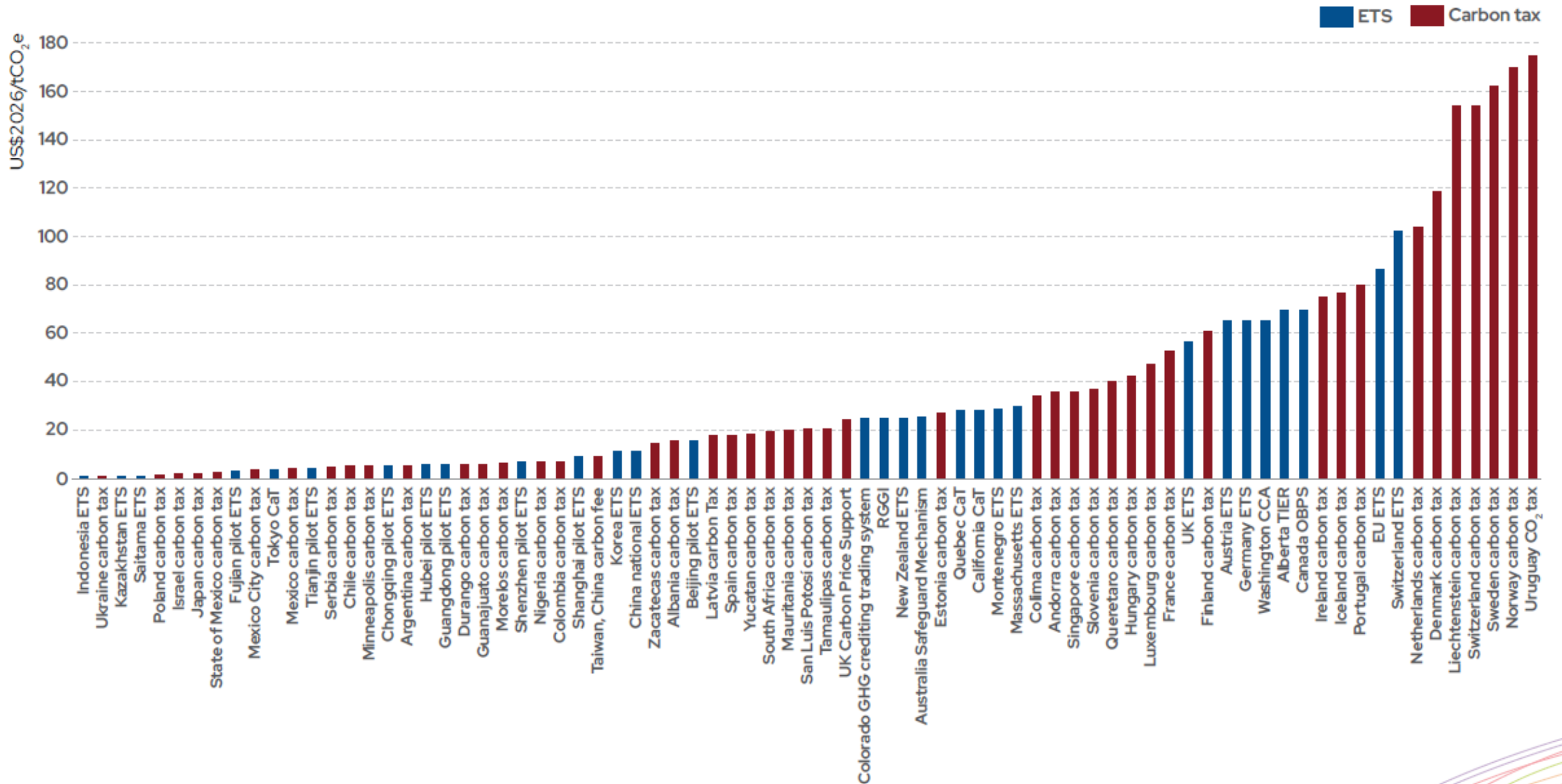
Note: Based on World Bank analysis. Values are not additive due to rounding. Aviation and maritime carbon tax coverage are both less than 1%, waste ETS coverage is 1%, and carbon tax coverage is < 1%.



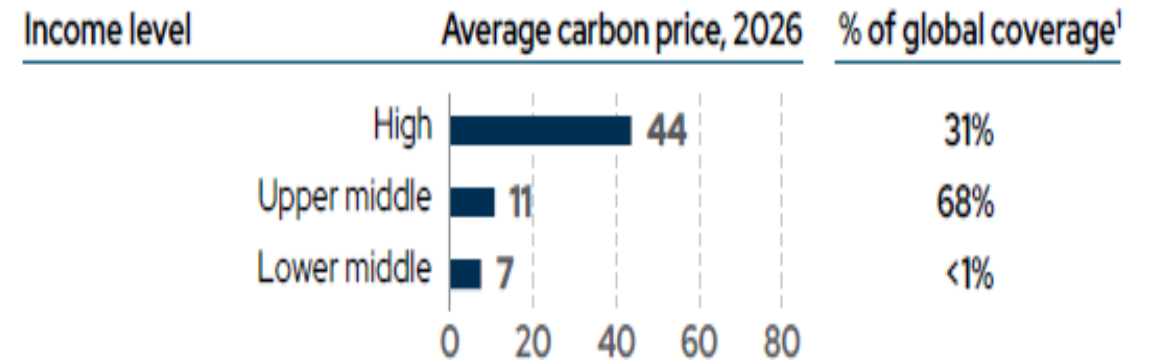
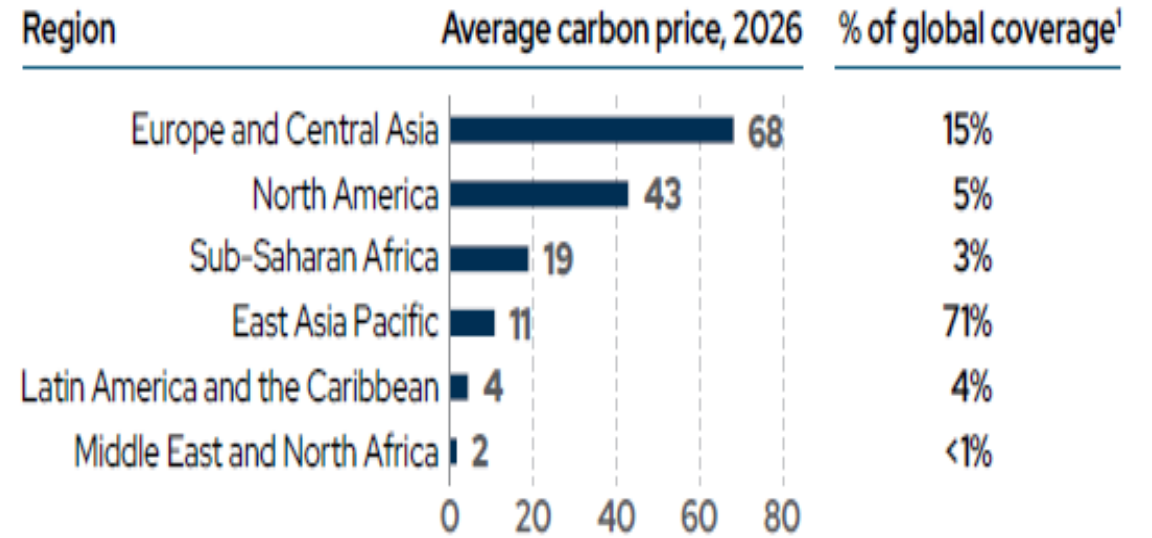
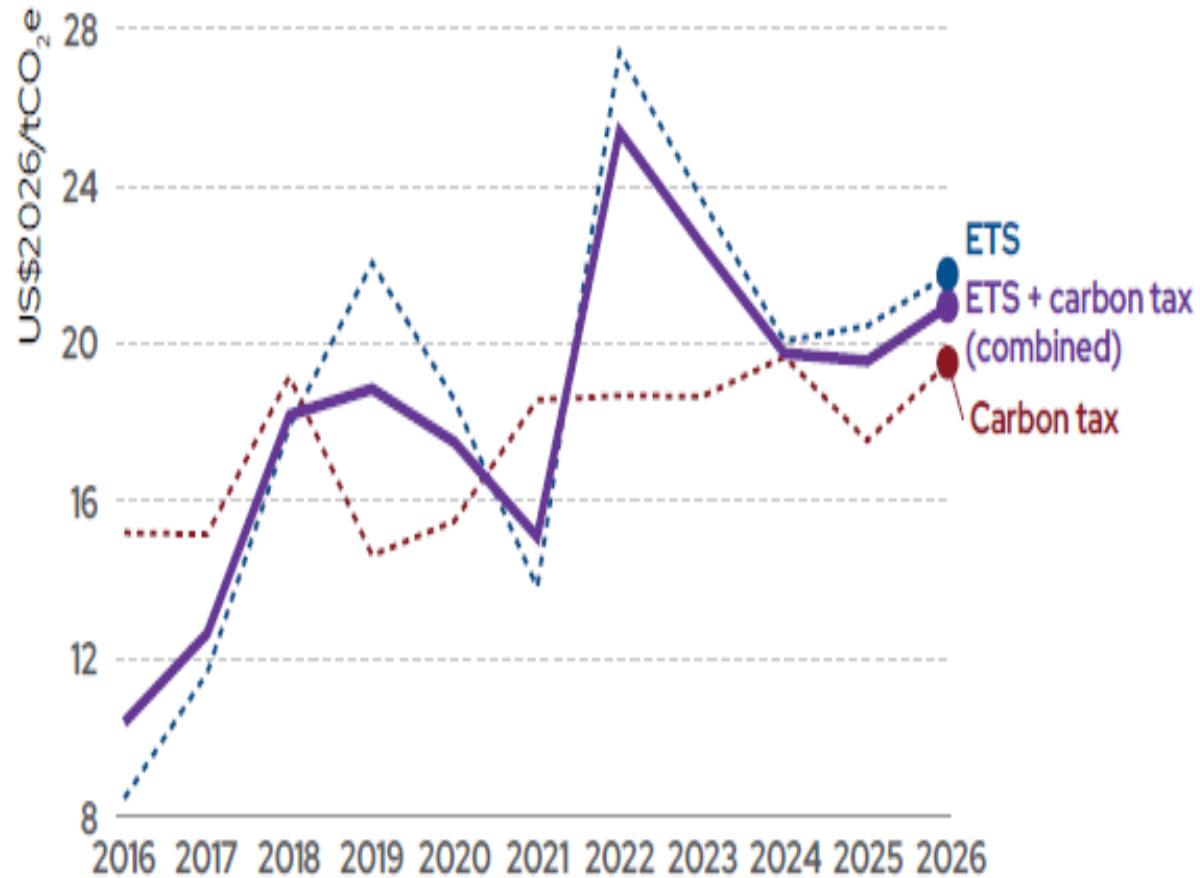
Economic sectors covered by a Carbon Pricing system



Carbon Price from ETS & CT system 1st April 2026



Average Carbon Price from ETS & CT system 2016 - 2026

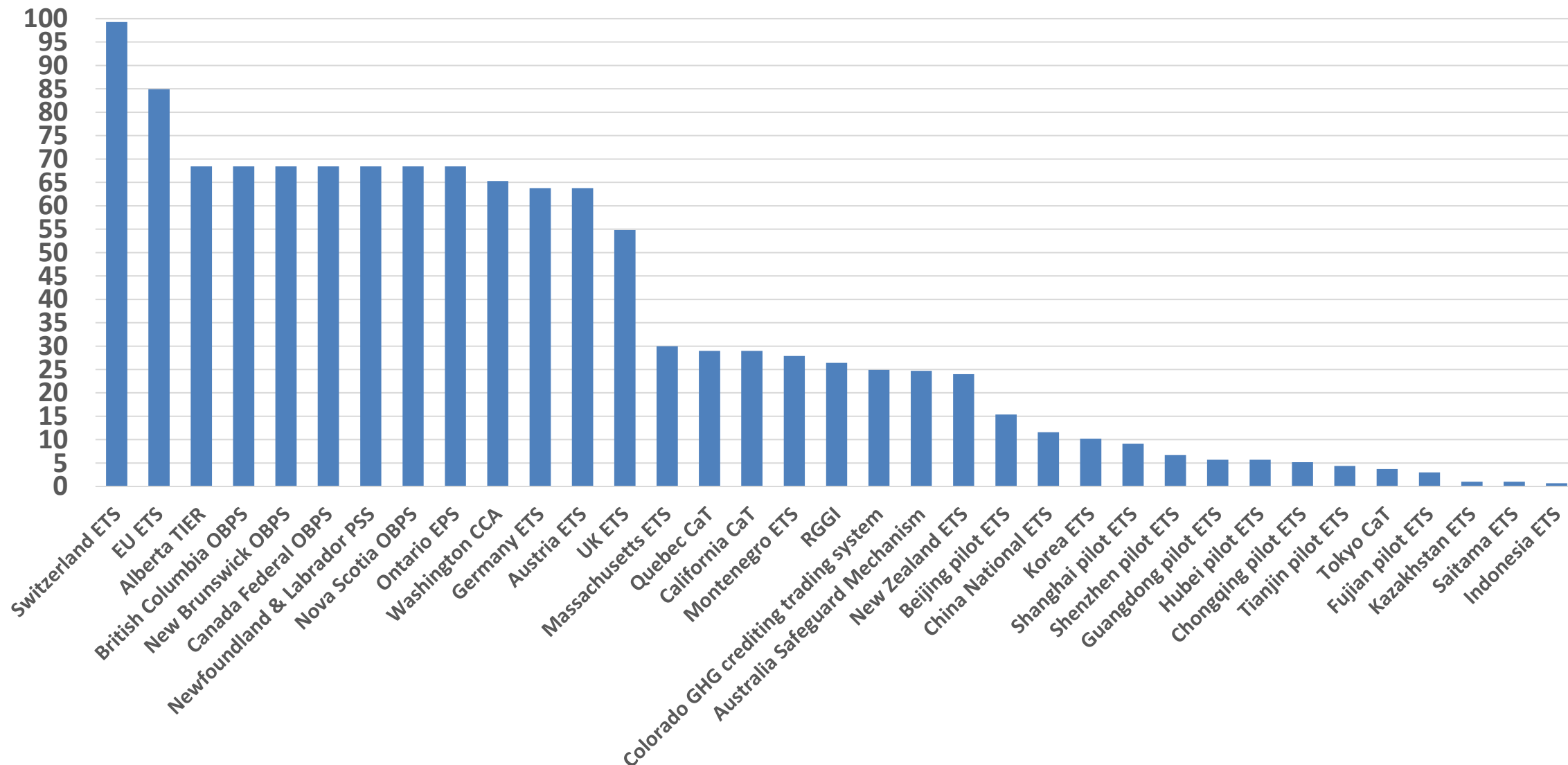


¹ Calculated as percentage of global GHG emissions covered by an ETS or carbon tax. Values exclude newly implemented ETSs in India, Japan and Viet Nam where carbon prices are not available at time of publication. Prices are as of April 1, 2026

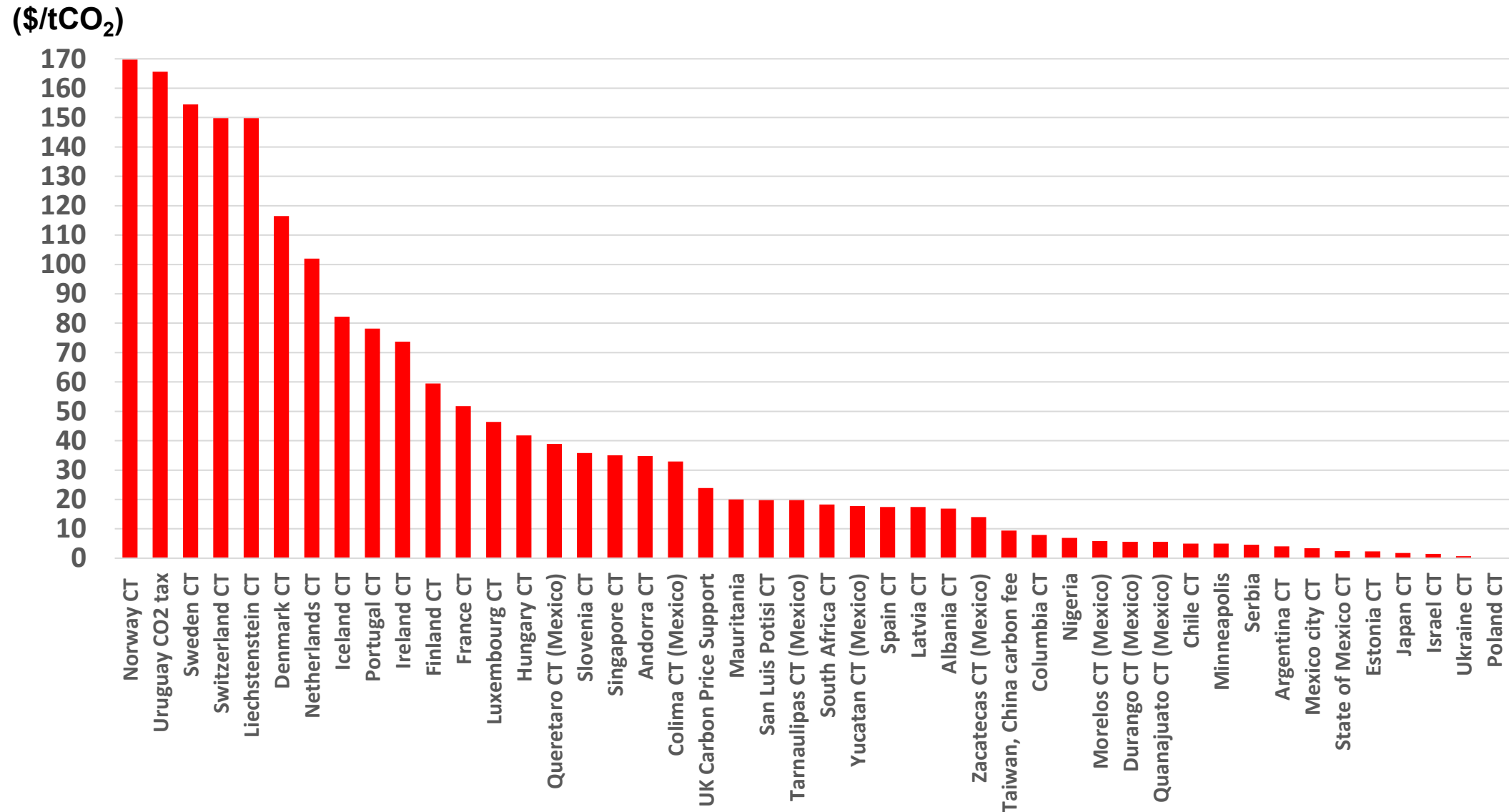


Carbon Price for existing ETS – 2026

(\$/tCO₂)

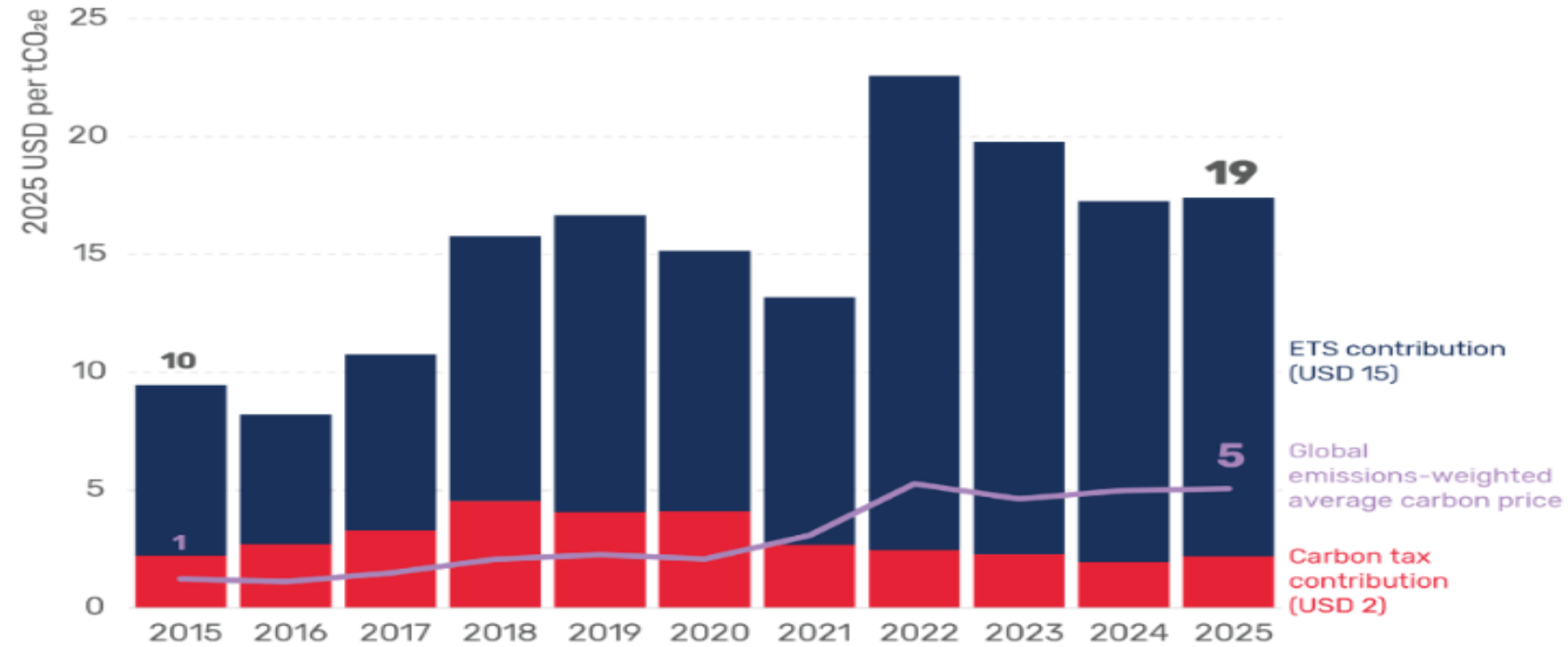


Carbon Price for existing CT Systems - 2026



Evolution of Emissions-weighted Carbon Price vs Global Emissions

Emissions-weighted average carbon prices for covered emissions and global emissions, 2015–2025

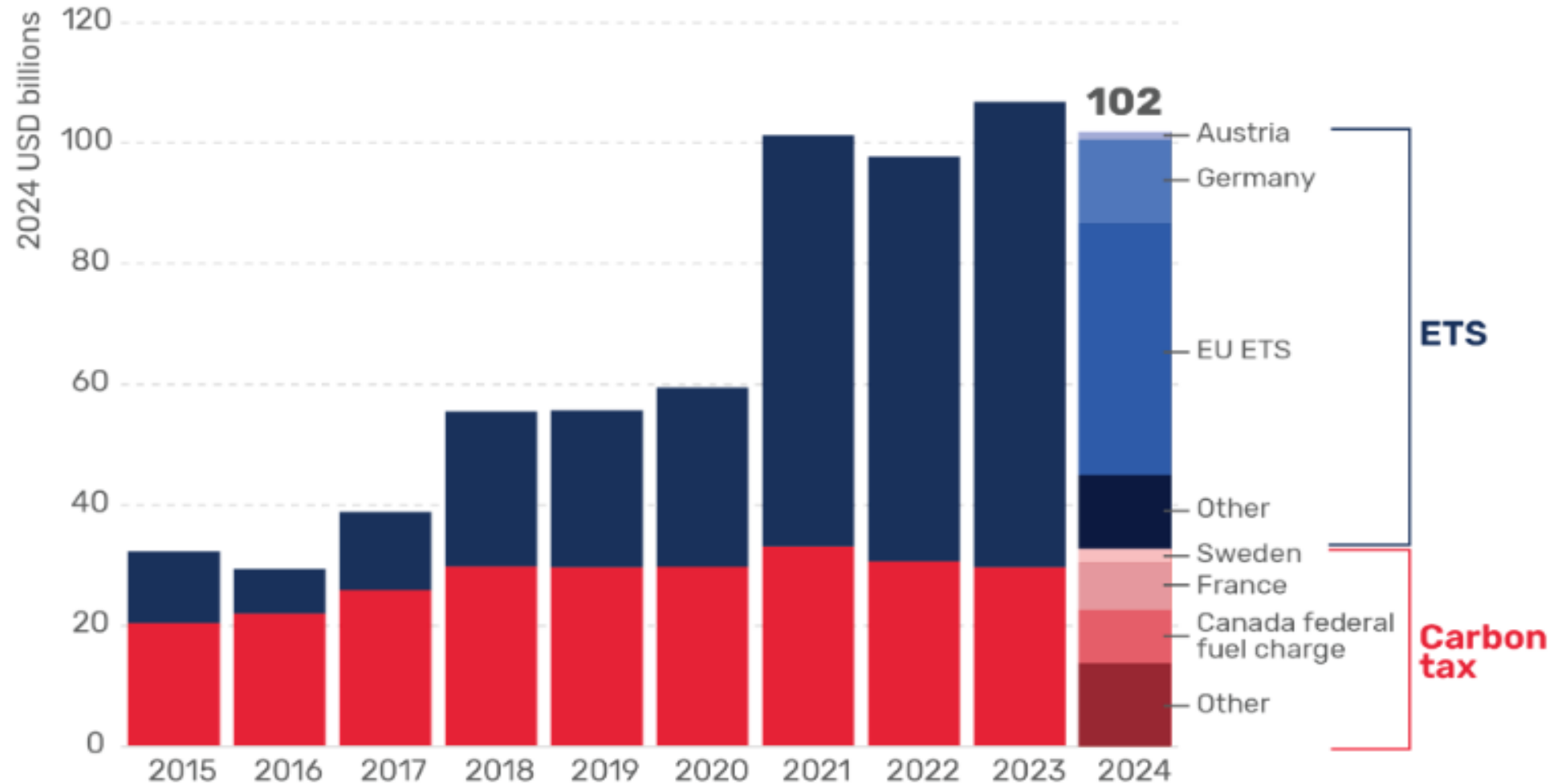


Note: The purple line shows the global emissions-weighted average carbon price. This price accounts for all global emissions, including those without a carbon price. Jurisdictions without a carbon price are included in the calculation of the global emissions-weighted average carbon price, but treated as having a carbon price of zero. The global emissions-weighted average carbon price metric provides an indication of global progress of carbon pricing, taking both price and coverage into account. The blue/red bars show average carbon price for implemented instruments. The global emissions-weighted average carbon price provides an estimate of the weighted average carbon price across countries with an implemented ETS or carbon tax. That is, each implemented carbon price is weighted by its contribution to global covered emissions, with covered emissions defined as the total emissions in each jurisdiction that are subject to that jurisdiction's carbon pricing instrument. As a result, the global emissions-weighted average carbon price only accounts for prices in those jurisdictions that have implemented a carbon price—it does not include those jurisdictions without a carbon price. The average carbon price for implemented instruments therefore provides a global snapshot of how carbon prices have changed over time in jurisdictions that have implemented a carbon price.

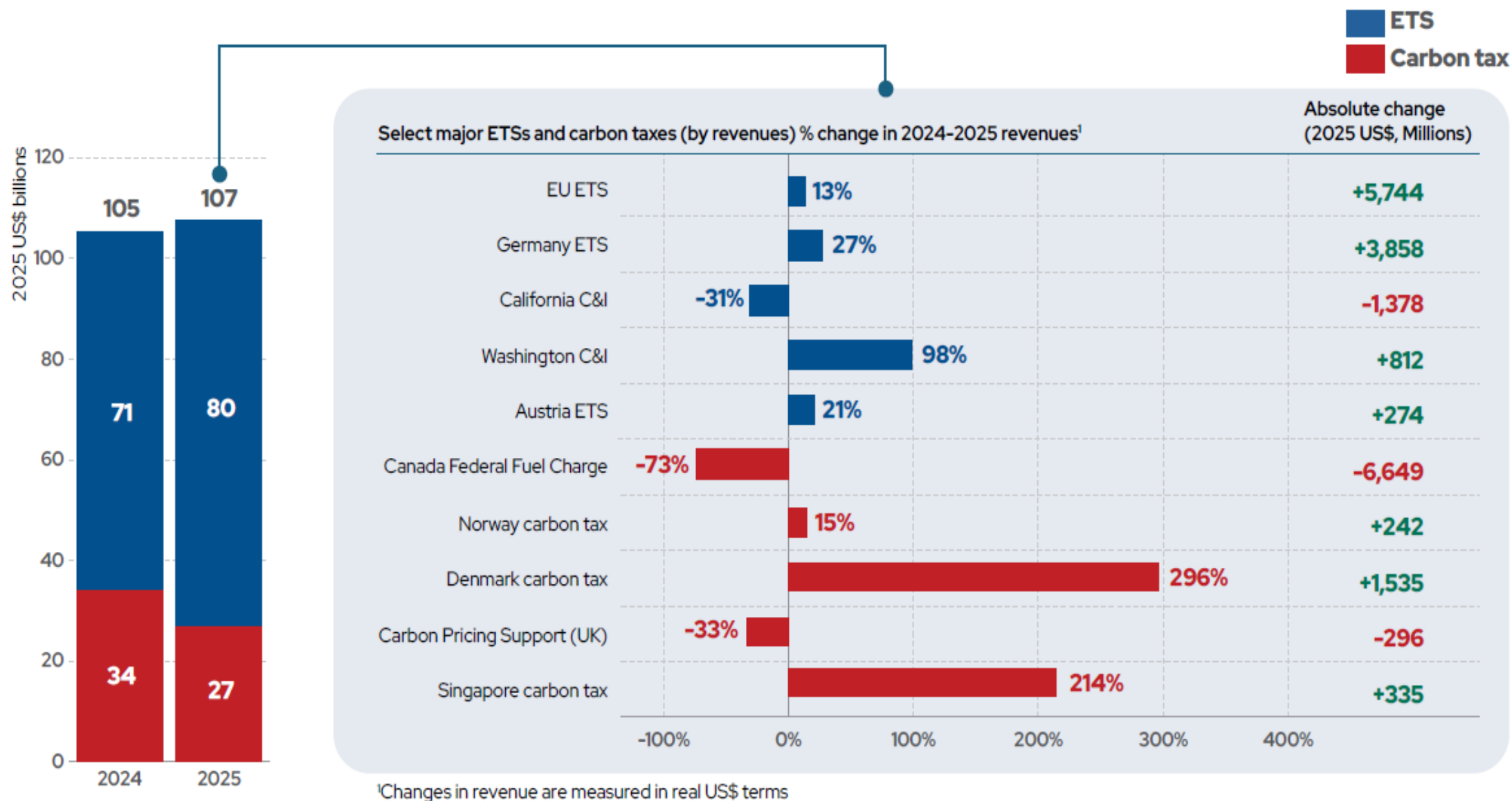


Total Revenues from ETS & CT systems

Total revenues from ETSs and carbon taxes, 2015–2024



Total Revenues from ETS & CT systems 2024 - 2025



Carbon Crediting Mechanism

Carbon Crediting Mechanism

Under a **Carbon Crediting Mechanism**, tradable credits (representing 1 tCO₂e) are generated through voluntary emissions reduction activities. Carbon credits are issued to activities that reduce emissions, according to protocols that aim to ensure each credit represents a genuine emission reduction. Credits can then be sold to buyers, generating revenue. Carbon credits can represent emissions reductions achieved through either avoidance (preventing GHG emissions from entering the atmosphere—like capturing methane from landfills before it is released), or removal (taking GHGs from the atmosphere, for example through sequestering carbon through afforestation). While carbon crediting mechanisms create a source of supply, they rely on a separate source of demand for credits in order to deliver a financial incentive to reduce emissions. Demand for credits can come from compliance instruments (ETEs or carbon taxes that allow the use of offsets), countries meeting Nationally Determined Contribution targets under the UNFCCC, voluntary offsetting (sometimes linked to internal carbon pricing), or results-based climate finance.



Carbon Credit Markets

Sources of demand and supply in global carbon credit markets

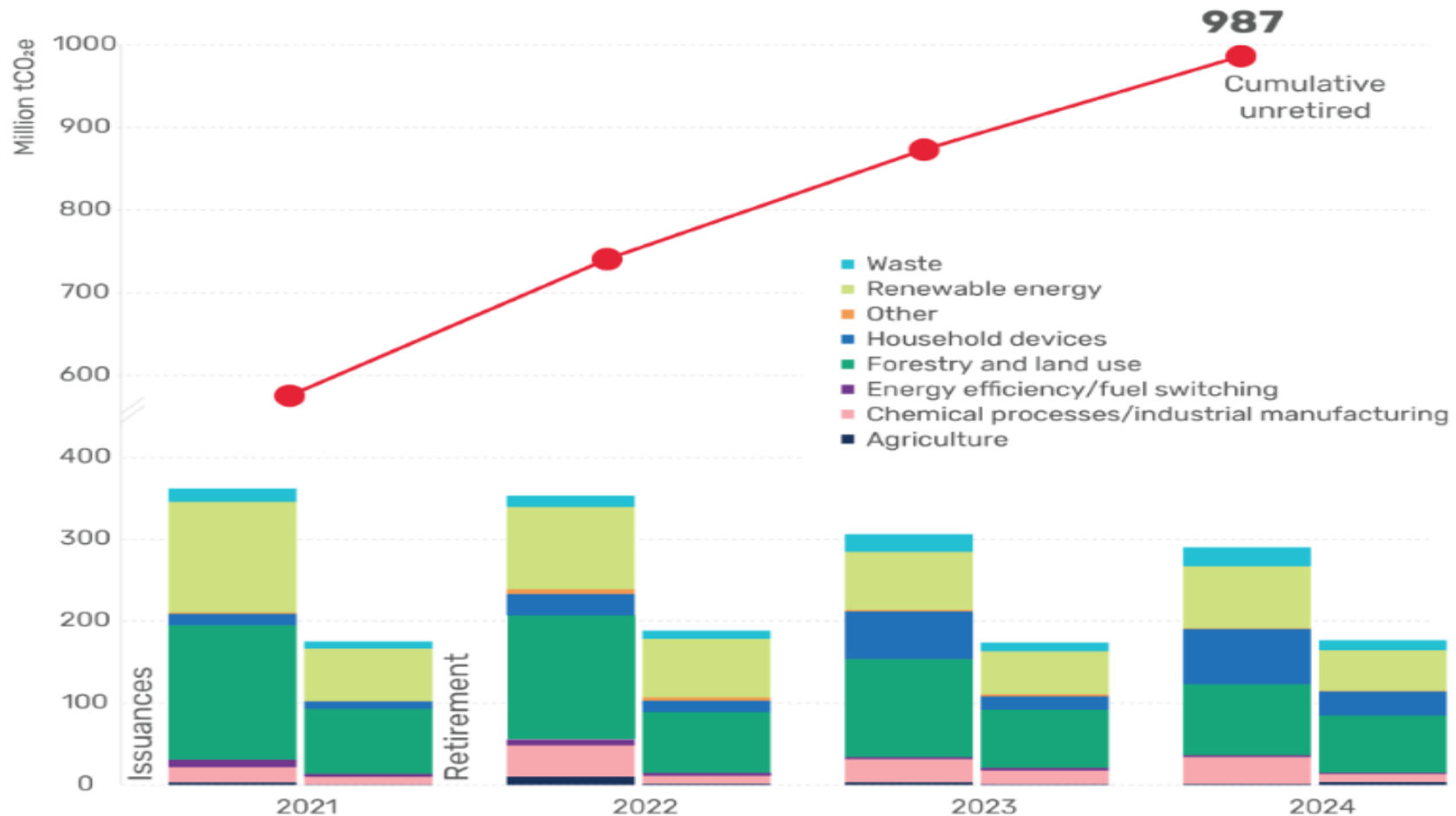


Note: While there is crossover between categories, not all sources of carbon credits are fully fungible across demand segments. For example, international compliance and nationally determined contribution achievement require authorized credits that include a corresponding adjustment.



Carbon Credit Markets

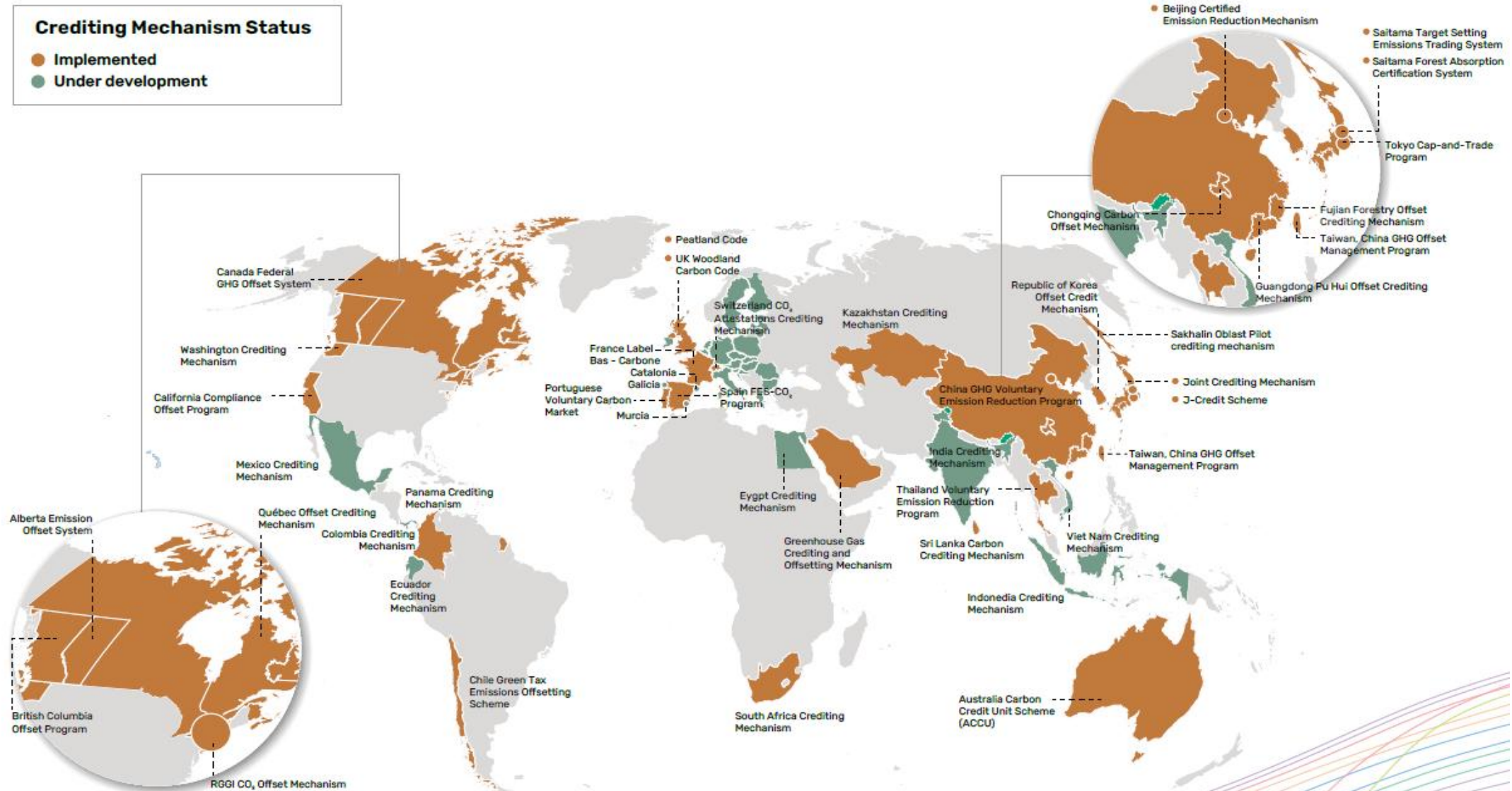
Carbon credit issuances and retirements from independent crediting mechanisms and volume of unretired credits, 2021–2024



Note: Based on data from Climate Focus's Voluntary Carbon Market Dashboard, using project categorizations based on those published by Ecosystem Marketplace. The volume of issuances and retirements by project category covers the following crediting mechanisms: American Carbon Registry, Architecture for Reducing Emissions from Deforestation and Forest Degradation Transactions, BioCarbon, Cercarbono, Climate Action Reserve, Climate Forward, Gold Standard, Plan Vivo, and Verra's VCS. All issuance and retirement data here refers to original issuances, which only include the first time a credit was issued for a specific emission reduction/removal activity to avoid double counting. Original issuances do not rely on previous issuances from other crediting mechanisms.

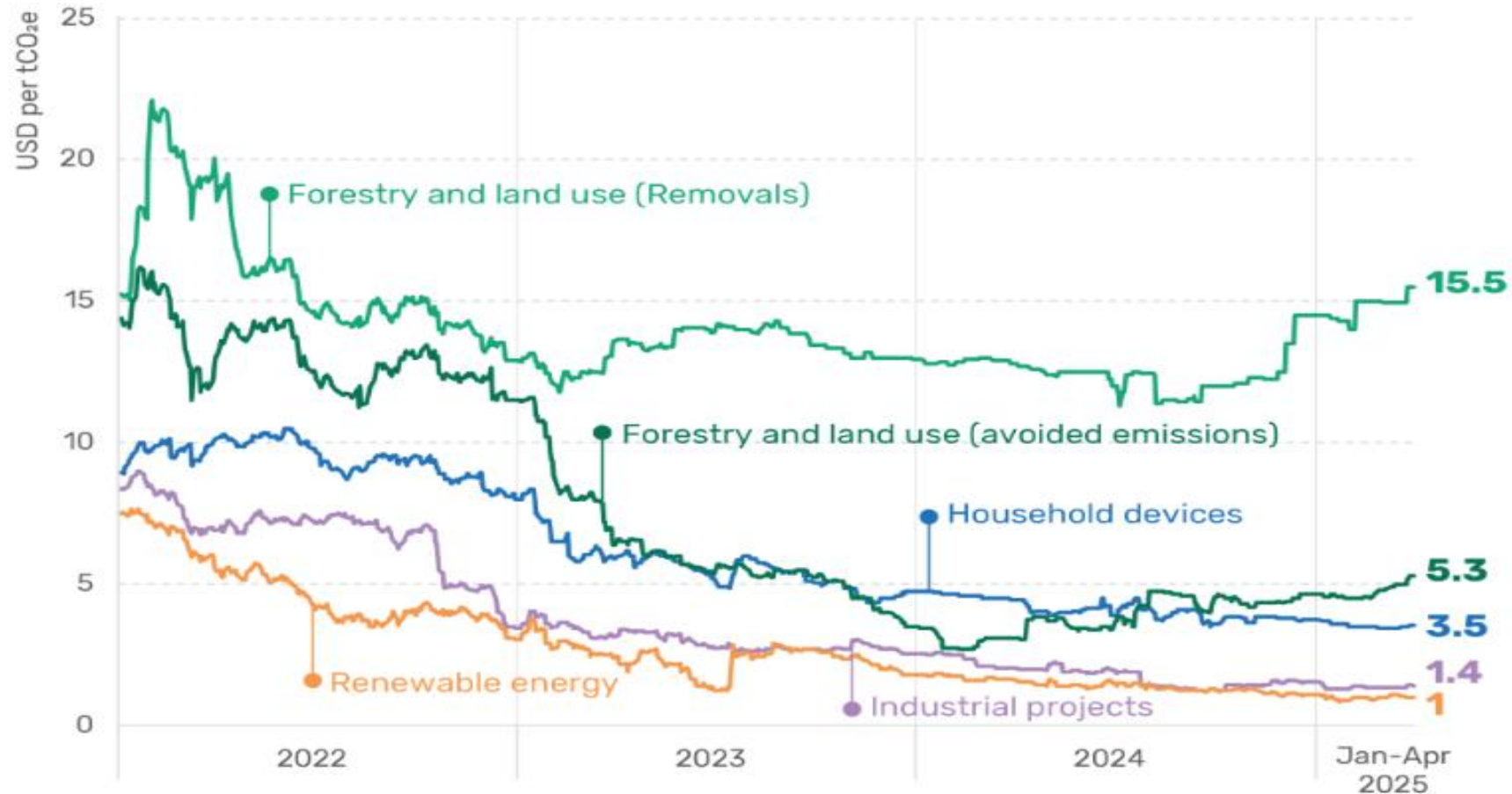


Map of government crediting mechanisms 1st April 2026



Exchange-traded Carbon Credit Prices 2022 - 2025

Exchange-traded carbon credit prices by project types, January 1, 2022 to April 1, 2025

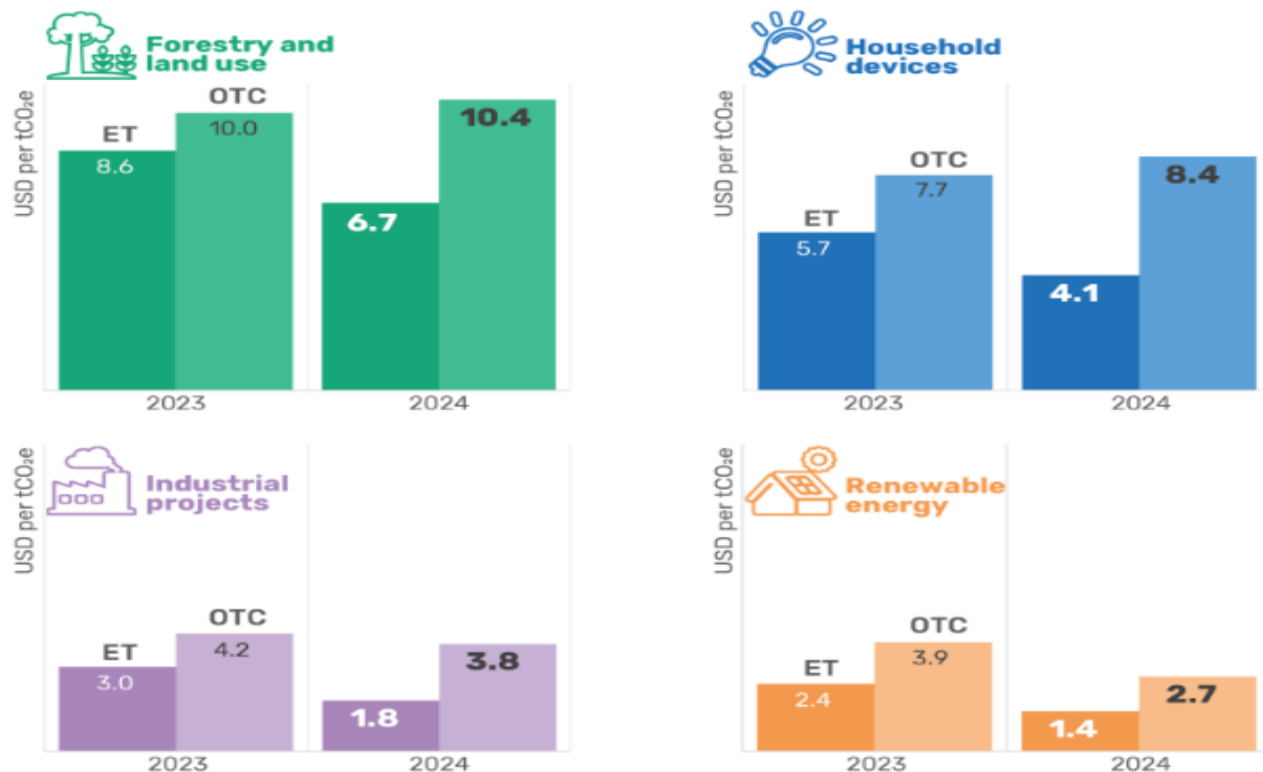


Note: Prices are based on monthly and yearly averages of the price assessments from Platts, S&P Global Commodity Insights (2025), provided by S&P Global.



Exchange-traded Carbon Credit Prices vs Over-The-Counter transactions 2023-2024

Comparison of average annual carbon credit prices from exchange-traded and over-the-counter transactions by project category, 2023–2024



Note: This figure illustrates the exchange-traded and OTC prices of carbon credits. Prices are based on monthly and yearly averages of the price assessments provided by Platts, S&P Global Commodity Insights, 2025. The Platts assessment reflects bids, offers, and trades for credits as reported in the Platts Market on Close assessment process, in the brokered market, or on trading and exchange platforms. For each of its price assessments Platts has identified a reference base to represent fungible credits across each market segment, considering certification, vintage, volume, and the Sustainable Development Goals. For the nature-based projects, a weighted average of Platts nature-based avoidance price and Platts nature-based removals price is used, rather than a singular price assessment. Adjustments are made for credits that vary from this base, normalizing values based on factors like technology, certification standards, geography, and additional benefits to align them with the market value of the reference base. OTC prices were provided by Ecosystem Marketplace and updated as of February 26, 2025. OTC prices represent volume-weighted yearly averages of carbon credit trades in the voluntary carbon markets. Discrepancies may exist in project categorizations between the exchange-traded and OTC data due to different source methodologies. See Annex C, Definitions, for a detailed note on the carbon credit categorizations used in this figure. Details on Platts's assessments can be found in the Platts' Specification Guide.



Carbon Pricing used by Companies **in the past**

Carbon Pricing then has been revised upwards

Microsoft Google Walt Disney Devon Energy	ConocoPhillips Cairn Energy BP Shell Total	Encana	Azko Nobel ExxonMobil
0 – 20 \$/t	20 – 40 \$/t	40 – 60 \$/t	60 – 80 \$/t



Carbon Pricing within TotalEnergies - 2023

Regional carbon prices

- EU27 + NO + UK:

From 2023 onwards the carbon price shall be the higher of (1) 100 \$_{mod}/t and (2) the local carbon tax implemented in the country. ETS quota purchases and free quotas can be applied in the following cases, and under the following conditions:

- Quotas shall be considered in the current and the first year of the LTP (2023 and 2024), in line with PdC and Budget forecast
- Quotas can be considered in years 2025+ under the condition (1) they are officially notified by Authorities, and (2) the resulting carbon price is higher than 100 \$_{mod}/t.

- Other countries w/ carbon price regulation:

Current price for 2023, 100 \$_{mod}/t from 2024 onwards

- Countries w/o carbon price regulation:

0 \$_{mod}/t in 2023 and 2024, 100 \$_{mod}/t from 2025 onwards

If no different local regulations apply, carbon prices shall be applied from production start-up onwards.



Carbon Pricing within TotalEnergies - 2025

Even though CO₂ pricing does not currently apply in all the countries where the Company operates, TotalEnergies includes as base case in its investment criteria a minimum CO₂ price of **100 \$/t (or the prevailing price in a given country if higher) and beyond 2030, the CO₂ price is increased by 2% per year.**

Source: TotalEnergies Sustainability & Climate 2025 Progress Report



Carbon Pricing Scenarios by IEA WEO 2025 (\$/tCO₂)

USD (2024, MER) per tonne of CO ₂	2035	2040	2050
Current Policies Scenario			
Canada	70	70	70
China	14	14	14
European Union	87	87	87
Japan	2	2	2
Korea	13	13	13
Stated Policies Scenario			
Canada	126	126	126
China	22	26	34
European Union	89	92	174
Japan	39	61	105
Korea	52	62	75
Net Zero Emissions by 2050 Scenario			
Advanced economies with net zero emissions pledges	180	205	250
Selected emerging markets and developing economies*	125	160	200
Other emerging market and developing economies	25-50	35-85	55-180

*Includes Brazil, China, India, Indonesia and South Africa.

Notes: USD = United States dollar; MER = market exchange rate. Values are rounded.

Source: IEA WEO 2025



Carbon Pricing in 2025



State & Trends of Carbon Pricing – World Bank 2025

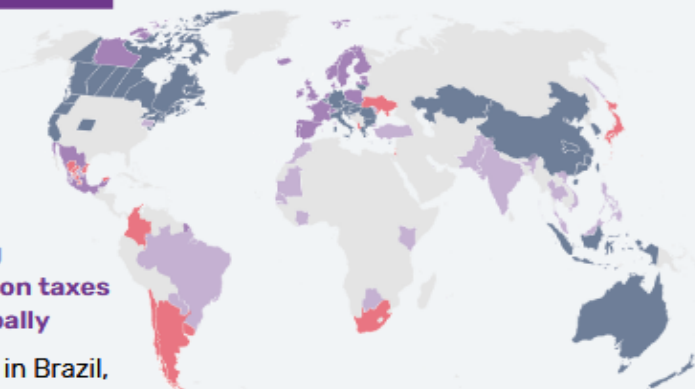
State and Trends of Carbon Pricing 2025

CARBON PRICING

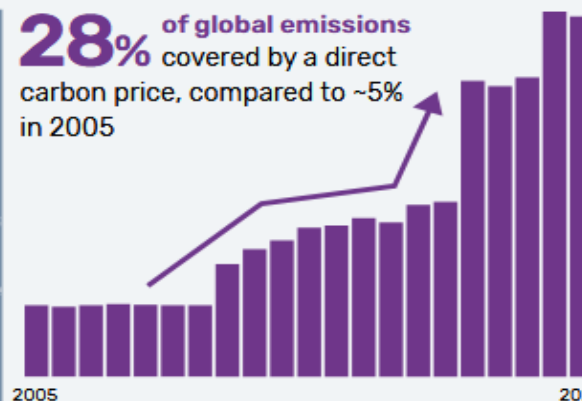
80

emissions trading systems and carbon taxes implemented globally

Plus ETSs planned in Brazil, India, and Türkiye



28% of global emissions covered by a direct carbon price, compared to ~5% in 2005



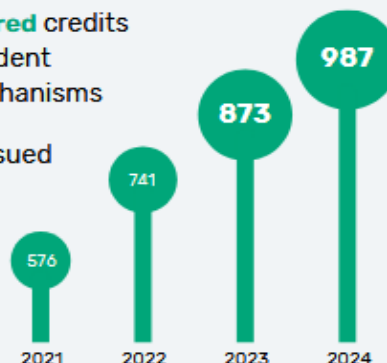
USD 100+ billion in revenues raised for second consecutive year

Over **50%** of revenue was used to support environmental, infrastructure, and development projects

CARBON CREDIT MARKETS

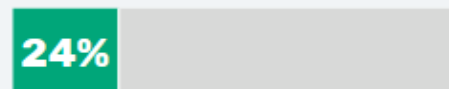
~1 billion unretired credits from independent crediting mechanisms

2/3 are from credits issued before 2022

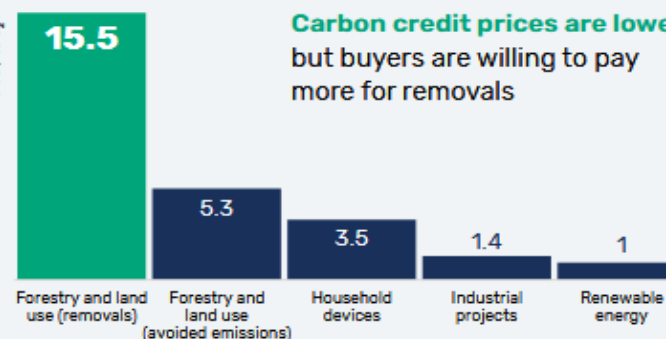


~3x more domestic compliance retirements in 2024, compared to 2023

In 2024, almost **a quarter** of global credit retirements were to meet domestic compliance obligations



USD/tCO₂e

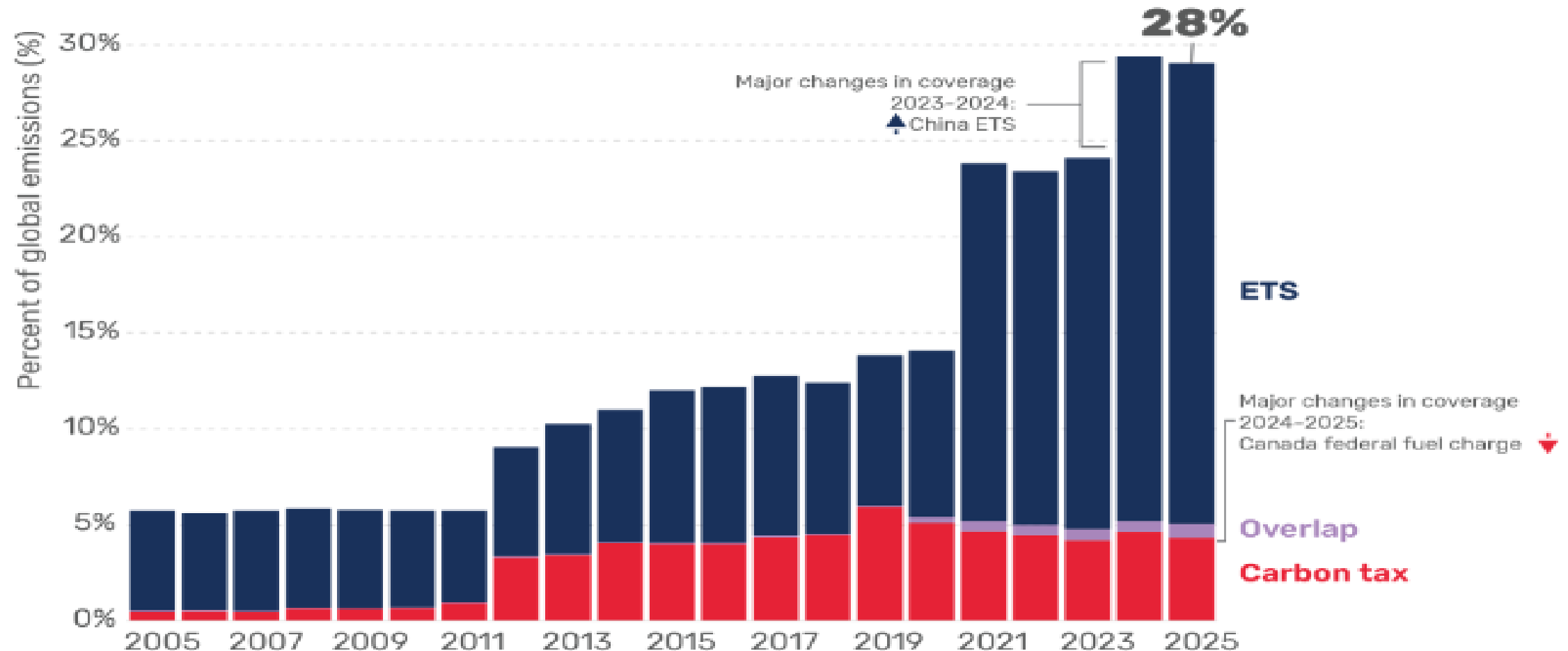


Carbon credit prices are lower but buyers are willing to pay more for removals



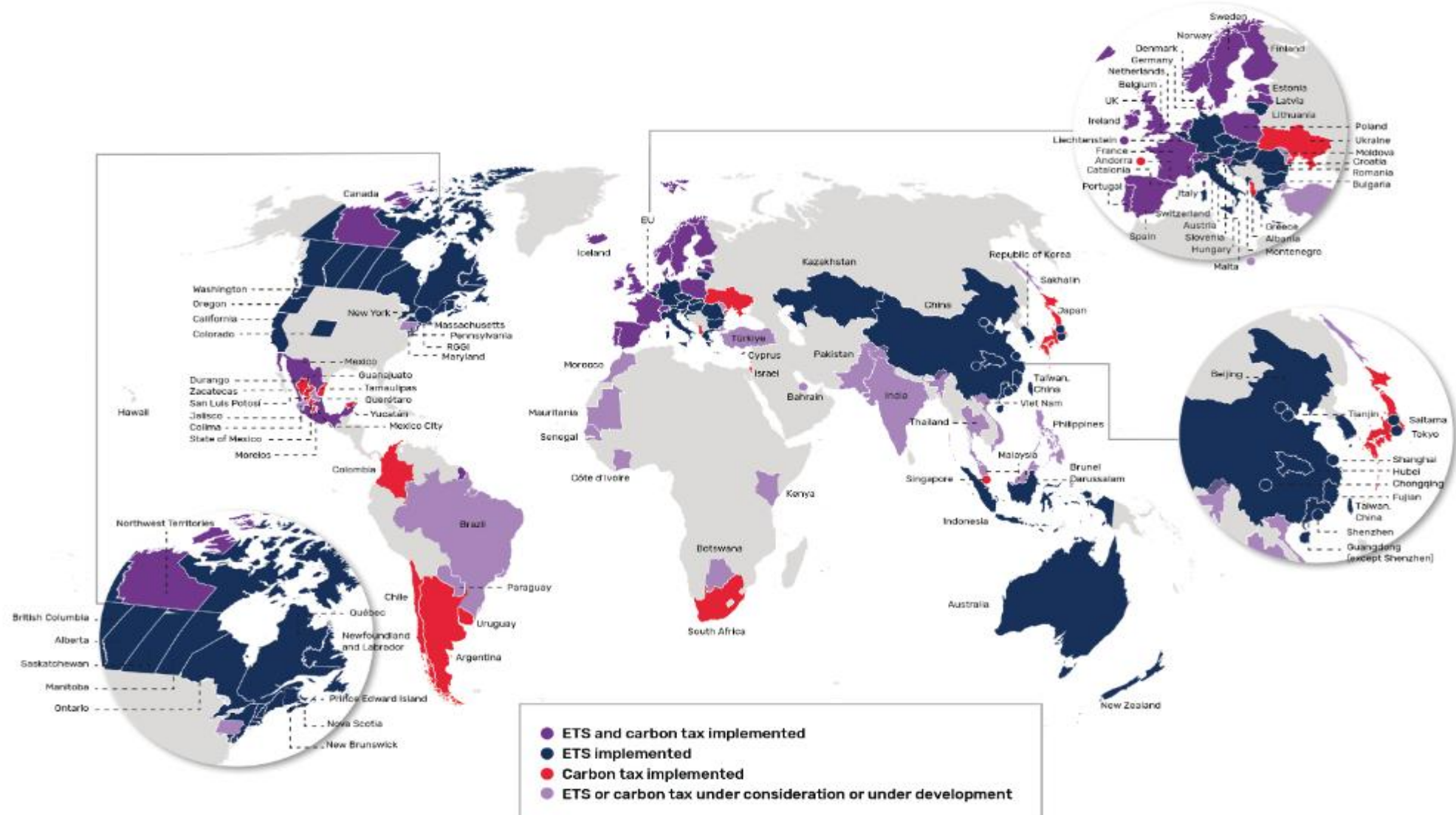
Global Emissions Coverage

Share of global greenhouse gas emissions covered by an ETS or carbon tax, 2005–2025



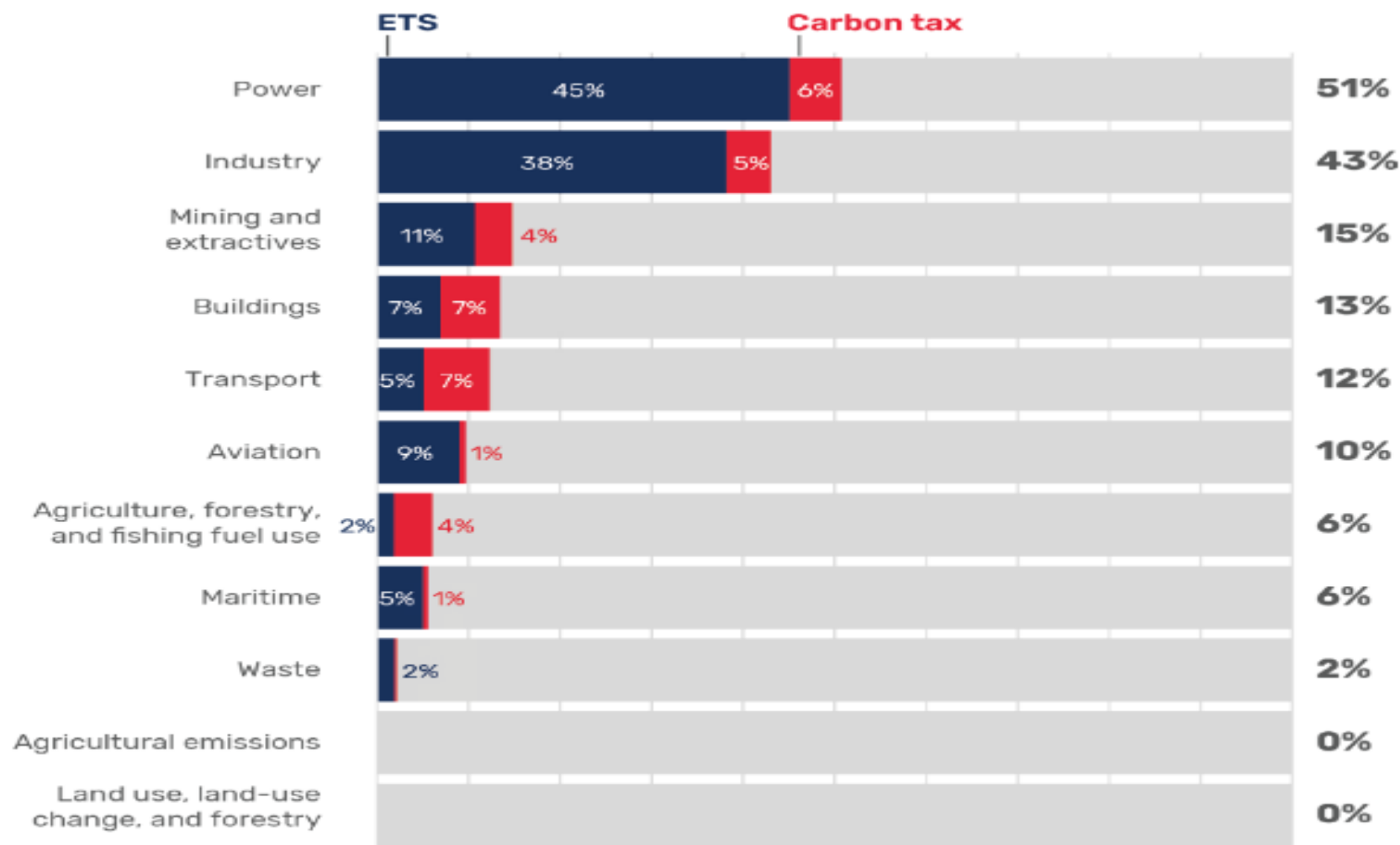
Global map of ETS & Carbon Taxes systems 2024/2025

Global map of ETS and carbon taxes implemented, under development, or under consideration



Economic sectors covered by a Carbon Pricing system

Share of economic sectors' global GHG emissions covered by an ETS or carbon tax

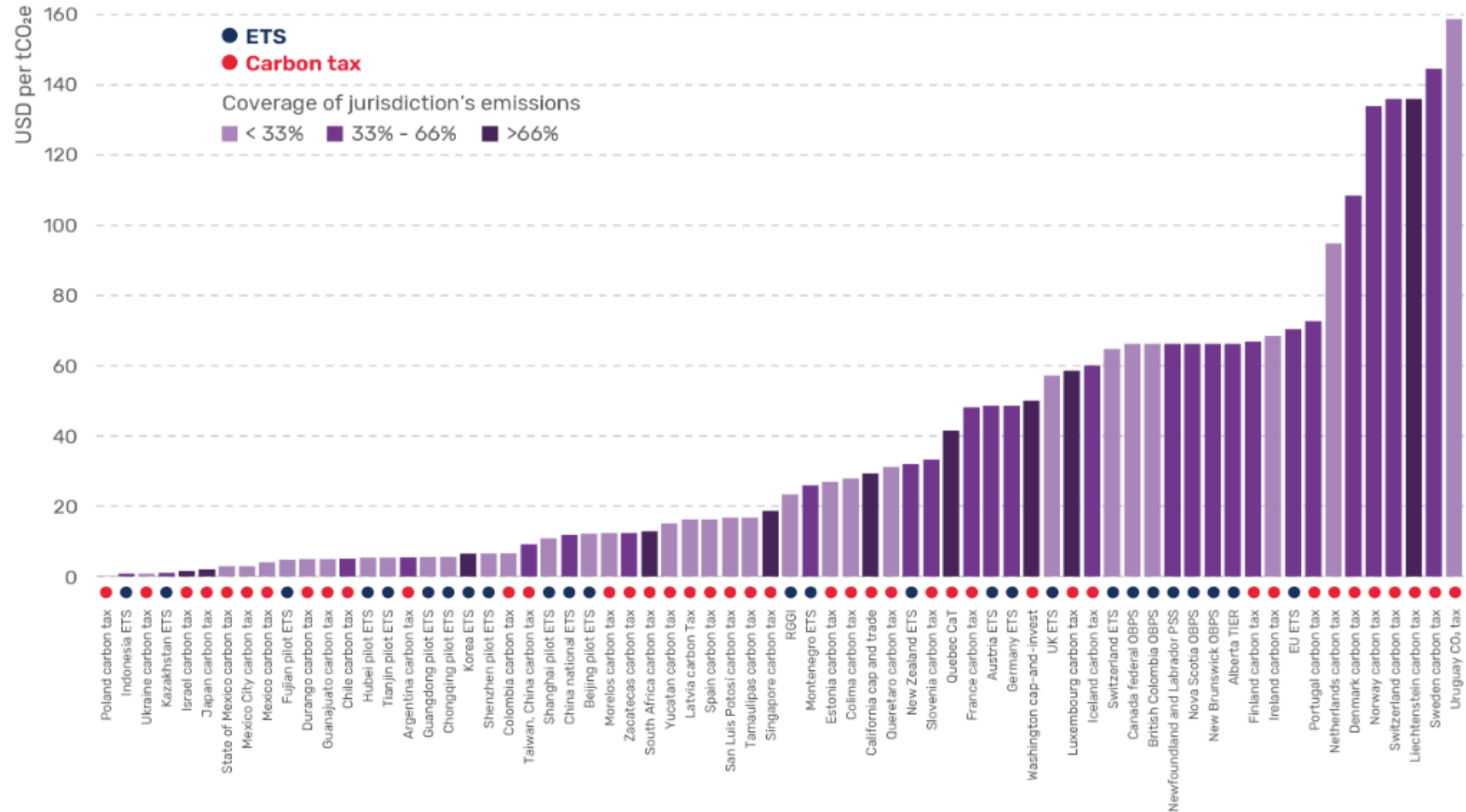


Note: Based on World Bank analysis. Values are not additive due to rounding. Aviation and maritime carbon tax coverage are both less than 1%, waste ETS coverage is 1%, and carbon tax coverage is < 1%.



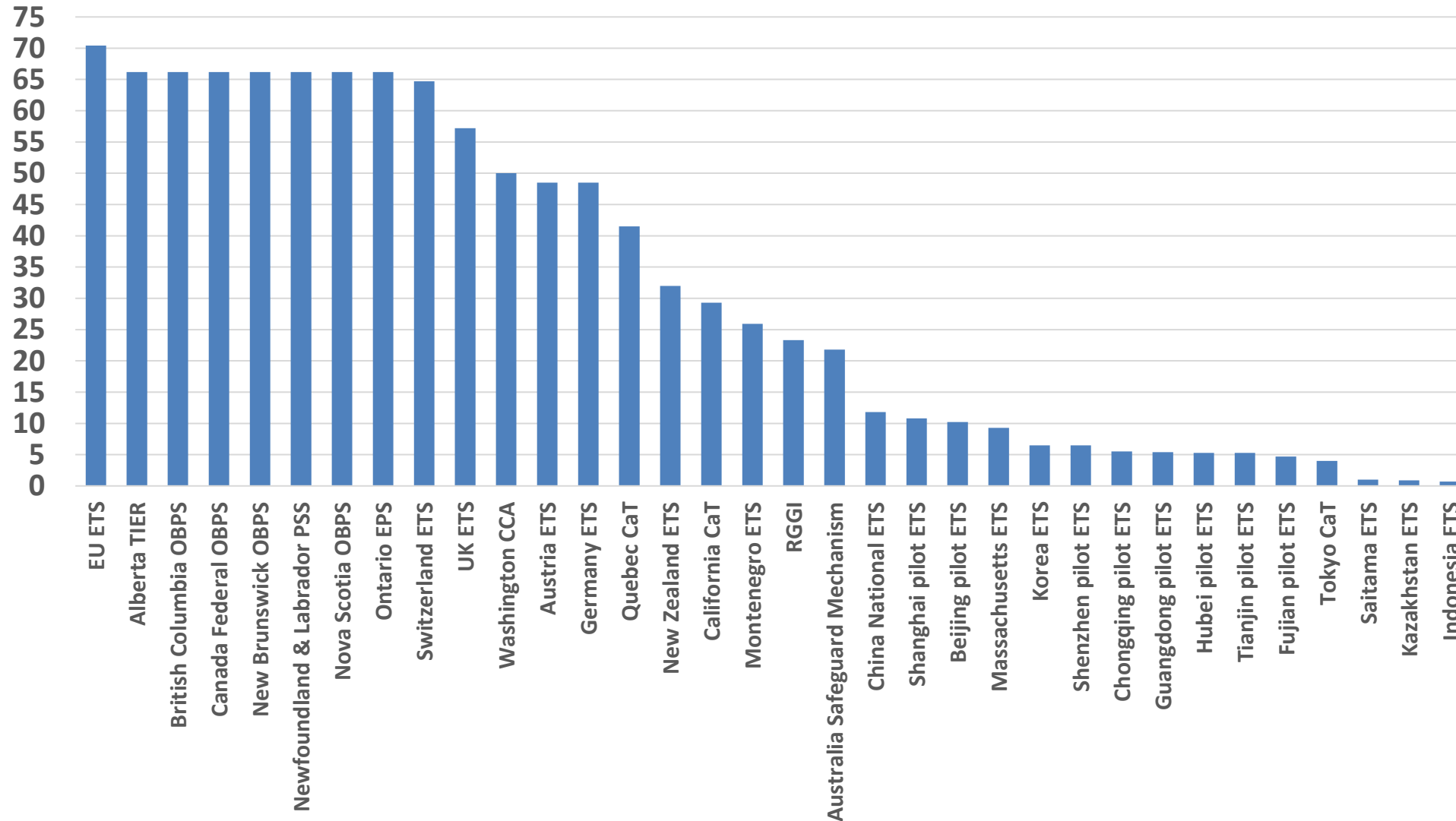
Carbon Price from ETS & CT system 1st April 2025

Prices and coverage across ETSs and carbon taxes, as of April 1, 2025

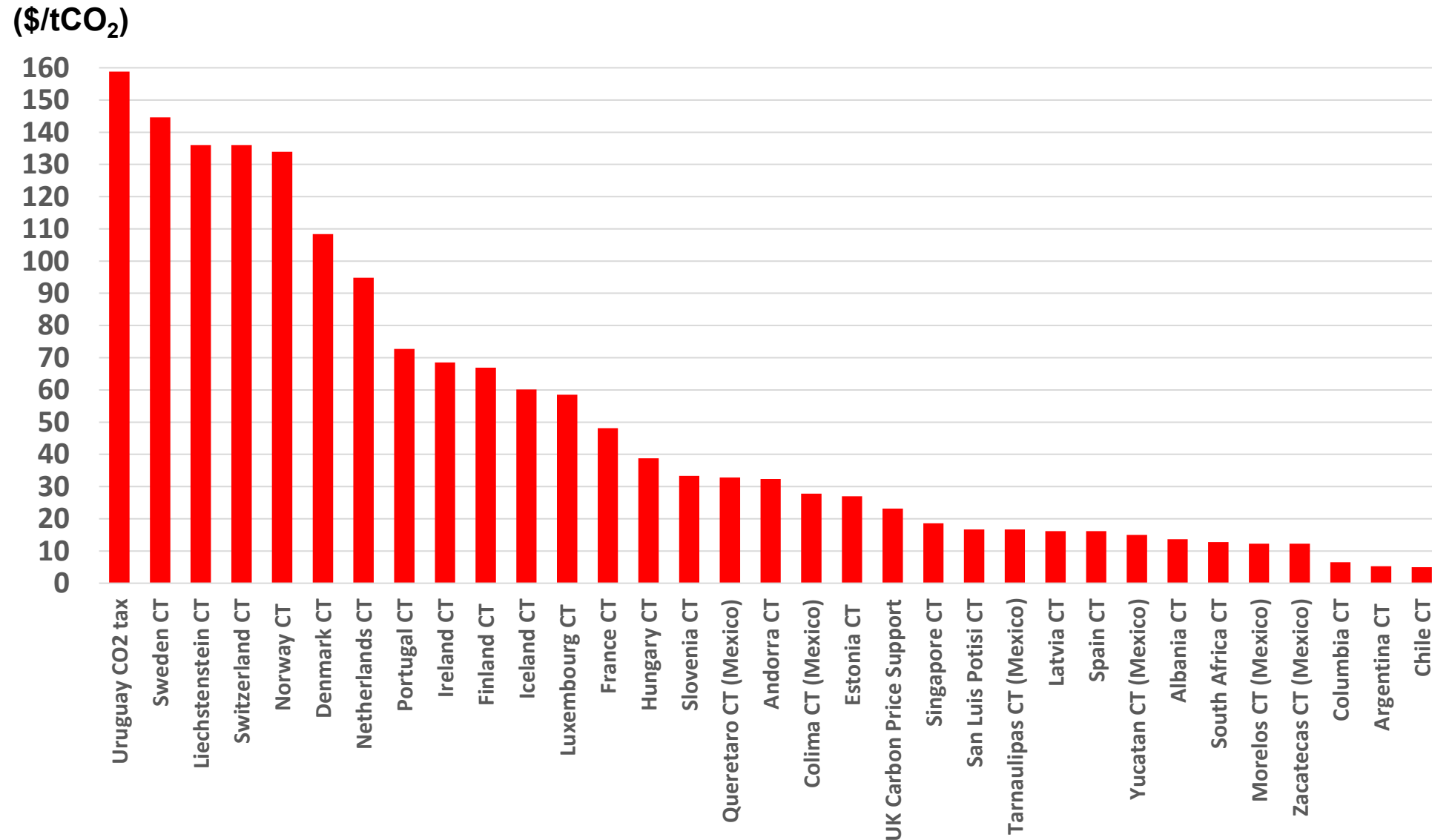


Carbon Price for existing ETS – 2025

(\$/tCO₂)

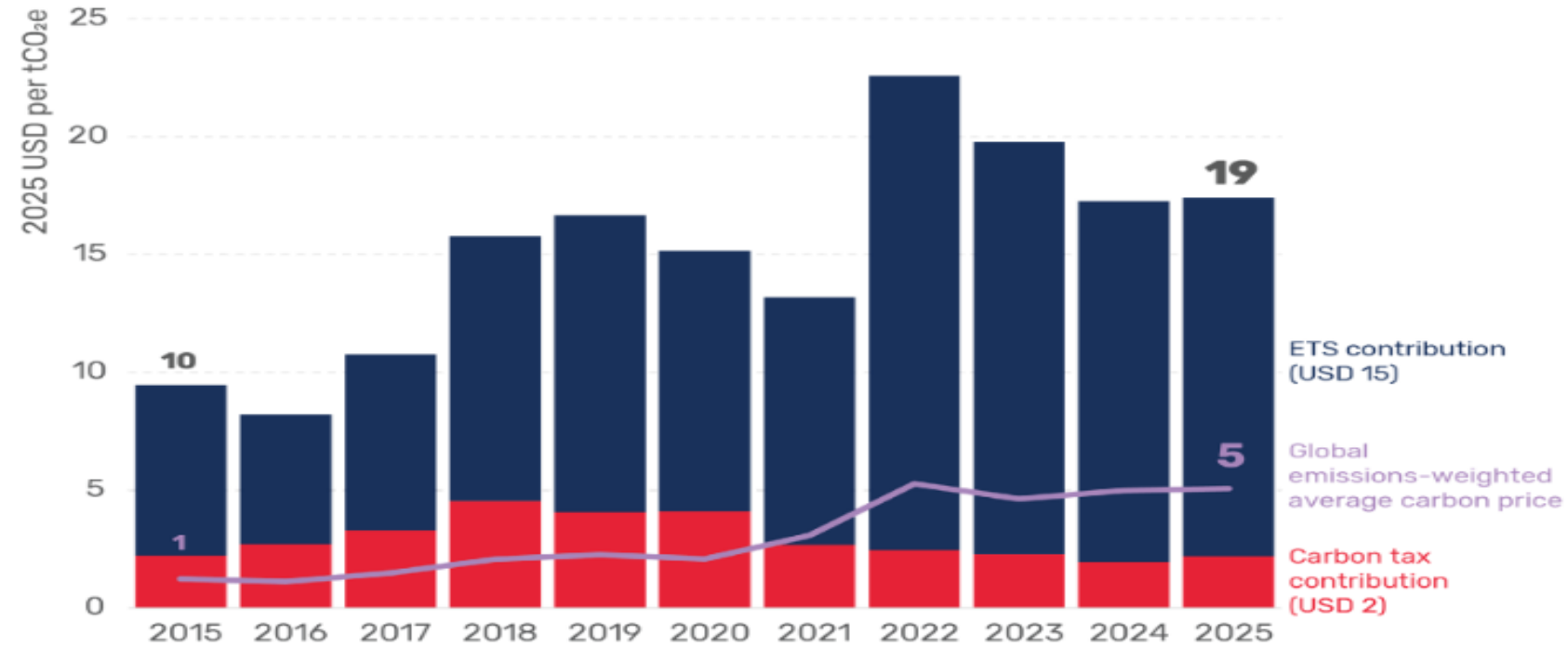


Carbon Price for existing CT Systems - 2025



Evolution of Emissions-weighted Carbon Price vs Global Emissions

Emissions-weighted average carbon prices for covered emissions and global emissions, 2015–2025

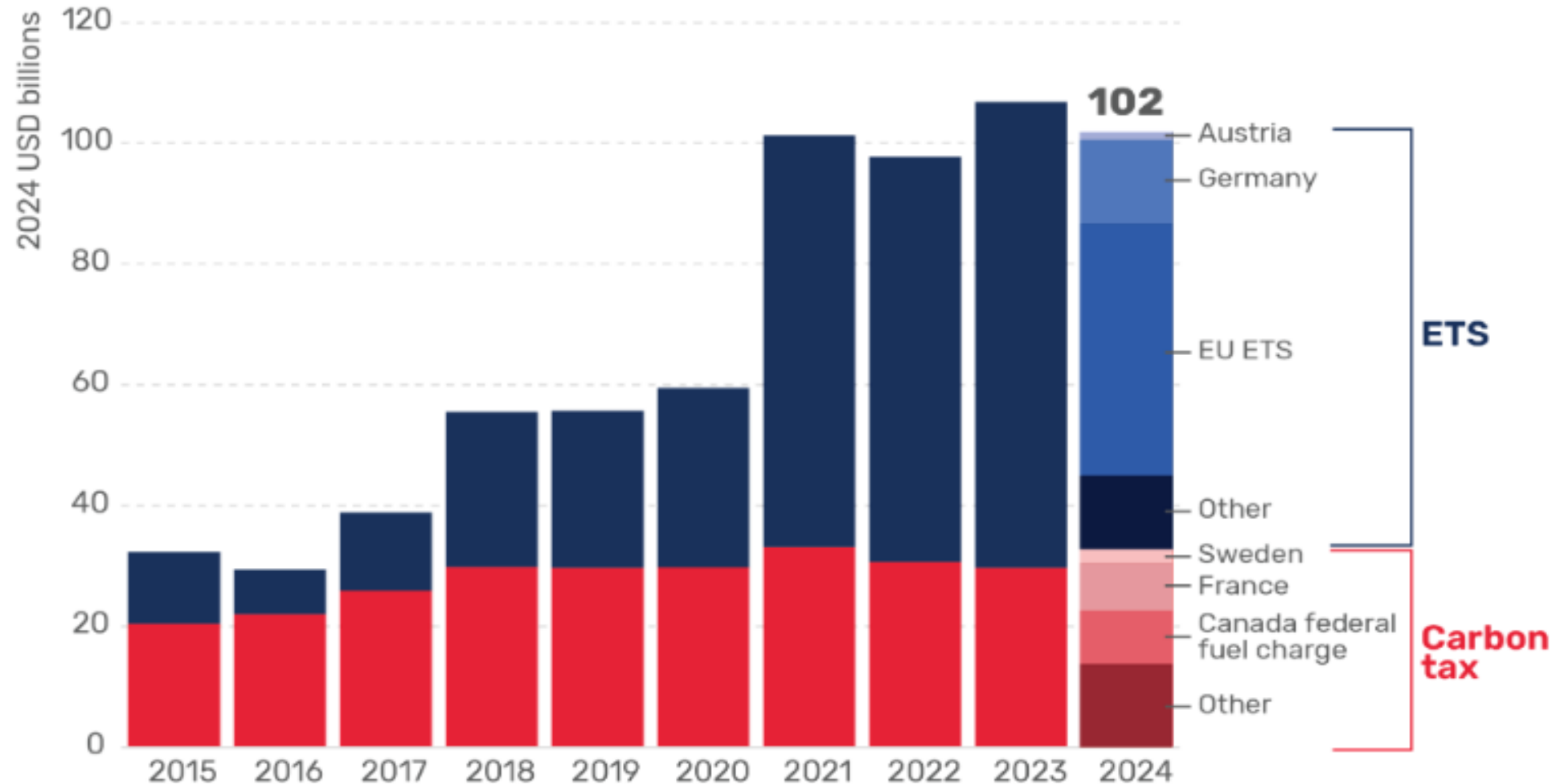


Note: The purple line shows the global emissions-weighted average carbon price. This price accounts for all global emissions, including those without a carbon price. Jurisdictions without a carbon price are included in the calculation of the global emissions-weighted average carbon price, but treated as having a carbon price of zero. The global emissions-weighted average carbon price metric provides an indication of global progress of carbon pricing, taking both price and coverage into account. The blue/red bars show average carbon price for implemented instruments. The global emissions-weighted average carbon price provides an estimate of the weighted average carbon price across countries with an implemented ETS or carbon tax. That is, each implemented carbon price is weighted by its contribution to global covered emissions, with covered emissions defined as the total emissions in each jurisdiction that are subject to that jurisdiction's carbon pricing instrument. As a result, the global emissions-weighted average carbon price only accounts for prices in those jurisdictions that have implemented a carbon price—it does not include those jurisdictions without a carbon price. The average carbon price for implemented instruments therefore provides a global snapshot of how carbon prices have changed over time in jurisdictions that have implemented a carbon price.



Total Revenues from ETS & CT systems

Total revenues from ETSs and carbon taxes, 2015–2024



Carbon Credit Markets

Sources of demand and supply in global carbon credit markets

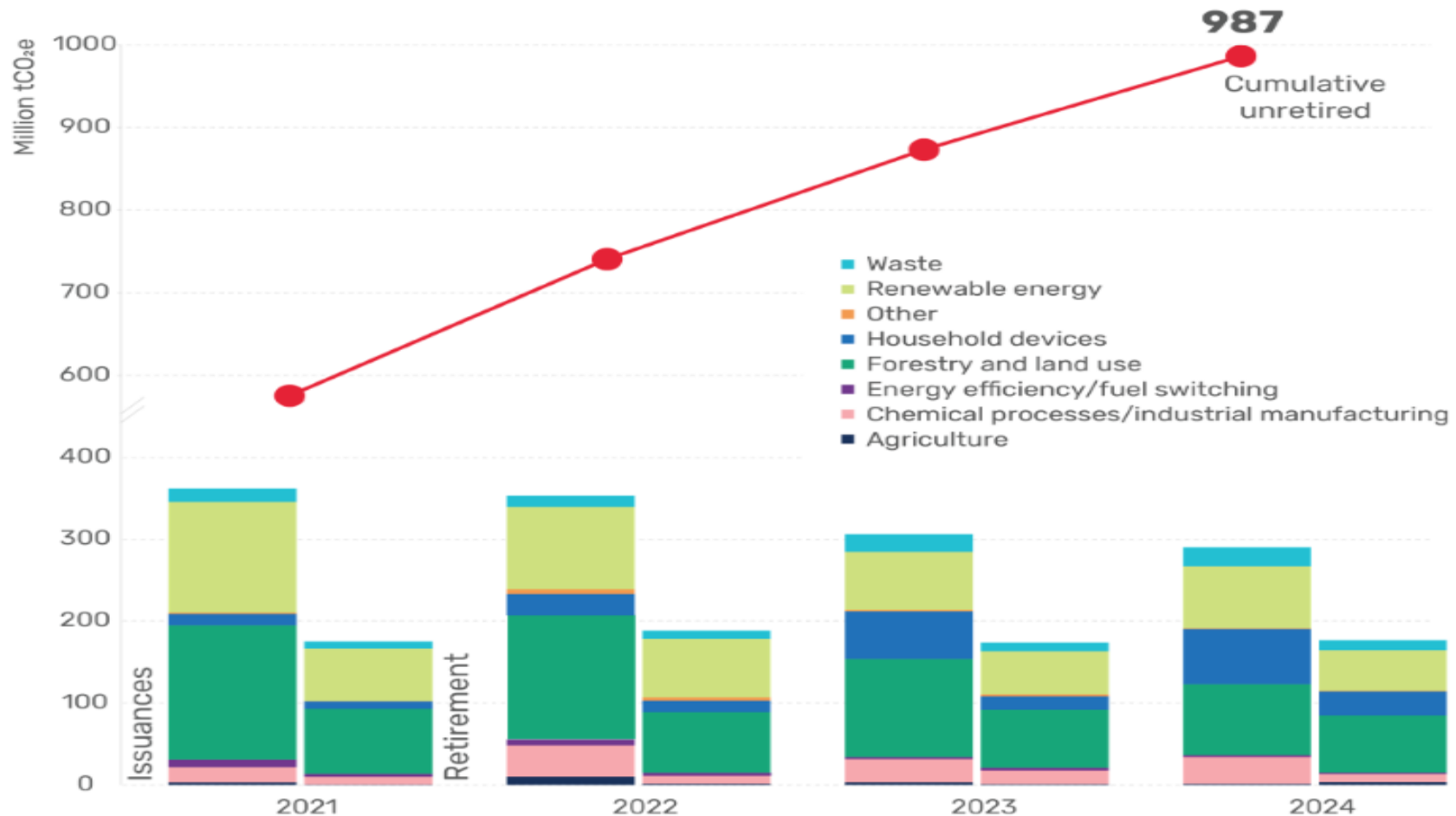


Note: While there is crossover between categories, not all sources of carbon credits are fully fungible across demand segments. For example, international compliance and nationally determined contribution achievement require authorized credits that include a corresponding adjustment.



Carbon Credit Markets

Carbon credit issuances and retirements from independent crediting mechanisms and volume of unretired credits, 2021–2024



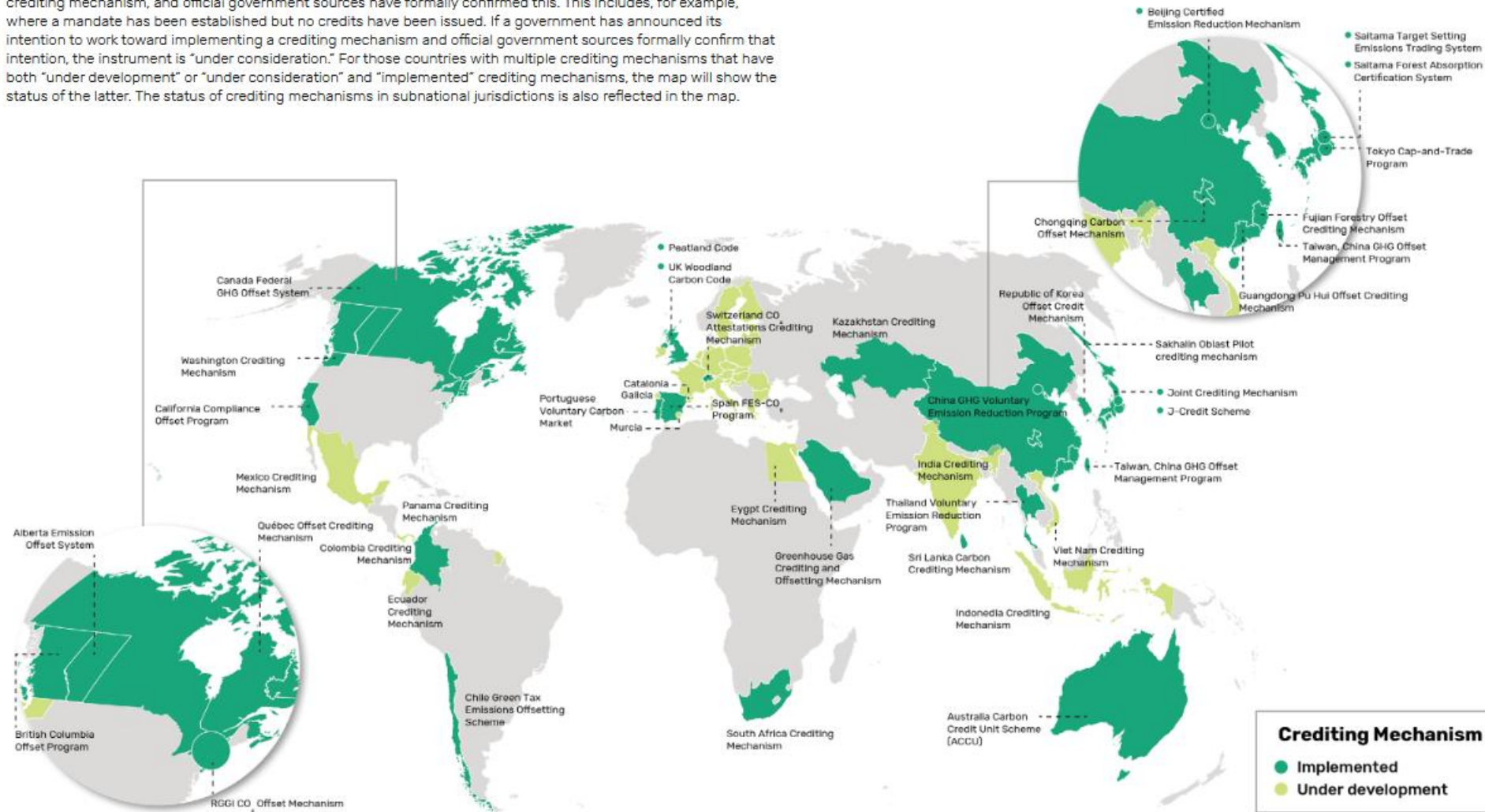
Note: Based on data from Climate Focus's Voluntary Carbon Market Dashboard, using project categorizations based on those published by Ecosystem Marketplace. The volume of issuances and retirements by project category covers the following crediting mechanisms: American Carbon Registry, Architecture for Reducing Emissions from Deforestation and Forest Degradation Transactions, BioCarbon, Cercarbono, Climate Action Reserve, Climate Forward, Gold Standard, Plan Vivo, and Verra's VCS. All issuance and retirement data here refers to original issuances, which only include the first time a credit was issued for a specific emission reduction/removal activity to avoid double counting. Original issuances do not rely on previous issuances from other crediting mechanisms.



Map of government crediting mechanisms 1st April 2025

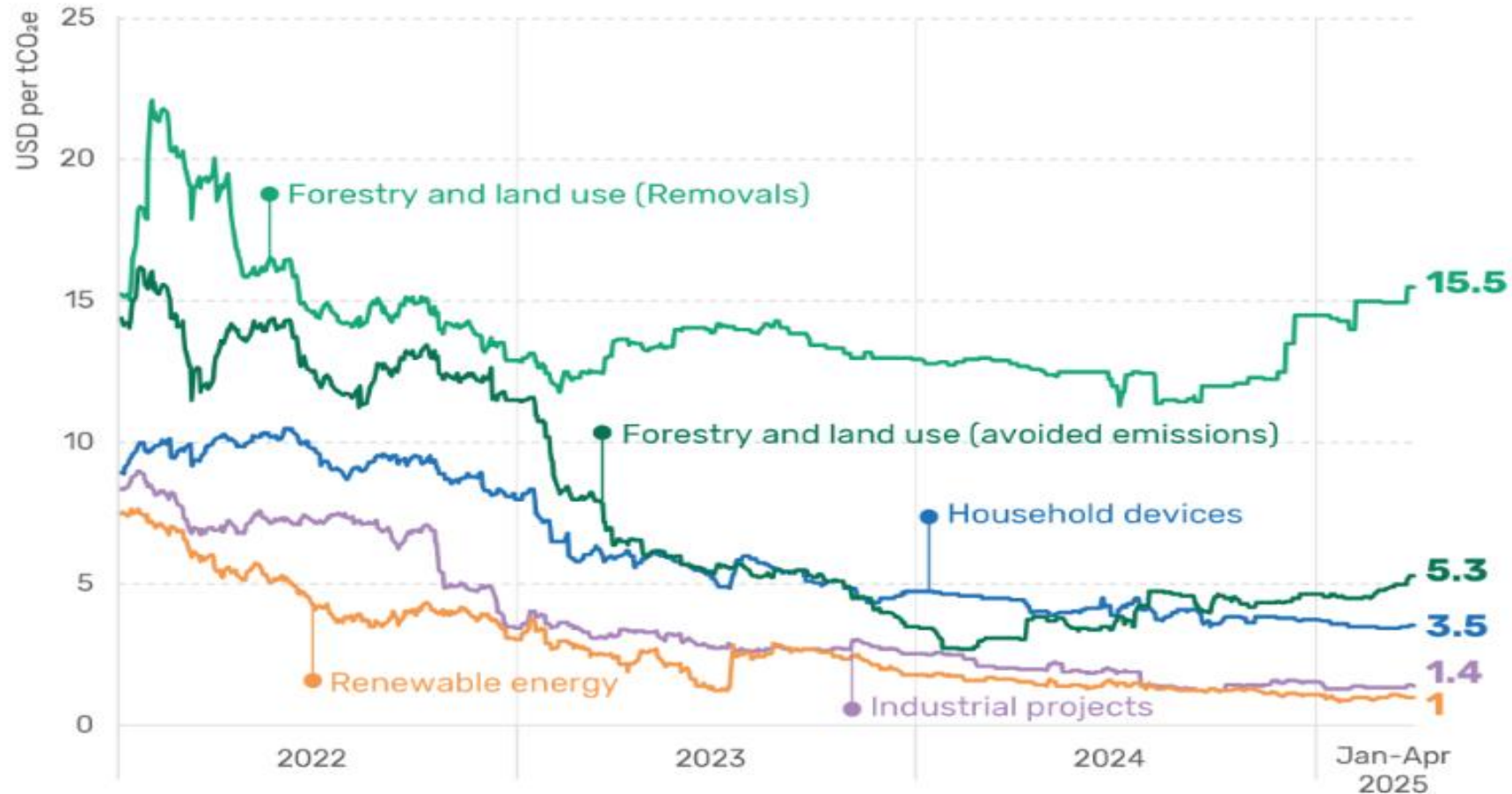
Map of governmental crediting mechanisms as of April 1, 2025

Note: An instrument "under development" means that a government is actively working toward implementing a crediting mechanism, and official government sources have formally confirmed this. This includes, for example, where a mandate has been established but no credits have been issued. If a government has announced its intention to work toward implementing a crediting mechanism and official government sources formally confirm that intention, the instrument is "under consideration." For those countries with multiple crediting mechanisms that have both "under development" or "under consideration" and "implemented" crediting mechanisms, the map will show the status of the latter. The status of crediting mechanisms in subnational jurisdictions is also reflected in the map.



Exchange-traded Carbon Credit Prices 2022 - 2025

Exchange-traded carbon credit prices by project types, January 1, 2022 to April 1, 2025

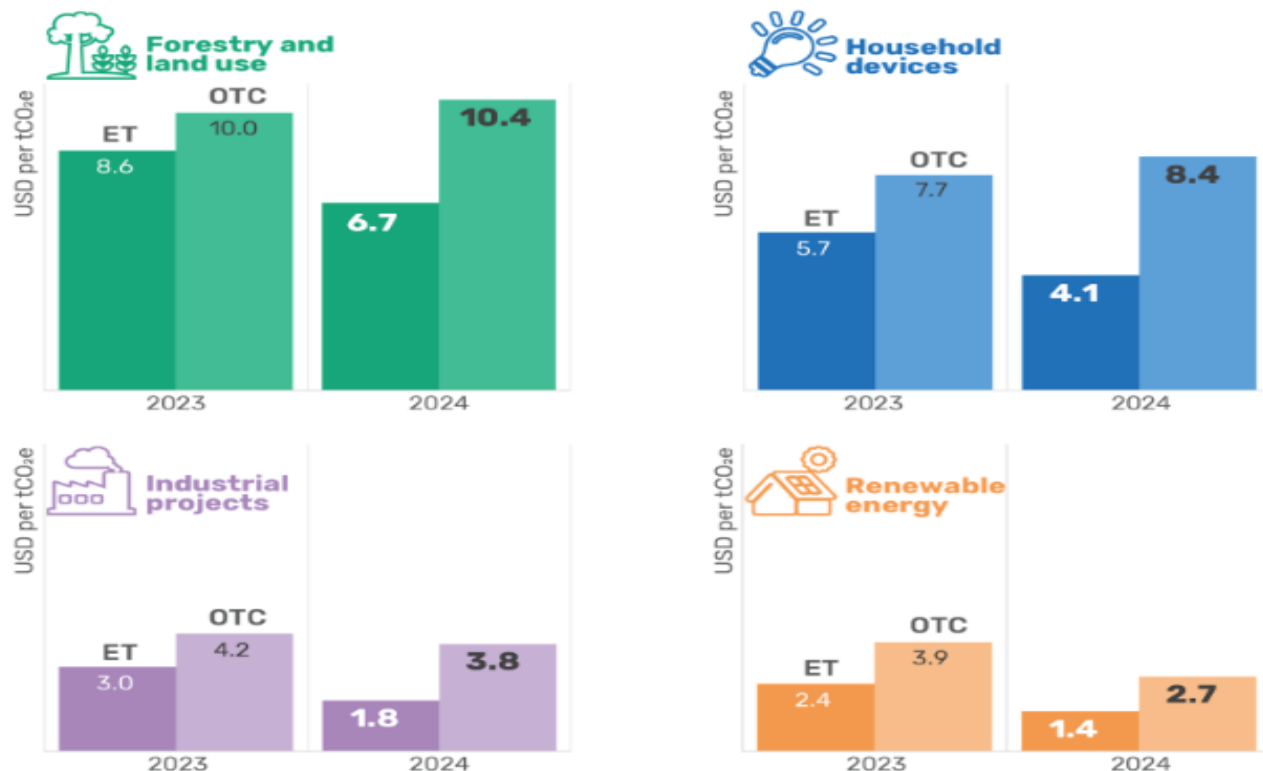


Note: Prices are based on monthly and yearly averages of the price assessments from Platts, S&P Global Commodity Insights (2025), provided by S&P Global.



Exchange-traded Carbon Credit Prices vs Over-The-Counter transactions 2023-2024

Comparison of average annual carbon credit prices from exchange-traded and over-the-counter transactions by project category, 2023–2024



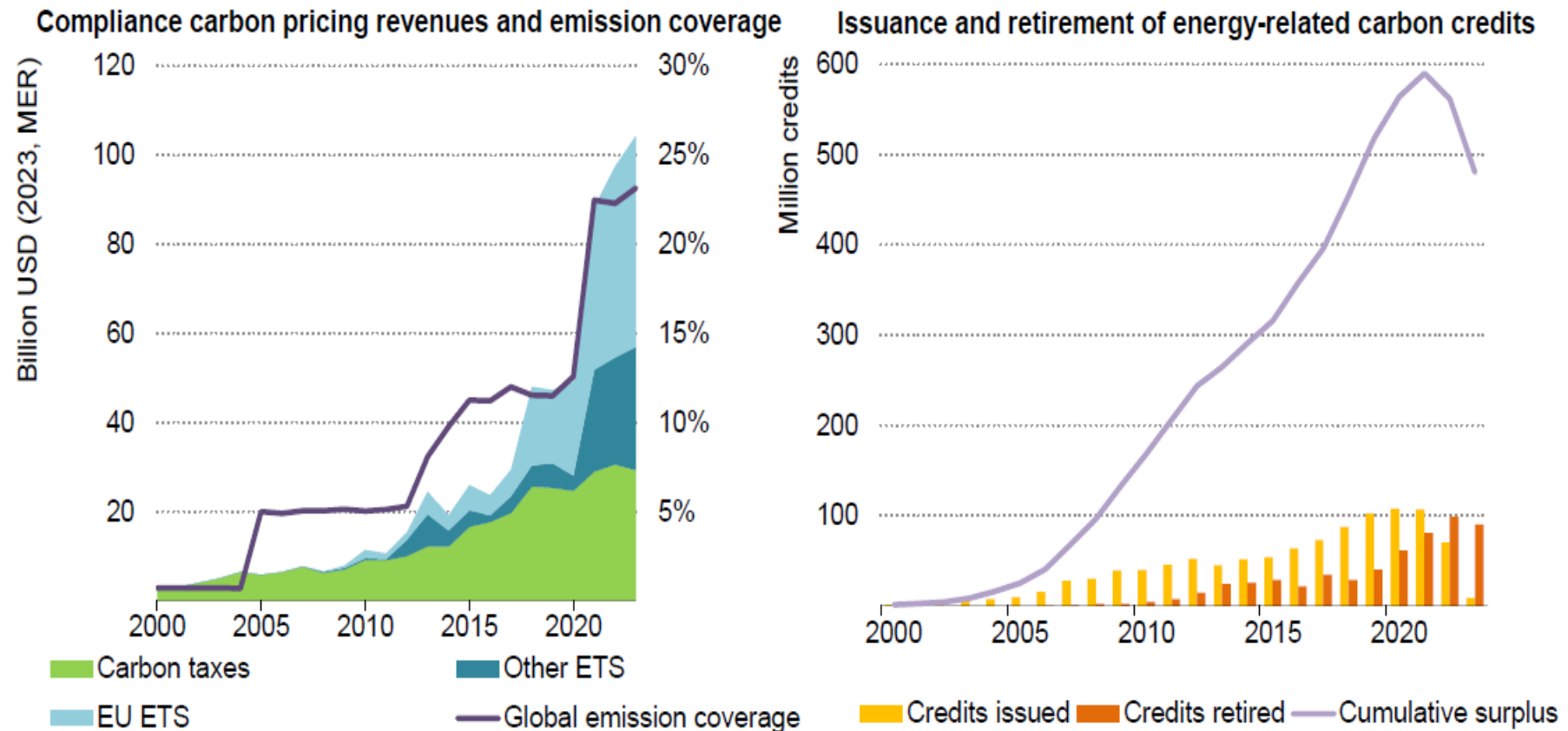
Note: This figure illustrates the exchange-traded and OTC prices of carbon credits. Prices are based on monthly and yearly averages of the price assessments provided by Platts, S&P Global Commodity Insights, 2025. The Platts assessment reflects bids, offers, and trades for credits as reported in the Platts Market on Close assessment process, in the brokered market, or on trading and exchange platforms. For each of its price assessments Platts has identified a reference base to represent fungible credits across each market segment, considering certification, vintage, volume, and the Sustainable Development Goals. For the nature-based projects, a weighted average of Platts nature-based avoidance price and Platts nature-based removals price is used, rather than a singular price assessment. Adjustments are made for credits that vary from this base, normalizing values based on factors like technology, certification standards, geography, and additional benefits to align them with the market value of the reference base. OTC prices were provided by Ecosystem Marketplace and updated as of February 26, 2025. OTC prices represent volume-weighted yearly averages of carbon credit trades in the voluntary carbon markets. Discrepancies may exist in project categorizations between the exchange-traded and OTC data due to different source methodologies. See Annex C, Definitions, for a detailed note on the carbon credit categorizations used in this figure. Details on Platts's assessments can be found in the Platts' Specification Guide.



Carbon Pricing in 2024



Carbon Pricing, Emission coverage & Carbon credits



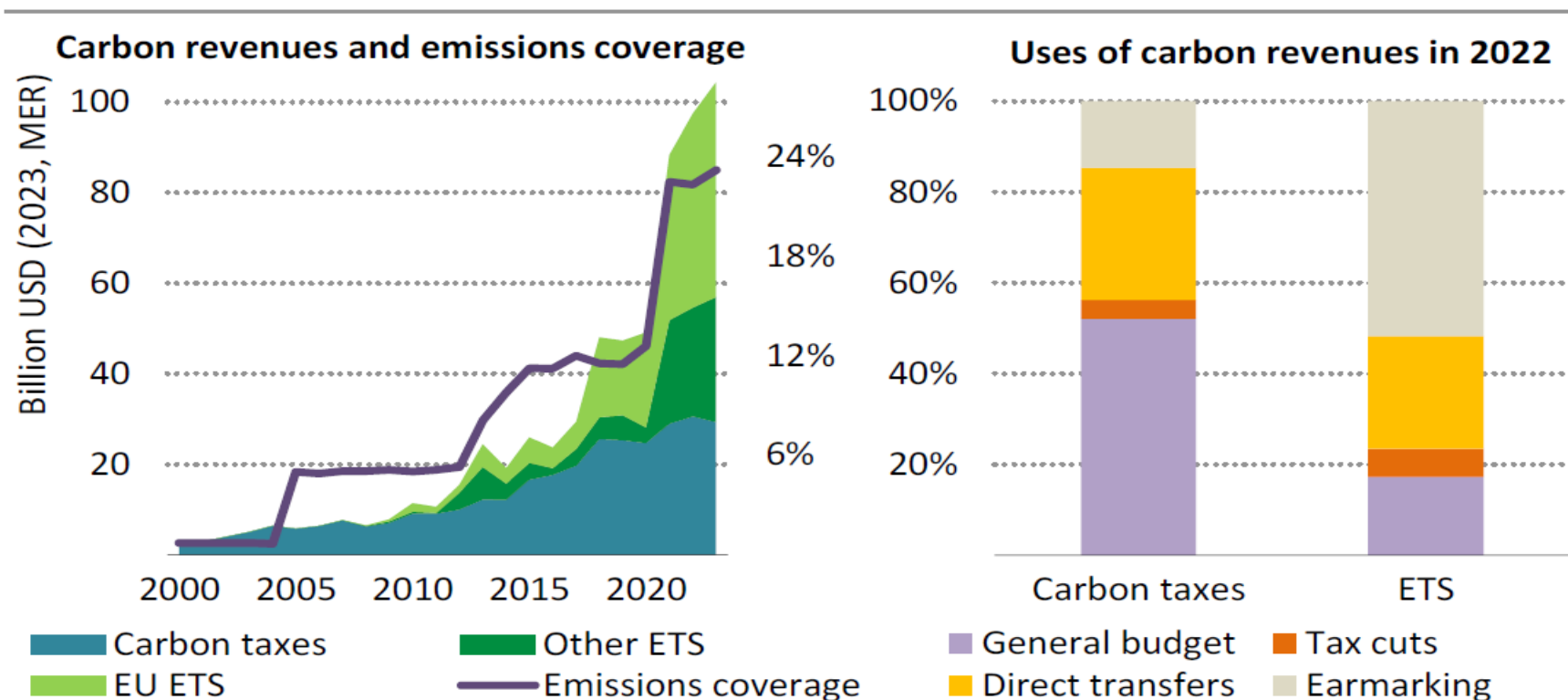
IEA. CC BY 4.0

Note: Data on carbon credits relates to the following voluntary carbon markets registries: American Carbon Registry, Climate Action Reserve, Gold Standard, Verra's Verified Carbon Standard, California Air Resources Board, Washington State Climate Commitment Act. The categories considered under energy-related carbon credits are: renewable energy, industry, transport, energy efficiency, carbon capture and storage. ETS = Emissions Trading System.

Source: IEA analysis based on data from the [World Bank](#), and [Berkeley](#), 2024 .



Carbon Pricing, Emission coverage & Use of Carbon Revenues



IEA. CC BY 4.0.

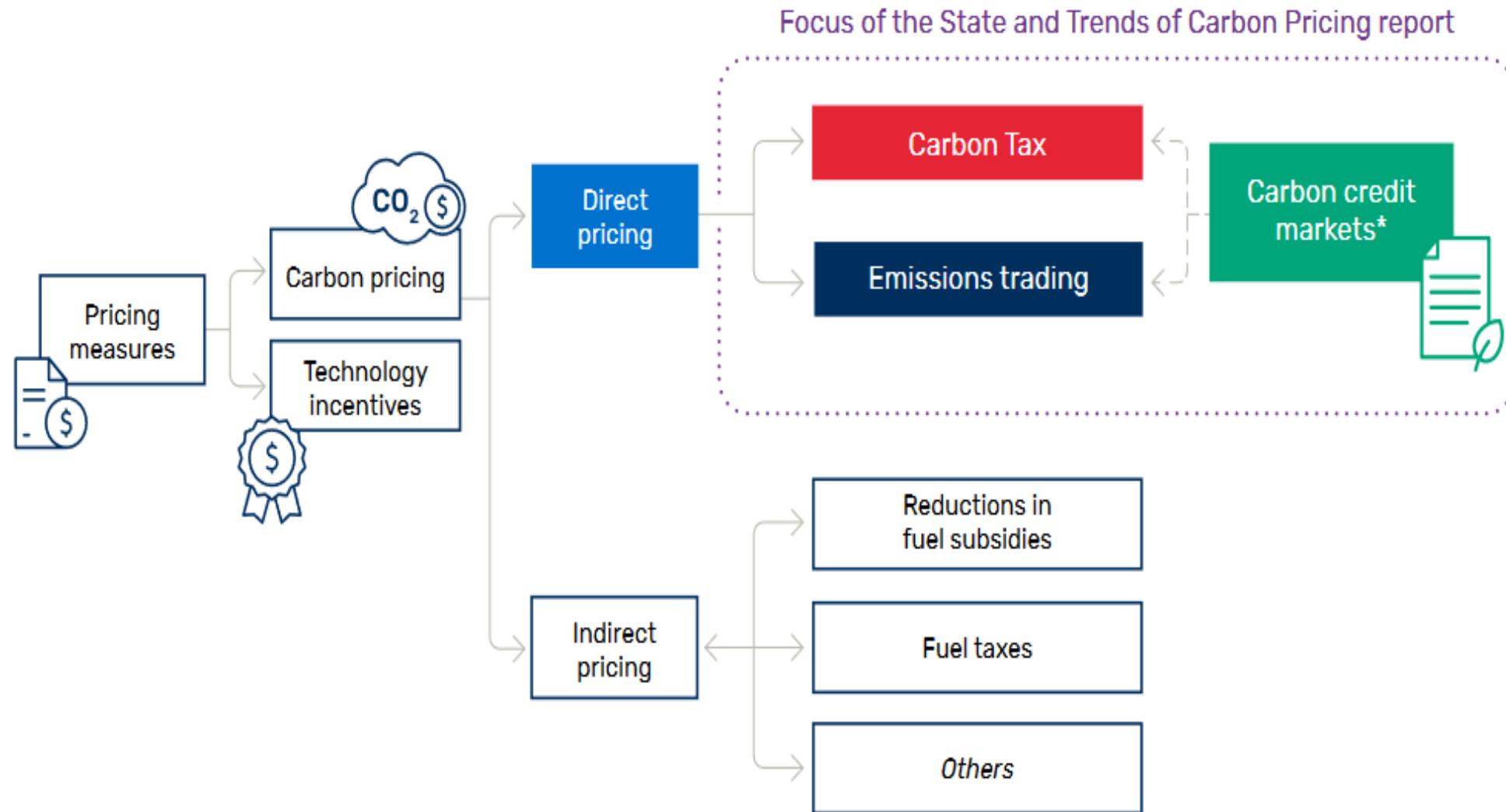
ETSs generated 70% of revenues from carbon pricing in 2022. Half of ETS revenue was earmarked for specific uses; the corresponding figure for carbon taxes was less than 20%

Sources: ETS = emissions trading system. IEA analysis based on World Bank (2024a) and I4CE (2023).

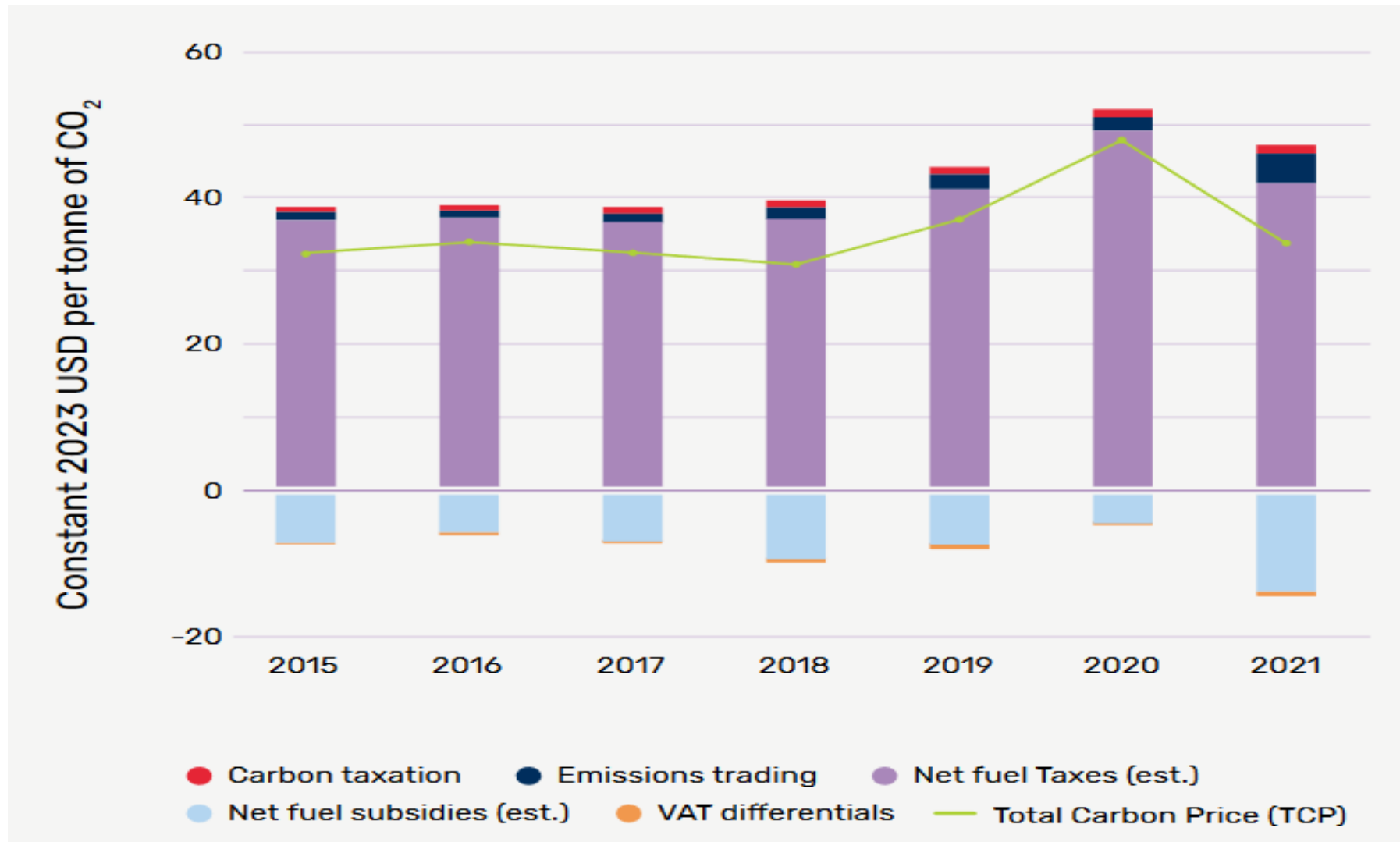
Source: IEA Strategies for Affordable and Fair Clean Energy Transition - June 2024



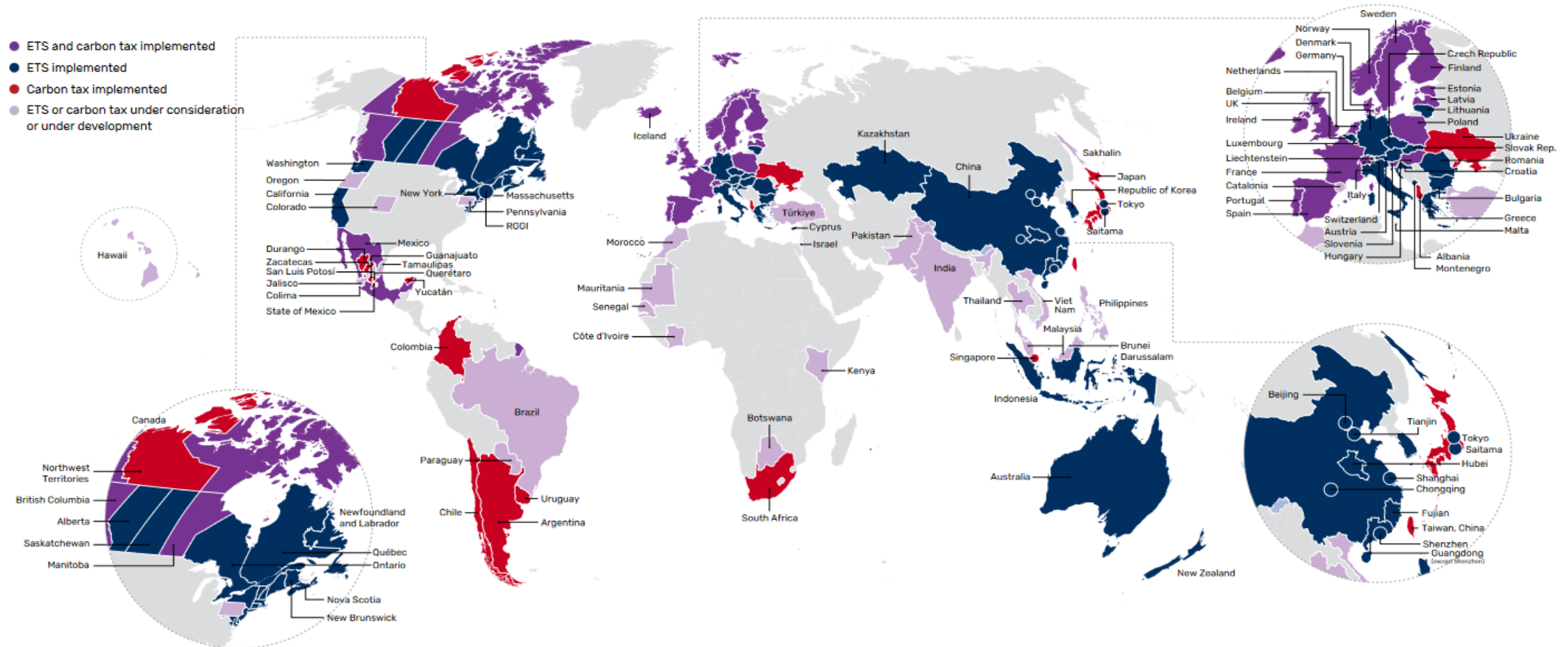
Pricing Policy Ecosystem



Global total Carbon Price 2015 – 2021 (\$2023)



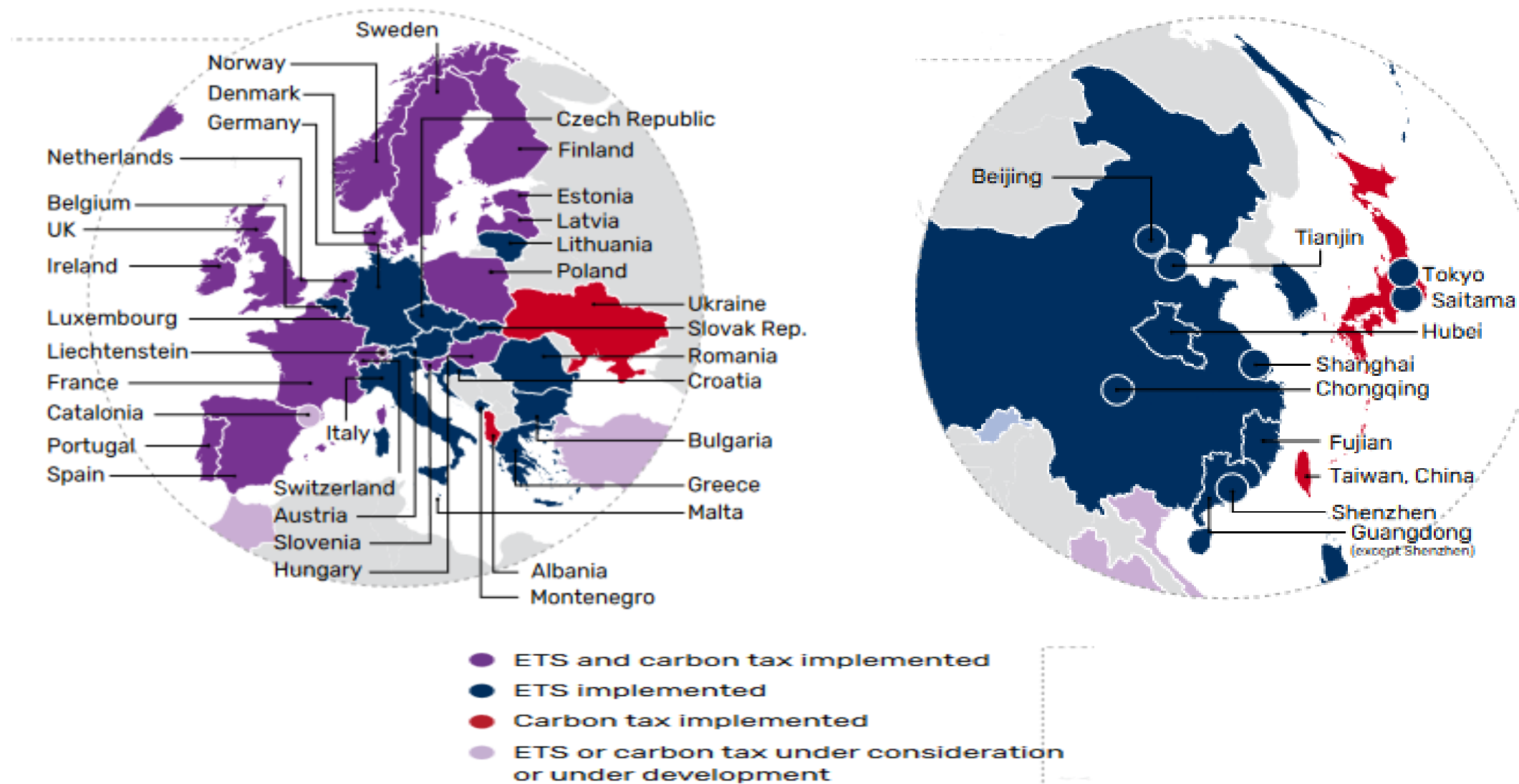
Map of Carbon Tax & ETS



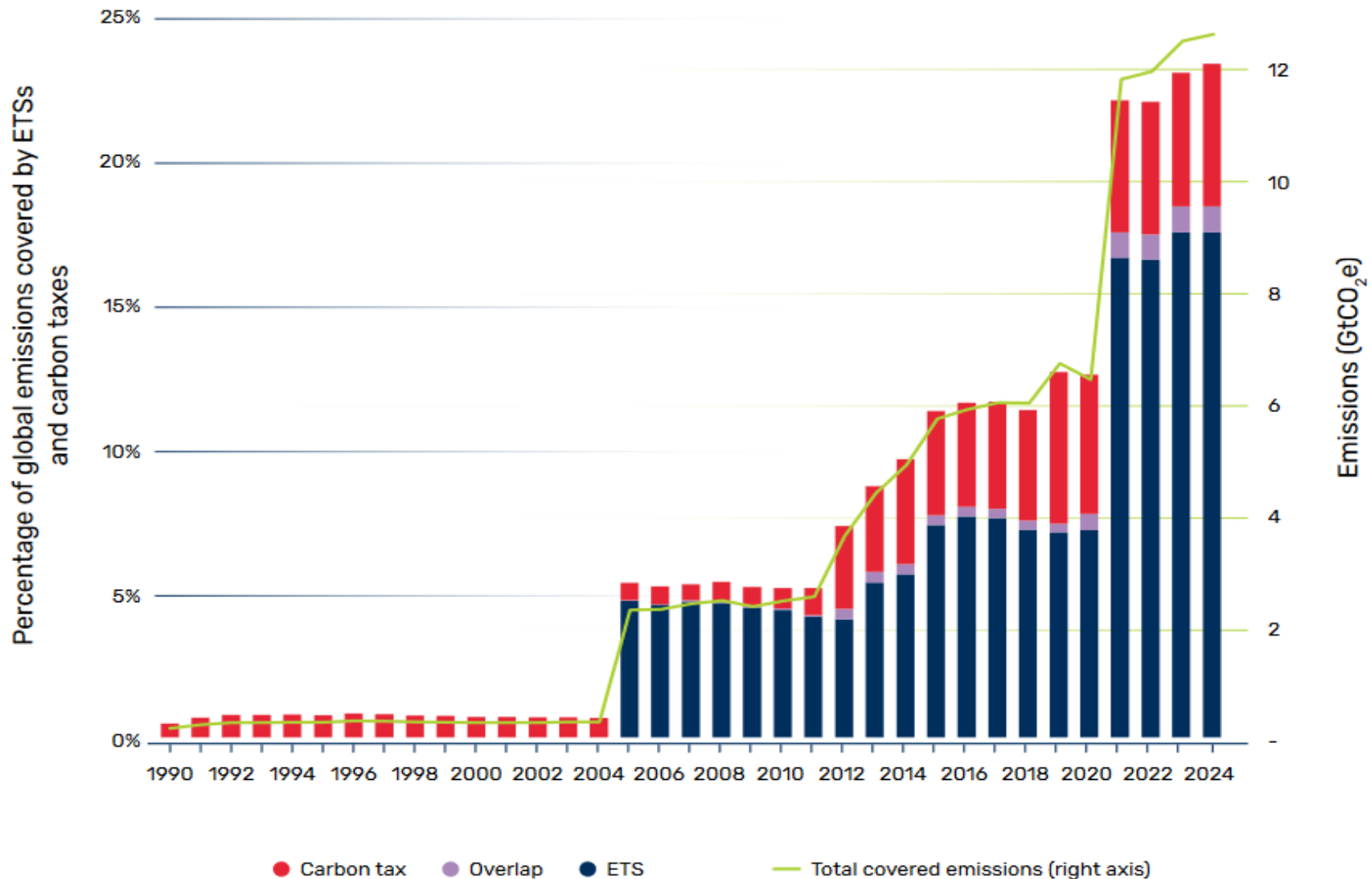
Instruments "under development" are where a government is actively working toward the implementation of a carbon pricing instrument and this has been formally confirmed by official government sources. This includes, for example, where a mandate has been established, but regulated entities do not yet face compliance obligations. If a government has announced its intention to work toward the implementation of a carbon pricing instrument and official government sources formally confirm that intention, the instrument is "under consideration." For those countries with multiple instruments that have both "under development" or "under consideration" and "implemented" instruments, the map will show the status of the latter. The status of instruments in subnational jurisdictions is also reflected in the map.



Map of Carbon Tax & ETS – A Zoom on Europe & Asia

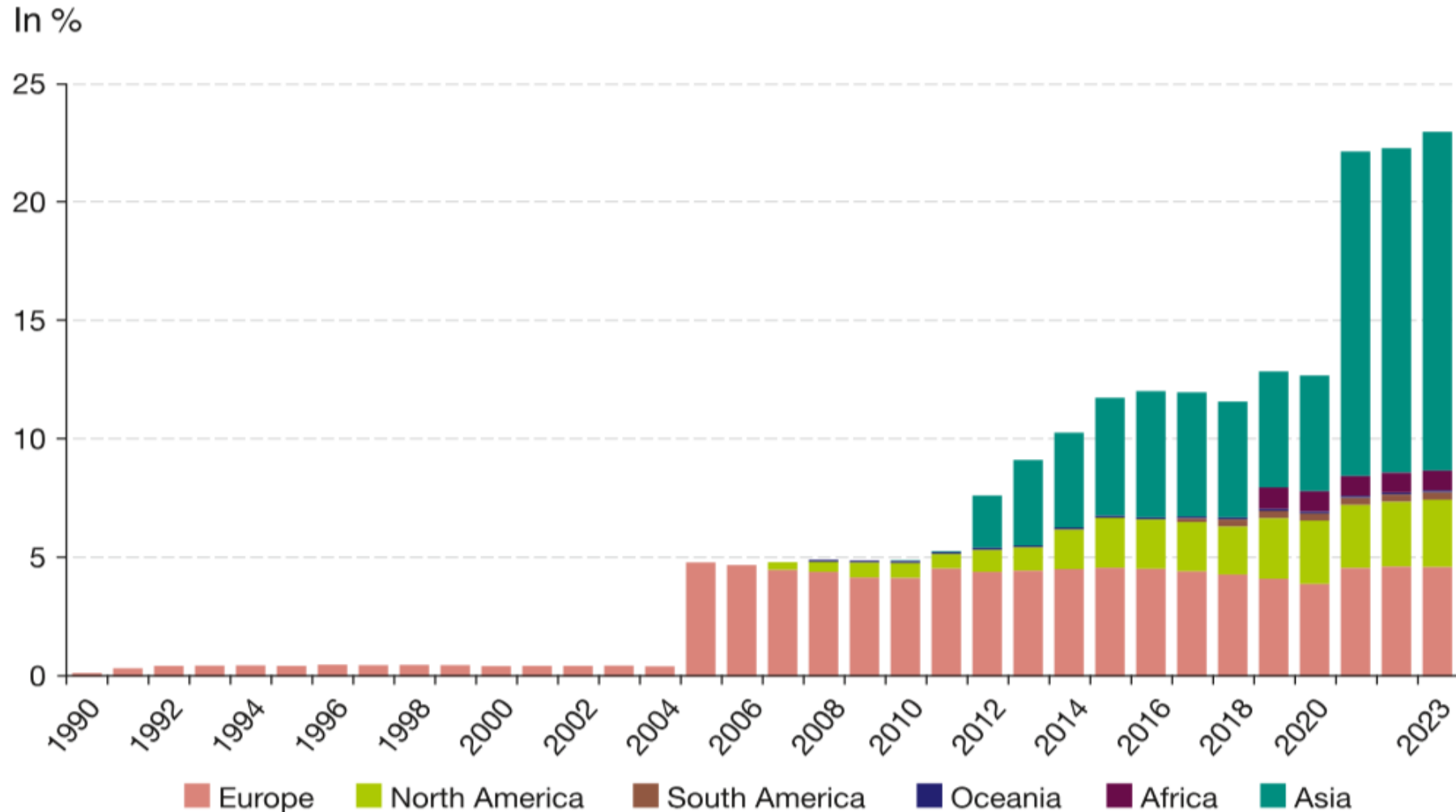


Global Emissions Coverage

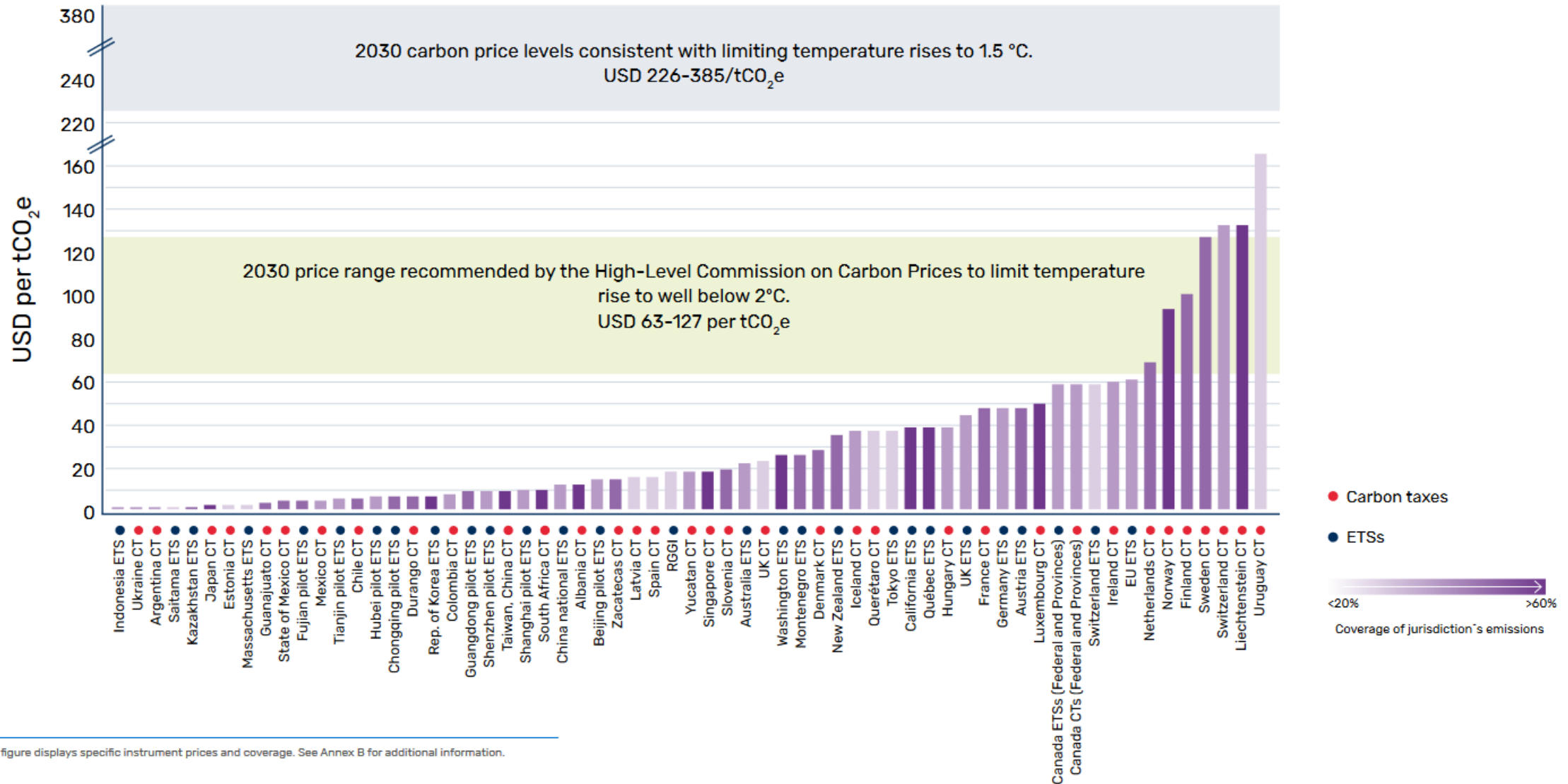


Global Emissions Coverage

EVOLUTION OF THE SHARE OF GLOBAL GHG EMISSIONS COVERED BY A CARBON PRICING INSTRUMENT

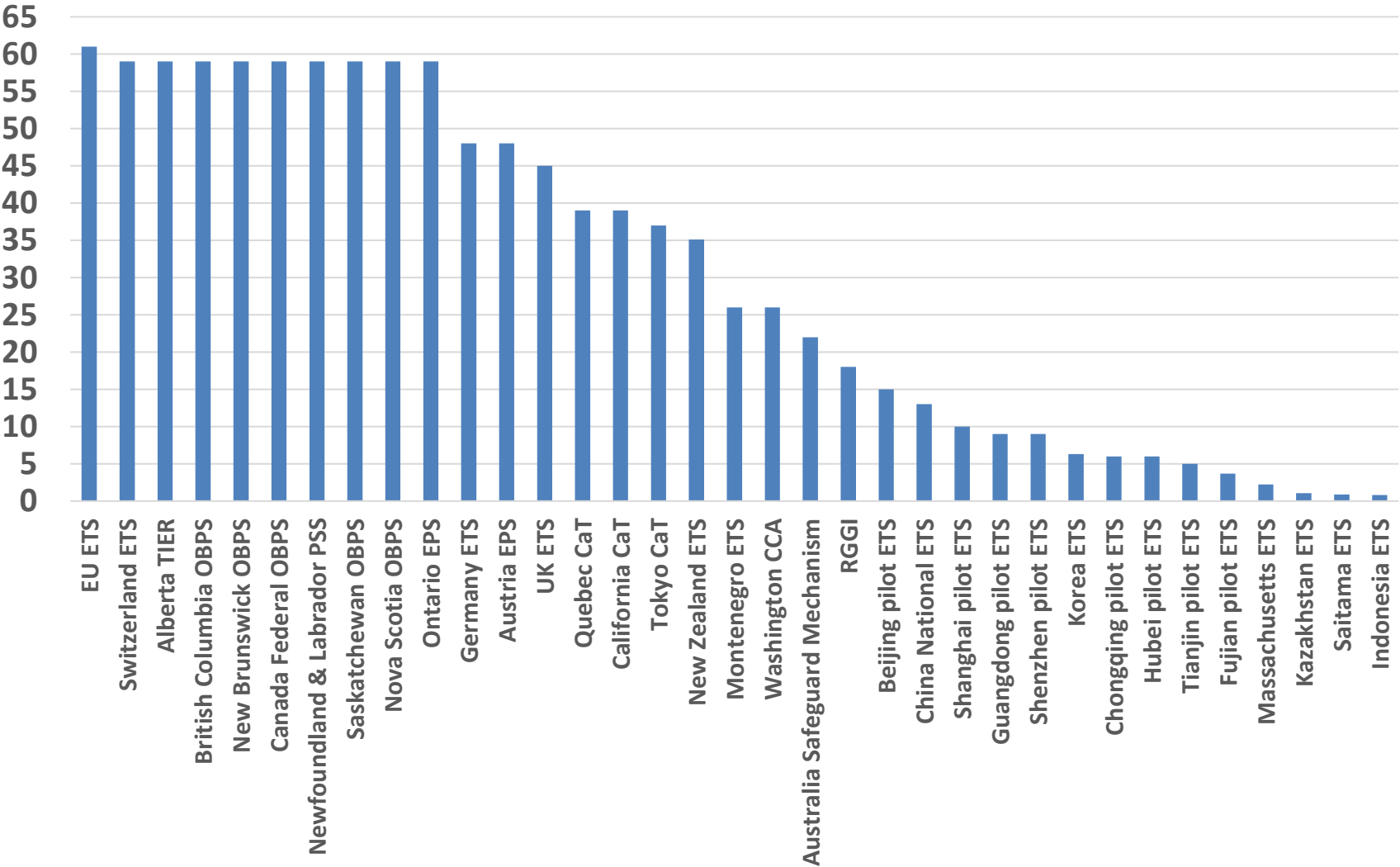


Carbon Price needed to limit Temperature increase



Carbon Price for existing ETS – 2024

(\$/tCO2)

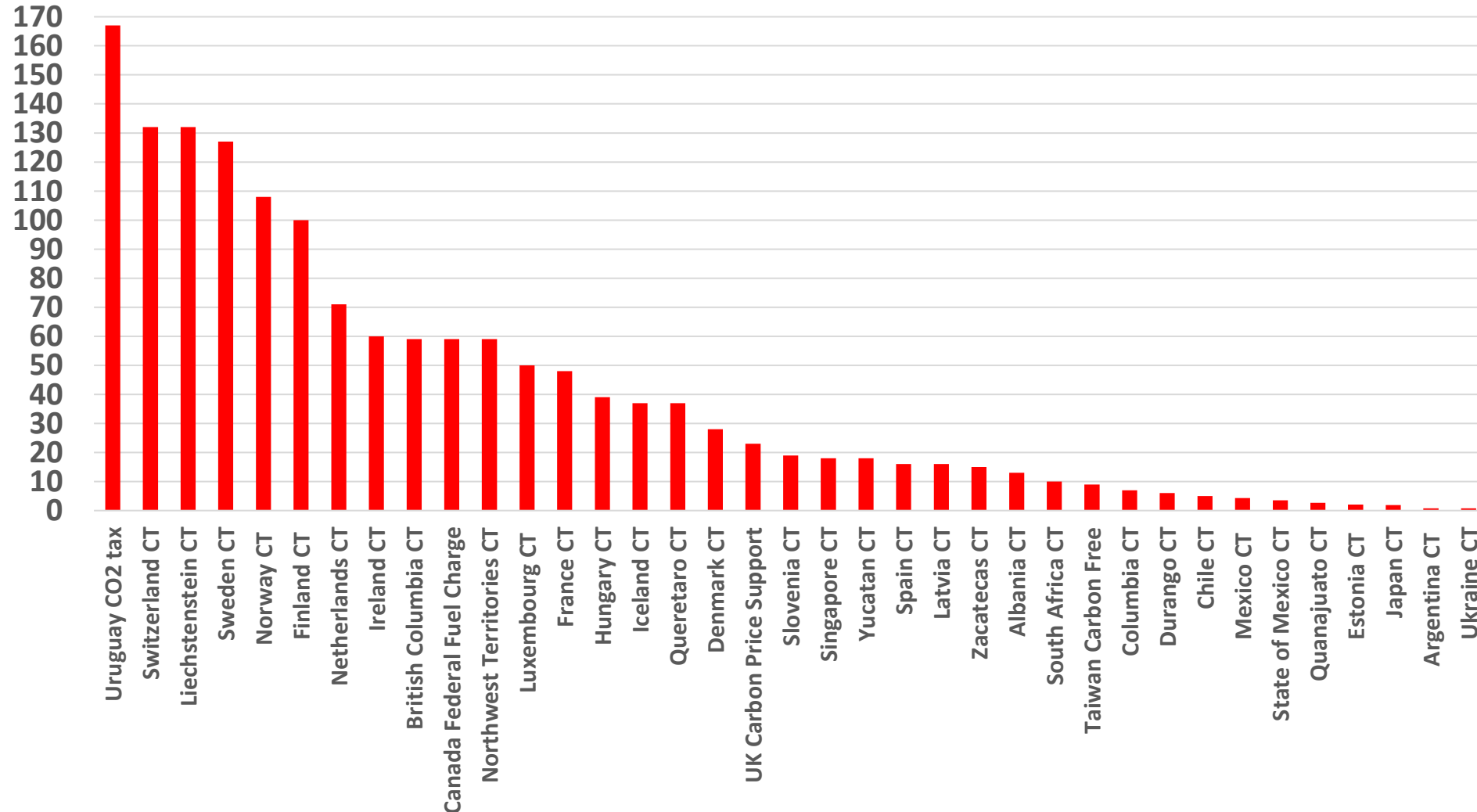


Data from World Bank
State & Trends in Carbon Pricing 2024



Carbon Price for existing CT Systems - 2024

(\$/tCO₂)

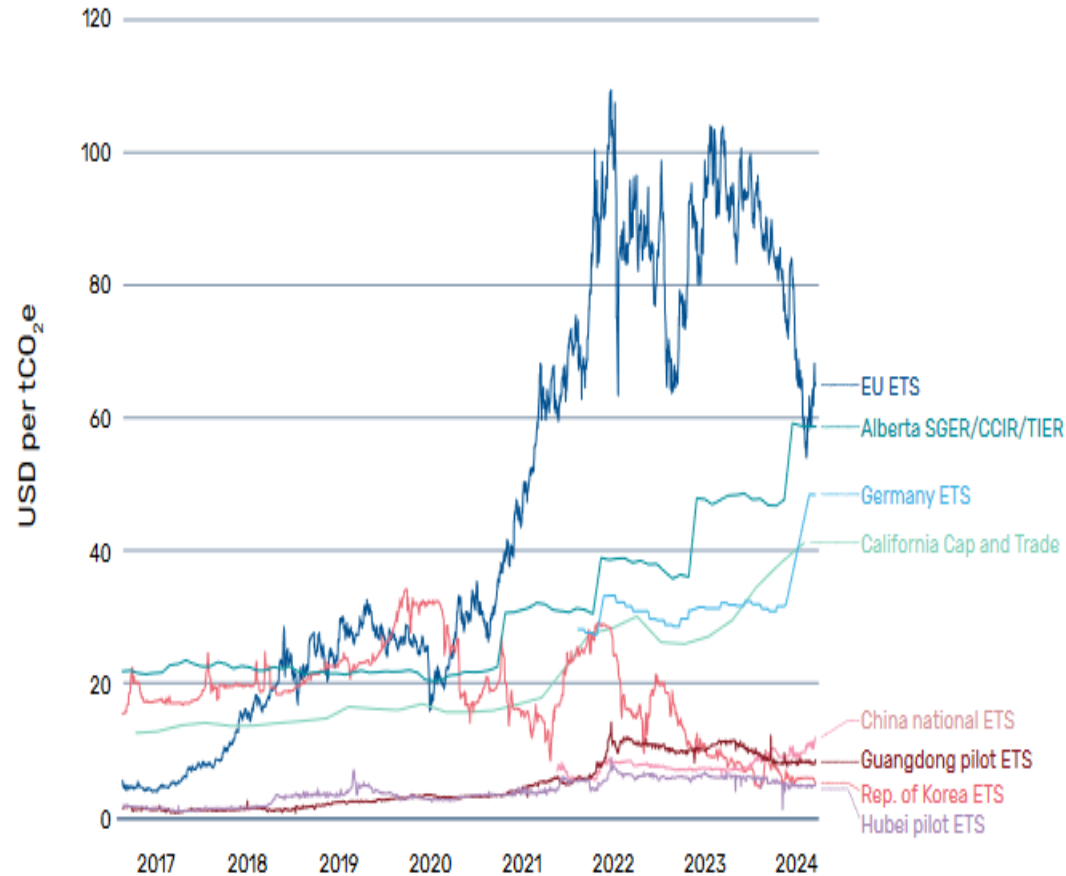


Data from World Bank
State & Trends in Carbon Pricing 2024

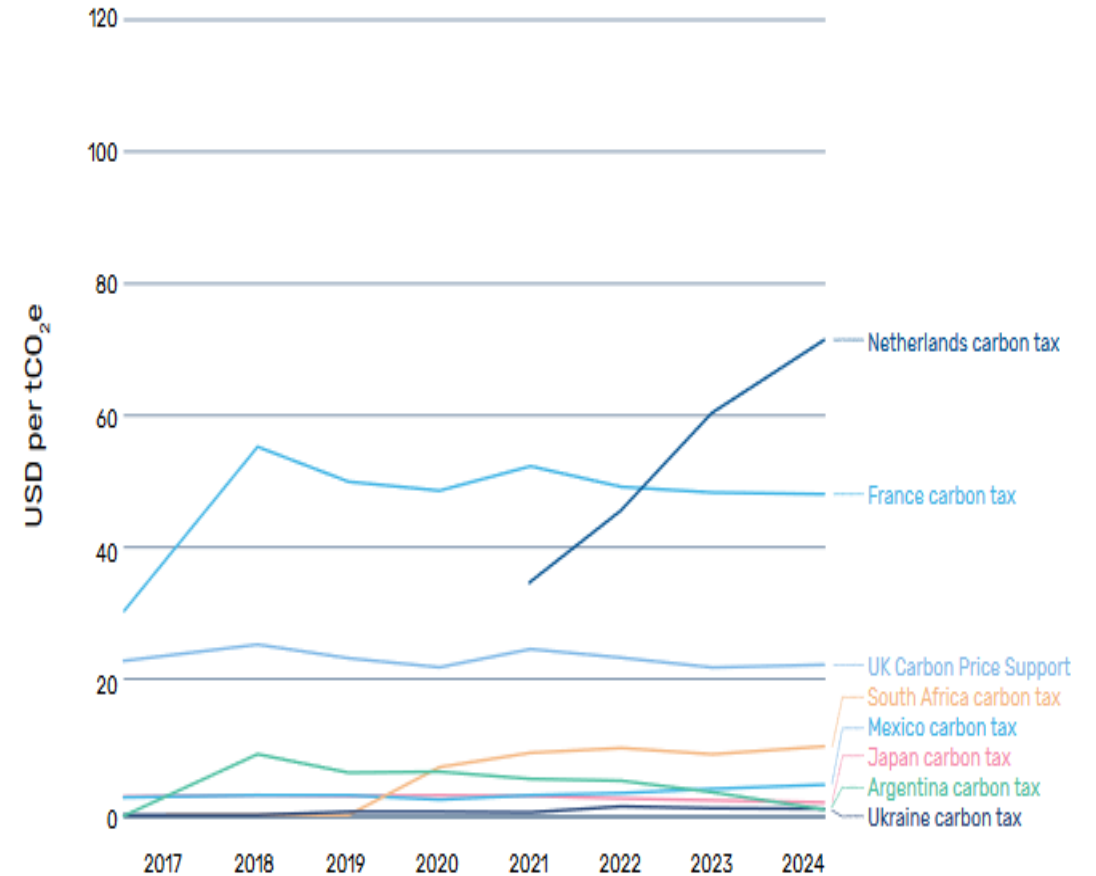


Nominal Prices in the largest ETS & CT 2017 - 2024

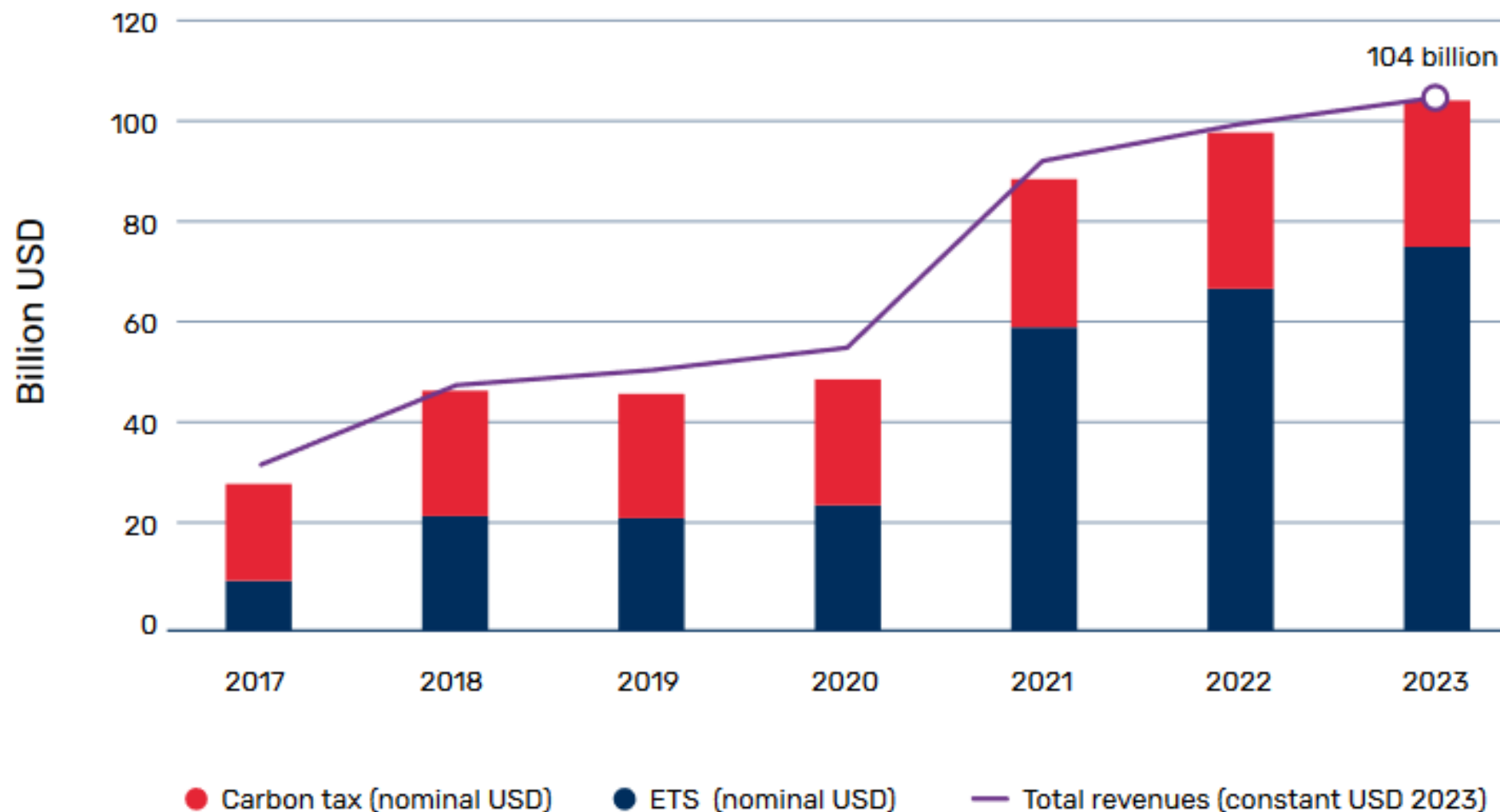
Emissions trading systems



Carbon taxes



Global Revenues for jurisdictions for ETS & CT 2017 - 2023



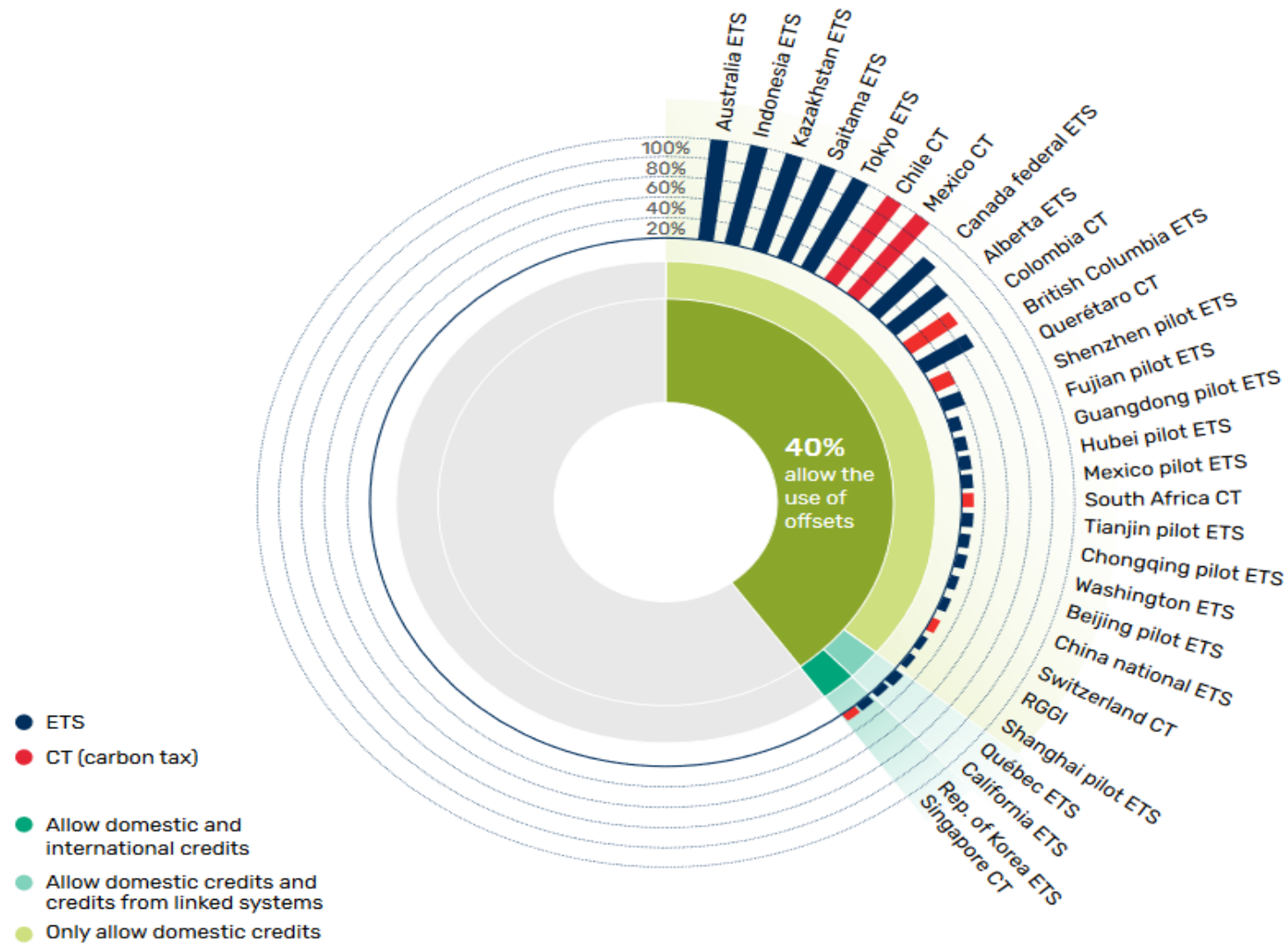
Carbon Crediting Mechanism

Carbon Crediting Mechanism

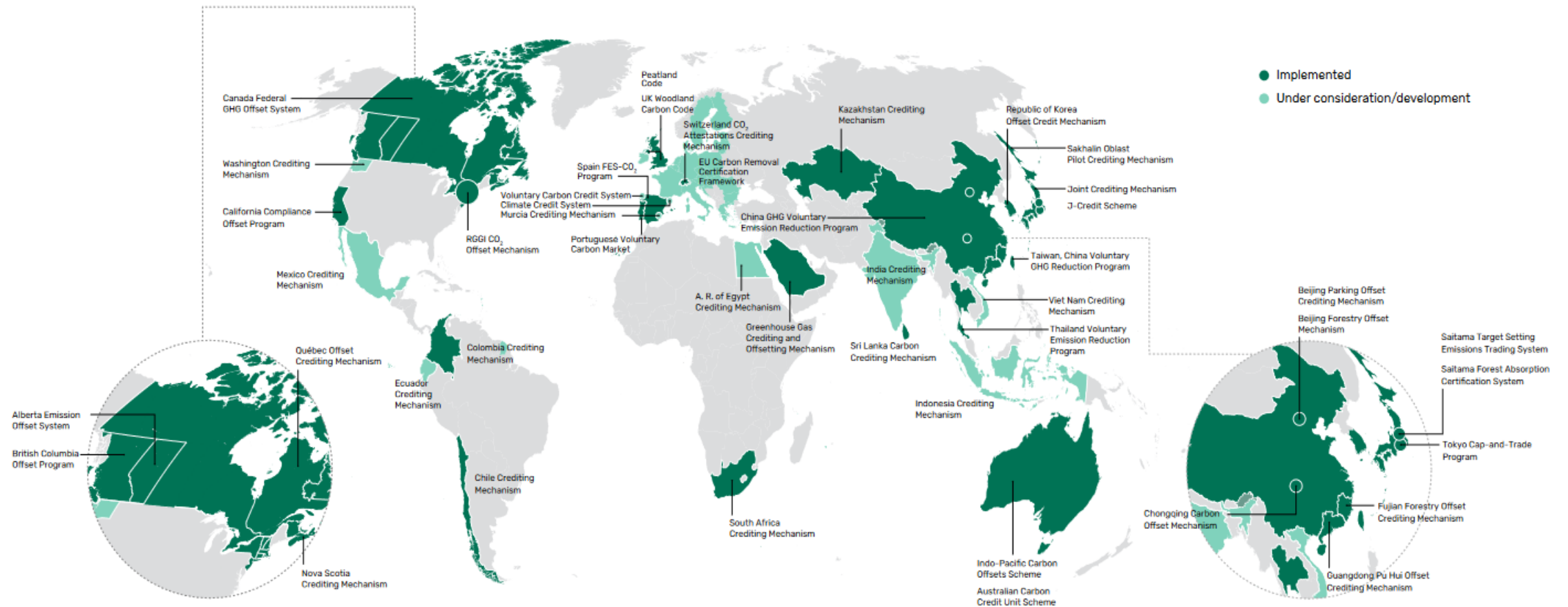
Under a **Carbon Crediting Mechanism**, tradable credits (representing 1 tCO₂e) are generated through voluntary emissions reduction activities. Carbon credits are issued to activities that reduce emissions, according to protocols that aim to ensure each credit represents a genuine emission reduction. Credits can then be sold to buyers, generating revenue. Carbon credits can represent emissions reductions achieved through either avoidance (preventing GHG emissions from entering the atmosphere—like capturing methane from landfills before it is released), or removal (taking GHGs from the atmosphere, for example through sequestering carbon through afforestation). While carbon crediting mechanisms create a source of supply, they rely on a separate source of demand for credits in order to deliver a financial incentive to reduce emissions. Demand for credits can come from compliance instruments (ETSs or carbon taxes that allow the use of offsets), countries meeting Nationally Determined Contribution targets under the UNFCCC, voluntary offsetting (sometimes linked to internal carbon pricing), or results-based climate finance.



Carbon Credits used in ETS & CT in 2023



Map of Governmental Crediting Mechanisms



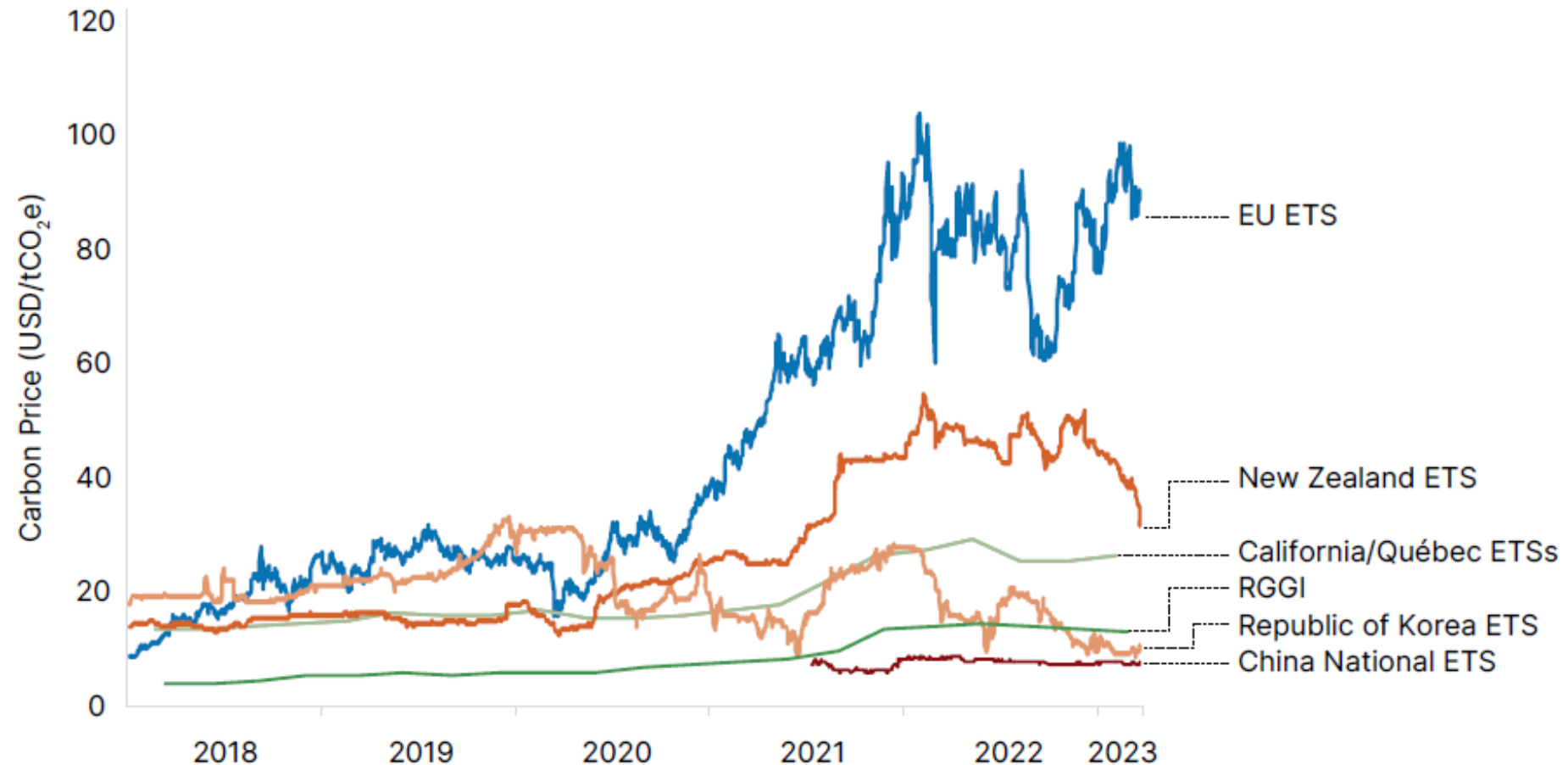
An instrument "under development" means that a government is actively working towards the implementation of a crediting mechanism, and this has been formally confirmed by official government sources. This includes, for example, where a mandate has been established but no credits have been issued. If a government has announced its intention to work toward the implementation of a crediting mechanism and official government sources formally confirm that intention, the instrument is "under consideration." For those countries with multiple crediting mechanisms that have both "under development" or "under consideration" and "implemented" crediting mechanisms, the map will show the status of the latter. The status of crediting mechanisms in subnational jurisdictions is also reflected in the map.



Carbon Pricing in 2023



Price evolution of selected ETS 2018 - 2023



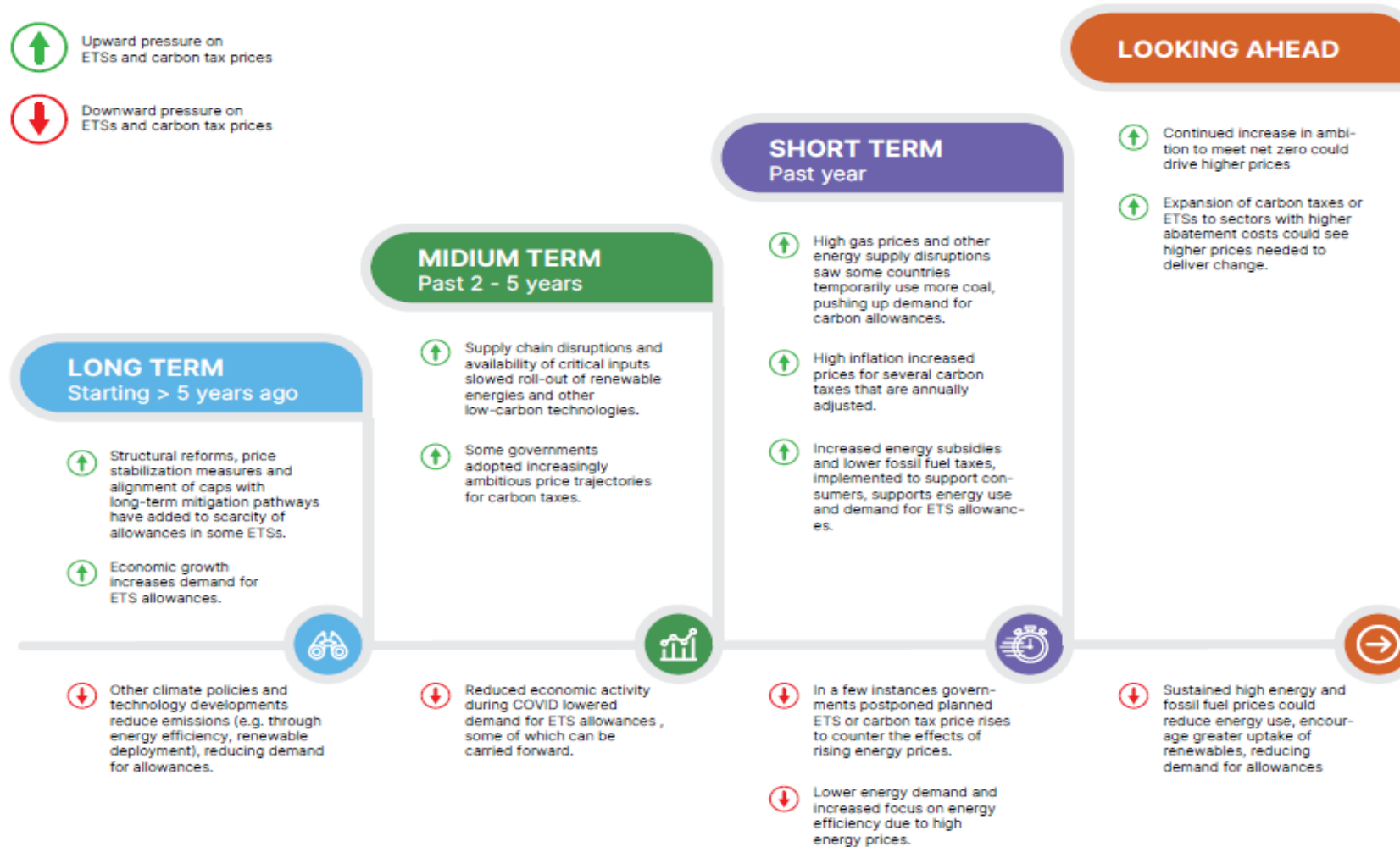
Note: Based on data from ICAP Allowance Price Explorer. Prices for the RGGI Initiative and for California and Québec CaT, come from the primary market, whereas for the other systems the prices reflect the secondary market

Source: World Bank State & Trends in Carbon Pricing 2023

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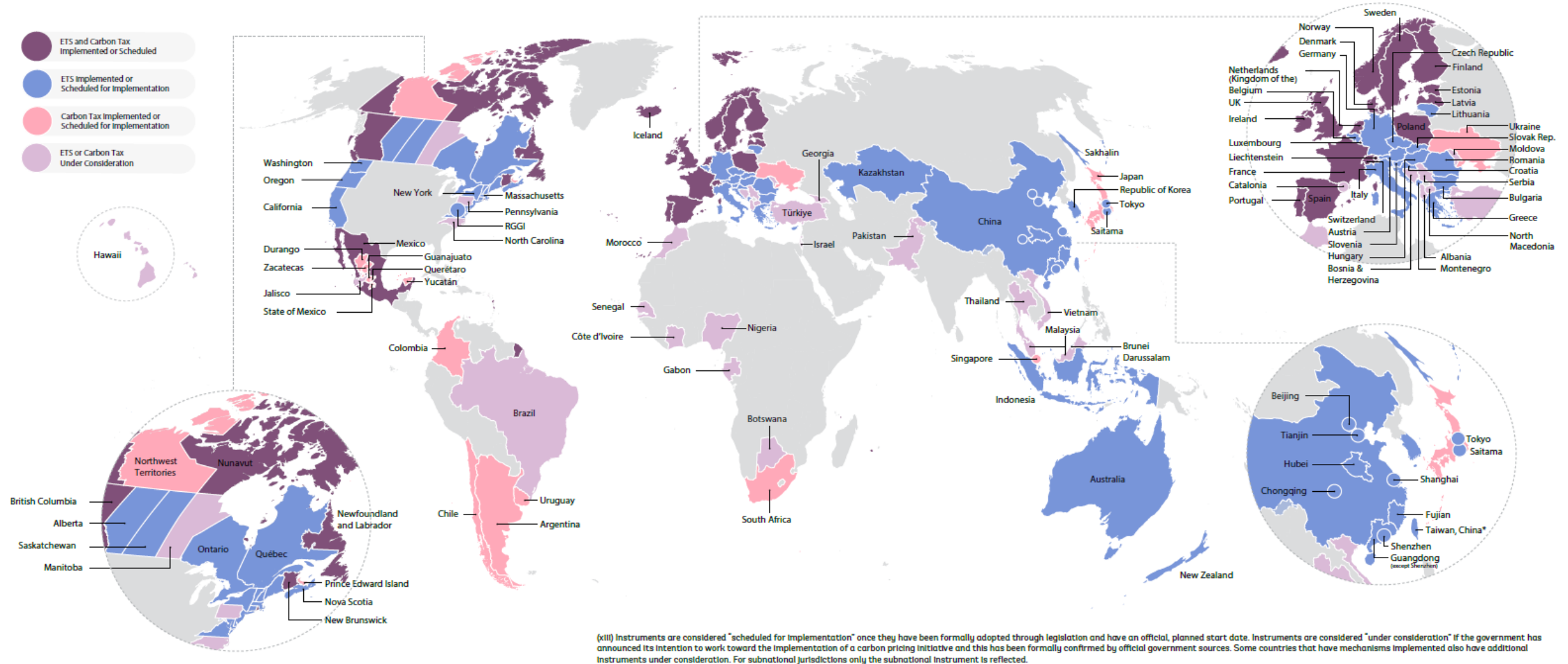
Key drivers of recent evolution for ETS & CT systems



Source: World Bank State & Trends in Carbon Pricing 2023



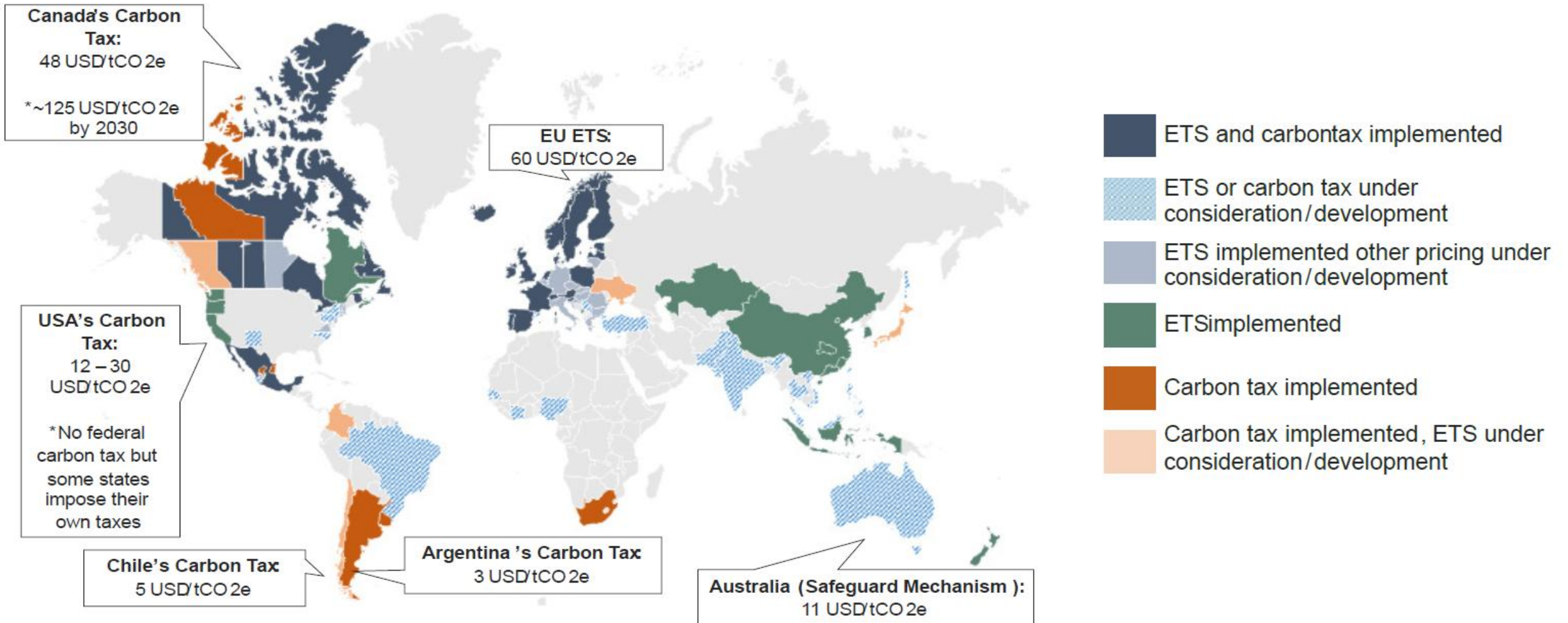
Map of ETS & CT systems



Source: World Bank State & Trends in Carbon Pricing 2023



Map of ETS & CT systems

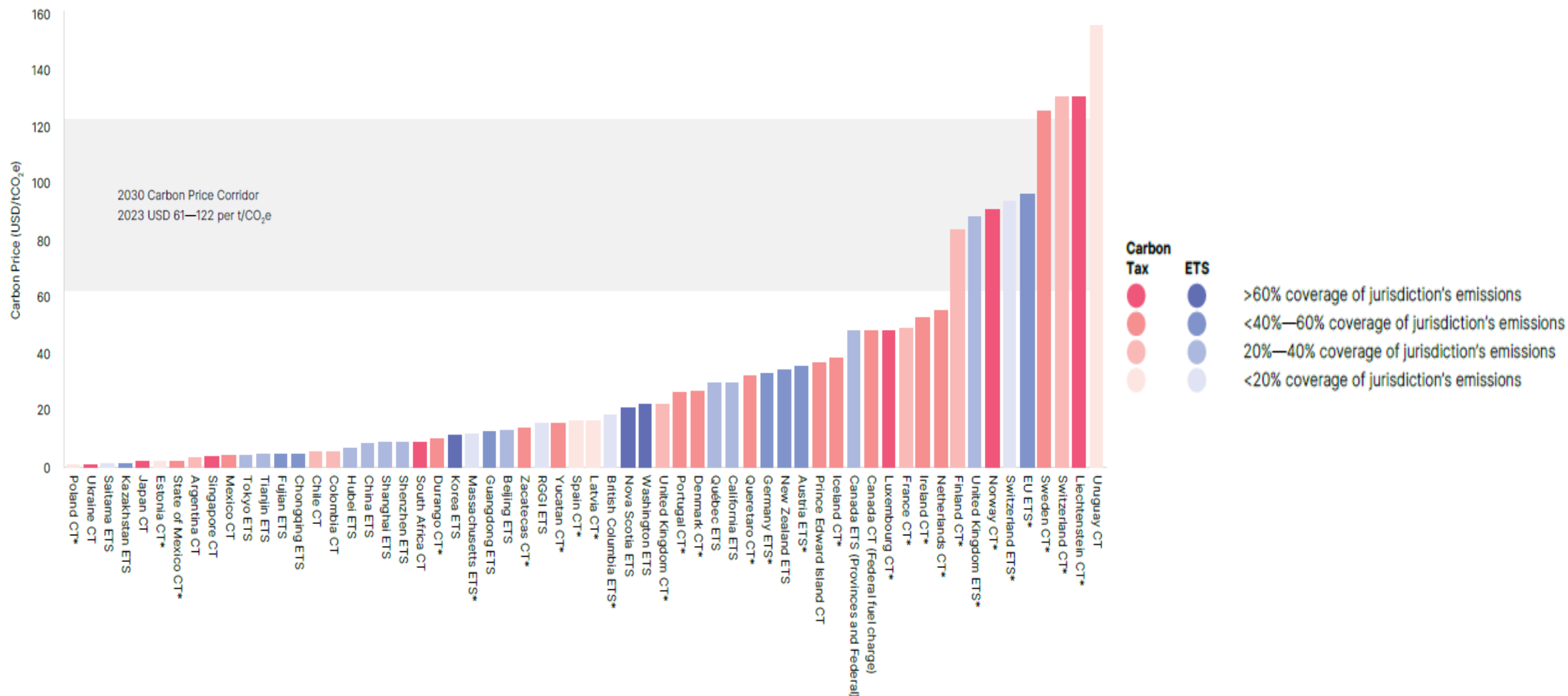


Source: Rystad Energy; World Bank

Source: International Gas Union (IGU) Global Gas Report 2023/Rystad Energy



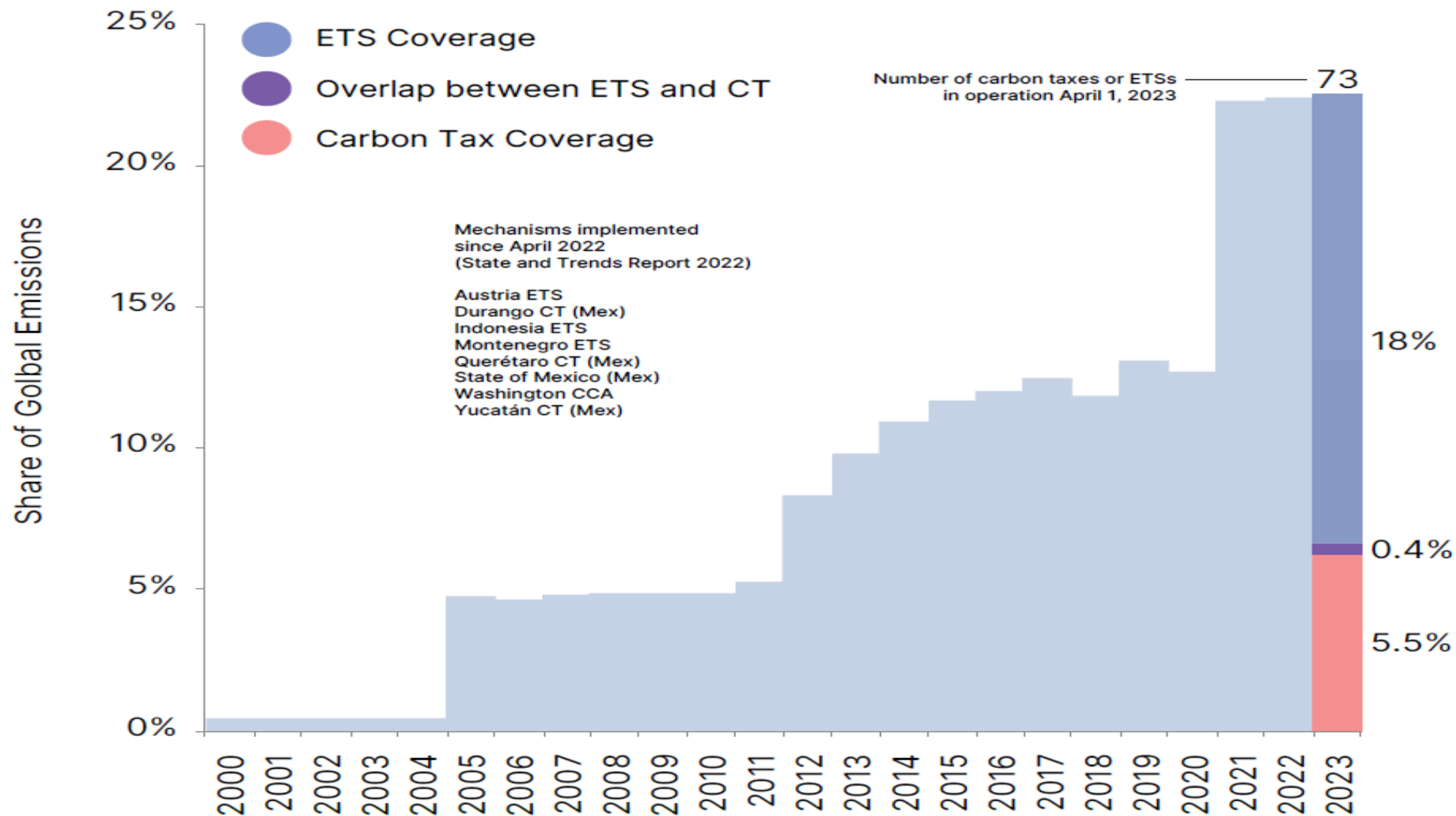
Carbon Prices for ETS & CT systems - April 2023



Source: World Bank State & Trends in Carbon Pricing 2023



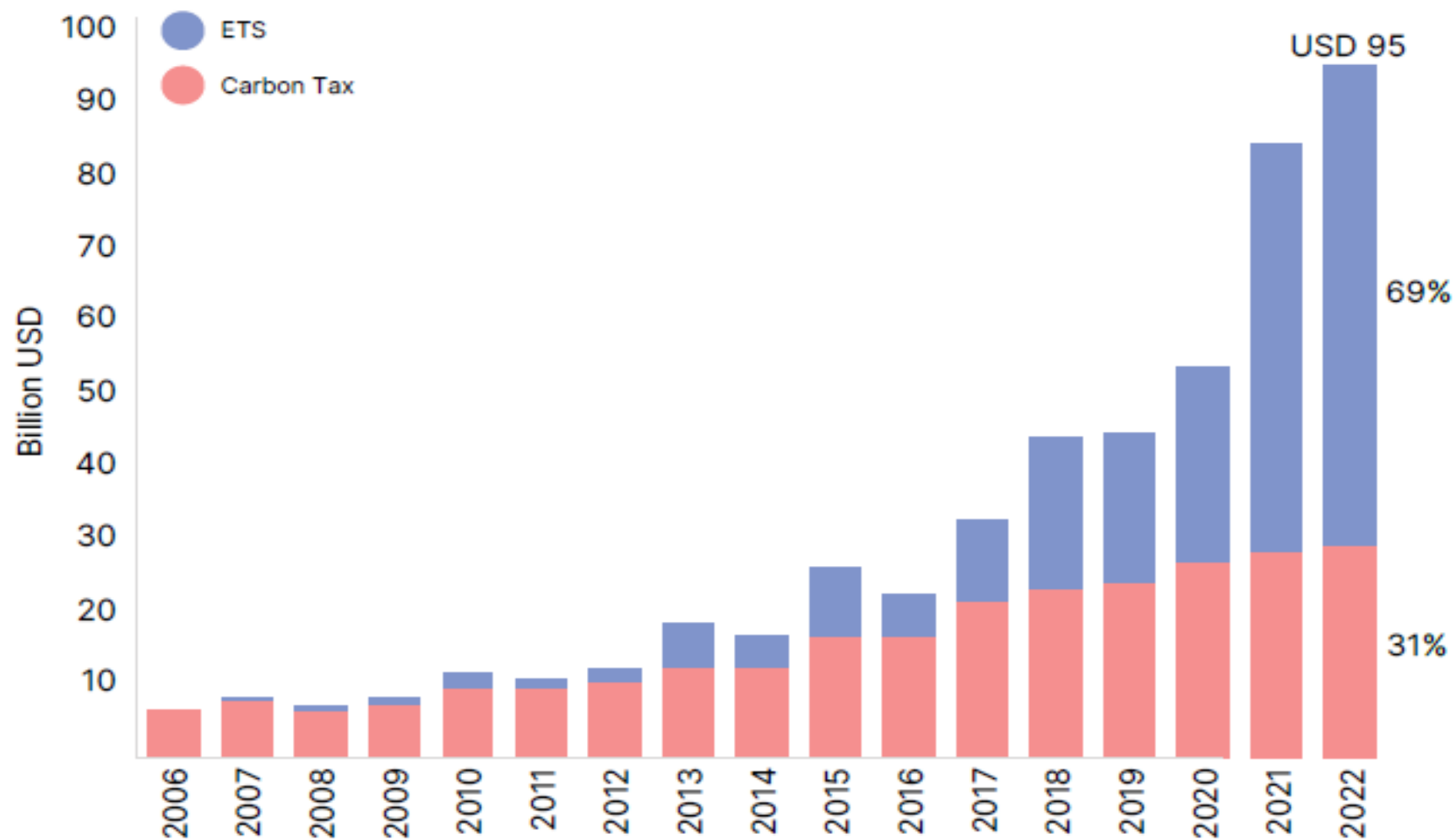
Share of global GHG covered by ETS and CT



Source: World Bank State & Trends in Carbon Pricing 2023



Global revenues generated by ETS and CT over time



Source: World Bank State & Trends in Carbon Pricing 2023



CO₂ Prices by IEA WEO 2023 by Scenarios

USD (2022, MER) per tonne of CO ₂	2030	2040	2050
Stated Policies Scenario			
Canada	130	150	155
Chile and Colombia	13	21	29
China	28	43	53
European Union	120	129	135
Korea	42	67	89
Announced Pledges Scenario			
Advanced economies with net zero emissions pledges*	135	175	200
Emerging market and developing economies with net zero emissions pledges**	40	110	160
Other emerging market and developing economies	-	17	47
Net Zero Emissions by 2050 Scenario			
Advanced economies with net zero emissions pledges	140	205	250
Emerging market and developing economies with net zero emissions pledges	90	160	200
Selected emerging market and developing economies (without net zero emissions pledges)	25	85	180
Other emerging market and developing economies	15	35	55

Note: Values are rounded.

*Includes all OECD countries except Mexico.

**Includes China, India, Indonesia, Brazil and South Africa.

Source: IEA WEO 2023



Carbon Credit Market mechanisms

Carbon credit markets trade “carbon credits,” which are units that are generated through voluntarily implemented emission reduction activities. Carbon credits can represent emission reductions achieved through either avoidance, for instance by capturing methane from landfills, or removal from the atmosphere, such as sequestering carbon through afforestation or directly capturing carbon from the air and storing it. Each carbon credit represents 1 metric ton of carbon dioxide equivalent (tCO₂e) reduced or removed.

Supply of carbon credits is represented by issuances from carbon crediting mechanisms (see Annex A), including international crediting mechanisms established under international treaties, such as the Kyoto Protocol and Paris Agreement;^(xiv) domestic crediting mechanisms established by regional, national, or subnational governments, such as the California Compliance Offset Program; and independent crediting mechanisms (or independent standards), which include standards and crediting mechanisms managed by independent nongovernmental entities, for example Verra’s Verified Carbon Standard (VCS) and Gold Standard.

Demand for carbon credits comes from a range of sources. Voluntary demand consists of (mostly

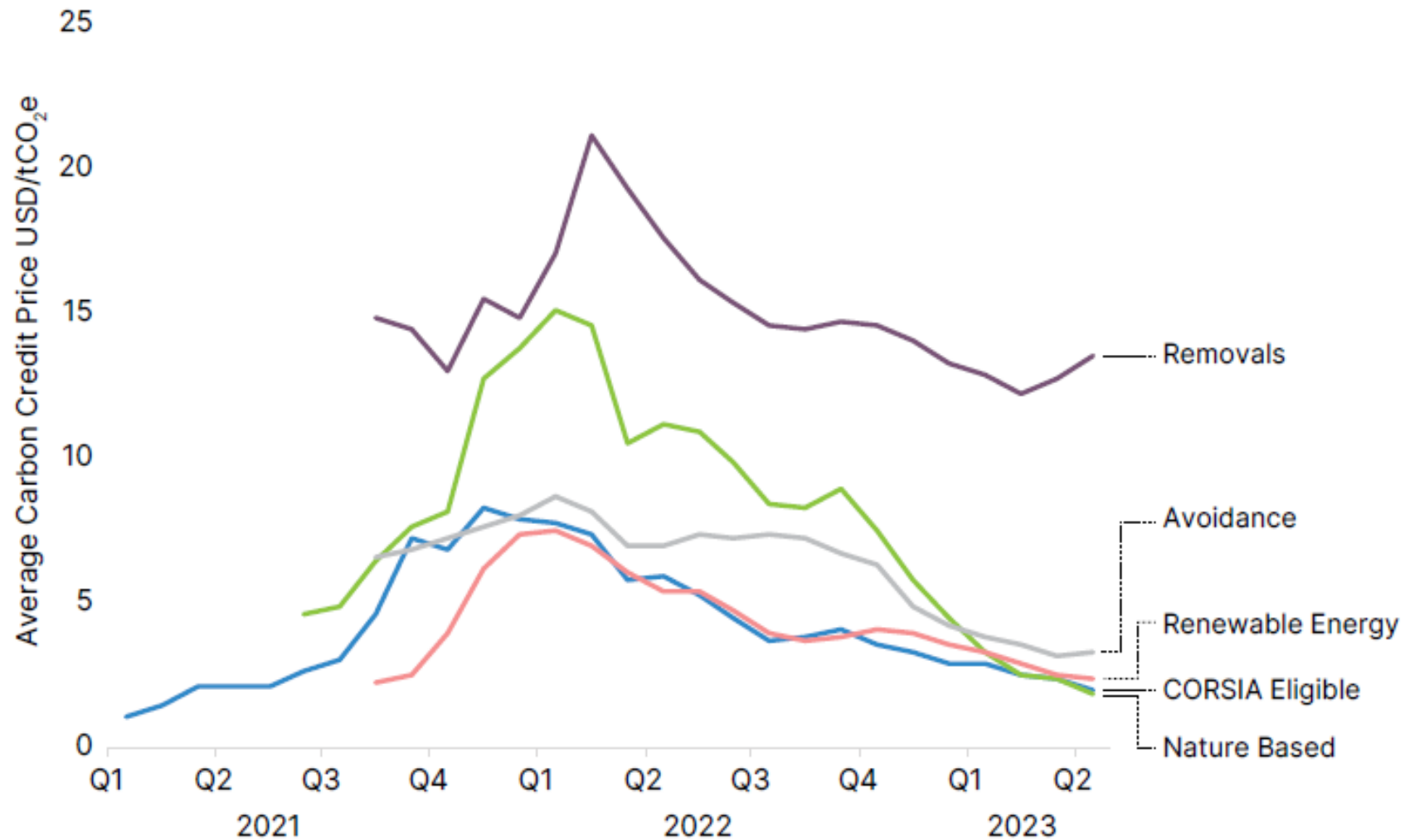
private) entities purchasing carbon credits to meet voluntary goals or green claims. International compliance demand includes countries seeking credits representing emission reductions in other countries to help meet their own emission reduction commitments, such as those established under the Paris Agreement, and airlines purchasing credits eligible for meeting their obligations established under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Domestic compliance demand comes from companies seeking credits to meet their obligations under a domestic law, usually an emissions trading system (ETS) or a carbon tax. In these cases, there are interactions between the price signals and emission reduction incentives provided through the carbon tax or ETS policy and carbon crediting.

Demand can also come from results-based climate finance where governments or international organizations incentivize climate action by purchasing carbon credits. This approach differs from the vast majority of public climate finance, which is provided up front. The emissions reductions achieved help recipient countries meet their nationally determined contribution (NDC) targets and are not claimed or counted by the governments or organizations providing the finance.

(xiv) Article 6 of the Paris Agreement provides the framework for international compliance carbon markets; Article 6.4 establishes a centralized mechanism supervised and governed by the United Nations Framework Convention on Climate Change, which is expected to be administratively similar to the CDM of the Kyoto Protocol; Article 6.2, on the other hand, provides a basis for bilateral or plurilateral voluntary cooperation among countries, which potentially offers flexibility to reduce greenhouse gas emissions through a variety of processes, mechanisms, and standards.



Prices of standardized Carbon Credit contracts



Source: World Bank State & Trends in Carbon Pricing 2023



Carbon Pricing in 2022



The Carbon Pricing situation in 2022/2021

- ◆ *Progress in Carbon Pricing has been made during the last 15 years.*
- ◆ *Beginning 2022, about 68 national jurisdictions have put a price on carbon. These jurisdictions are responsible for about 23% of carbon emissions. Number of jurisdictions putting a price on carbon has more than doubled over the past decades.*
- ◆ *In 2022, 68 carbon pricing instruments are operational compared to 64 carbon pricing initiatives in 2021 (in place plus those scheduled for implementation)*
- ◆ *Global quantity of carbon emissions under existing Carbon Pricing instruments: 13 GtCO_{2eq}. This represents about 23% of global worldwide GHG emissions (CO₂ + other GHG)*
- ◆ *# 84 G\$ raised in carbon pricing revenues in 2022.*
- ◆ *However, in a number of ETS markets, the price of CO₂ has decreased significantly and is characterized worldwide by a wide range of value (from less than 1\$/tCO_{2e} to 137 \$/tCO_{2e}) IMF calculated that the global average carbon price is 2\$/tCO₂.*



International CO2 markets – Main features

Situation & projects in year 2022



CARBON PRICING CAN PROVIDE THE IMPETUS FOR ECONOMIC TRANSFORMATION AND RECOVERY

- More ambitious carbon prices can help close the gap between pledges and policy and “keep 1.5 alive.”
- Along with lowering emissions, carbon pricing can improve energy and industrial efficiency, limit reliance on imported energy, promote cleaner air, protect and regenerate landscapes, and provide a valuable source of government revenue.
- But adopting carbon prices remains politically challenging, particularly amid rising inflation and energy prices. There is a clear need to ensure policies are fair, effective, and embedded within integrated climate and social policies.



DIRECT CARBON PRICING CONTINUES TO BE ADOPTED BUT GLOBAL COVERAGE REMAINS LOW

- Worldwide, 68 carbon pricing instruments (CPIs), including taxes and emissions trading systems (ETs), are operating and three more are scheduled for implementation.
- CPIs in operation cover approximately 23% of total global greenhouse gas (GHG) emissions. This represents a small increase in total global coverage as a result of four new systems commencing in the past year.
- The International Maritime Organization is considering placing a price on emissions from international shipping activities. If adopted, this would represent a major step in tackling global GHG emissions.



CROSS-BORDER APPROACHES TO CARBON PRICING ARE INCREASINGLY GAINING TRACTION

- The EU moved closer to adopting its Carbon Border Adjustment Mechanism, and Canada and the United Kingdom (UK) are exploring options for similar mechanisms.
- The International Monetary Fund (IMF) and World Trade Organization (WTO) are advocating for an international carbon pricing floor.
- Some countries have moved toward the adoption of international climate clubs, including the proposed United States (US)-EU Carbon-Based Sectoral Arrangement on Steel and Aluminum Trade.
- These approaches can fortify domestic support, prevent carbon leakage, and encourage mitigation beyond national borders.



MARKETS FOR CARBON CREDITS ARE GROWING RAPIDLY

- Credits from independent crediting mechanisms clearly dominate the carbon market.
- Annual voluntary carbon market value exceeded USD 1 billion for the first time, driven by corporate commitments.
- Compliance demand for carbon credits remains limited, though new rules for international carbon markets under Article 6 of the Paris Agreement provide clarity that may enable future growth.



CARBON PRICES HAVE HIT RECORD HIGHS IN MANY JURISDICTIONS

- Record ETS prices were observed in the European Union (EU), California, New Zealand, and Republic of Korea, among other markets, while several carbon taxes also saw prices hit their highest levels yet.
- A combination of policy reforms, anticipated changes, speculative investment interest, and broader economic trends, especially in global energy commodity markets, are driving these ETS price spikes.
- Nonetheless, prices must rise considerably more to meet the Paris Agreement temperature goals, as less than 4% of global emissions are currently covered by a direct carbon price within the range needed by 2030.



CARBON REVENUES HAVE INCREASED SHARPLY

- Global carbon pricing revenue increased by almost 60% in the past year, to around USD 84 billion.
- With prices rising and reduced free allocation, ETS revenues surpassed carbon tax revenues for the first time.
- Increasing carbon pricing revenues can support sustainable economic recovery, finance broader fiscal reforms, or help buffer countries from economic and international turbulence.



DIVERSE PURCHASER PREFERENCES MAKE MARKET GROWTH UNEVEN

- Nature-based credits are in especially high demand: Forestry and land use transactions more than doubled between 2020 and 2021.
- Increasing demand for carbon removals has resulted in price increases for these credits.
- The voluntary carbon market continues to be strongly diverse, with purchasers placing widely different values on characteristics such as sector, geography, and perceived co-benefits.

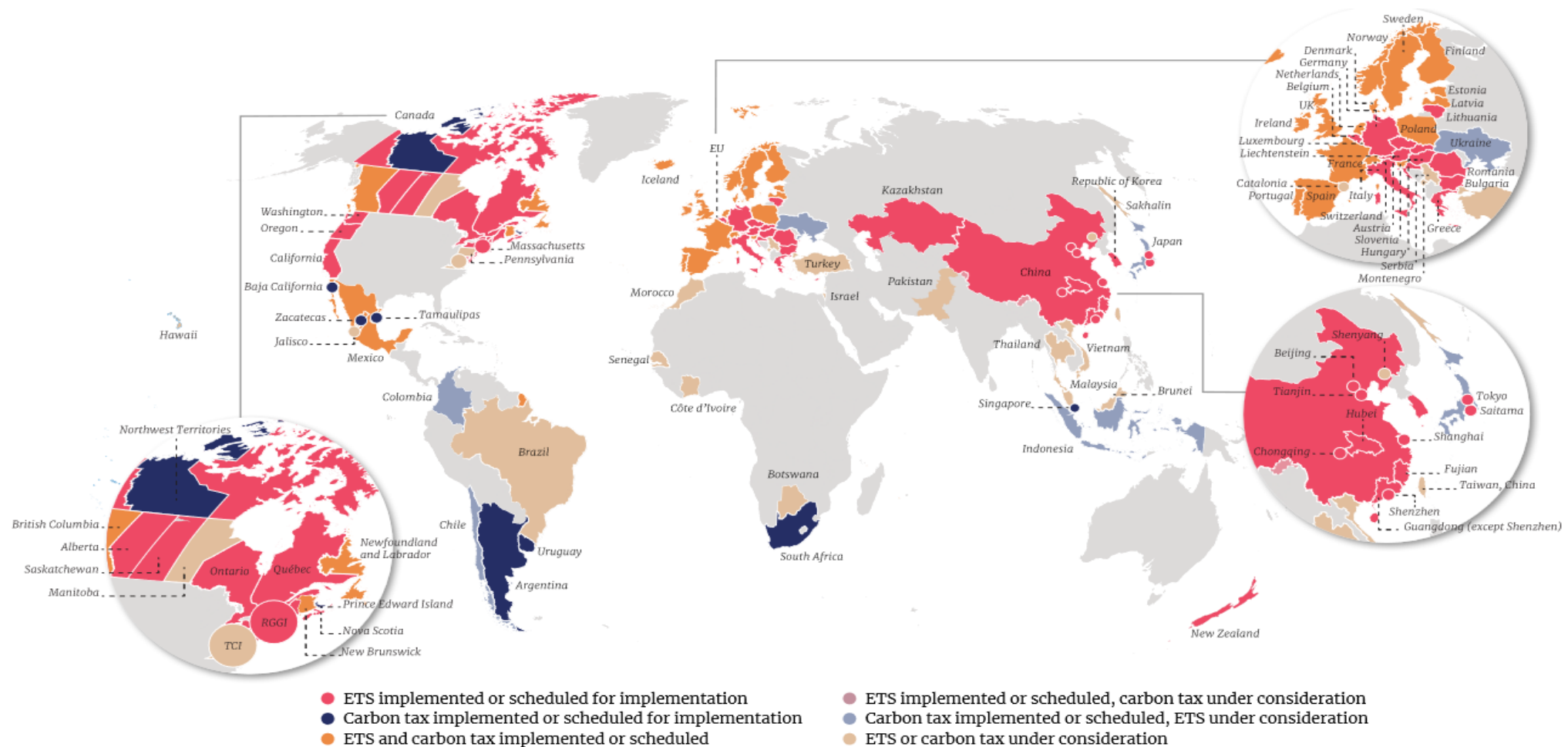


NEW FINANCIAL SERVICES, TECHNOLOGIES, AND GOVERNANCE FRAMEWORKS ARE SHAPING CARBON MARKETS

- Financial actors are becoming more active in the carbon market, while blockchain has enabled a new wave of decentralized financial innovations that show the technology's potential but have reignited some long-standing concerns about transparency and quality.
- Diverse governance frameworks are emerging from stakeholders and institutions that aim to address concerns regarding the integrity of carbon credits and how companies use them.
- New rules on Article 6 increase certainty while also adding complexity to carbon credit markets and may lead to increasingly divergent approaches emerging across actors and geographies.



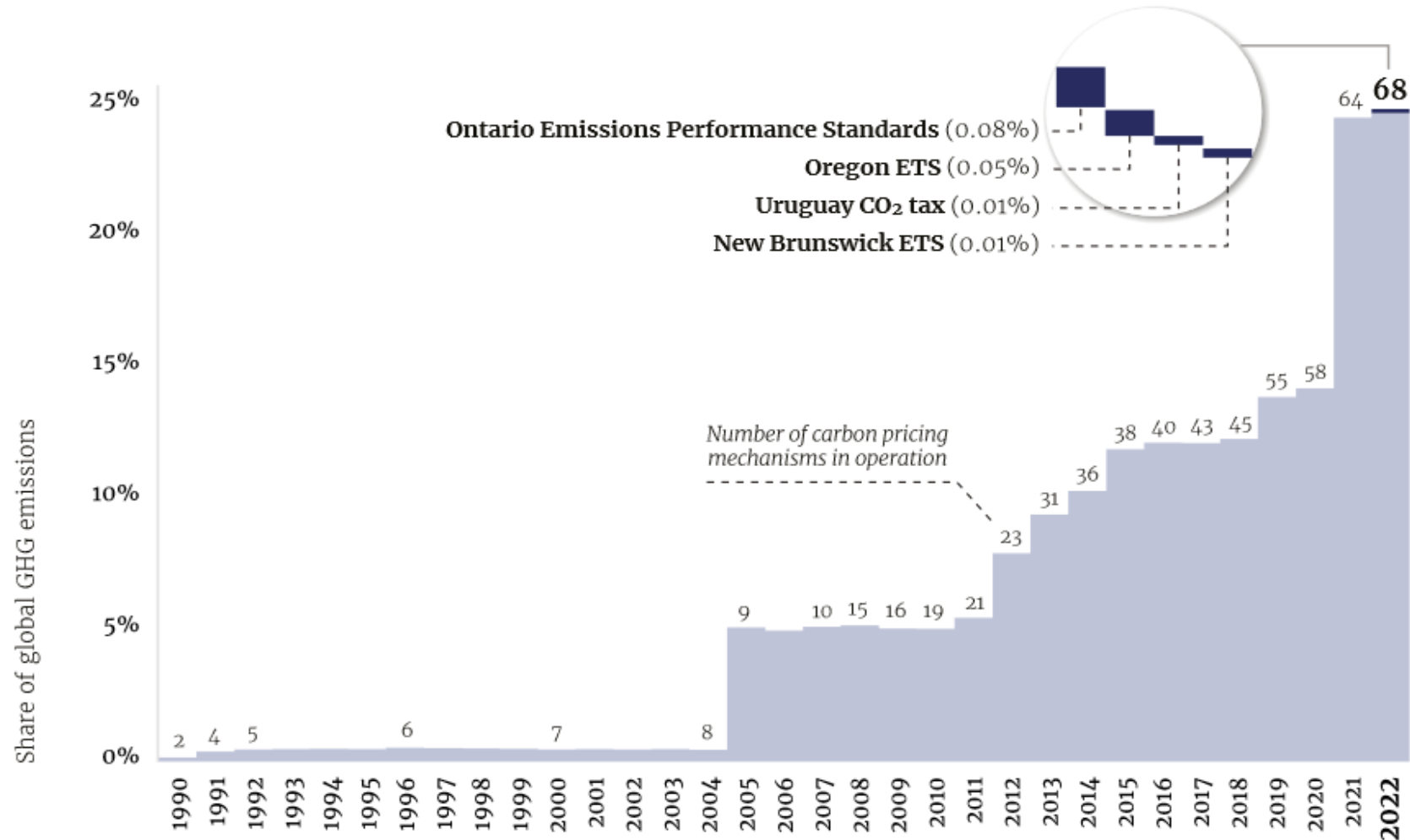
International CO2 markets Situation & projects in year 2022



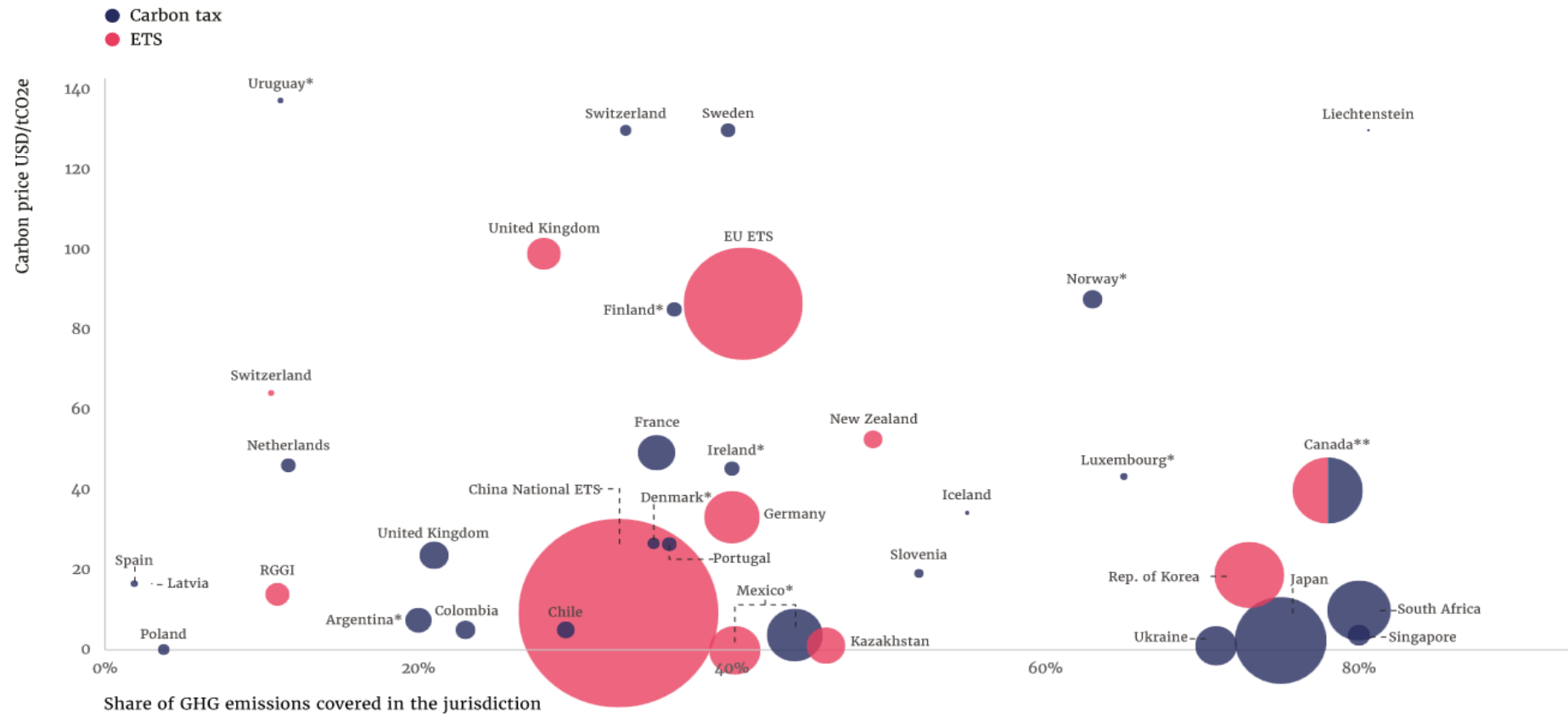
Carbon pricing initiatives are considered “scheduled for implementation” once they have been formally adopted through legislation and have an official, planned start date. Carbon pricing initiatives are considered “under consideration” if the government has announced its intention to work towards the implementation of a carbon pricing initiative and this has been formally confirmed by official government sources. TCI refers to Transportation and Climate Initiative. RGGI refers to the Regional Greenhouse Gas Initiative.



Carbon Pricing initiatives: Share of global GHG emissions covered by Carbon Pricing instruments – Year 2022



Carbon Pricing Initiatives: Emissions coverage, share of Emissions covered & Carbon Prices – Year 2022



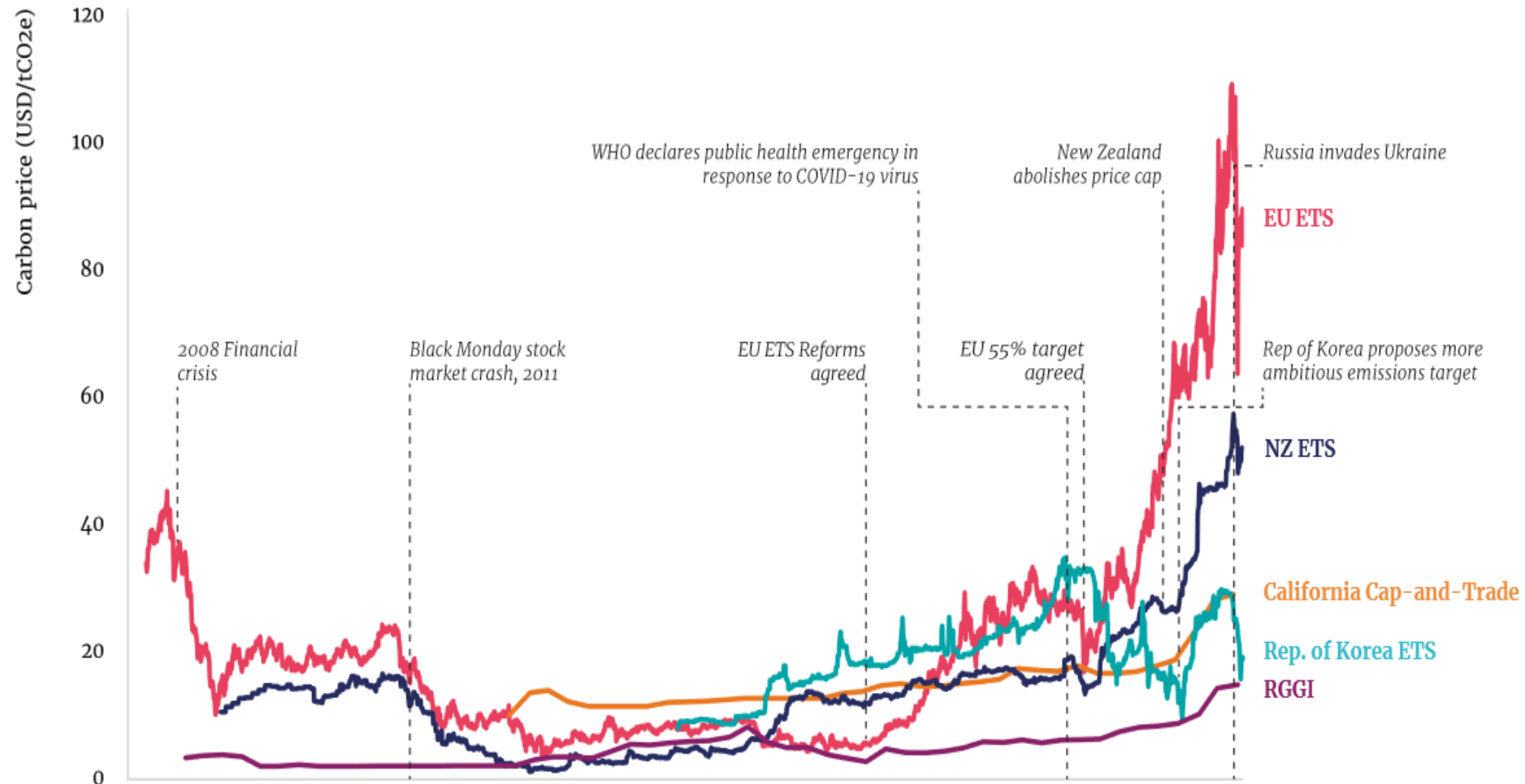
Bubble size represents absolute covered total greenhouse gas emissions.

*For CPIs that have multiple price levels, the price applying to the larger share of emissions is used.

**This is a composite presentation representing total emissions covered by carbon pricing instruments under the Pan-Canadian Framework. It includes a combination of ETS-like and carbon tax-like instruments, implemented at both provincial and federal levels.



Prices evolution in selected ETS 2008 - 2021



Source: World Bank
State & Trends in Carbon Pricing 2022

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EU's Carbon Border Adjustment Mechanism (CBAM)

The EU's proposed carbon border adjustment mechanism^{xxi}

The adoption of a CBAM is a key component of the EU's climate strategy and its ambition to achieve net zero emissions by 2050 while safeguarding competitiveness and avoiding carbon leakage. Under the draft regulations released in July 2021, the CBAM would effectively involve applying a carbon price to imports of certain goods to the EU, proportionate to the goods' "embodied emissions," or the GHG emissions generated during their manufacture. Importers of covered goods would be required to purchase emission certificates proportionate to their embodied emissions. The price of these certificates would mirror that of EU ETS allowances.

The CBAM is intended to gradually replace the current free allocation of allowances as the main measure to combat carbon leakage in the EU ETS. Under the draft proposal, the mechanism would be phased in proportionate to the phase-out of the existing free allocation. The European Commission would adjust the number of CBAM certificates to be surrendered to reflect the extent of free allowances allocated under the EU ETS, which would decline by 10% each year over the period to 2035.

According to the proposal, the CBAM would apply to the import of electricity and specified goods in the steel, iron, cement, fertilizer, and aluminum sectors. The proposal would initially only apply the CBAM to Scope 1 emissions, though importers would need to report on embodied Scope 2 indirect emissions from electricity consumption, leaving the door open to include these emissions in future years. Embodied emissions for products would be determined in two ways: Calculations would be based on actual emissions recorded at installation level, verified by accredited verifiers, while default values would be applied where importers cannot show actual emissions generated. For electricity, calculations would primarily rely on third-country default values that correspond to average CO₂ emission factors in the country.

Importers would be able to avoid or reduce potential costs imposed by the CBAM in a number of ways. First, imports from countries that participate in the EU ETS, or have a domestic ETS linked to them, would be fully exempt.^{xxii} Second, goods that are subject to a direct carbon price (i.e., a carbon tax or ETS) in their country of origin would be eligible for a rebate equal to the price already paid prior to export. Third, electricity imports from countries whose electricity markets are integrated with that of the EU would be exempt.

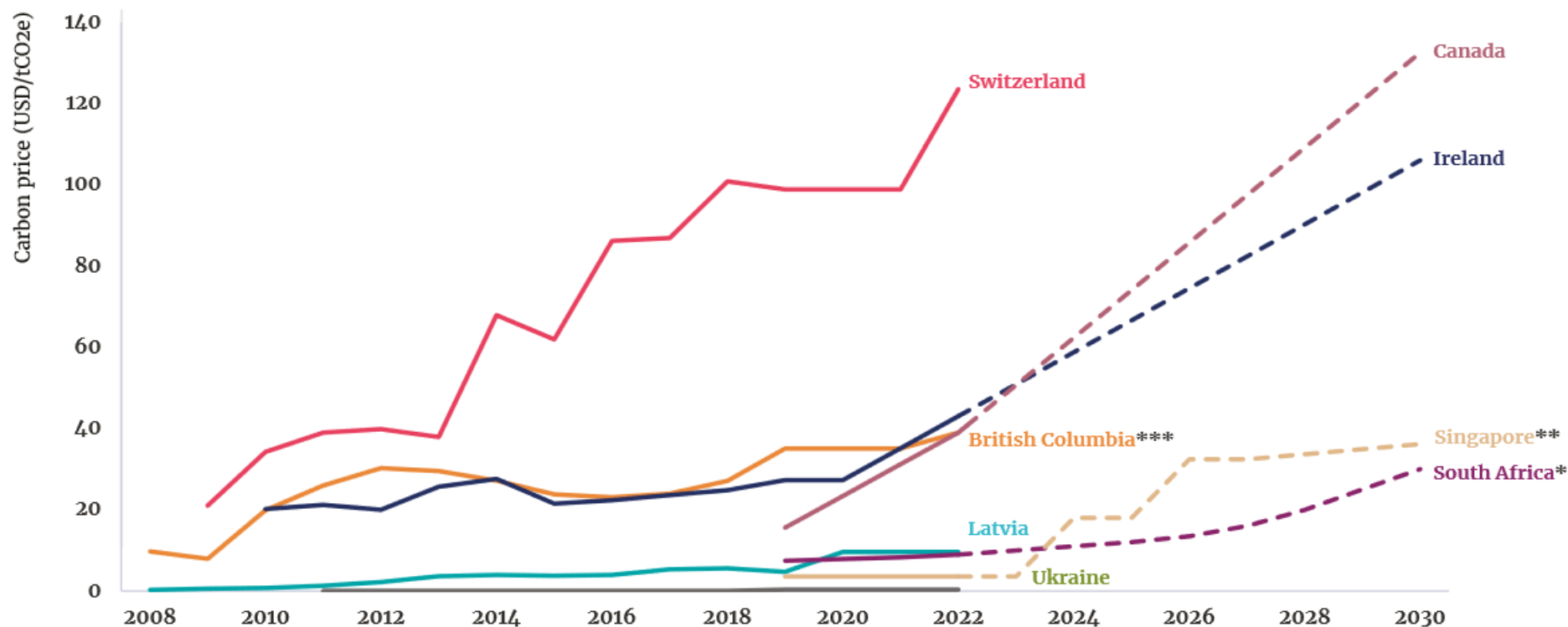
The proposal for the CBAM is currently under review by the European Parliament and the European Council. Potential amendments proposed in the parliament include making the 2025–2028 transitional period shorter and sooner, to 2023–2024, eliminating EU ETS free allocation much more rapidly. Scope 2 emissions from electricity use might be included, and use of CBAM revenues might be better targeted to support climate action outside the EU bloc. In March 2022, the Council released a draft text pushing for CBAM issues relating to free allocation phase-out and export rebates to be part of the upcoming EU ETS review. This move has been suggested to streamline the finalization of the CBAM regulation and shift decision-making power from finance ministers to environment ministers, considered better positioned to address these issues. The French Presidency of the EU is aiming to achieve agreement on the measure among lawmakers by June 2022, though it is as yet unclear if this will be achieved.

^{xxi} The European Commission presented its final draft regulations for the CBAM in July 2021. See European Commission, "[Proposal for a Regulation of the European Parliament and of the Council Establishing a Carbon Border Adjustment Mechanism](#)," July 14, 2021.

^{xxii} The proposed regulation allows for the possibility of further acts which increase the number of CBAM exemptions. Such cases would include a third country's inclusion into the EU ETS, or a linkage agreement between the EU ETS and the country's own emission trading system (as is the case for Switzerland).



Carbon Tax Rates 2008 – 2022 & Projections



Dotted line indicates scheduled price increases for those jurisdictions that have communicated future price trajectories.

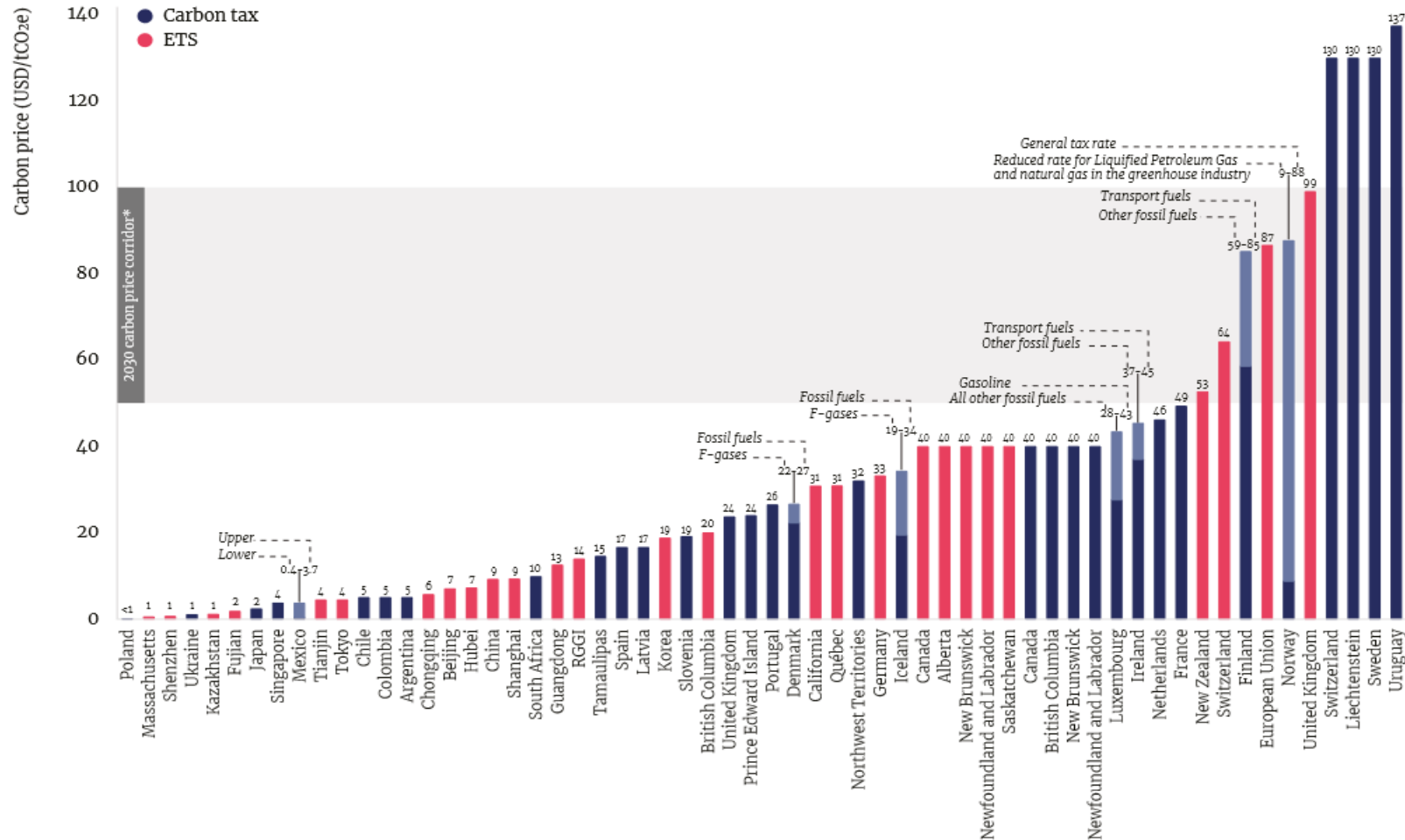
*Estimated path based on the government's ambition to increase the tax rate by at least USD 1 per year, and to increase the rate more rapidly from 2026 to reach USD 30/tCO₂e in 2030 and USD 120/tCO₂e beyond 2050.

**This is a low range projection as the Singapore government plans to reach a carbon tax rate of SGD 50–80/tCO₂e (36–58 USD/tCO₂e) by 2030.

***British Columbia has committed to meet or exceed the federal benchmark carbon price.



Carbon Prices as of April 2022



Nominal prices on April 1, 2022 are shown for illustrative purpose only. Prices are not necessarily comparable between CPIs because of (for example) differences in the sectors covered and allocation methods applied, specific exemptions, and compensation methods.

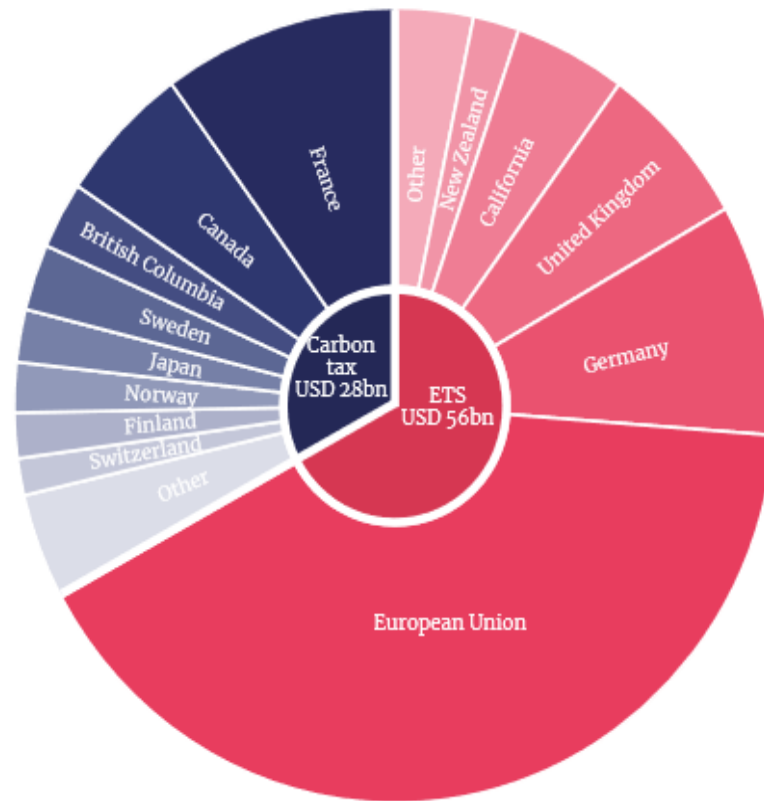
*The 2030 carbon price corridor is based on the recommendations in the report of the High-Level Commission on Carbon Prices.

**Several jurisdictions apply different carbon tax rates to different sectors or fuels. In these cases, we have indicated the range of tax rates applied, with the dark blue shading showing the lower rate and the combined dark blue and light blue shading representing the higher rate.

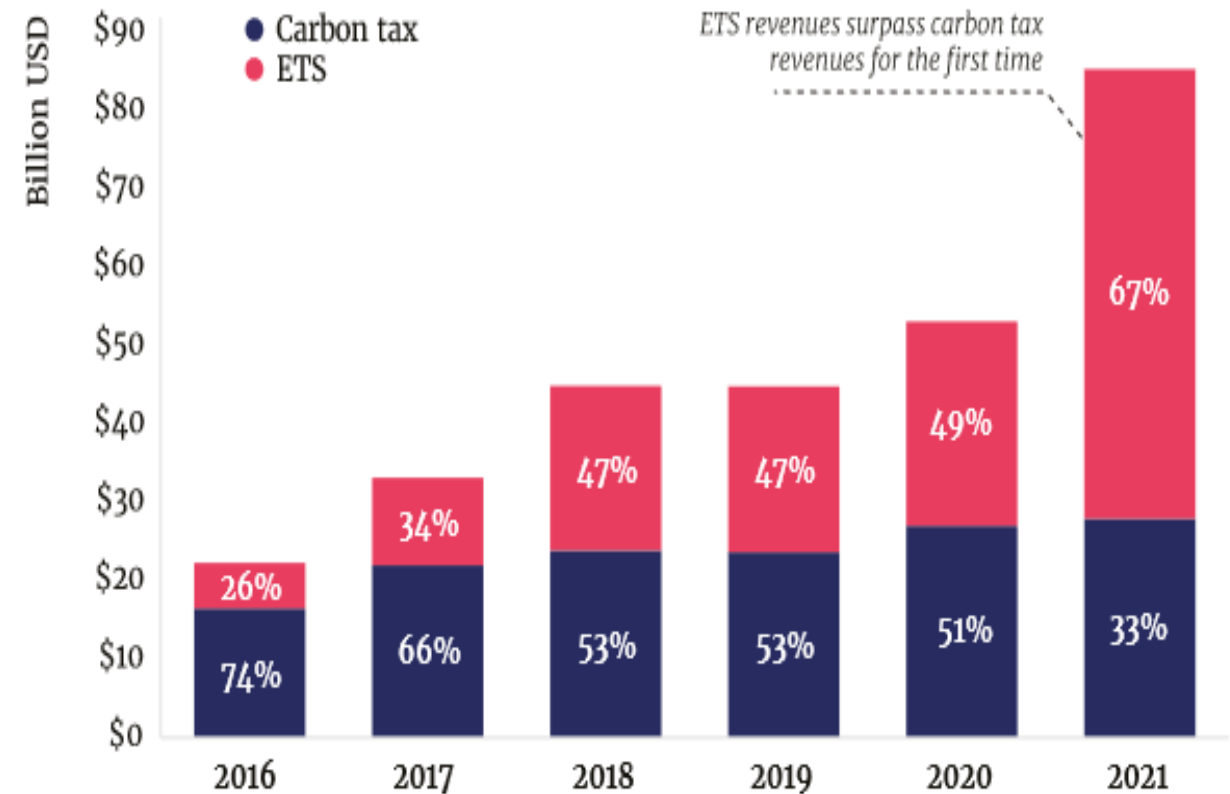


Carbon Prices as of April 2022

Revenue generated per carbon pricing instrument in 2021



Evolution of global carbon pricing revenues over time



Carbon Credit Markets

Understanding carbon credit markets

Global carbon credit markets consist of a diverse range of sources of supply, sources of demand, and trading frameworks.

Supply derives from different types of crediting mechanisms, including the following:

- *International crediting mechanisms* established under international treaties—the Kyoto Protocol (including the Clean Development Mechanism [CDM]) and the Paris Agreement.^{xxx}
- *Domestic crediting mechanisms* established by regional, national, or subnational governments, such as the California Compliance Offset Program and the Australia Emissions Reduction Fund.
- *Independent crediting mechanisms* includes standards and crediting mechanisms managed by independent, nongovernmental entities, such as Verra and Gold Standard.

Demand derives from a range of compliance obligations established under international agreements and national laws, as well as voluntary commitments adopted by companies, governments, and other organizations.

While most carbon credits tend to attract a range of different kinds of buyers, meaning that few sources of supply can be matched with only one source of demand, it is possible to identify **four broad segments**, largely based on demand drivers:

1. **International compliance markets** primarily respond to commitments made under international agreements. They primarily consist of (i) countries voluntarily purchasing/utilizing credits or “mitigation outcomes” recognized under international treaties to help meet their emission reduction commitments (previously established under the Kyoto Protocol and more recently the Paris Agreement); and (ii) airlines purchasing credits eligible for meeting their obligations established under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).^{xxxi}

2. **Domestic compliance markets** involve companies purchasing credits that are eligible for meeting their obligations under a domestic law, usually an ETS or a carbon tax. These may include credits issued under international, domestic, or independent crediting mechanisms depending on the rules established by respective governments.
3. **Voluntary carbon markets** consist of (mostly private) entities purchasing carbon credits for the purpose of complying with voluntary mitigation commitments. They largely consist of credits issued under independent crediting standards, though some entities also purchase those issued under international or domestic crediting mechanisms.
4. **Results-based finance** refers, in the context of the carbon market, to purchases of carbon credits by governments or international organizations for the purpose of incentivizing climate change mitigation or meeting national targets. Results-based finance can also refer to broader payments in return for the achievement of emissions reductions, without any transfer of credits or other ownership.

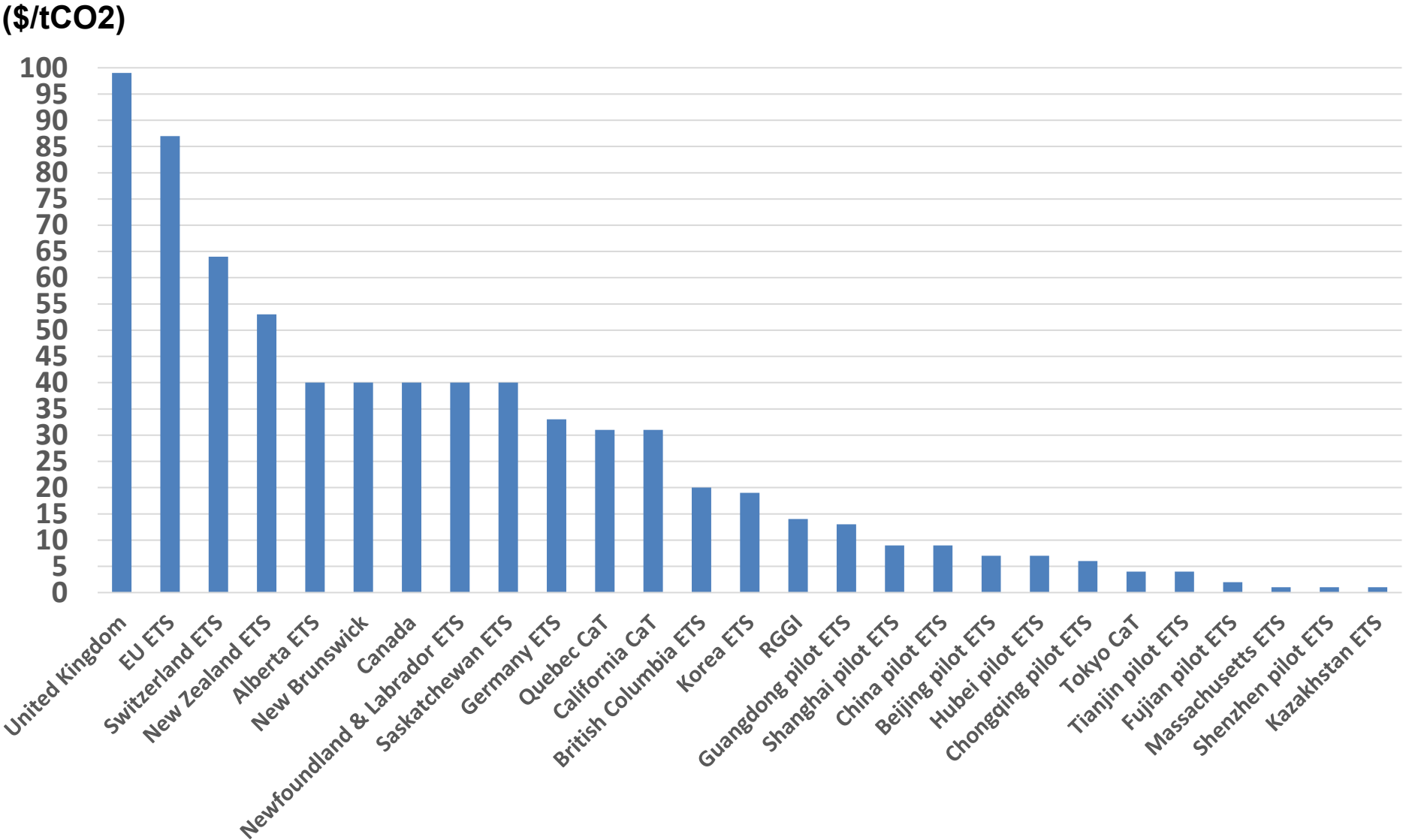
The linkages and overlaps across compliance and voluntary markets, as well as international and domestic markets, continue to evolve.

^{xxx} Article 6 of the Paris Agreement provides the framework for international carbon markets: Article 6.4 establishes a centralized mechanism supervised and governed by the UNFCCC, which is expected to be administratively similar to the CDM of the Kyoto Protocol, and Article 6.2, on the other hand, provides a basis for bilateral or plurilateral voluntary cooperation among countries, which potentially offers flexibility to reduce GHG emissions from a variety of processes, mechanisms, and standards.

^{xxxi} One of the key features that distinguishes international compliance markets from voluntary markets is the mandatory authorization by the governments in whose jurisdiction the credits are generated and transferred from. Under the Paris Agreement, the sale and purchase of carbon credits requires accounting by Parties to the Paris Agreement through a “corresponding adjustment.” While international compliance markets exclusively trade credits that are authorized (i.e., include a commitment for corresponding adjustments by the seller government), voluntary carbon markets may also trade in credits that are not accompanied by such authorization.



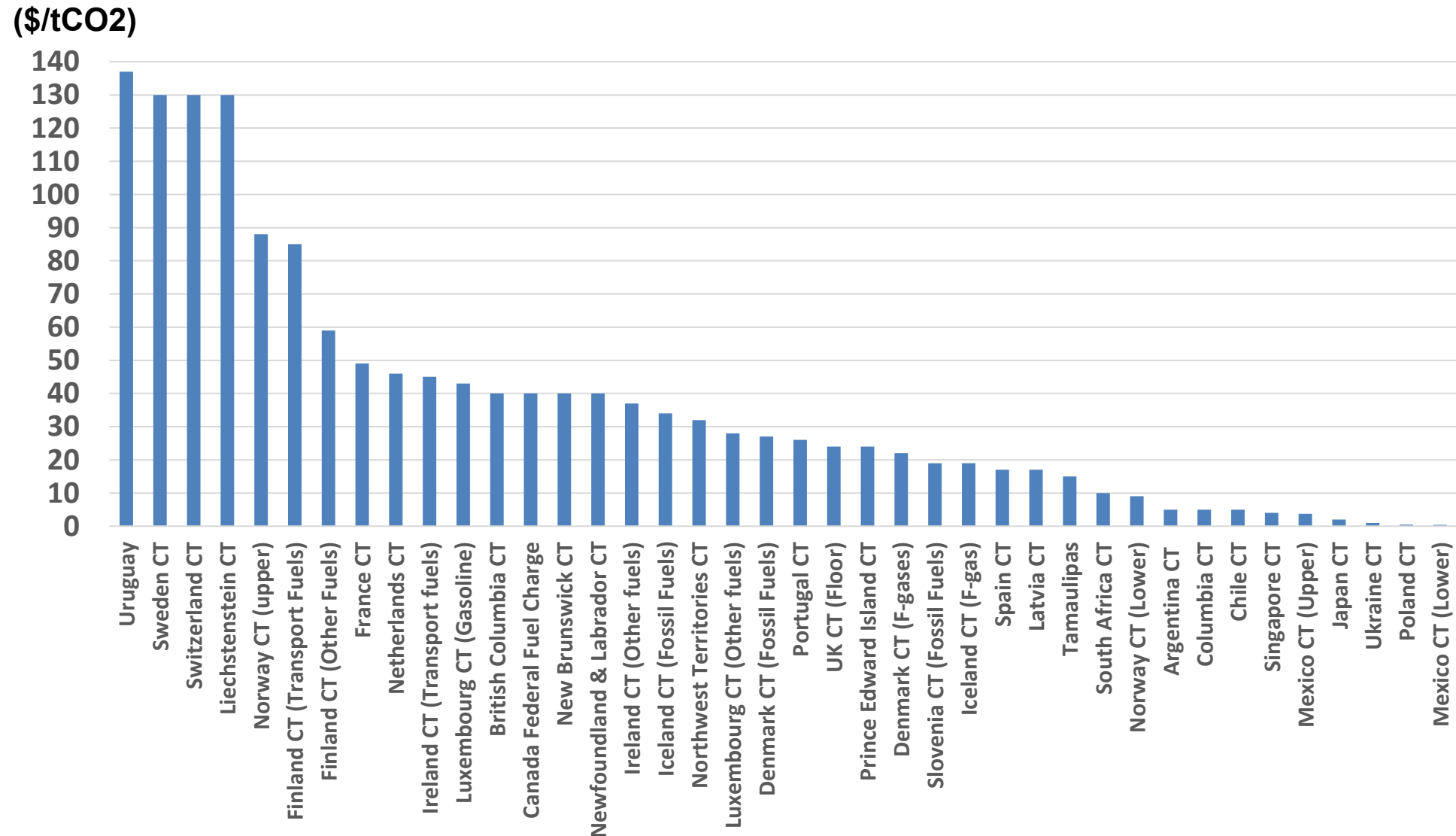
Carbon Price for existing ETS – 2022



Data from World Bank
State & Trends in Carbon Pricing 2022



Carbon Price for existing CT Systems - 2022



Data from World Bank
State & Trends in Carbon Pricing 2022

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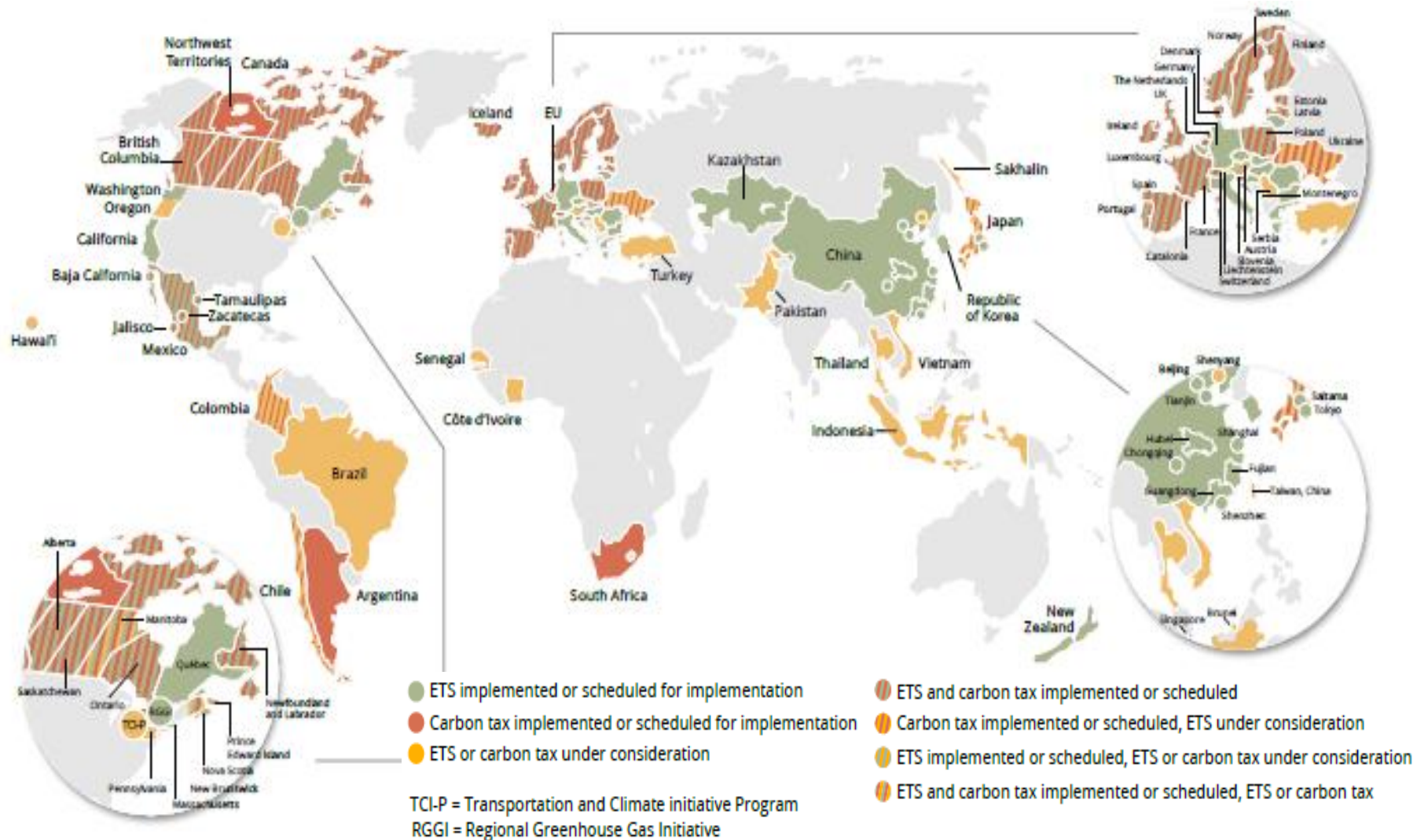
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Carbon Pricing in 2021



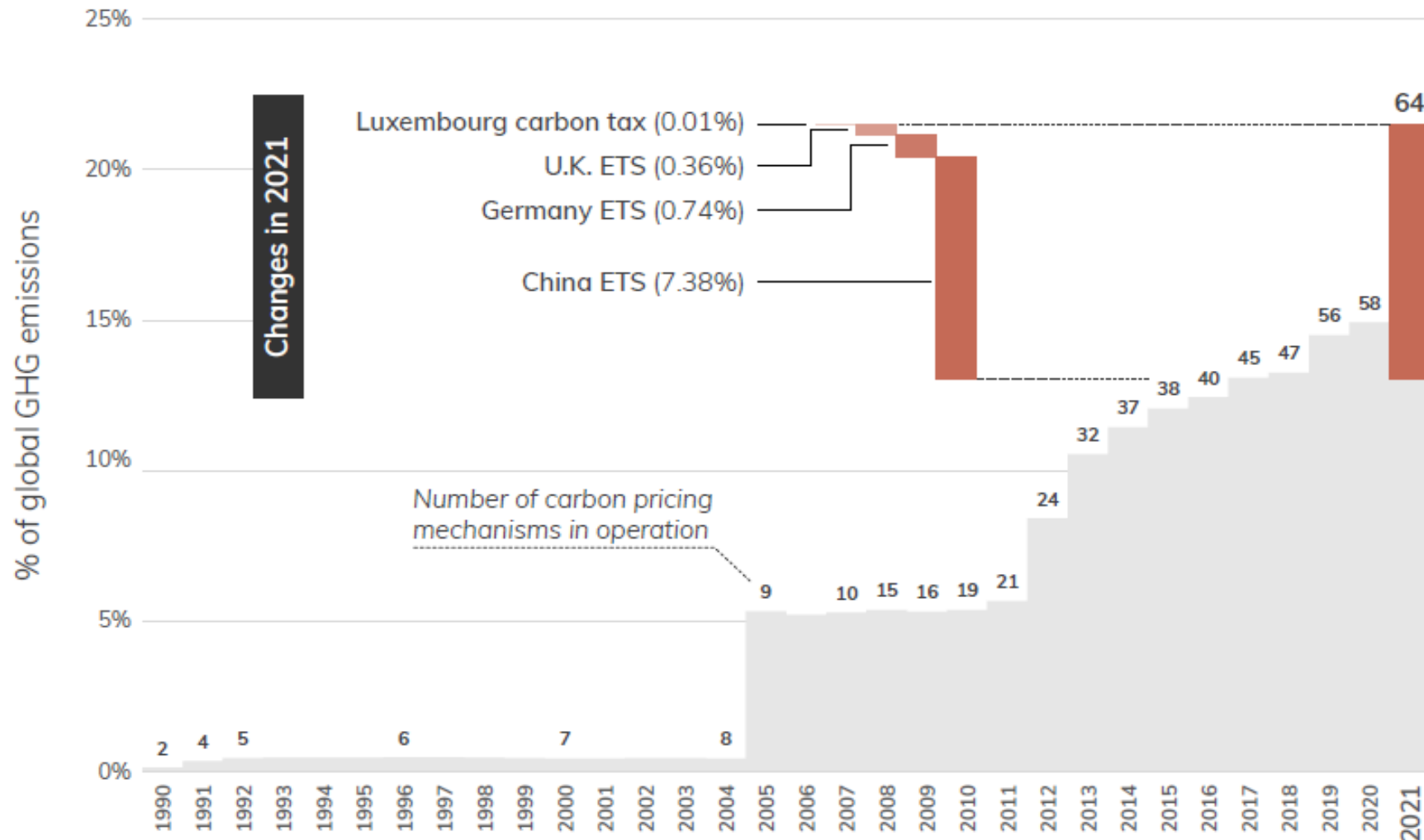
International CO2 markets Situation & projects in year 2021



Source: World Bank
State & Trends in Carbon Pricing 2021

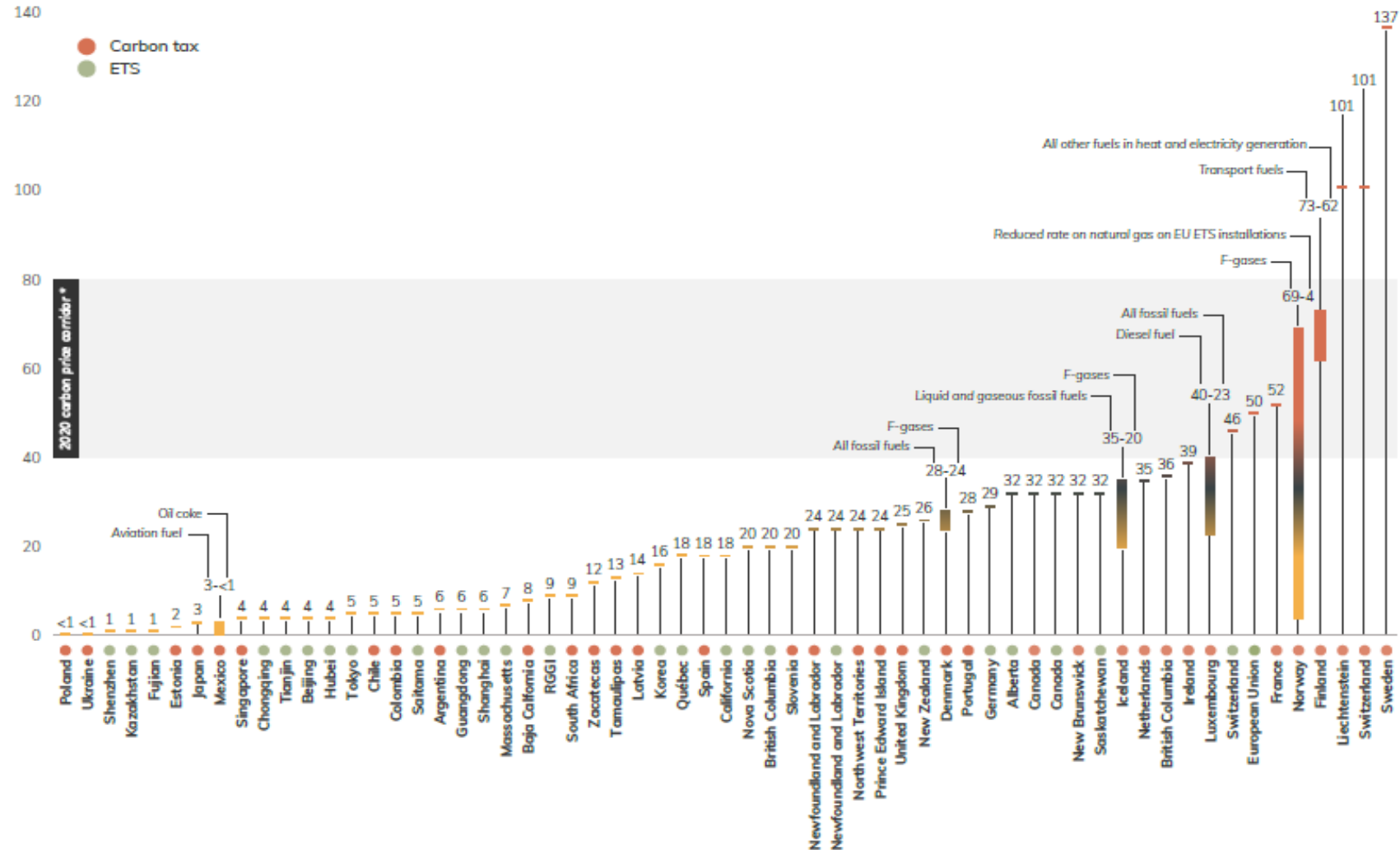


Carbon Pricing initiatives: share of global emissions (GHG) covered – Year 2021 adjust.



Carbon Pricing 2021

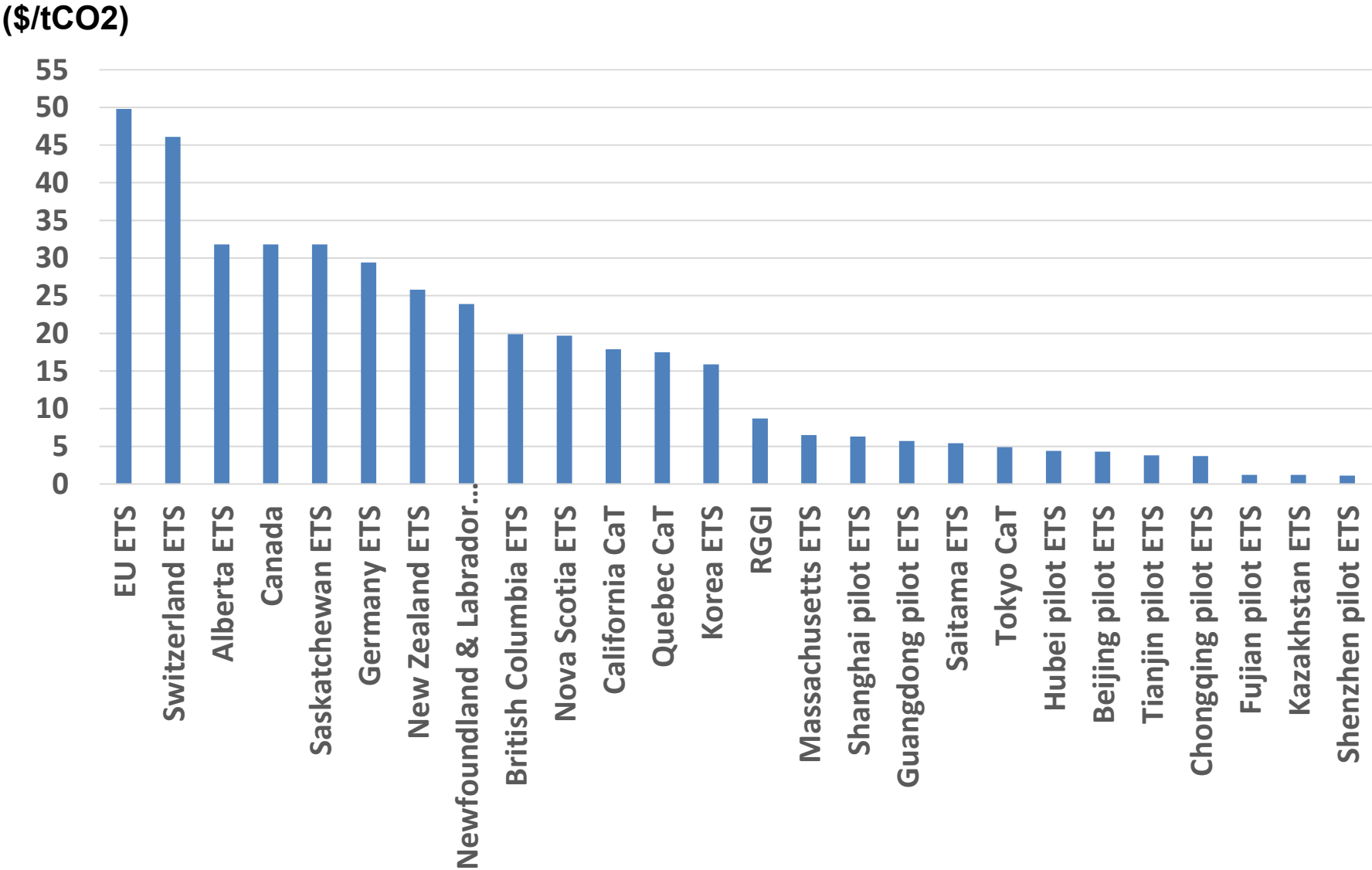
(\$/tCO₂)



Source: World Bank
State & Trends in Carbon Pricing 2021



Carbon Price for existing ETS – 2021

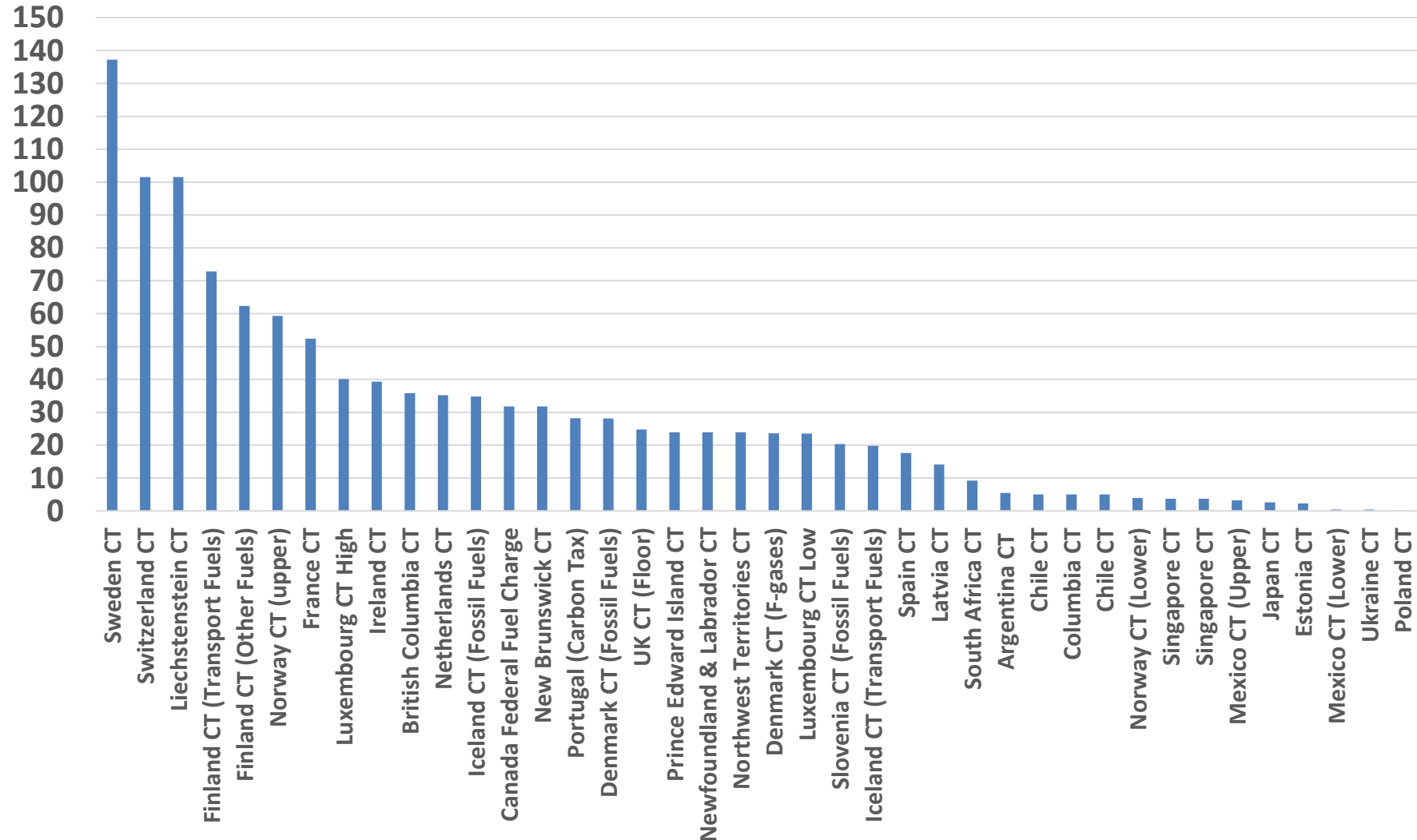


Data from World Bank
State & Trends in Carbon Pricing 2021



Carbon Price for existing CT Systems - 2021

(\$/tCO₂)

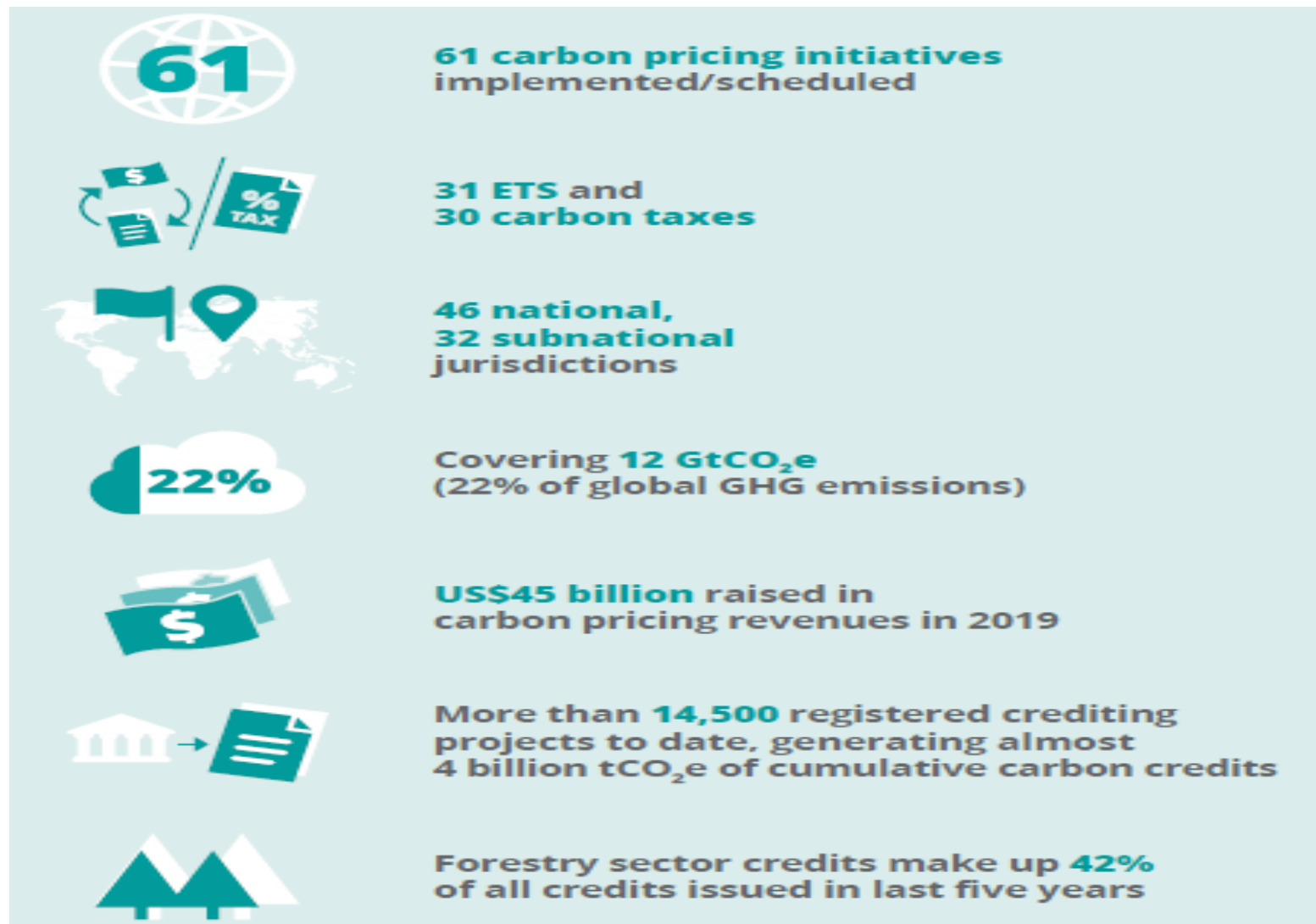


Data from World Bank
State & Trends in Carbon Pricing 2021



International CO2 markets

Situation & projects in year 2020



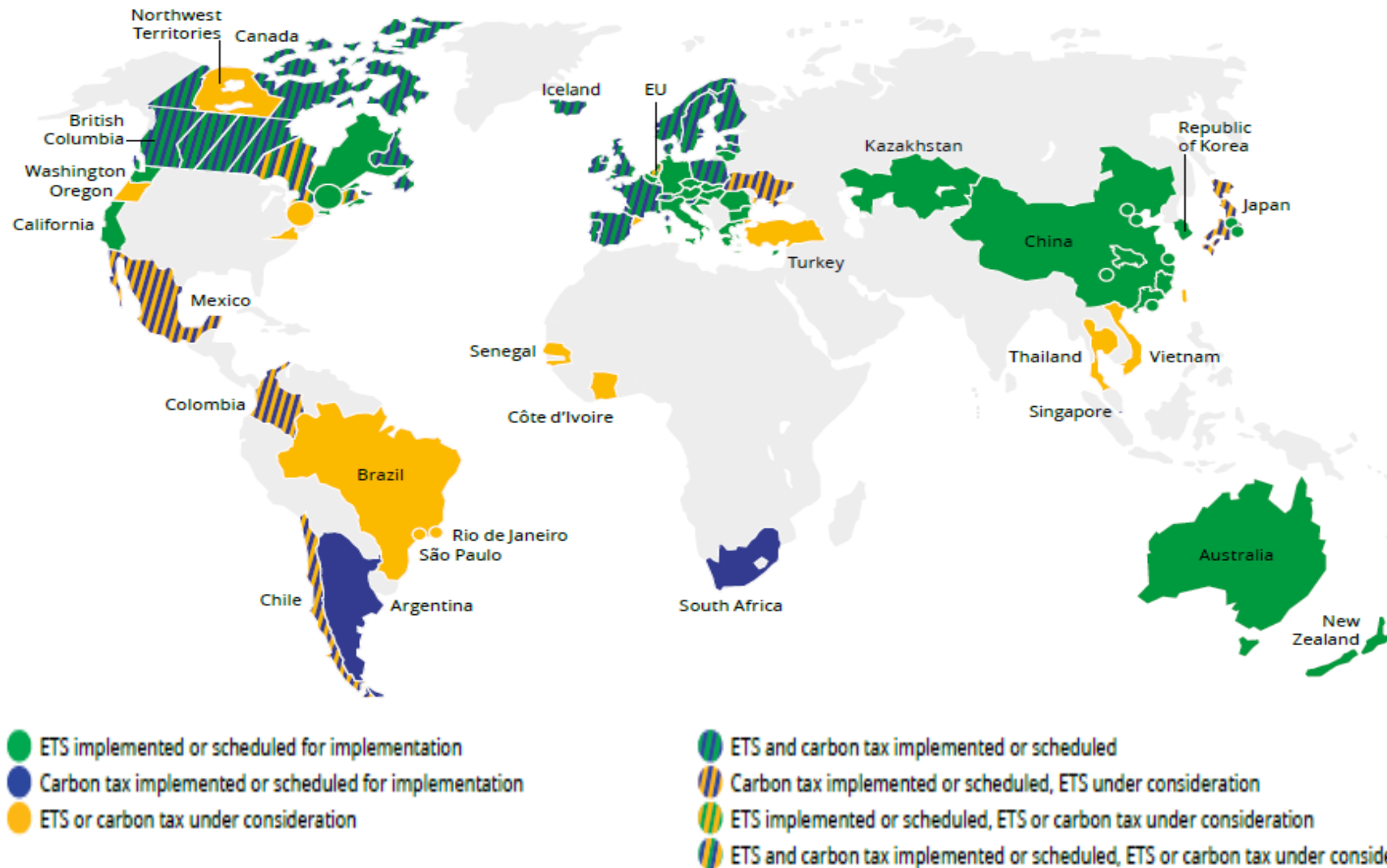
Source: World Bank
State & Trends in Carbon Pricing May 2020

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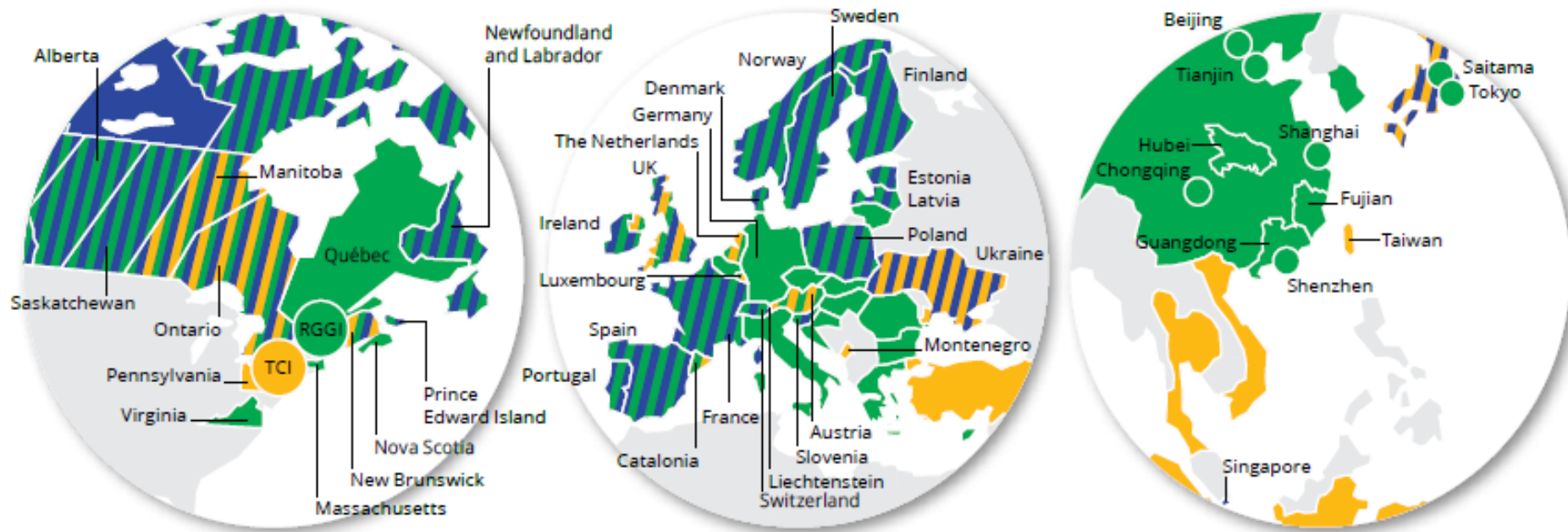
International CO2 markets Situation & projects in year 2020



Source: World Bank
State & Trends in Carbon Pricing 2020



International CO2 markets Situation & projects in year 2020



- ETS implemented or scheduled for implementation
- Carbon tax implemented or scheduled for implementation
- ETS or carbon tax under consideration

- ETS and carbon tax implemented or scheduled
- Carbon tax implemented or scheduled, ETS under consideration
- ETS implemented or scheduled, ETS or carbon tax under consideration
- ETS and carbon tax implemented or scheduled, ETS or carbon tax under consideration

List of Countries/Entities developing Carbon Pricing Regional & National Initiatives - Situation 2020

Finland carbon tax (1990 →)	Japan carbon tax (2012 →)	Ontario CaT (2017 - 2018)
Poland carbon tax (1990 →)	Australia CPM (2012 - 2014)	Alberta carbon tax (2017 →)
Norway carbon tax (1991 →)	Québec CaT (2013 →)	Chile carbon tax (2017 →)
Sweden carbon tax (1991 →)	Kazakhstan ETS (2013 →)	Colombia carbon tax (2017 →)
Denmark carbon tax (1992 →)	UK carbon price floor (2013 →)	Massachusetts ETS (2018 →)
Slovenia carbon tax (1996 →)	Shenzhen pilot ETS (2013 →)	Argentina carbon tax (2018 →)
Estonia carbon tax (2000 →)	Shanghai pilot ETS (2013 →)	Canada federal OBPS (2019 →)
Latvia carbon tax (2004 →)	Beijing pilot ETS (2013 →)	Singapore carbon tax (2019 →)
EU ETS (2005 →)	Guangdong pilot ETS (2013 →)	Nova Scotia CaT (2019 →)
Alberta TIER (2007 →)	Tianjin pilot ETS (2013 →)	Saskatchewan OBPS (2019 →)
Switzerland ETS (2008 →)	France carbon tax (2014 →)	Newfoundland and Labrador carbon tax (2019 →)
New Zealand ETS (2008 →)	Mexico carbon tax (2014 →)	Newfoundland and Labrador PSS (2019 →)
Switzerland carbon tax (2008 →)	Spain carbon tax (2014 →)	Canada federal fuel charge (2019 →)
Liechtenstein carbon tax (2008 →)	Hubei pilot ETS (2014 →)	Prince Edward Island carbon tax (2019 →)
BC carbon tax (2008 →)	Chongqing pilot ETS (2014 →)	South Africa carbon tax (2019 →)
RGGI (2009 →)	Korea ETS (2015 →)	Northwest Territories carbon tax (2019 →)
Iceland carbon tax (2010 →)	Portugal carbon tax (2015 →)	Mexico pilot ETS (2020 →)
Tokyo CaT (2010 →)	BC GGIRCA (2016 →)	Virginia ETS (2020 →)
Ireland carbon tax (2010 →)	Australia ERF Safeguard Mechanism (2016 →)	New Brunswick carbon tax (2020 →)
Ukraine carbon tax (2011 →)	Fujian pilot ETS (2016 →)	Germany ETS (2021 →)
Saitama ETS (2011 →)	Washington CAR (2017 →)	China national ETS (2021 →)
California CaT (2012 →)		

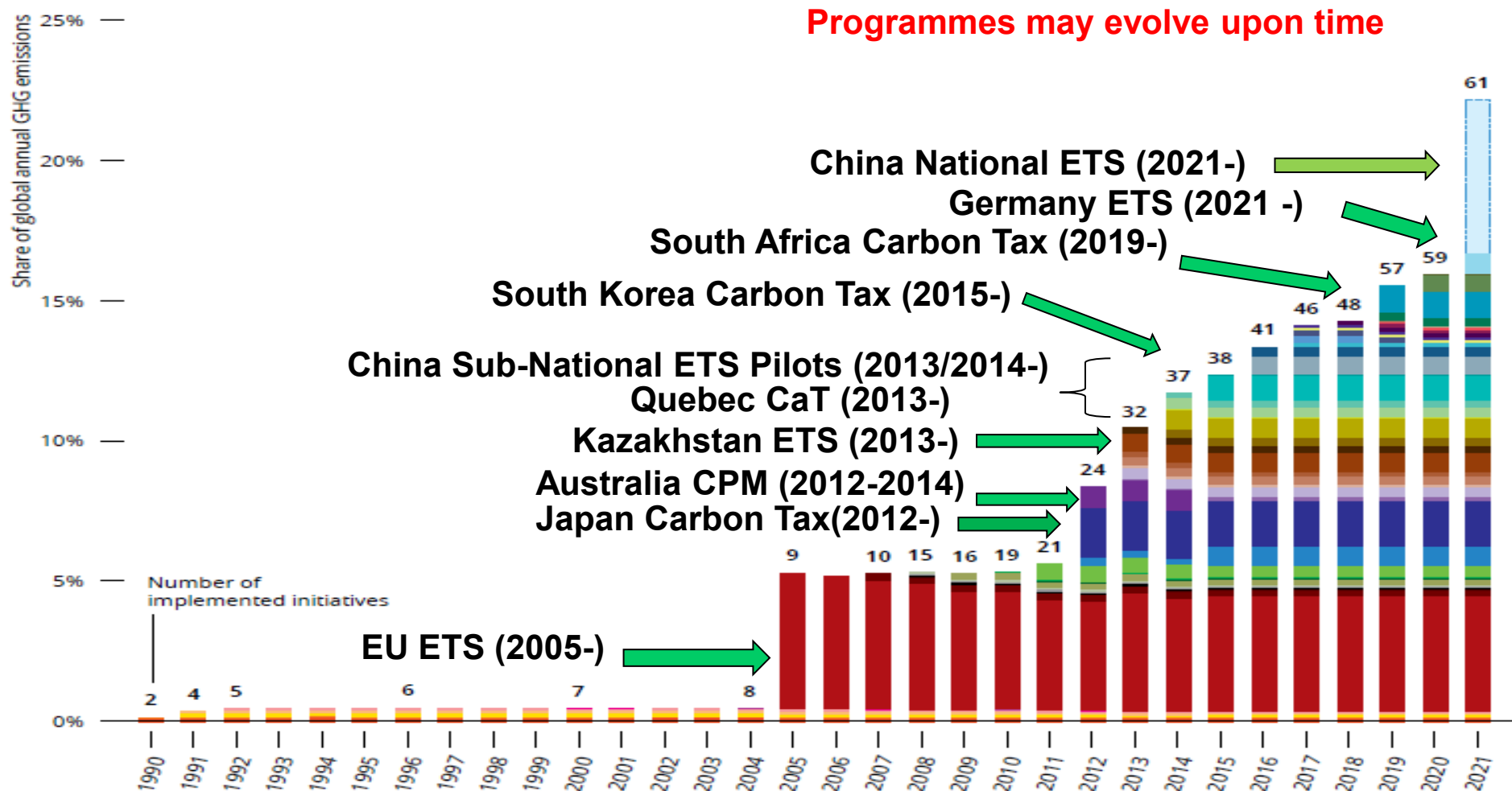
Source: World Bank
State & Trends in
Carbon Pricing 2020

CCIR: Carbon Competitive Incentive Regulation, SGER: Specified Gas Emitters Regulation, OBPS: Output-Based Pricing System, ERF: Emissions Reduction Fund, RGGI: Regional Greenhouse Gas Initiative N W USA, Australia CPM: Carbon Pricing Mechanism till 2014



Carbon Pricing initiatives: share of global emissions (GHG) covered – Year 2020

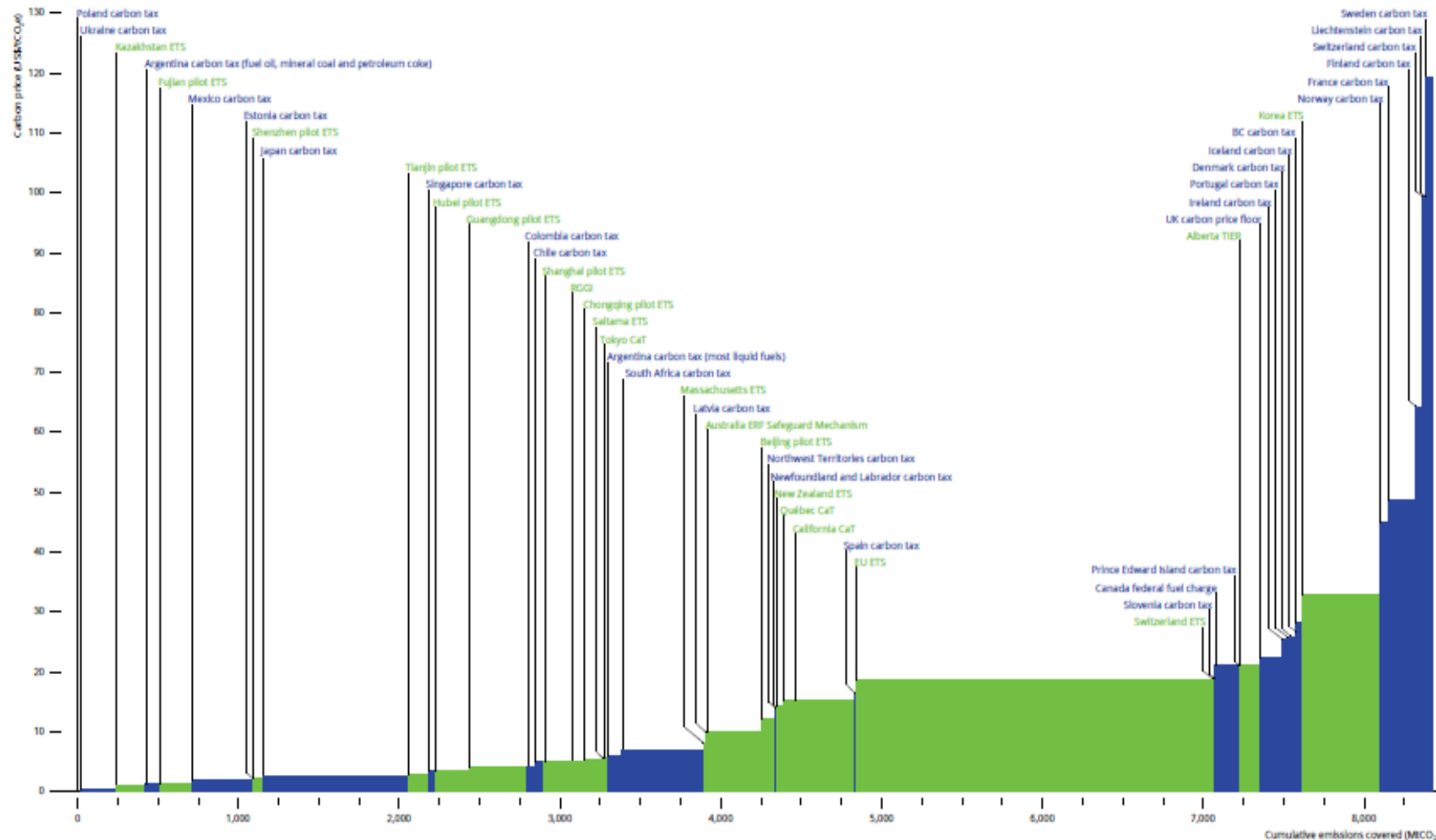
Share of global GHG emissions



Nota: CPM: Carbon Pricing Mecanism



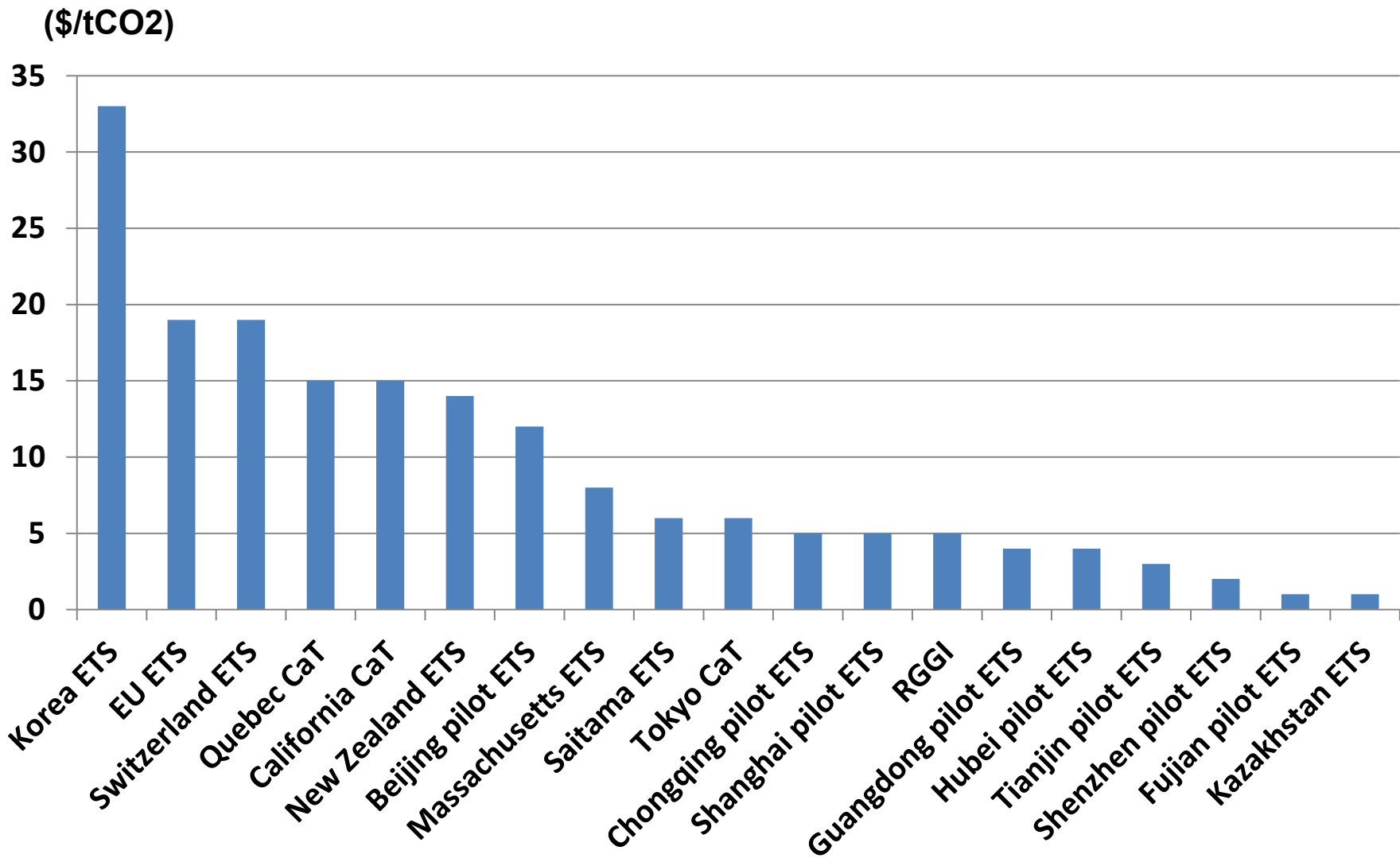
Carbon Pricing and Emissions Coverage Year 2020



Source: World Bank
State & Trends in Carbon Pricing 2020



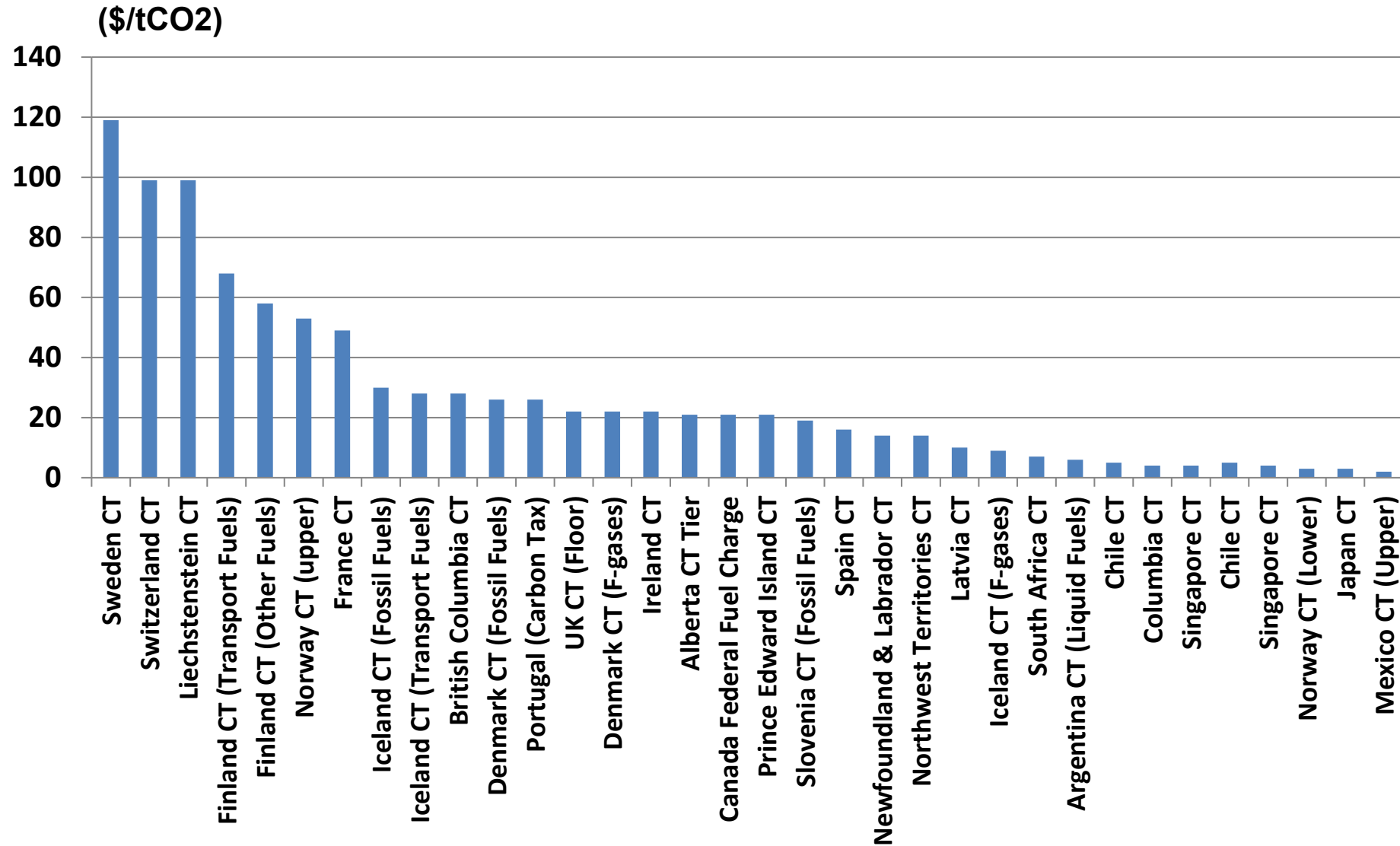
Carbon Price for existing ETS – 2020



Data from World Bank
State & Trends in Carbon Pricing 2020



Carbon Price for existing CT Systems - 2020



Data from World Bank
State & Trends in Carbon Pricing 2020



The EU example



EU: The Key Drivers - 3x20% by 2020

European Council March 2007, integrated in the law in 2009

+ 20% by 2020
EFFICIENCY

By 2020 - 20% GHG vs 1990

By 2020 20% RENEWABLES
(France: 23%)

BIO-FUELS

10 % 2020
binding

E-ELECTRICITY

HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS



EU: The Key Drivers - 32%x40%x32% by 2030

New objectives of European Council 2018, for the period 2021-2030

**+ 32,5% by 2030
EFFICIENCY**

By 2030 - 40% GHG vs 1990

By 2030 32% RENEWABLES

BIO-FUELS

- 1st Generation Biofuels frozen at their 2020 level and < 7%
- Palm Oil: 0 as from 2030
- Other modern Biofuels and Biogas > 3,5%

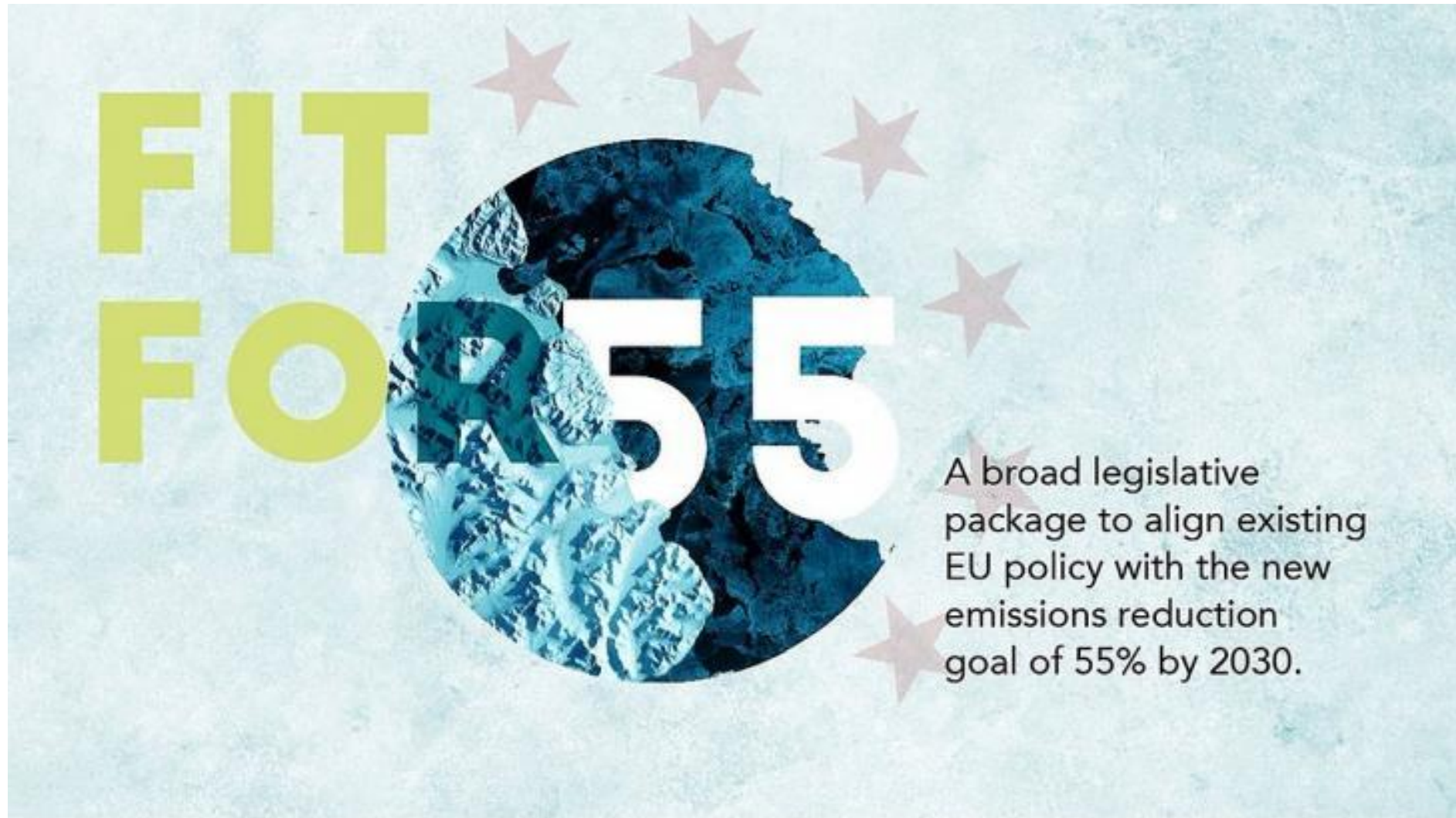
E-ELECTRICITY

HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS



New objectives of European Council 2021 -55% GHG Emissions by 2030 vs 1990



History of EU ETS



International/EU CO₂ markets

During Kyoto 1, 8 markets have been created: Korea-China, EU-Switzerland, Australia-New-Zeland, California-Quebec, Kazakhstan, South America.

In Europe, Establishment of ETS (EU-Emission Trading System), EU-28 + Iceland, Norway and Liechtenstein.

2005-2007 (EU-ETS Phase 1): Pilot phase/Definition of quotas.

2008-2012 (EU-ETS Phase 2) : 79 Gt AAU's allocated worldwide, surplus of 13 Gt. 2,1 Gt allocated yearly to EU. EU : Inclusion of civil aviation in quotas allocations as from 2012.

2013-2020 (EU-ETS Phase 3) : 2,0 Gt allocated yearly to EU.

Price of CO₂ (Monthly average & maximum, yearly average):

2005: 30 €/t

2008: 22 €/t, maximum 30 €/t

2011: 13 €/t, maximum 17 €/t

2012: 7 €/t, maximum 9 €/t

2013: 4 €/t, maximum 7 €/t

2015: 7 €/t, maximum 8 €/t

2017: 5 €/t, end 2017, rebound in 2018

2018: 23 €/t, end 2018

2019: 17 €/t, end 2019

2021: 50 €/t, Average

2022: 81 €/t, Average

2023: 83 €/t, Average

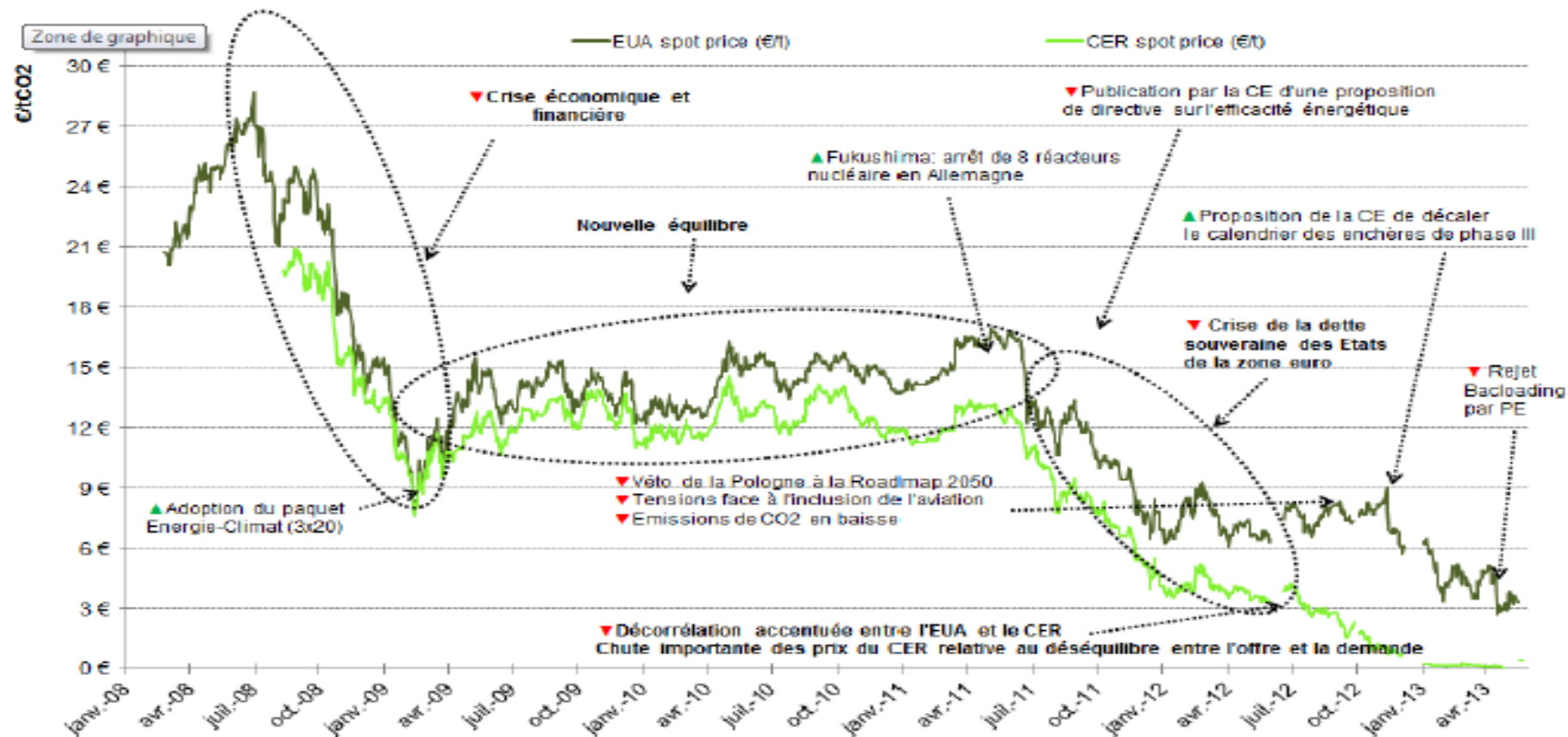
2025: 84 €/t, December 2025

AAU: Assigned Amount Unit



Reminder - CO₂ UE-ETS price evolution 2008 - 2014

Evolution prix-volume des quotas EUA depuis le début de la phase 2

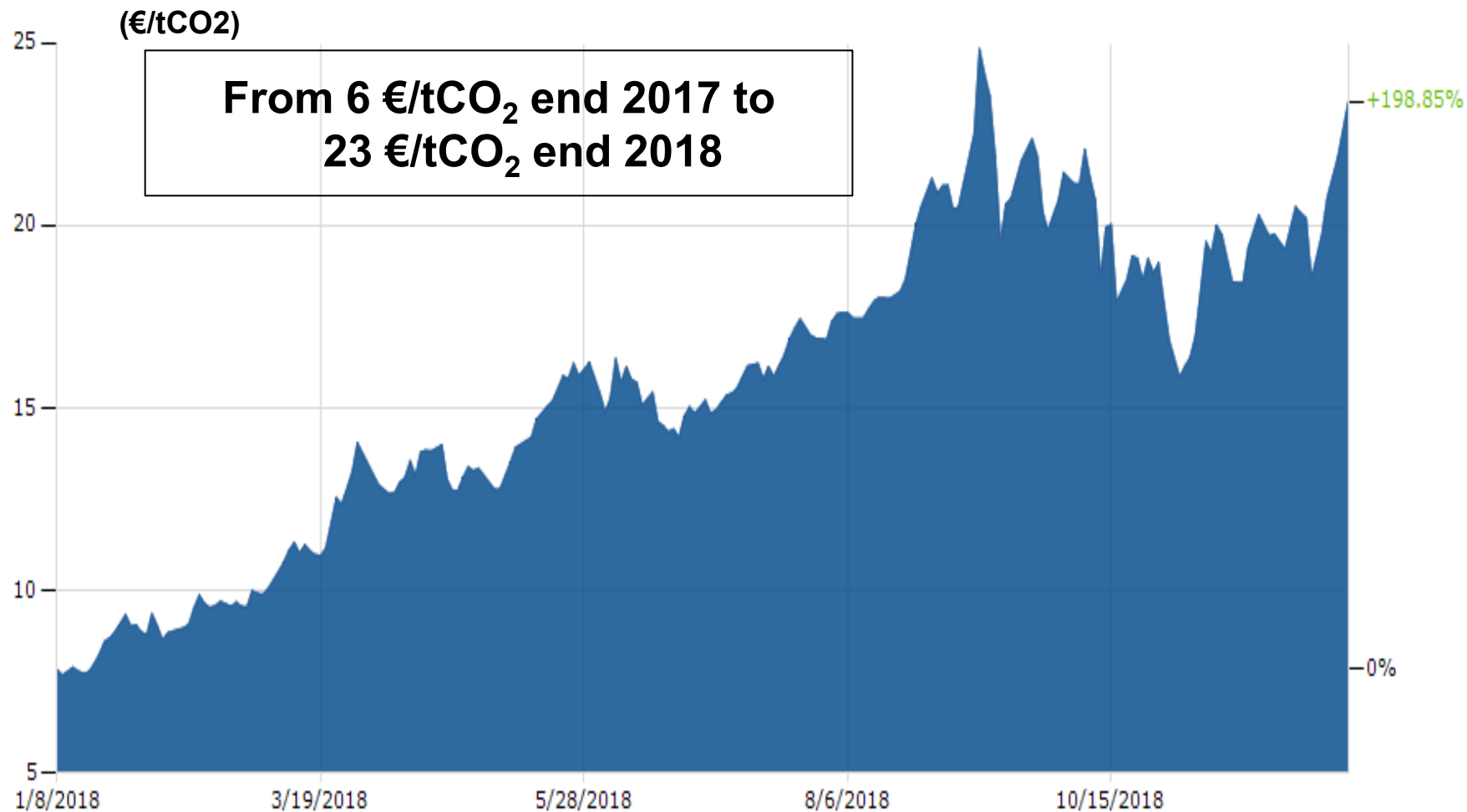


EUA: European Union Allowances
CER: Certified Emissions Reduction

Source : CDC Climat Recherche, BlueNest, ICE Futures Europe Point Carbon



Reminder - CO₂ EU-ETS Price Evolution From January 2018 to mid-December 2018 The Rebound: Allowances to be reduced in EU)



Source: Marketsinsider

393

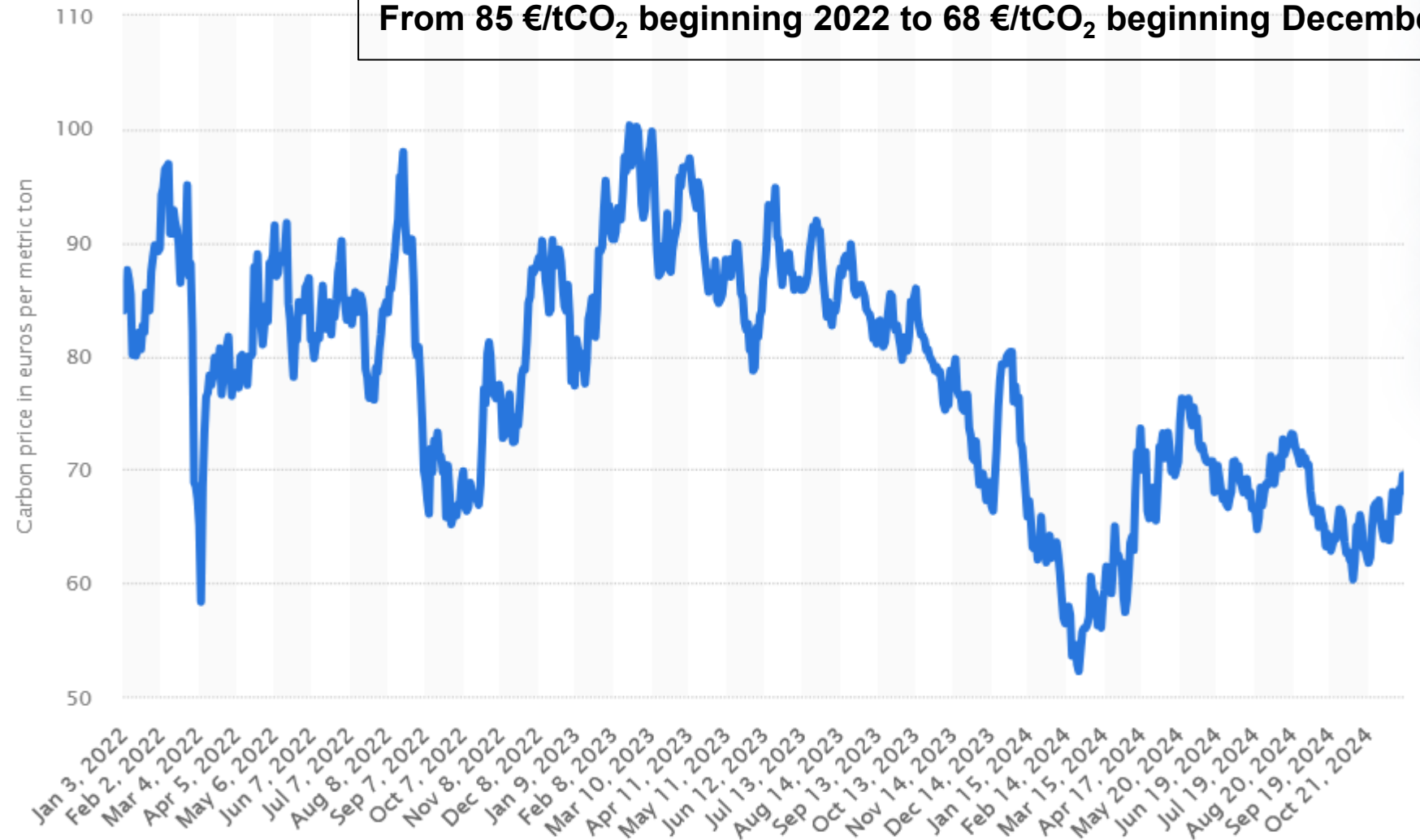
TPA Toolbox Energy Book 3 - GHG



CO₂ EU-ETS Price Evolution From January 2022 to November 2024

(€/tCO₂)

From 85 €/tCO₂ beginning 2022 to 68 €/tCO₂ beginning December 2024



Source: Statista

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TPA Toolbox Energy Book 3 - GHG



CO₂ EU-ETS Price Evolution From January 2020 to beginning December 2024



Past, present and future Evolution of EU ETS

- ❑ From 2005 to 2013, the sectors covered by emissions trading have reduced their emissions by 13%. EU ETS has raised Companies awareness of carbon costs and mitigation potential.
- ❑ But, after a peak mid-2008, CO₂ spot price decrease substantially following the 2008/2009 financial and economic crisis, further later due to the debt crisis of euro zone states.
- ❑ These events generated important accumulated surplus allowances resulting in a decrease of spot prices.
- ❑ Third Trading period started in 2013. The system has been unified under a common cap, instead of national allocation plans. CO₂ prices are going to increase.
- ❑ Fourth Trading period is deemed to start from 2021.
- ❑ Proposal for a Market Stability Reserve (MSR)
- ❑ Important increase of EU Carbon Price in 2021, 2022 & 2023.
- ❑ Impact of russian invasion of Ukraine in 2022.



Carbon Tax in France

- **Contribution Énergie Climat (CCE): implementation in 2014.**
- **7,0 €/tCO₂ in 2014**
- **14,5 €/tCO₂ in 2015, 22 €/tCO₂ in 2016, 30,5 €/tCO₂ in 2017**
- **44,6 €/tCO₂ in 2018**
- **Unchanged since then**
- ***Initial Objective: 100 €/tCO₂ in 2030?***
- **Applied on all fuels consumption: gasoline, diesel, fuel, gas, coal.**
- **Short term consequence: gasoline and diesel prices will substantially increase in the years to come.**



Carbon Tax in France (On Fuels Consumption)

	Gasoline (Alcane)	Diesel (Hexadecane)
Carbon Tax 2018 Unchanged since then	44,6 €/tCO ₂	44,6 €/tCO ₂
Volumic mass	0,74 kg/l	0,85 kg/l
CO ₂ Emissions	3,09 tCO ₂ /t	3,16 tCO ₂ /t
CO ₂ Emissions	2,28 kg/l	2,68 kg/l
Carbon Tax/Volume	0,10 €/l	0,12 €/l



Carbon Pricing used by Companies in the past

Carbon Pricing has been revised upwards

Microsoft Google Walt Disney Devon Energy	ConocoPhillips Cairn Energy BP Shell Total	Encana	Azko Nobel ExxonMobil
0 – 20 \$/t	20 – 40 \$/t	40 – 60 \$/t	60 – 80 \$/t



Carbon Pricing within Total - Evolution 2008 - 2017

Carbon Pricing by the Numbers

67

Number of national (42) and subnational (25) jurisdictions that put a price on carbon emissions.

USD 52 billion

Value in 2017 of carbon pricing initiatives, including emissions trading schemes and carbon taxes — an increase of 7% over the previous year.

Around 1,400

Number of companies that disclosed the use of an internal carbon price.
Source: <http://www.worldbank.org/en/results/2017/12/01/carbon-pricing>

OIL AND GAS COMPANIES CALL FOR CARBON PRICING

In May 2015, six global oil and gas companies — BG, BP, Eni, Equinor (then Statoil), Shell and Total — sent an open letter to the United Nations Framework Convention on Climate Change (UNFCCC) and the Presidency of COP21 calling for the introduction of carbon pricing mechanisms. Their goal was to reduce uncertainty and promote more economically efficient methods to decrease carbon emissions worldwide.

Milestones



Carbon Pricing within Total – 2023/2024

Regional carbon prices

- EU27 + NO + UK:

From 2023 onwards the carbon price shall be the higher of (1) 100 \$_{mod}/t and (2) the local carbon tax implemented in the country. ETS quota purchases and free quotas can be applied in the following cases, and under the following conditions:

- Quotas shall be considered in the current and the first year of the LTP (2023 and 2024), in line with PdC and Budget forecast
- Quotas can be considered in years 2025+ under the condition (1) they are officially notified by Authorities, and (2) the resulting carbon price is higher than 100 \$_{mod}/t.

- Other countries w/ carbon price regulation:

Current price for 2023, 100 \$_{mod}/t from 2024 onwards

- Countries w/o carbon price regulation:

0 \$_{mod}/t in 2023 and 2024, 100 \$_{mod}/t from 2025 onwards

If no different local regulations apply, carbon prices shall be applied from production start-up onwards.



CO₂ Price in selected Regions vs Scenarios IEA WEO 2025 (\$/tCO₂)

USD (2024, MER) per tonne of CO ₂	2035	2040	2050
Current Policies Scenario			
Canada	70	70	70
China	14	14	14
European Union	87	87	87
Japan	2	2	2
Korea	13	13	13
Stated Policies Scenario			
Canada	126	126	126
China	22	26	34
European Union	89	92	174
Japan	39	61	105
Korea	52	62	75
Net Zero Emissions by 2050 Scenario			
Advanced economies with net zero emissions pledges	180	205	250
Selected emerging markets and developing economies*	125	160	200
Other emerging market and developing economies	25-50	35-85	55-180

*Includes Brazil, China, India, Indonesia and South Africa.

Notes: USD = United States dollar; MER = market exchange rate. Values are rounded.



Lack of confidence in the collective objective to reduce the GHG emissions and lack of credibility on the « price » of CO₂ discourage large investments to mitigate emissions.



Necessity to build-up a system leading to an « international » Price of CO₂. But such a system will be difficult to implement due to the diversity of situations and countries policies.

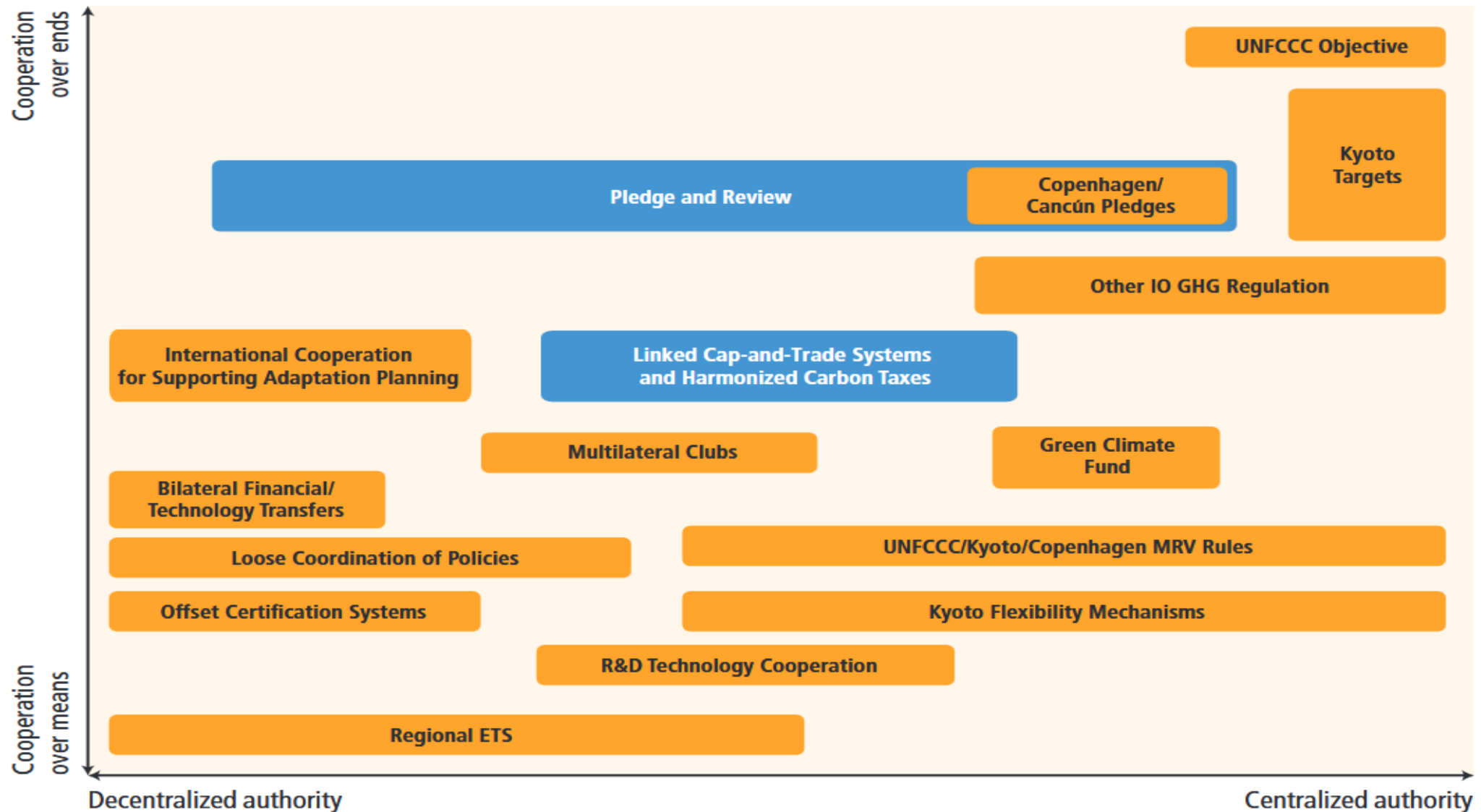
However, the increasing real concerns in relation with Climate Change challenges could promote new efforts to build-up a high level for Carbon pricing.



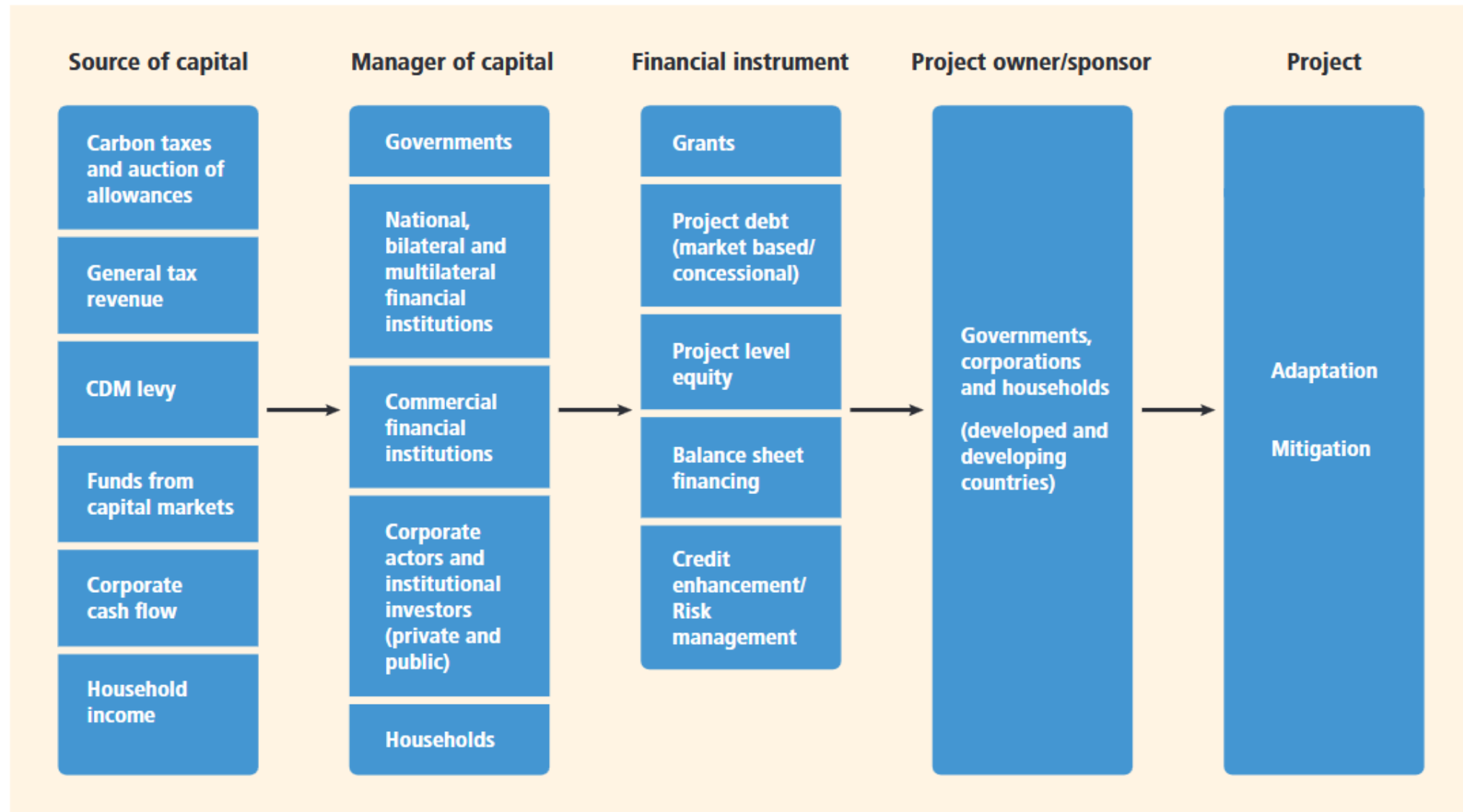
Reminder
Summary Policies, Mitigation & Adaptation
IPCC – 5th Assessment Synthesis Report November 2014



Need for a efficient international cooperation and management & control



Need for a efficient international cooperation and management & control

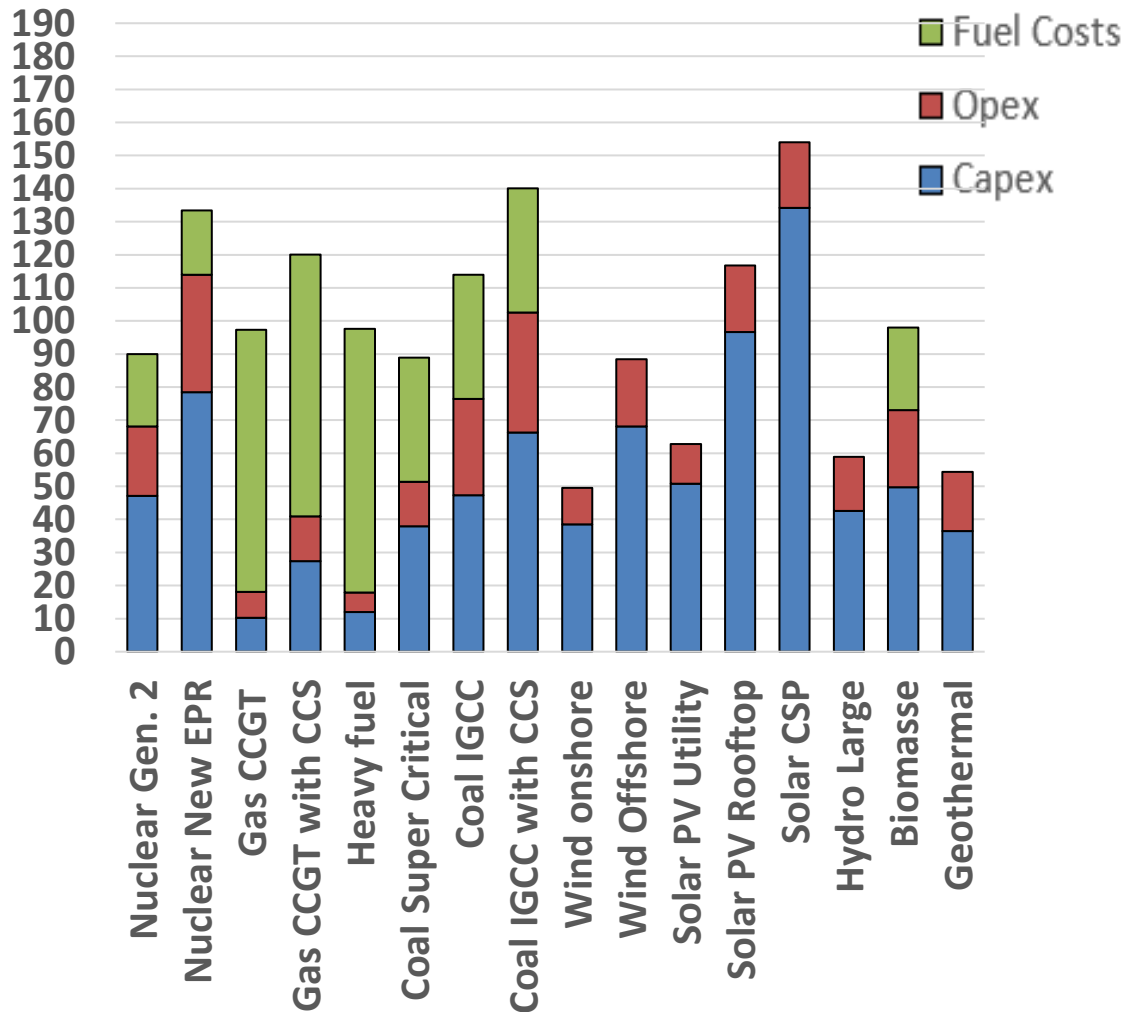


**Levelized Cost of Electricity
the Impact of a CO₂ penalty pricing
See also Book 2**

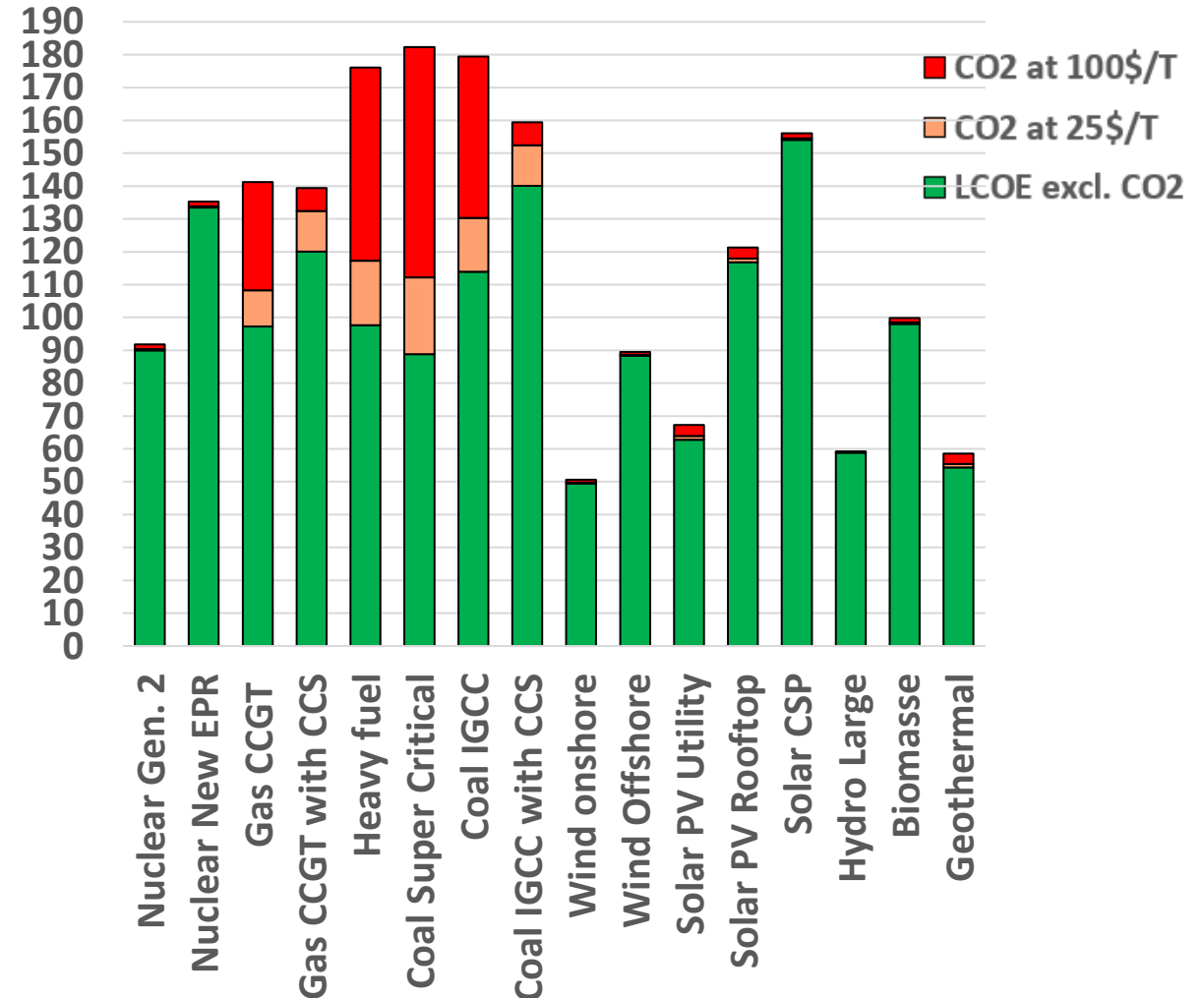


LCOE 2023/2024 Environment @ 5% (excluding & including CO₂ Penalty) (€/MWh)

Excluding CO2 penalty



Including CO2 penalty



From 2013 to 2025, LCOE have evolved very much, in particular for Renewable Energy, following the changes of the technical and economical environment



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Carbon Capture and Storage (CCS) technologies Carbon Capture Use and Storage (CCUS)



TABLE OF CONTENTS

1. What is science telling us about climate change ?
2. Economic consequences for energy and industries
3. The Kaya Equation
4. Agenda for Climate Change Negotiations
5. CO2 Markets, Pricing and Trading
6. Carbon Capture and Storage technologies
7. What implications for oil companies:
the case of TotalEnergies



CCS/CCUS – Carbon Capture Utilization & Storage



CCS: Carbon Capture and Storage

CCUS: Carbon Capture Utilisation and Storage



CCS basis principle

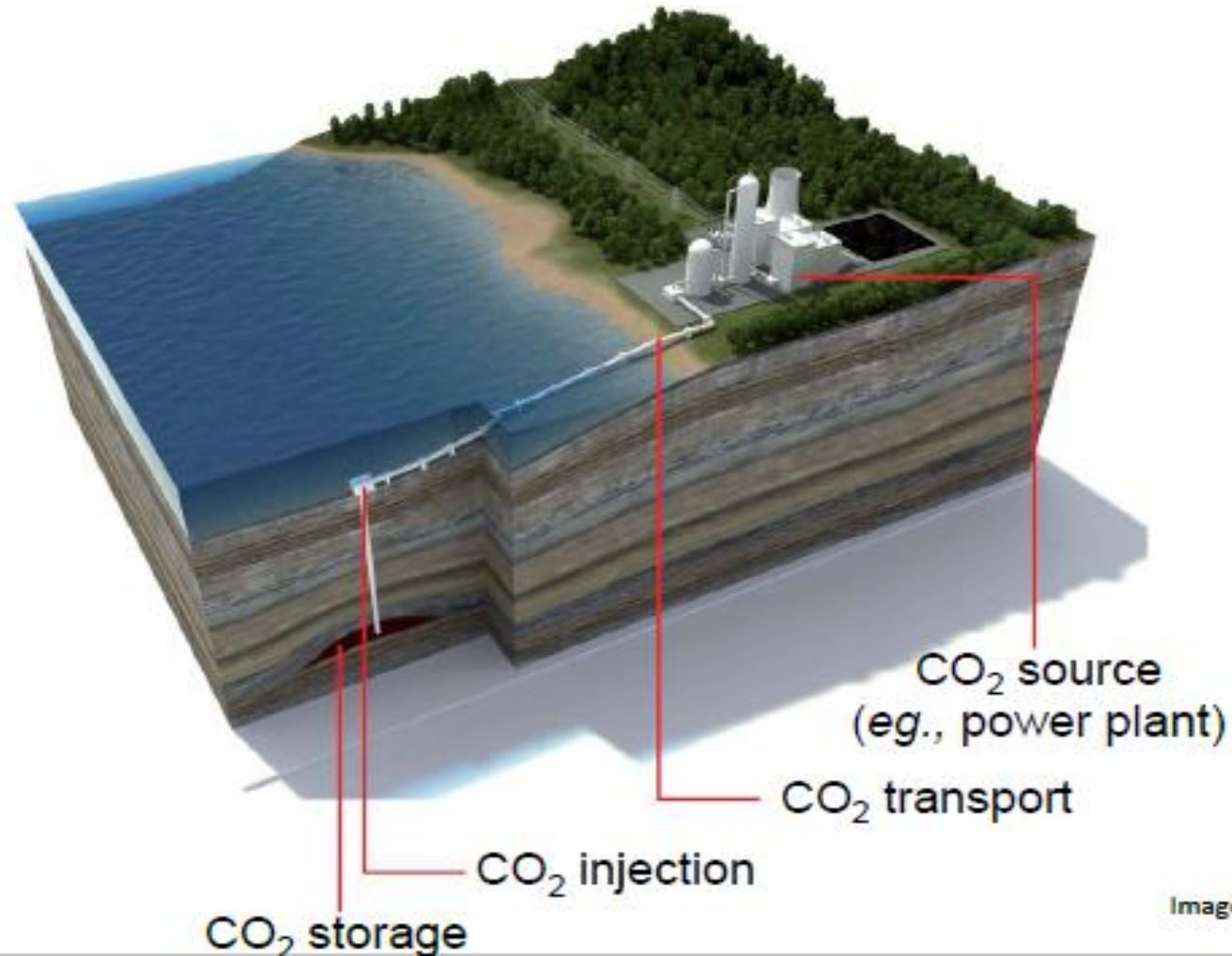
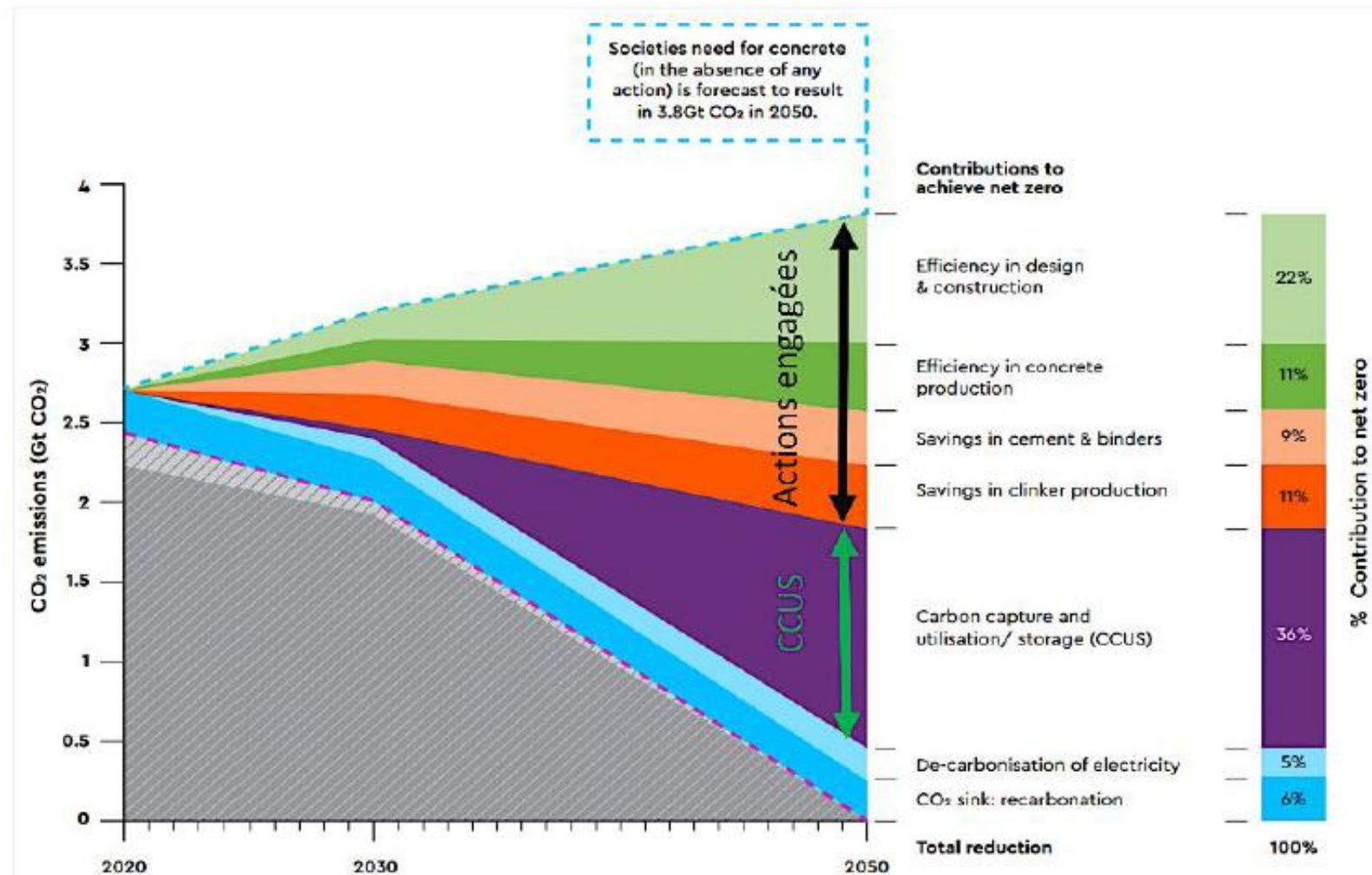


Image courtesy Bellona Foundation



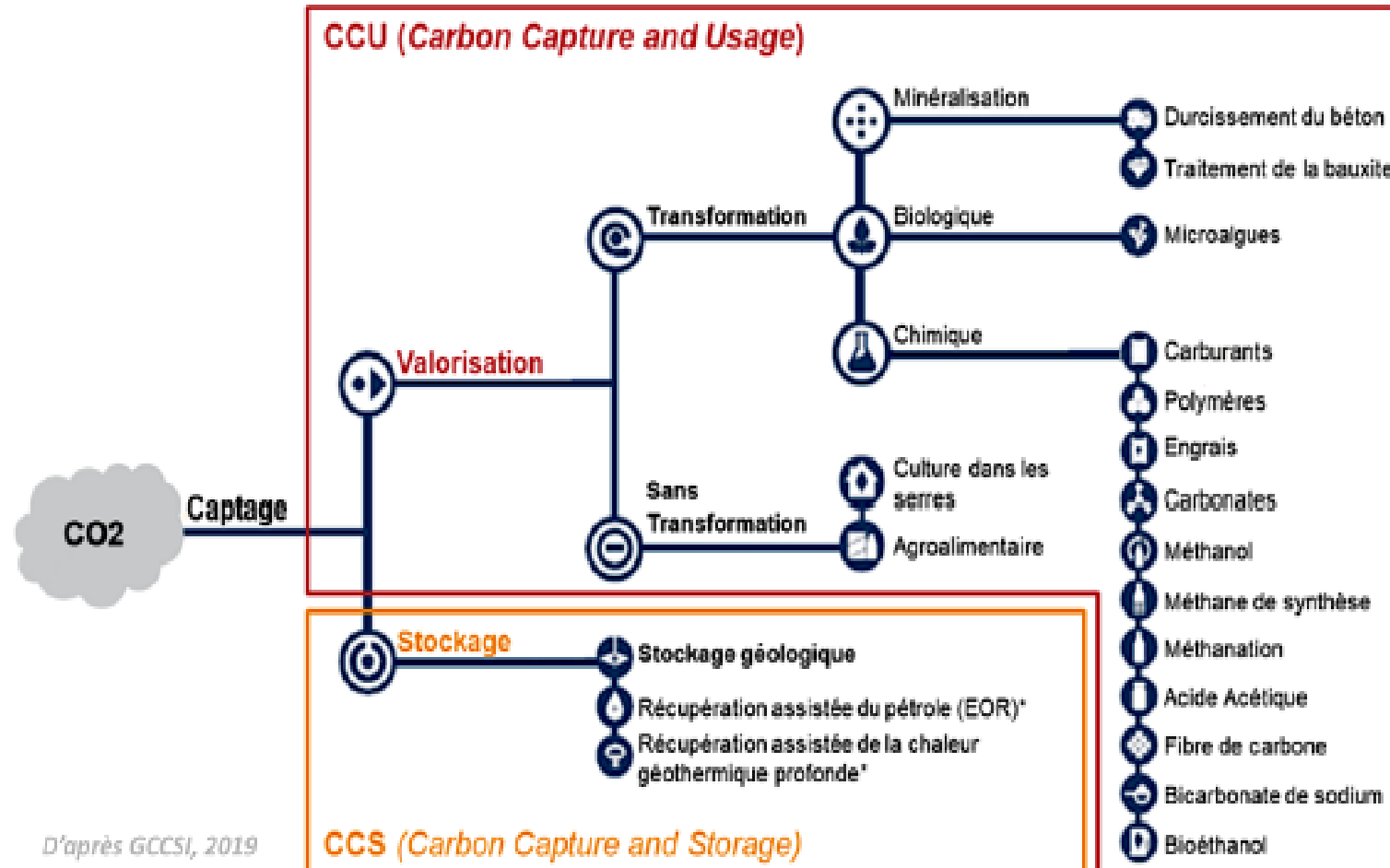
The Role of CCUS



Source: April 2024

Mission sur les projets européens de stockage géologique de carbone

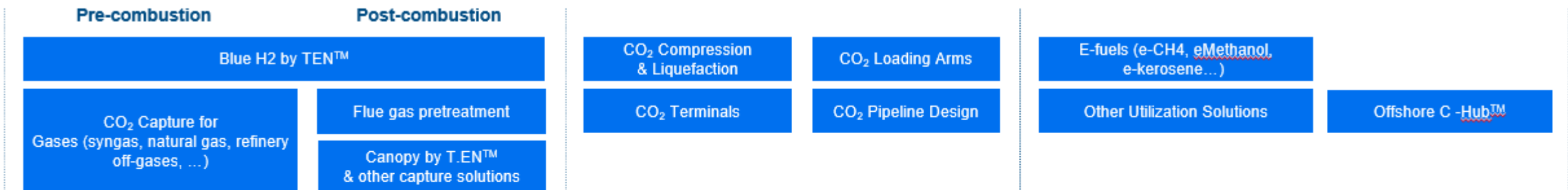
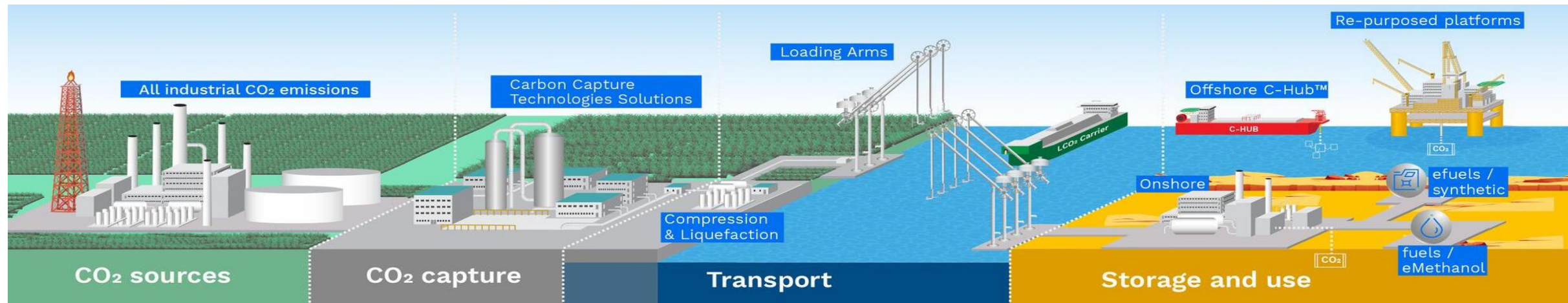
The Role of CCUS



Source: April 2024

Mission sur les projets européens de stockage géologique de carbone

Capture.Now™ & CO₂ value chain



SUPPORTING CLIENTS FROM EARLY STAGE TO TURNKEY DELIVERY AND BEYOND

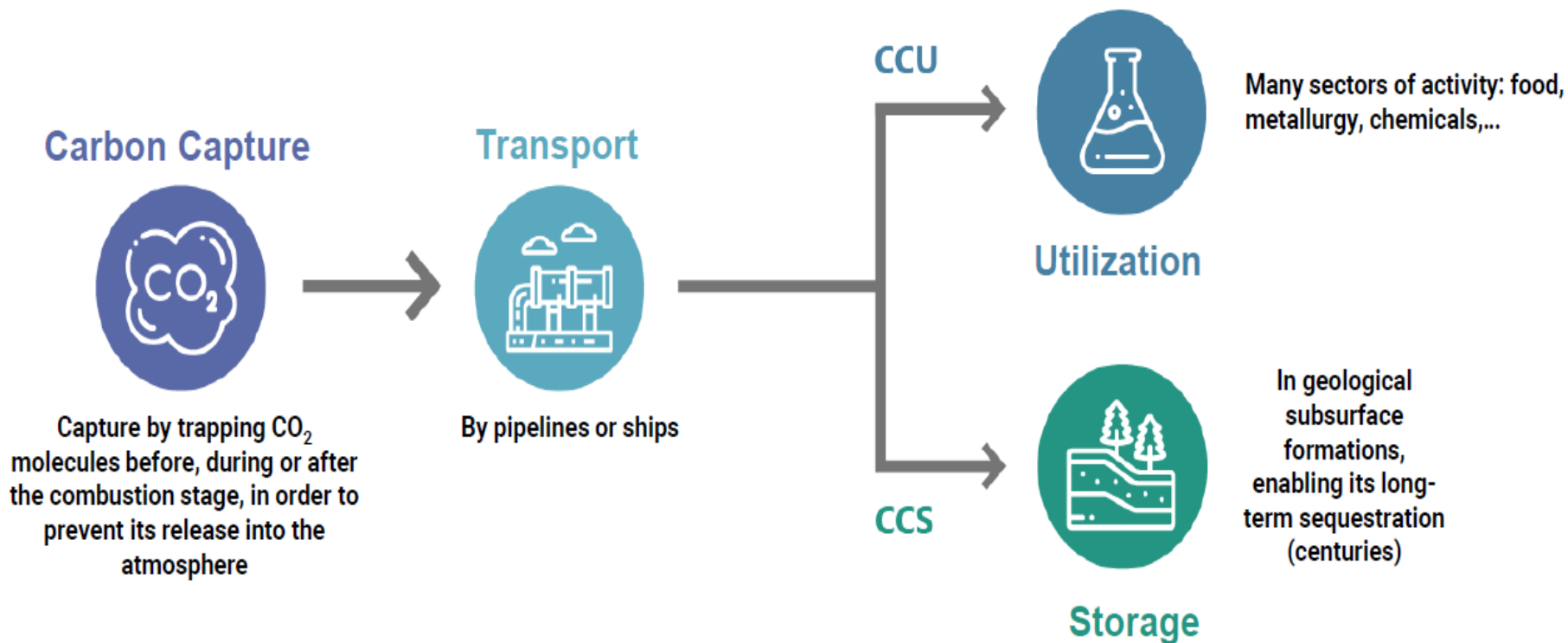


Source: EVOLEN 2023

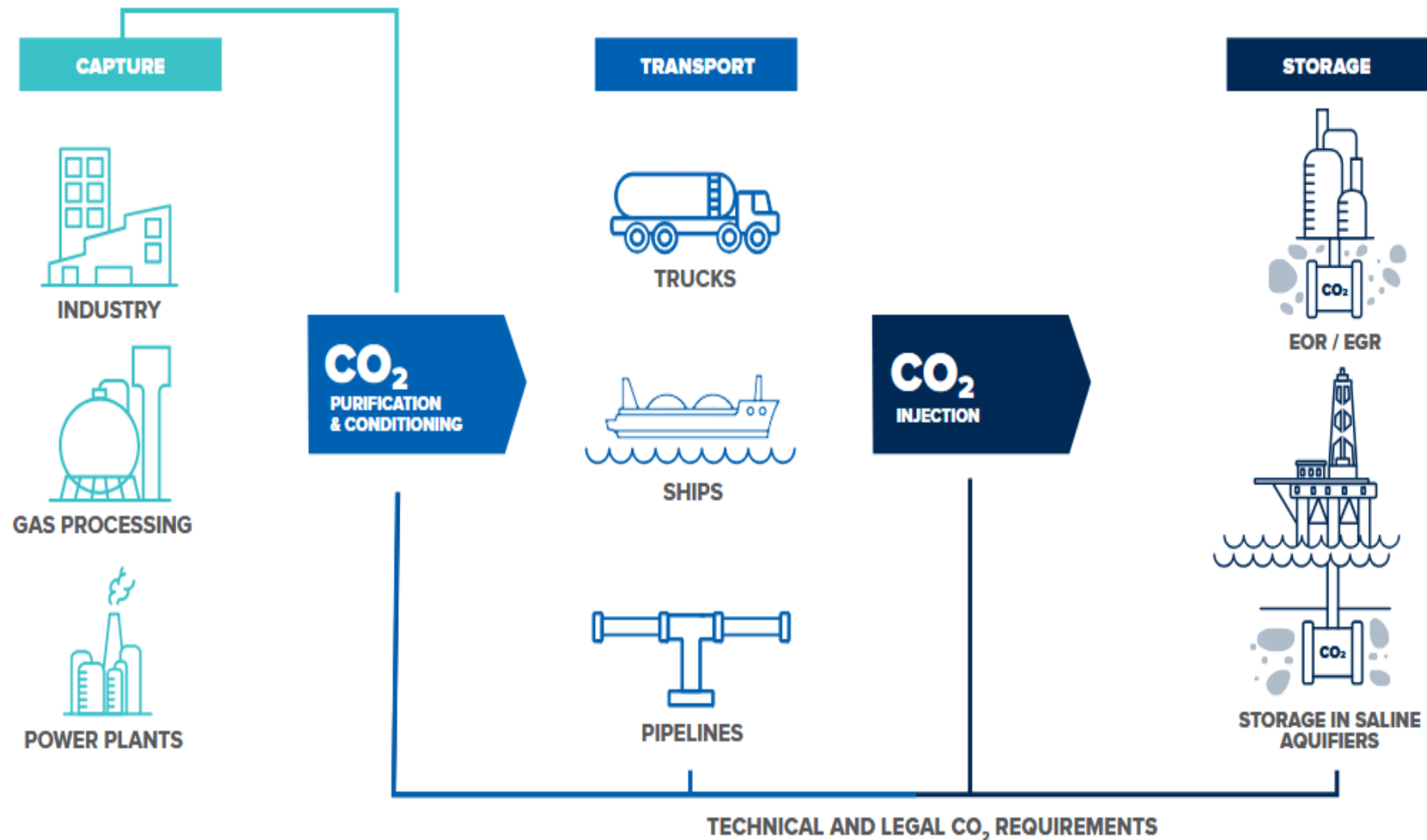


CCUS Value Chain

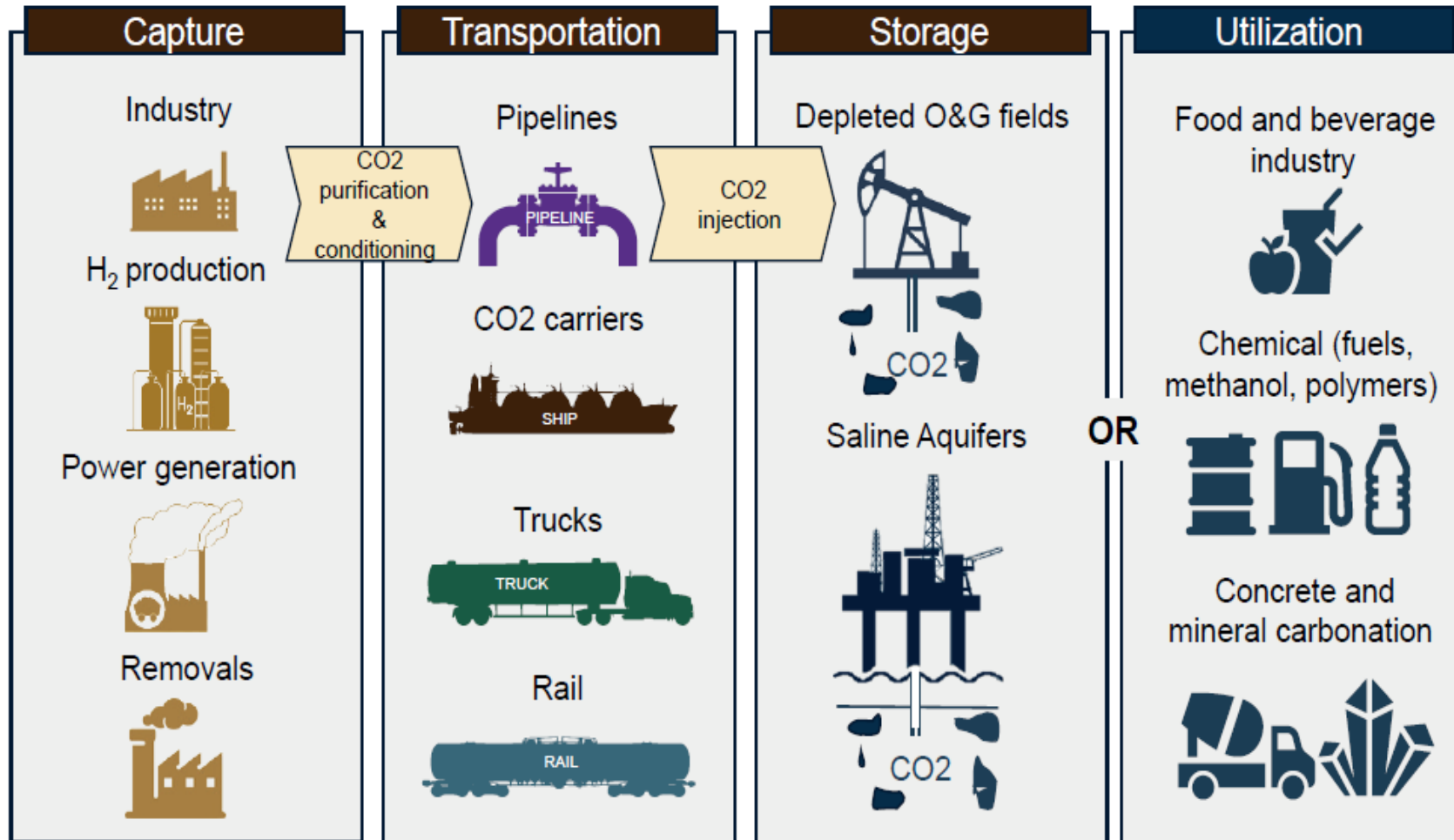
Carbon Capture Storage & Utilization (CCUS)



CCUS Value Chain



CCUS Value Chain

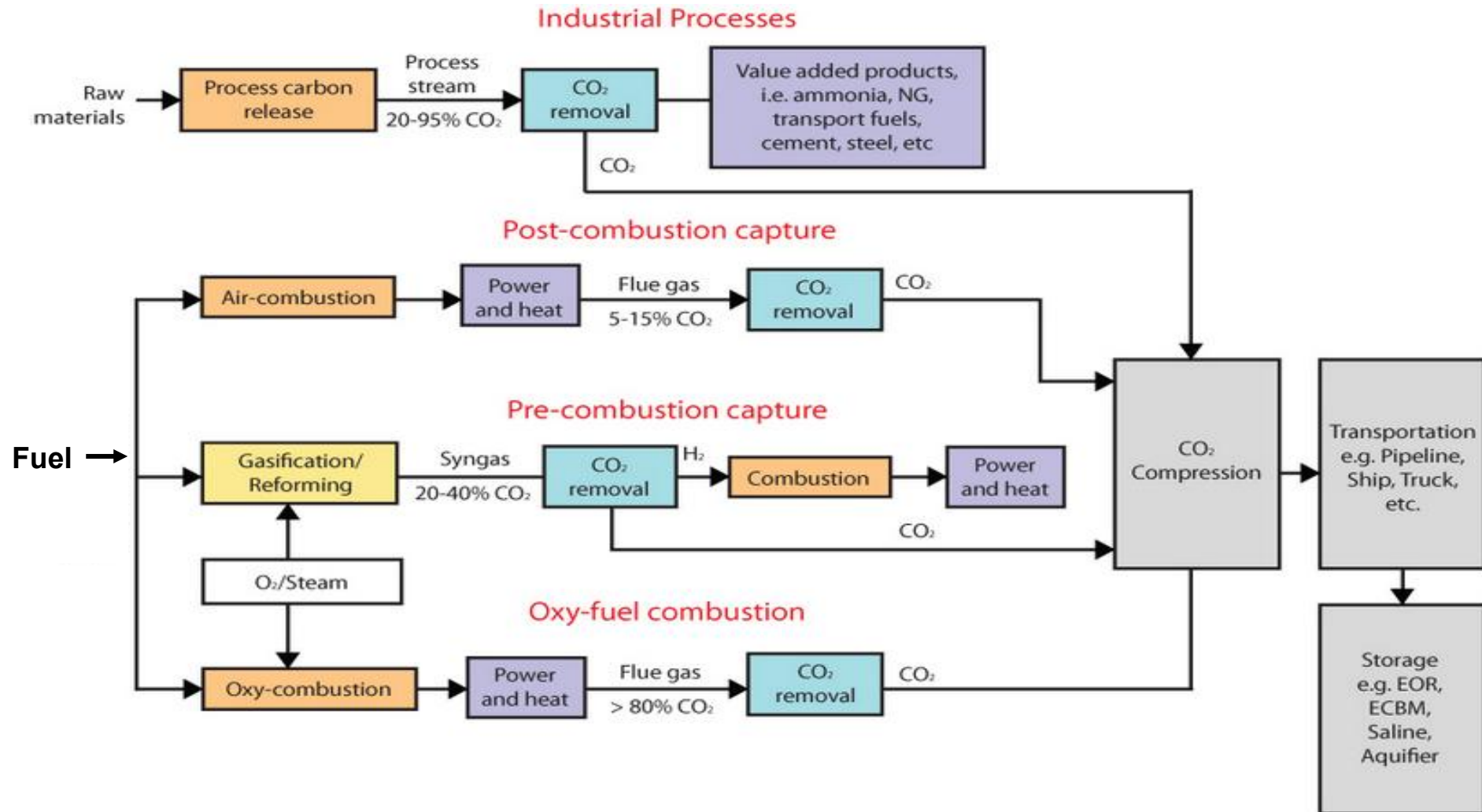


Source: Rystad Energy

Source: IGU/Rystad Energy

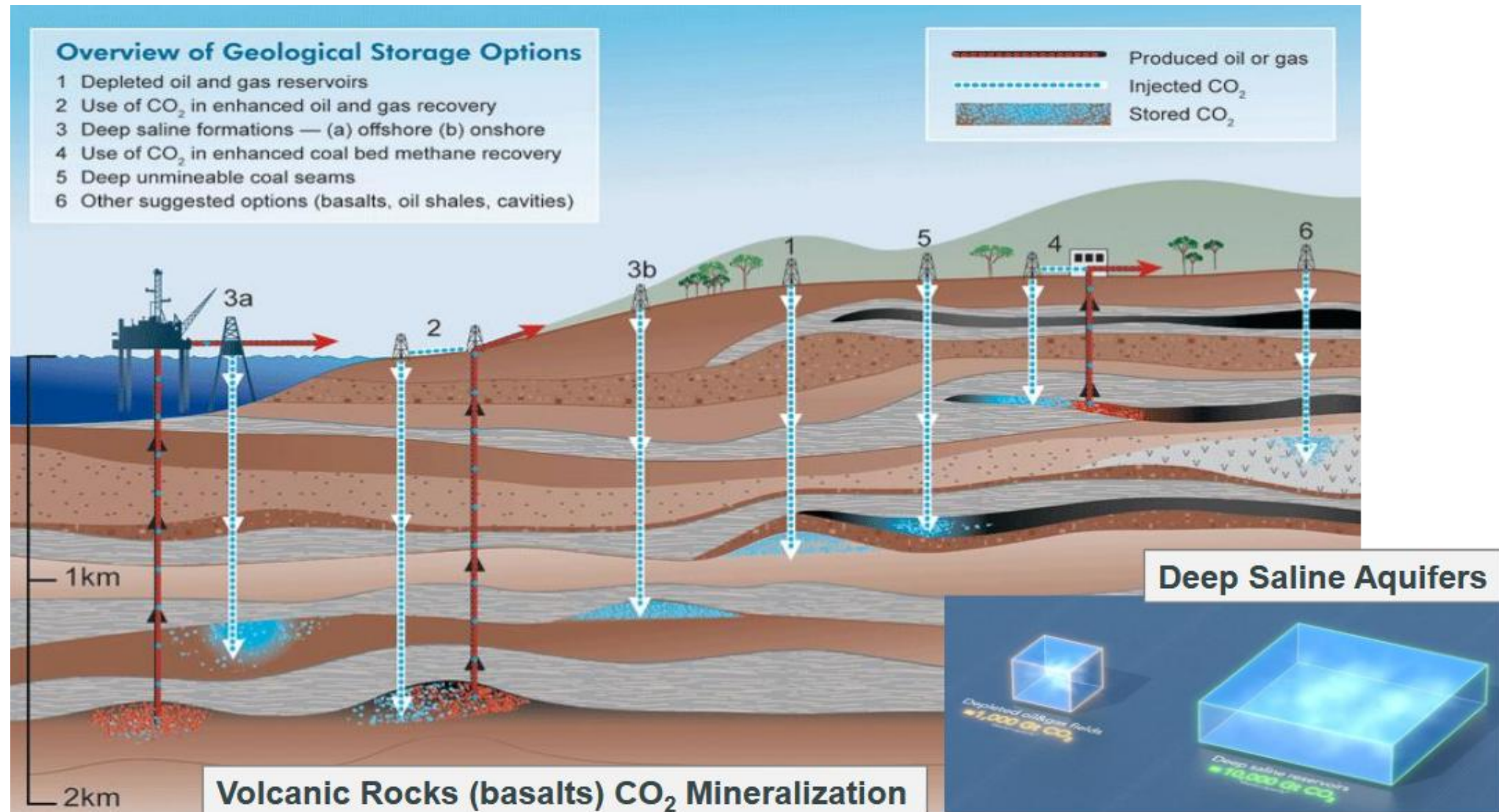
Carbon Capture (& Transport & Storage)

Three main Technologies



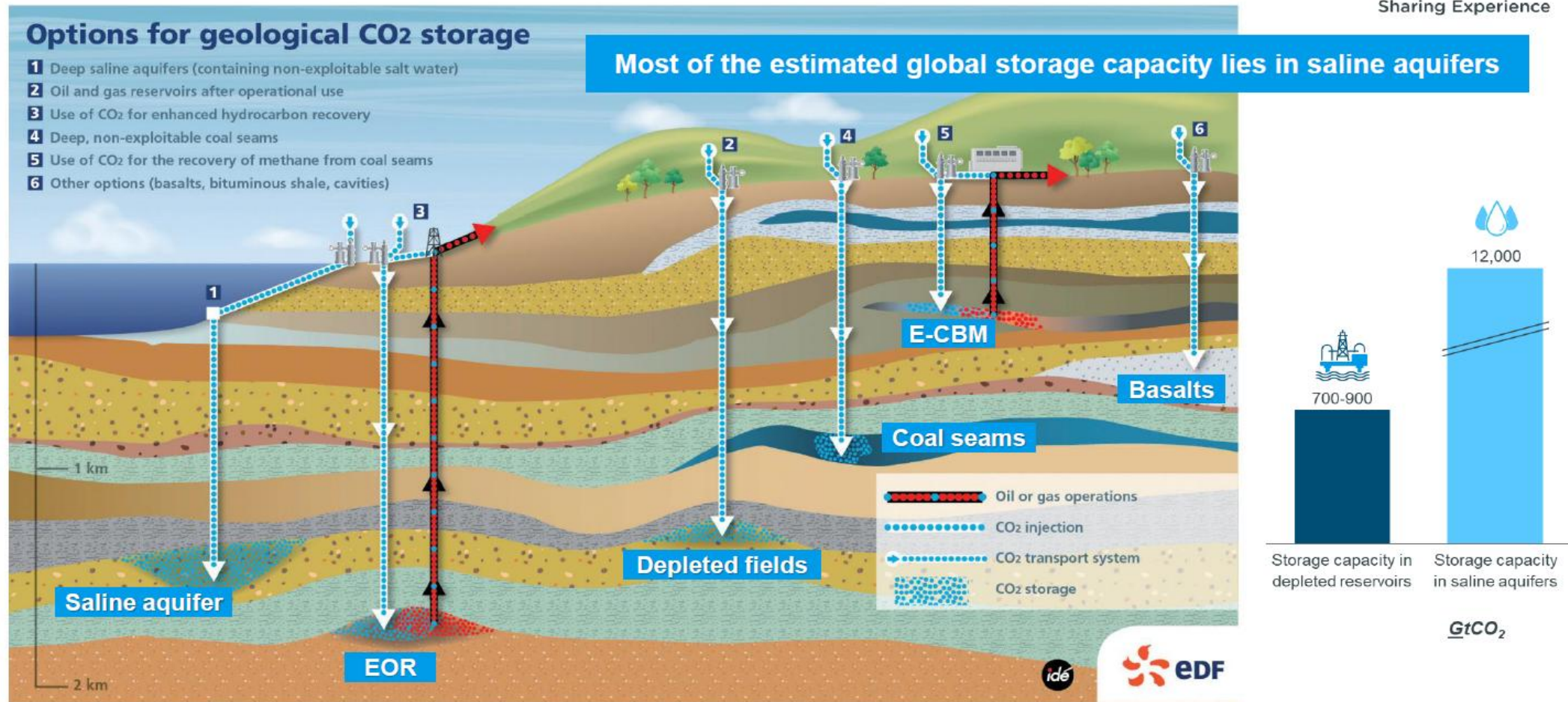
Source: Natural Resources Canada

CCS (Carbon Capture & Storage) and CCUS (+ Utilization) To Reduce CO₂ Emissions: Various options for geological storage



Various options for geological storage

Geological Storage Types

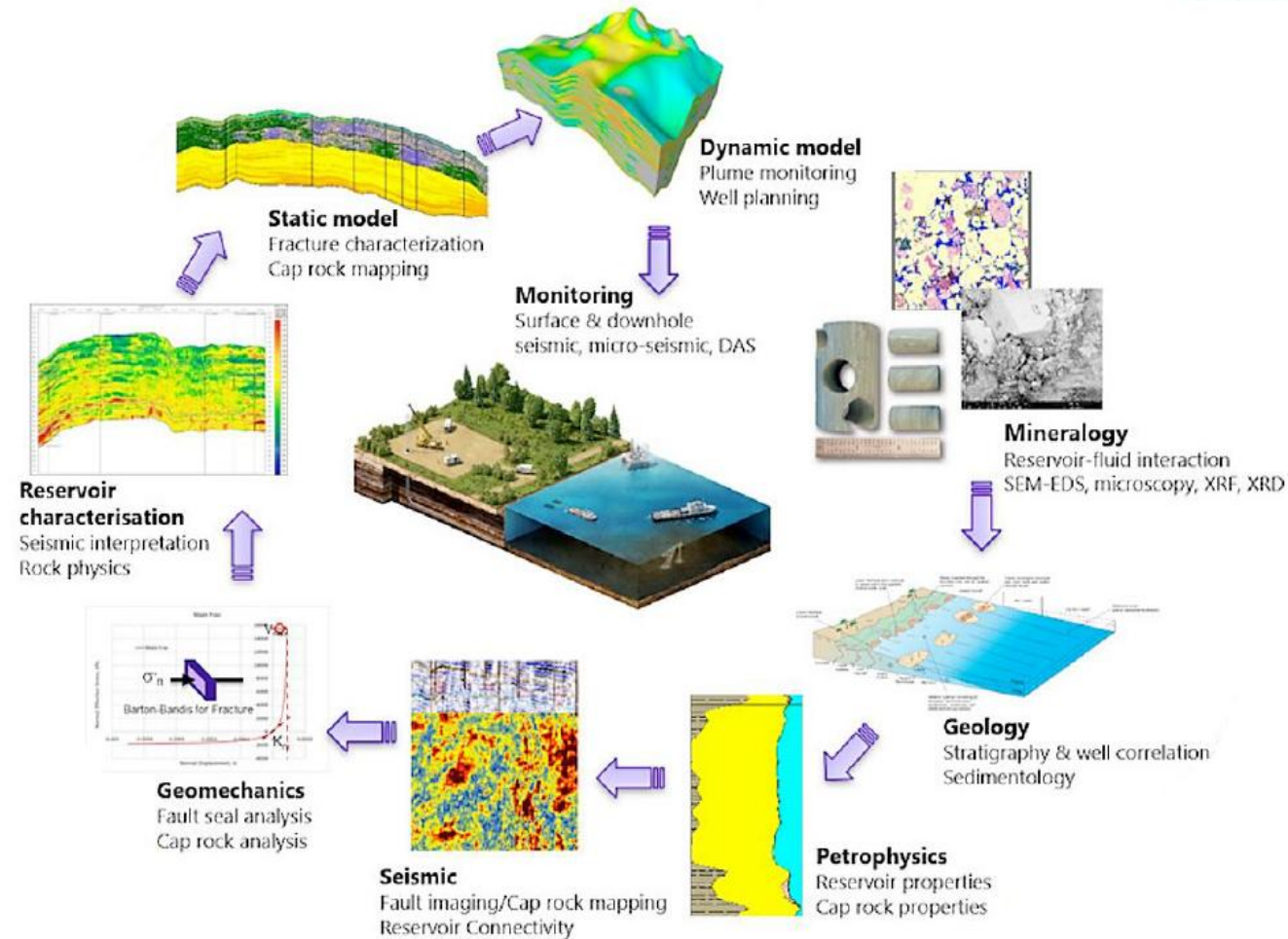


Source: Nicolas Nosjean

Geosciences for CCUS

Geoscience Disciplines Required in CCUS

- The **CCS technology** starts with mapping of the subsurface in order to find large volumes for storage.
- CCS technique & methods will need seismic interpreters, but also geologists for well data, understand and model the seal integrity, monitor the pressure and the fluid flows (4D)...



Source: Nicolas Nosjean

CCS Projects – Important challenges

Sleipner and Snøhvit demonstrate carbon capture and storage is not without material ongoing risks that may ultimately negate some or all the benefits it seeks to create.

Every project site has unique geology, so field operators must expect the unexpected, make detailed plans, update the plans and prepare for contingencies.

Ensuring storage is securely maintained implies a high level of proactive regulatory oversight, activities for which governments may not be adequately equipped.

Sleipner and Snøhvit cast doubt on whether the world has the technical prowess, strength of regulatory oversight, and unwavering multi-decade commitment of capital and resources needed to keep carbon dioxide sequestered below the sea – as the Earth needs – permanently.



Source: Institute for Energy Economics and Financial Analysis - June 2023

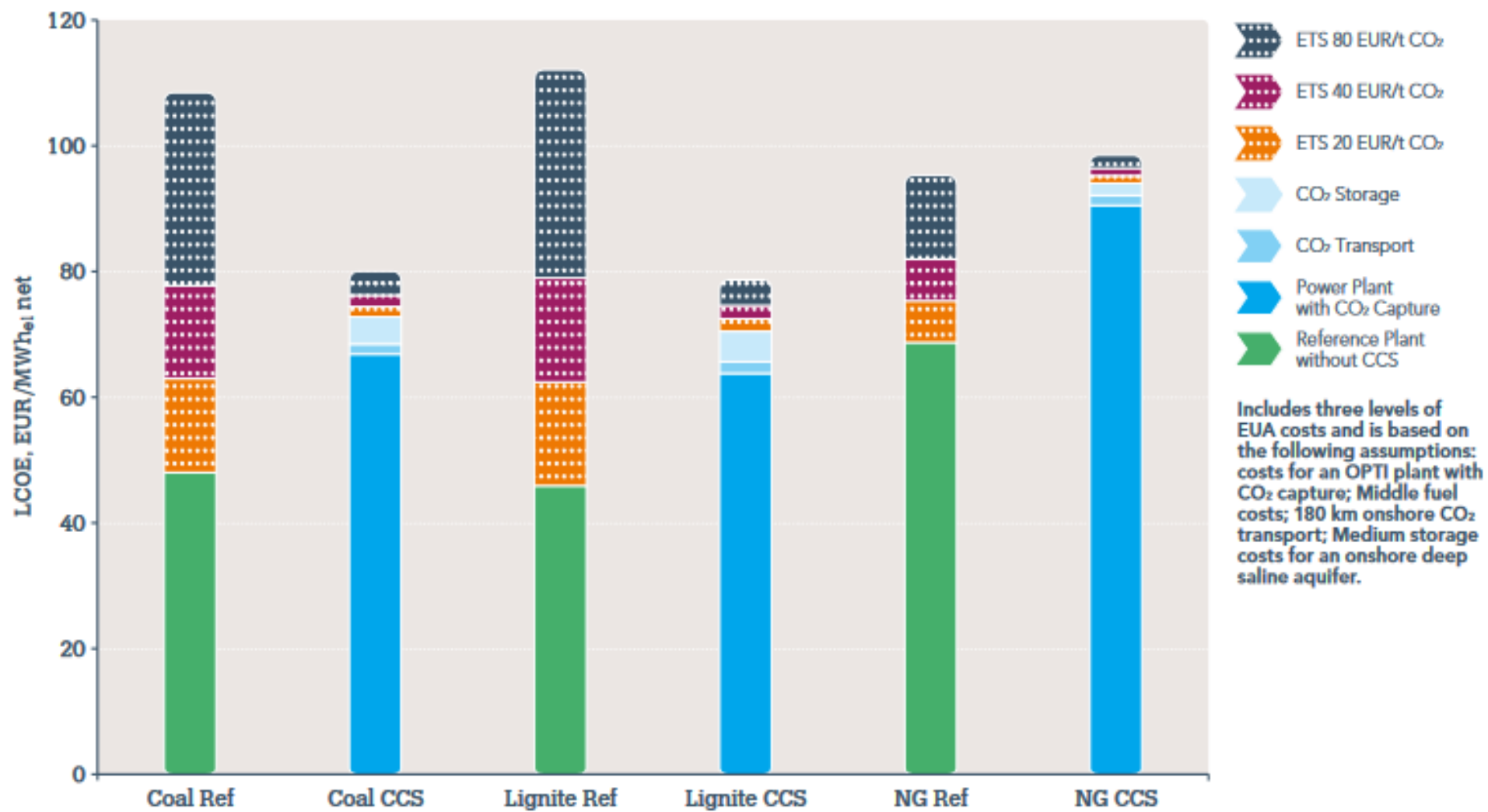


Example of a CCS Project



Source: European Technology Platform for Zero Emission
Fossil Fuel Power Plants

Typical LCOE of Projects with and without CCS

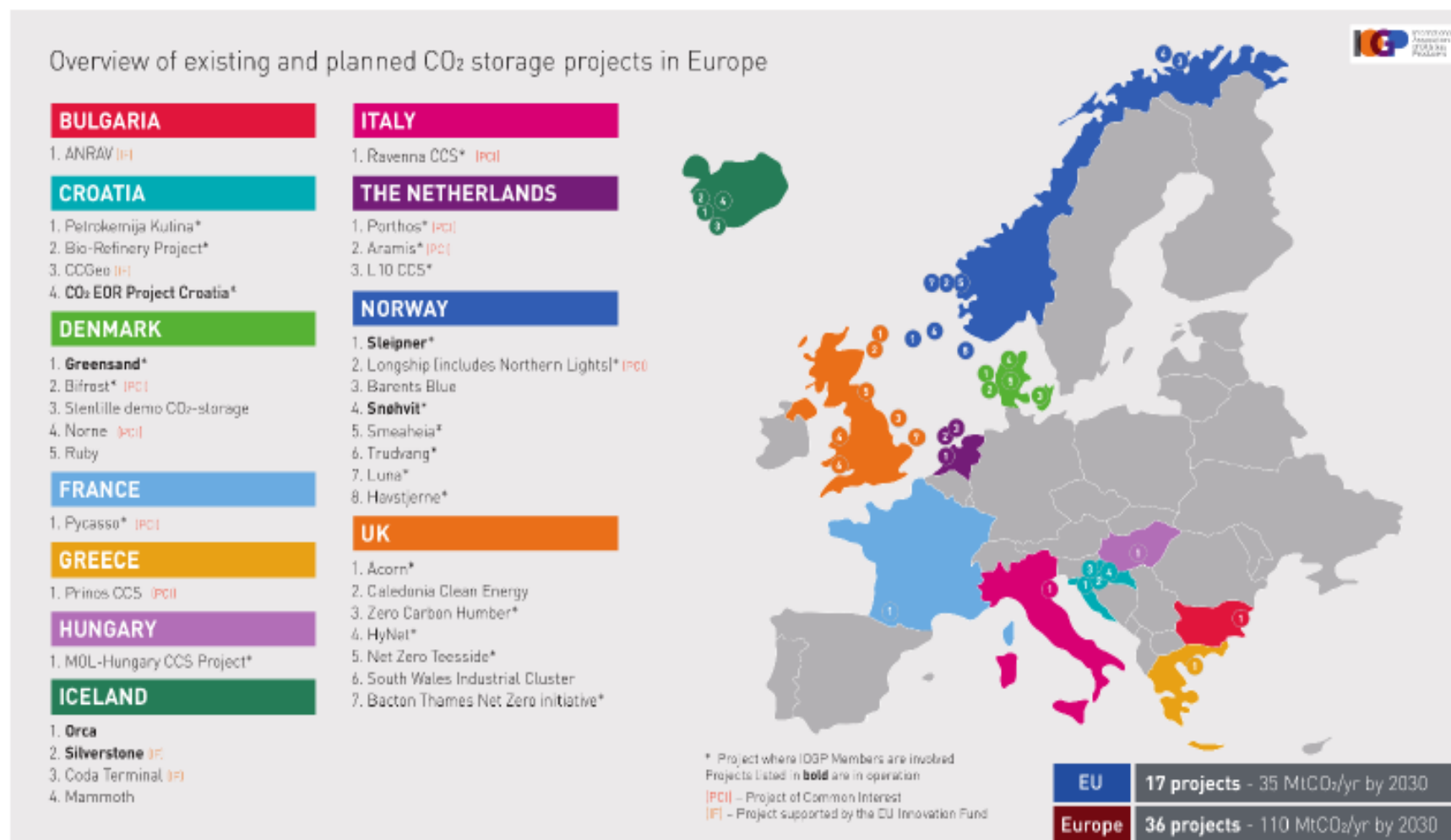


Source: European Technology Platform for Zero Emission Fossil Fuel Power Plants

A number of « paper » projects in the past years, but recently some important industrial realizations emerge
Some examples below, new projects emerge regularly, depending upon their economic viability



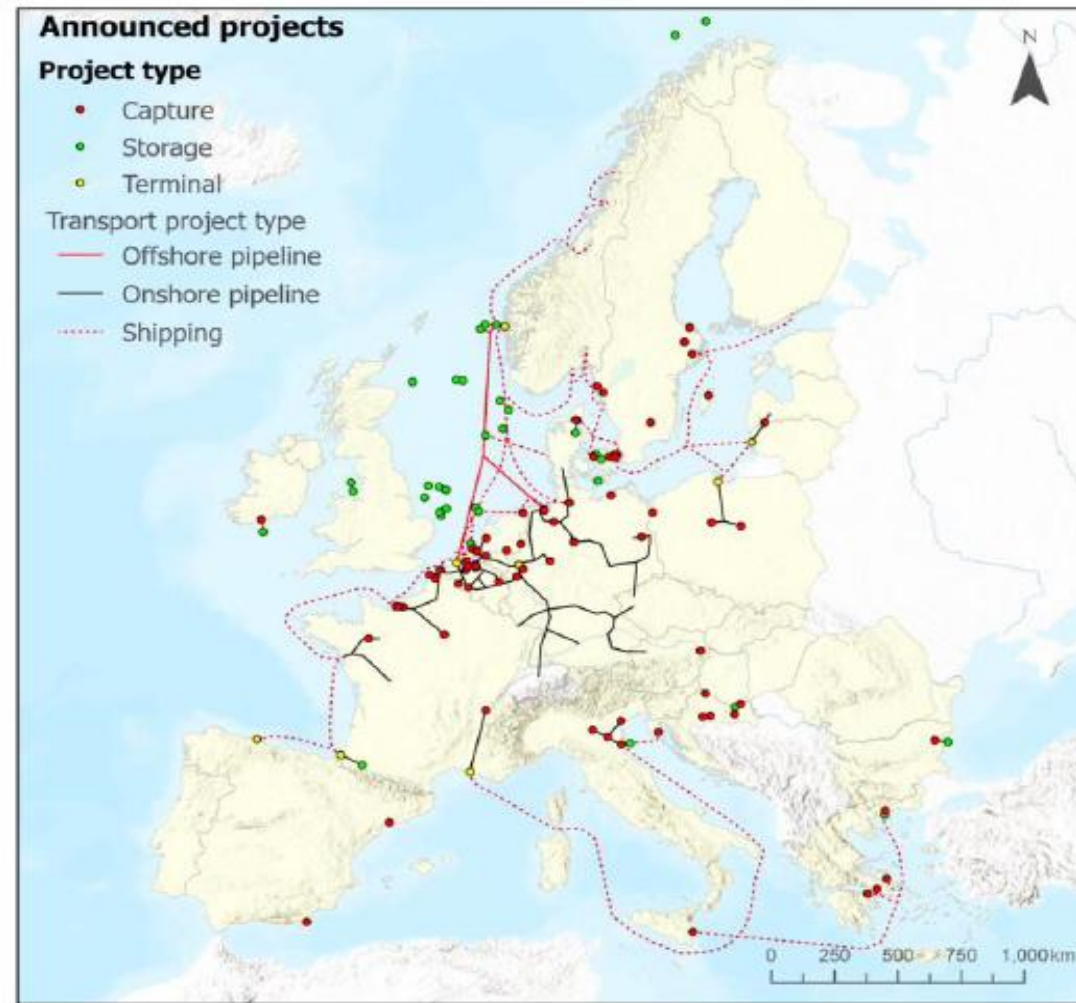
CCUS Projects in Europe



Source: April 2024

Mission sur les projets européens de stockage géologique de carbone

CCUS Projects in Europe



Source: April 2024

Mission sur les projets européens de stockage géologique de carbone

CCUS Projects in Europe



Mtpa 2030-2035	Number of projects	Capacity (Mtpa)
EOR	0	0
Natif CO2	2	1.6
Industrial CO2	34	115
Bio + atm CO2	6	19

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- Gas Storage
- Mineralization
- Saline Aquifer
- Depleted field

Concept/FEED - in construction - in operation
Years on the map = first injection

Source: TotalEnergies EP Data Book 2023

CCUS Projects outside Europe



Source: TotalEnergies EP Data Book 2023

CCUS Capture Capacities 2020 – 2025 by Energy Institute

From 180 MtCO₂/year to 260 MtCO₂/year (# 0,7% of emissions)



Carbon Carbon capture, usage and storage (CCUS)

Capture capacity Million tonnes per year*							Growth rate per annum		Share
	2020	2021	2022	2023	2024	2025	2025	2020–25	2025
Canada	10.6	10.6	10.8	13.0	13.2	19.3	45.7%	12.7%	7.5%
Mexico	0.5	0.5	0.5	0.5	0.5	0.5	†	†	0.2%
US	77.9	78.0	78.4	82.4	84.1	93.9	11.7%	3.8%	36.3%
Total North America	89.1	89.2	89.7	95.9	97.9	113.7	16.2%	5.0%	43.9%
Brazil	28.5	28.5	28.5	28.5	28.5	33.0	16.1%	3.0%	12.8%
Total S. & Cent. America	28.5	28.5	28.5	28.5	28.5	33.0	16.1%	3.0%	12.8%
Germany	2.9	2.9	2.9	2.9	2.9	3.6	23.0%	4.3%	1.4%
Norway	5.4	5.4	5.5	5.5	5.5	6.3	14.7%	2.8%	2.4%
Other Europe	10.8	10.8	11.6	11.7	12.8	18.1	42.0%	11.0%	7.0%
Total Europe	19.1	19.1	19.9	20.1	21.1	28.0	32.3%	7.9%	10.8%
Total CIS	–	–	–	–	–	–	–	–	–
Qatar	4.2	4.2	8.4	8.4	8.4	8.4	†	14.9%	3.2%
Saudi Arabia	2.6	2.6	2.6	2.6	2.6	2.6	†	†	1.0%
UAE	1.6	1.6	1.6	1.6	1.6	7.6	373.3%	36.6%	2.9%
Other Middle East	–	–	–	–	^	^	†	–	†
Total Middle East	8.4	8.4	12.6	12.6	12.6	18.6	47.6%	17.2%	7.2%
South Africa	0.3	0.3	0.3	0.3	0.3	0.3	†	†	0.1%
Total Africa	0.3	0.3	0.3	0.3	0.3	0.3	†	†	0.1%
Australia	18.0	18.0	18.0	18.0	22.8	22.8	†	4.8%	8.8%
China	9.9	10.1	13.0	15.3	16.3	28.5	74.7%	23.5%	11.0%
Other Asia Pacific	6.8	6.8	6.8	6.8	6.9	13.9	101.8%	15.3%	5.4%
Total Asia Pacific	34.7	35.0	37.9	40.2	46.0	65.2	41.7%	13.4%	25.2%
Total World	180.1	180.5	188.9	197.6	206.5	258.9	25.4%	7.5%	100.0%
of which: OECD	130.9	131.0	132.3	138.7	146.6	169.7	15.8%	5.3%	65.5%
Non-OECD	49.2	49.5	56.6	58.9	59.9	89.3	49.0%	12.6%	34.5%
European Union	11.3	11.3	12.1	12.1	13.1	17.4	33.0%	9.0%	6.7%

* Technologies include direct air capture, oxy-combustion, pre-combustion, and post-combustion.

^ Less than 0.05.

† Less than 0.05%.

Source: S&P Global Energy, ©2026 by S&P Global Inc.

Source: EI Stat. Review of World Energy 2026. Figures may differ according to sources & categorization/status of projects



Some existing projects for CO₂ Storage & EOR, not forgetting technical challenges



Five large-scale integrated projects are successfully storing CO₂

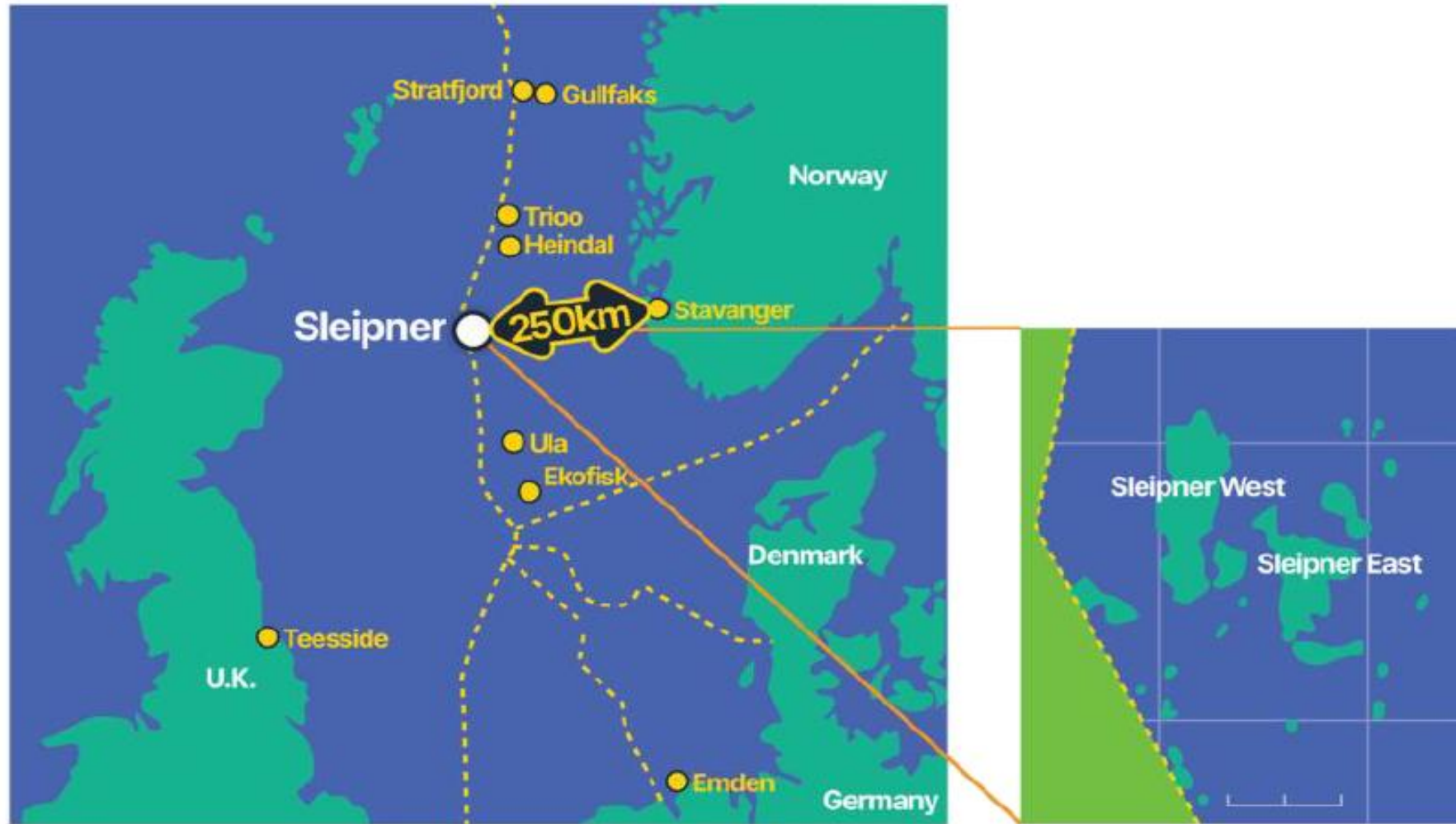
Sleipner	Norway	Natural Gas Processing	Start-up: 1996	1,0 Mt/year	16 MtCO ₂ injected at end 2016
Snohvit	Norway	Natural Gas Processing	Start-up: 2008	0,7 Mt/year	3 MtCO ₂ injected at end 2016
In Salah	Algeria	Natural Gas Processing	Start-up: 2004	1,0 Mt/year	suspended since 2011
Rangely	US	Natural Gas Processing	Start-up: 1980		
Weyburn	Canada	Synthetic Natural Gas	Start-up: 2000	3,0 Mt/year	26 MtCO ₂ injected at end 2016



A Zoom on Sleipner Project - Norway and Weyburn - Canada



Sleipner Project in Norway



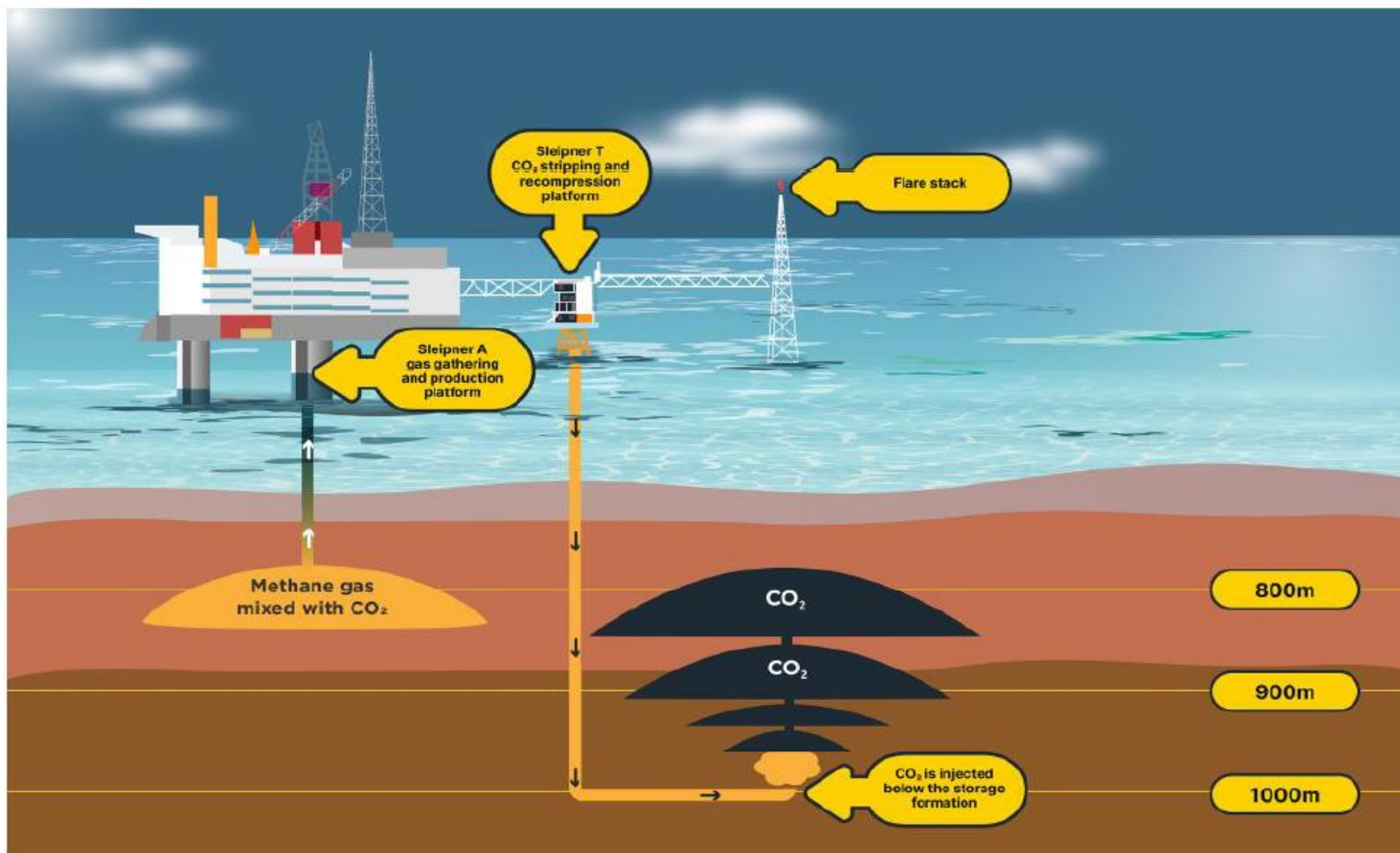
Source: Zhu Laboratory, Indiana University Bloomington.

IEEFA

Source: Institute for Energy Economics and Financial Analysis - June 2023



Sleipner Project in Norway

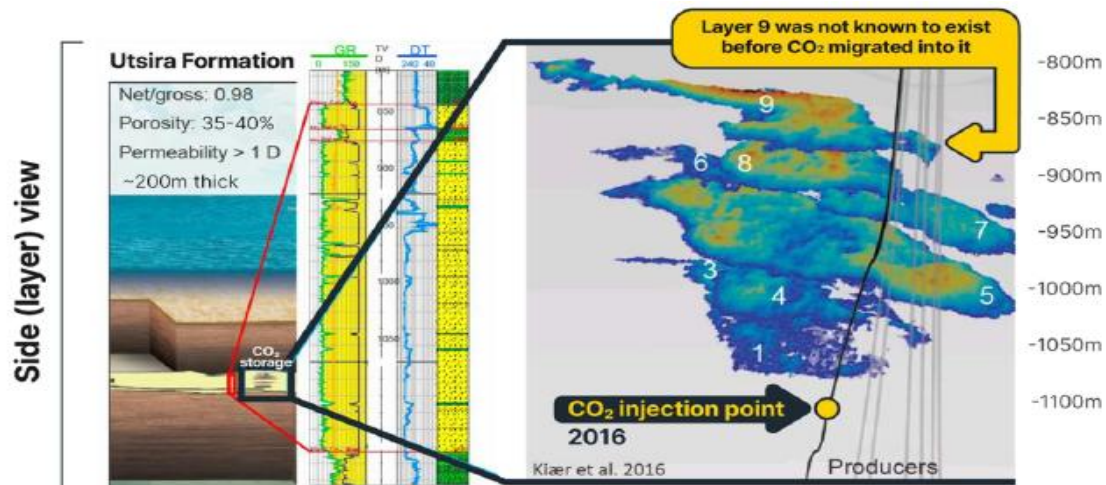


Source: Geological storage of CO₂: project design and global scale-up. Ringrose. March 29, 2021.

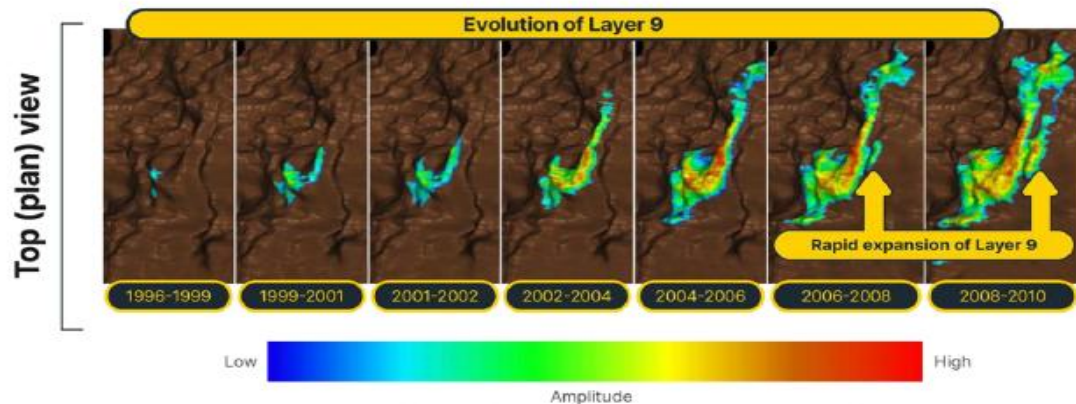
IEEFA

Source: Institute for Energy Economics and Financial Analysis - June 2023

Sleipner Project in Norway

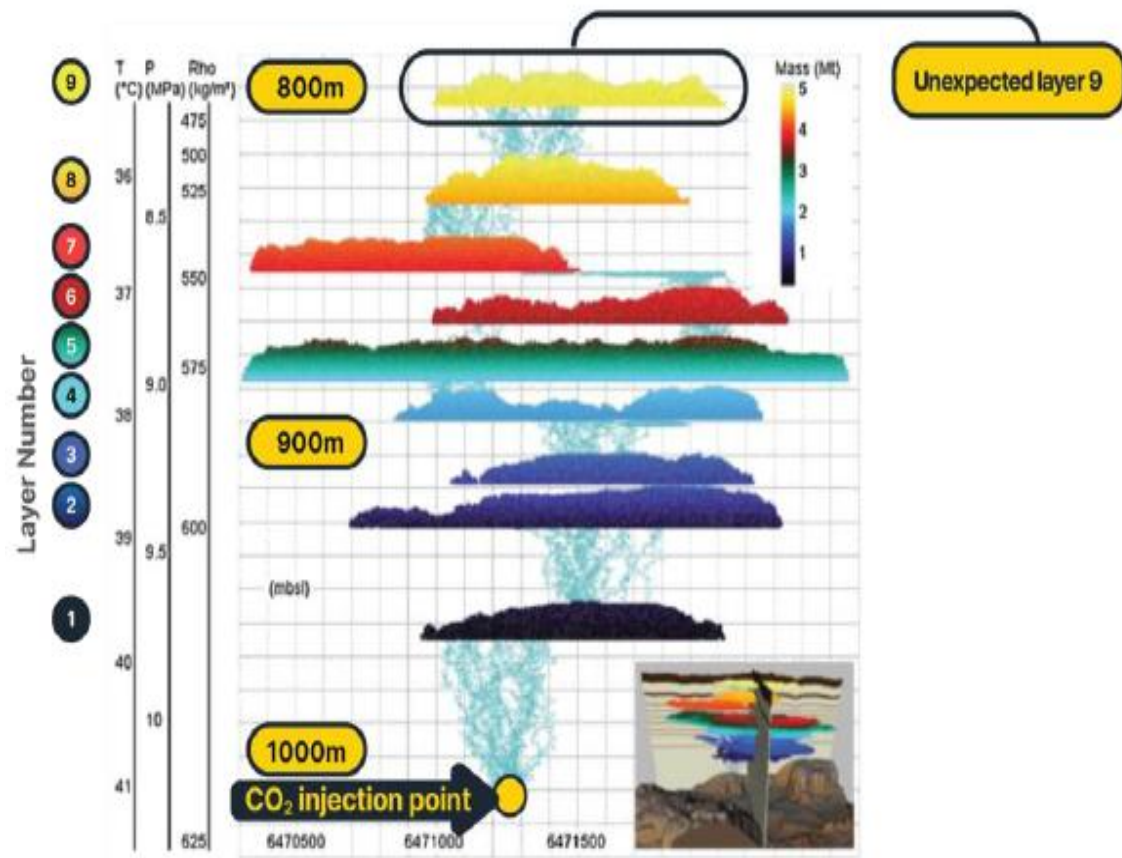


Source: Geological storage of CO₂: project design and global scale-up. Ringrose. March 29, 2021.



Source: Statoil ASA. Sleipner – 20 years of successful storage operations and key learning for future projects: Skalmerraas. June 29, 2016.

IEEFA



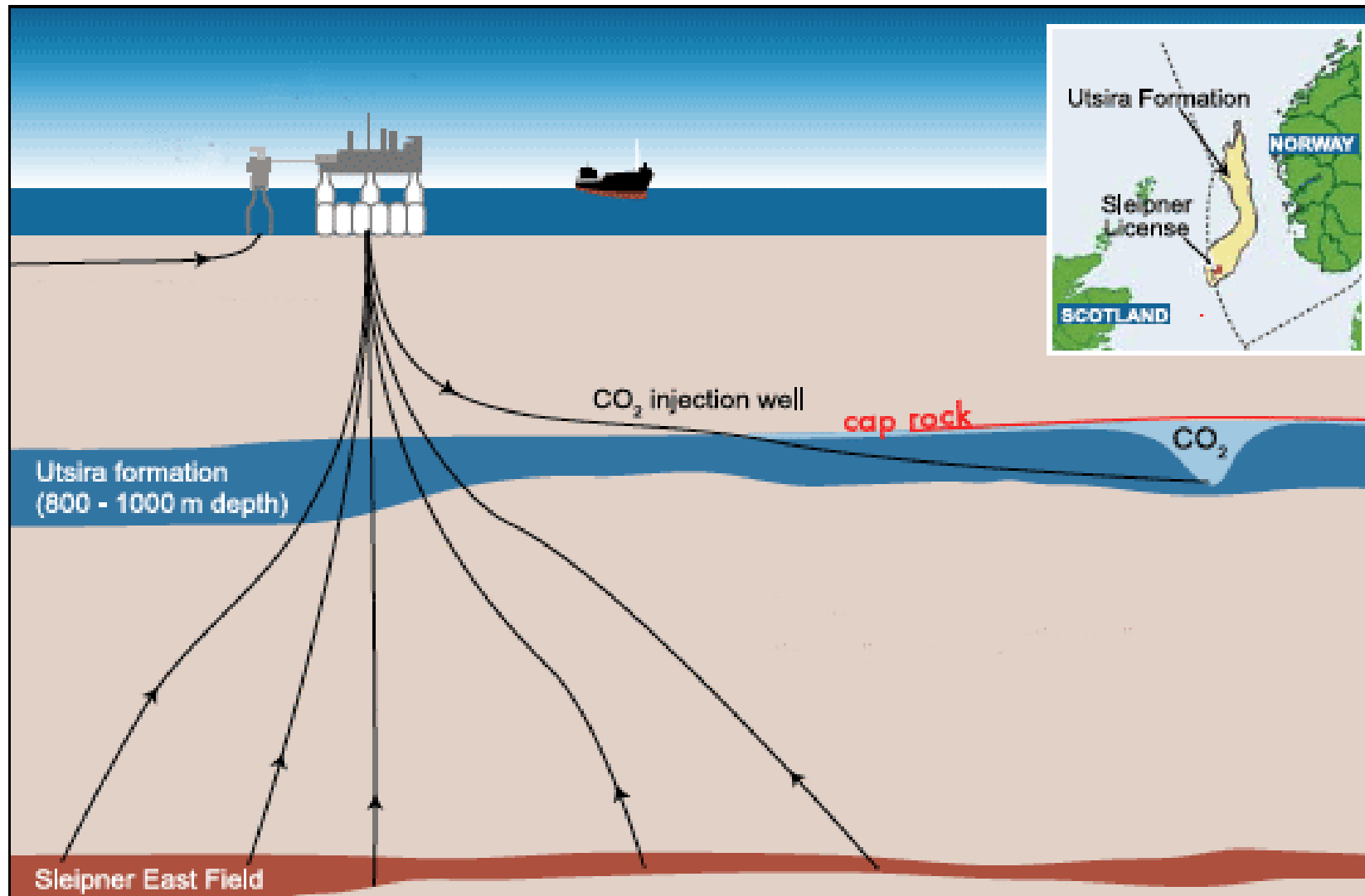
Source: International Journal of Greenhouse Gas Control. Cavanagh and Haszeldine. 2014.

IEEFA

Source: Institute for Energy Economics and Financial Analysis – June 2023

TPA Toolbox Energy Book 3 - GHG

Sleipner Project in Norway



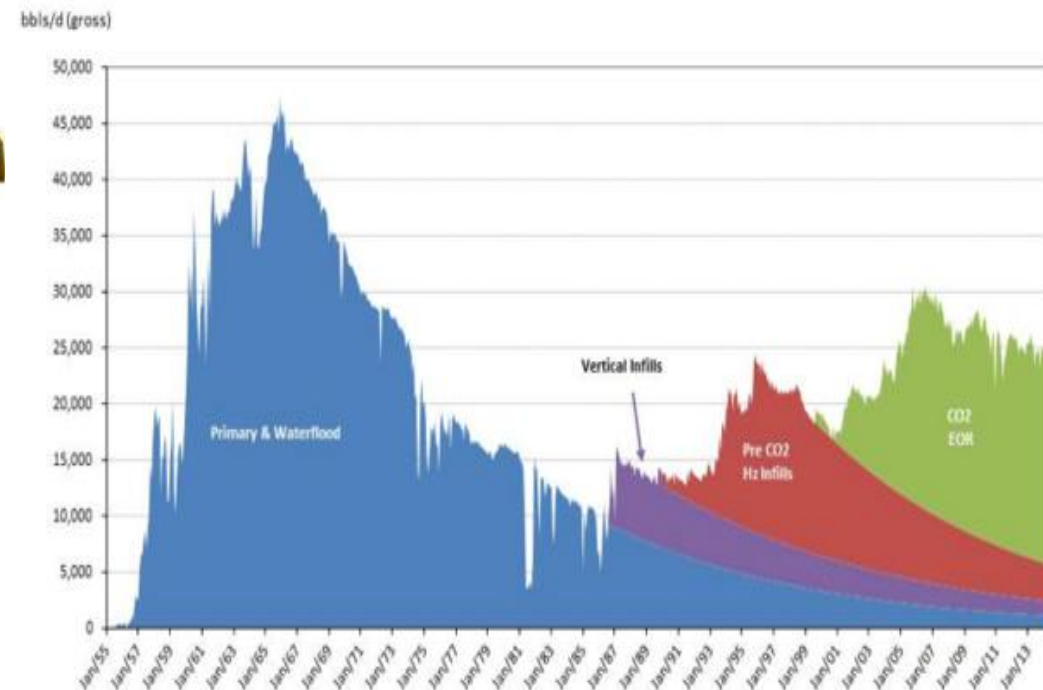
Weyburn Project in Canada



- 25 000 b/d, 6500 tCO₂/day
- 320 miles pipelines
- 40 MtCO₂ captured from Dakota Gasification Company synfuels plant along the life of the project

The world's largest industrial demonstration project for CO₂ enhanced recovery

Weyburn unit oil production



Courtesy Cenovus Energy Inc.

Projects for CO₂ Capture and Sequestration Situation end 2019

- **Two types of CCS projects:**
 - 1) allocated to the power sector and
 - 2) allocated to other industrial sectors.
- **End 2019, 19 large-scale CCS projects are in operation and 4 projects are under construction. Overall Capture capacity end 2019 # 40 Mt/year.**
- **10 more CCS projects are at an advanced stage of development planning.**
- **The first large scale commercial project involving coal based emissions was commissioned in October 2014 in Saskatchewan, Canada: Saskpower Boundary Dam involves the addition of post-combustion capture to an existing pulverized coal unit for power generation. Power 110 MW, 1MT/year CO₂, the CO₂ is sold to oil operators for EOR.**
- **To comply with the proposed US regulations, new coal fired power plants would need to be equipped with CCS within 10 years**



Boundary Dam, Saskatchewan, Canada



Some large commercial CCUS Projects 1980 - 2020

Project	Location	Start-up	Industry type	Capture Capacity	Storage type
Terrell natural Gas plant	US	1972	Natural Gas Processing	0,5 MtCO2	EOR
Enid fertiliser	US	1982	Fertiliser Production	0,7 MtCO2	EOR
Shute Creek Gas process.	US	1986	Natural Gas Processing	7,0 MtCO2	EOR
Sleipner CO2 Storage proj.	Norway	1996	Natural Gas Processing	1,0 MtCO2	Geological Storage
Weyburn/ Midale	US/Canada	2000	Synthetic Natural Gas	3,0 MtCO2	EOR
Snovhit CO2 Storage proj.	Norway	2008	Natural Gas Processing	0,7 MtCO2	Geological Storage
Century Plant	US	2010	Natural Gas Processing	8,4 MtCO2	EOR
Ordos Inn. Mongolia	China	2011	Coal Liquef. Plant	0,1 MtCO2	Geological Storage (Deep saline form.)



Some large commercial CCUS Projects 1980 - 2020

Project	Location	Start-up	Industry type	Capture Capacity	Storage type
Air Products Steam methane	US	2013	Hydrogen Production	1,0 MtCO2	EOR
Lost Cabin Gas Plant	US	2013	Natural Gas Processing	0,9 MtCO2	EOR
Coffeyville	US	2013	Fertilizer Production	1,0 MtCO2	EOR
Pre-salt Oil Field CCS	Brazil	2013	Natural Gas Processing	3,0 MtCO2	EOR
Boundary Dam CCS	Canada	2014	Power Gen. (Coal)	1,0 MtCO2	EOR
Uthmaniyah	Saudi Arabia	2015	Natural Gas Processing	0,8 MtCO2	EOR
Quest	Canada	2015	Hydrogen Production	1,0 MtCO2	Geological Storage (Deep saline form.)
Abu Dhabi CCS Project	Abu Dhabi	2016	Iron and Steel Prod.	0,8 MtCO2	EOR



Some large commercial CCUS Projects 1980 - 2020

Project	Location	Start-up	Industry type	Capture Capacity	Storage type
Tomakomai	Japan	2016	Hydrogen Production	0,1 MtCO2	Geological Storage
Kemper IGCC	US	2016	Power Generation	3,0 MtCO2	EOR
Petra Nova	US	2017	Power Gen. (Coal)	1,4 MtCO2	EOR
Illinois Industrial	US	2017	Ethanol Production	1,0 MtCO2	Geological Storage
Sinopec Qilu	China	2017	Chemical Production	0,5 MtCO2	EOR
Jilin Oil Field CO2 EOR	China	2018	Natural Gas Processing	0,6 MtCO2	EOR
Sinopec Shengli	China	2018	Power Generation	1,0 MtCO2	EOR
Gorgon	Australia	2019	Natural Gas Processing	4,0 MtCO2	Geological Storage (Onshore saline)



Some large commercial CCUS Projects 1980 - 2020

Project	Location	Start-up	Industry type	Capture Capacity	Storage type
ROAD (Barendrecht)	Netherlands	2019/2020	Power Generation	1,1 MtCO ₂	Geological Storage (Suspended)
Peterhead	UK	2019/2020	Power Generation	1,0 MtCO ₂	Geological Storage Goldeneye
Alberta Carbon Trunk Line	Canada	2020	Fertiliser Production	0,3-0,6 MtCO ₂	EOR
Alberta Carbon Trunk Line	Canada	2020	Hydrogen Production	1,2-1,4 MtCO ₂	EOR
White Rose	UK	2020/2021	Power Generation	2,0 MtCO ₂	Geological Storage

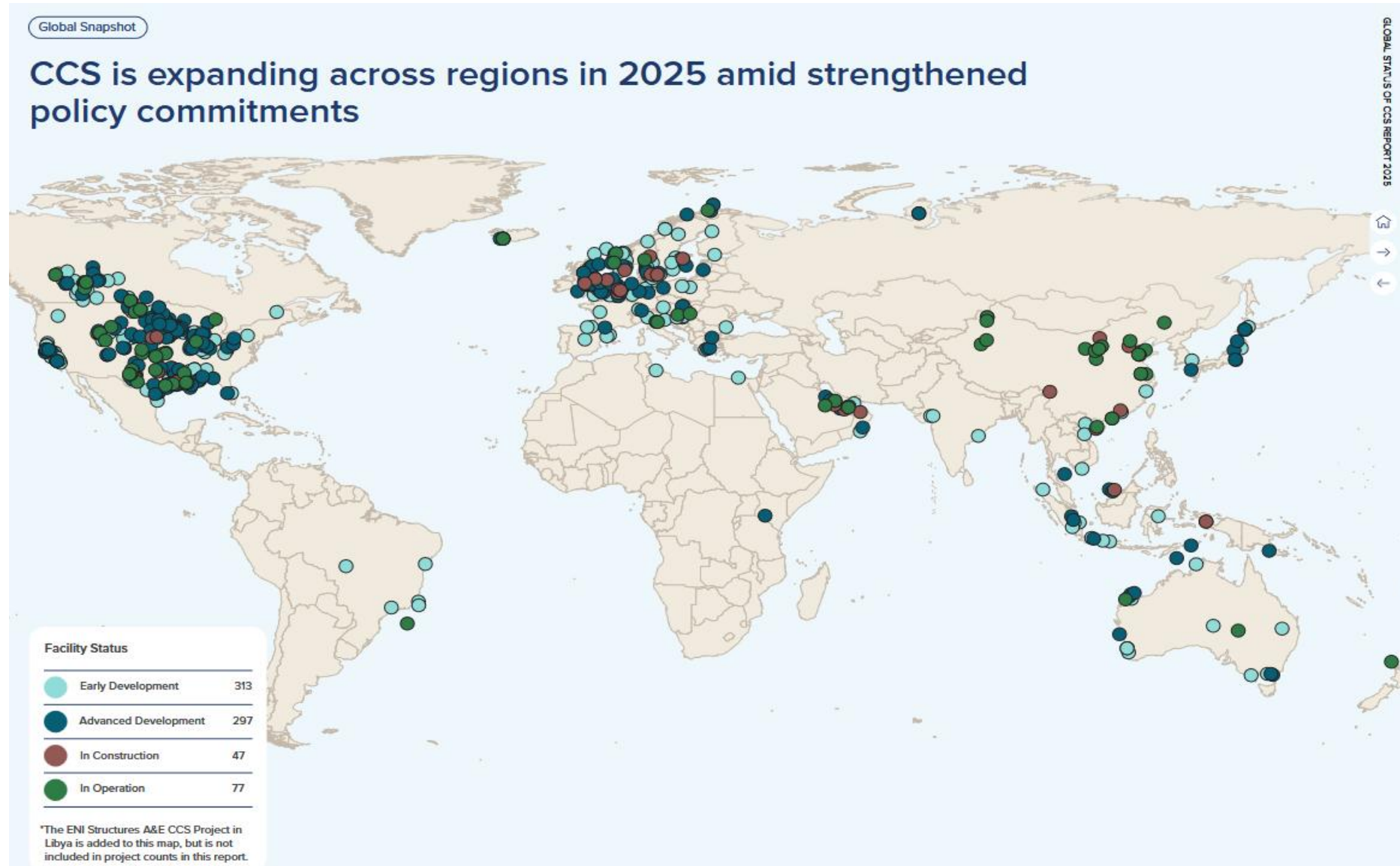
Source: Global CCS Institute & IEA Special Report on CCUS 2020



Global Status of CCS 2025 by Global CCS Institute



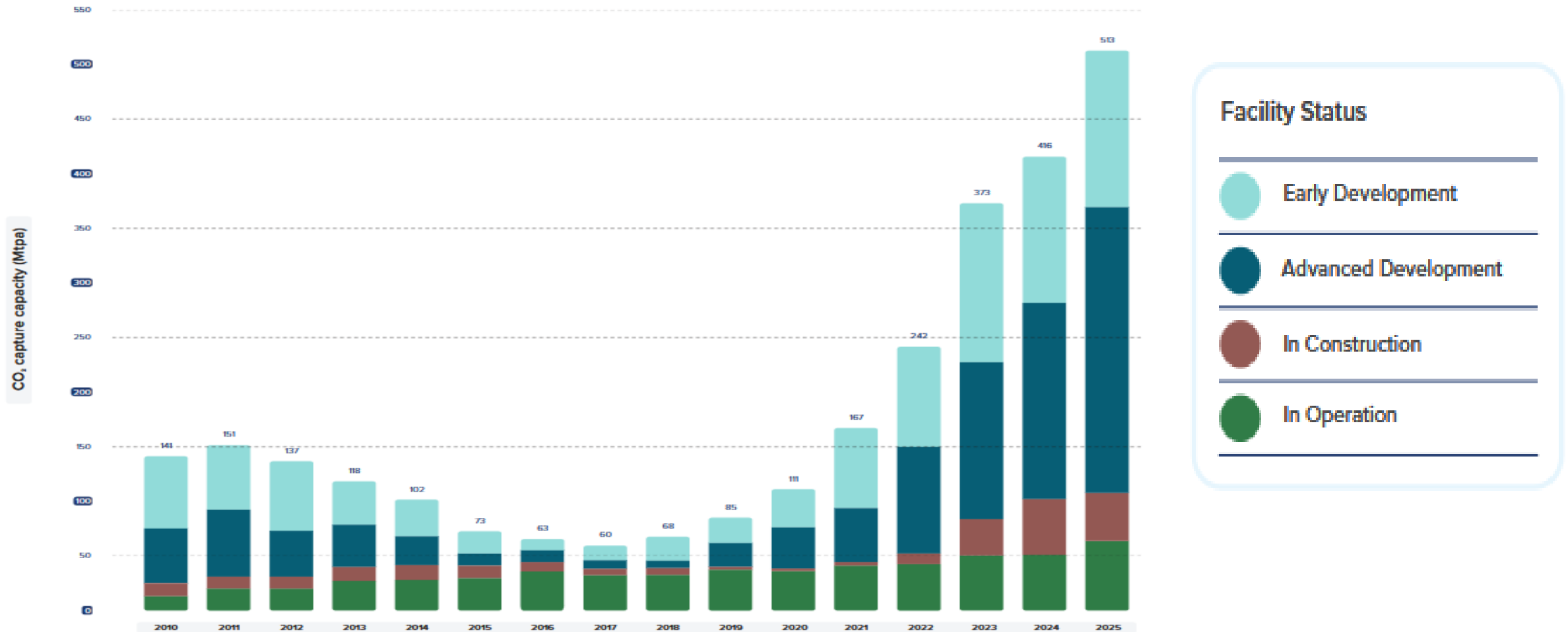
CCS projects in the World - 2025



CCS projects Capture Capacity 2010 – 2025

513 MtCO₂ in 2025 vs # 35 GtCO₂ worldwide emissions (1,5 %)

CO₂ capture capacity of commercial CCS facility pipeline since 2010



CCS projects Capture Capacity 2024 – 2025

Number of facilities in operation rises 54% year on year



77

Number of facilities in operation rises 54% year on year



64 Mtpa

Capture capacity in operation rises 25% year on year



734

Total number of facilities rises 17% year on year



46%

Increase in the capture capacity of facilities in advanced development (FEED) from 180 to 262 Mtpa.



513 Mtpa

Total capture capacity rises 23% year on year

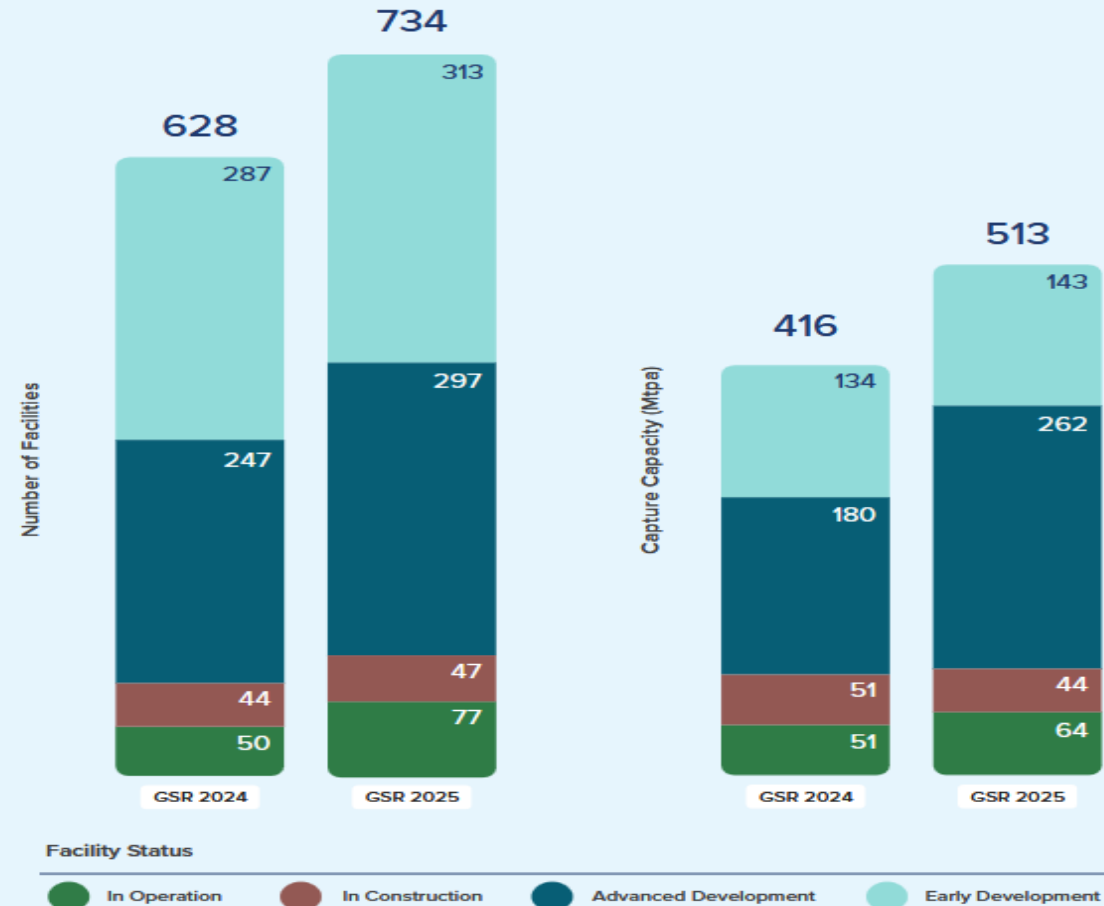


44 Mtpa

Capture capacity in construction in July 2025

* Current as of July 2025.

Commercial CCS facilities by number and total capture capacity



CCS projects Capture Capacity Developments 2025 – 2030

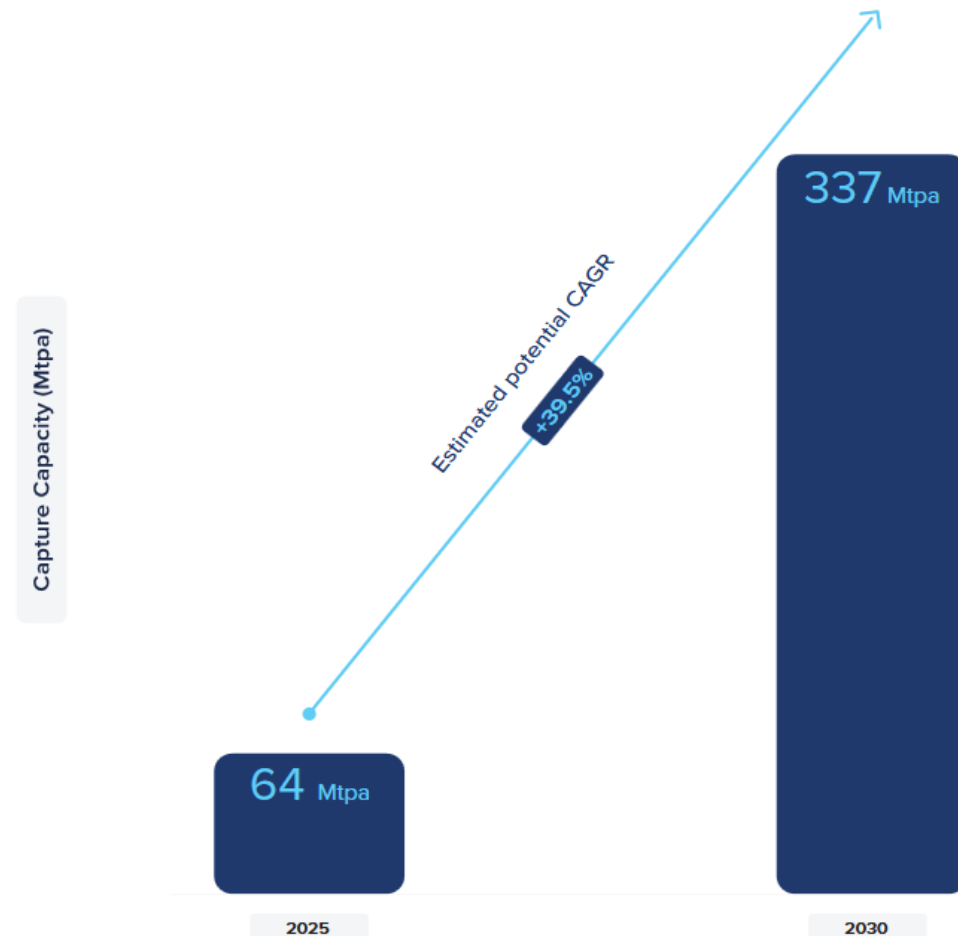
CCS capture capacity continues to expand and grow through 2030

The capture capacity of facilities in operation globally in 2030 is projected to be five times higher than in 2025, based on the development and construction pipeline captured by the Institute's CO₂RE database.

Considering projects currently under development, the total operating capacity could increase to 337 Mtpa within the next five years, from 64 Mtpa today, with a potential compound annual growth rate (CAGR) of nearly 40%.

Including planned projects, or projects commencing operations after 2030, takes the total capture capacity in the pipeline to 513 Mtpa. While significant, it remains well short of the required deployment to meet climate agreements, and additional capacity expansion must be brought online.

Potential capture capacity 2025-2030, based on entire CO₂RE project database pipeline



Some large operational CCUS Projects 2015 – 2025 (1)

Facility Name	Country	Operational Year	Industry	Capture Capacity (Mtpa CO ₂)	Storage Type
Saudi Aramco Uthmaniyah	Saudi Arabia	2015	Natural Gas / LNG	0.8	Enhanced Oil Recovery
Shell Quest	Canada	2015	Hydrogen / Ammonia / Fertiliser	1.3	Deep Saline Formation
Xinjiang Dunhua Karamay	China	2015	Chemical	0.1	Enhanced Oil Recovery
ADNOC Al-Reyadah	United Arab Emirates	2016	Iron and Steel	0.8	Enhanced Oil Recovery
ADM Illinois Industrial	USA	2017	Ethanol / Biomass Fermentation	1	Deep Saline Formation
Petra Nova Carbon Capture	USA	2017	Coal Power Generation and Heat	1.4	Enhanced Oil Recovery
Campo Viejo Gas Processing Plant	USA	2018	Natural Gas / LNG	Not Specified	Enhanced Oil Recovery
CNPC Jilin Oil Field	China	2018	Natural Gas / LNG	0.6	Enhanced Oil Recovery
Midstream 30-30 Gas Plant	USA	2019	Natural Gas / LNG	0.01	Enhanced Oil Recovery
Chevron Gorgon	Australia	2019	Natural Gas / LNG	4	Deep Saline Formation
QatarEnergy LNG	Qatar	2019	Natural Gas / LNG	2.2	Deep Saline Formation
Enhance Clive Oil Field	Canada	2020	CO ₂ Transport / Storage	N/A (CO ₂ Transport / Storage)	Enhanced Oil Recovery
Wolf Alberta Carbon Trunk Line	Canada	2020	CO ₂ Transport / Storage	N/A (CO ₂ Transport / Storage)	N/A
Nutrien Redwater	Canada	2020	Hydrogen / Ammonia / Fertiliser	0.3	N/A
NWR Sturgeon Refinery	Canada	2020	Oil Extraction / Refining	1.6	N/A
Climeworks Orca	Iceland	2021	Direct Air Capture	0.004	N/A
China National Energy Guohua Jinjie 1	China	2021	Coal Power Generation and Heat	0.15	Not Specified
Sinopec Nanjing Chemical	China	2021	Chemical	0.2	Enhanced Oil Recovery
Yanchang Yan'an CO ₂ -EOR	China	2021	Chemical	0.1	Enhanced Oil Recovery
Dark Horse Storage	USA	2021	CO ₂ Transport / Storage	N/A (CO ₂ Transport / Storage)	Deep Saline Formation
Entropy Glacier Gas Plant (Phase 1A,1B)	Canada	2022	Natural Gas Power Generation and Heat	0.054	Deep Saline Formation
Gevo Net Zero North	USA	2022	Ethanol / Biomass Fermentation	0.18	Deep Saline Formation
Sinopec Qilu-Shengli	China	2022	Chemical	1	Enhanced Oil Recovery
Targa Red Hills natural gas processing complex	USA	2022	Natural Gas / LNG	0.5	Deep Saline Formation
Yanchang Yulin CO ₂ -EOR	China	2022	Chemical	0.3	Enhanced Oil Recovery
Barnett Zero CCS	USA	2023	Natural Gas / LNG	0.21	Deep Saline Formation
China National Energy Taizhou	China	2023	Coal Power Generation and Heat	0.5	Not Specified
China National Energy Xinjiang Chemicals CCUS Phase 1	China	2023	Chemical	Not Specified	Enhanced Oil Recovery

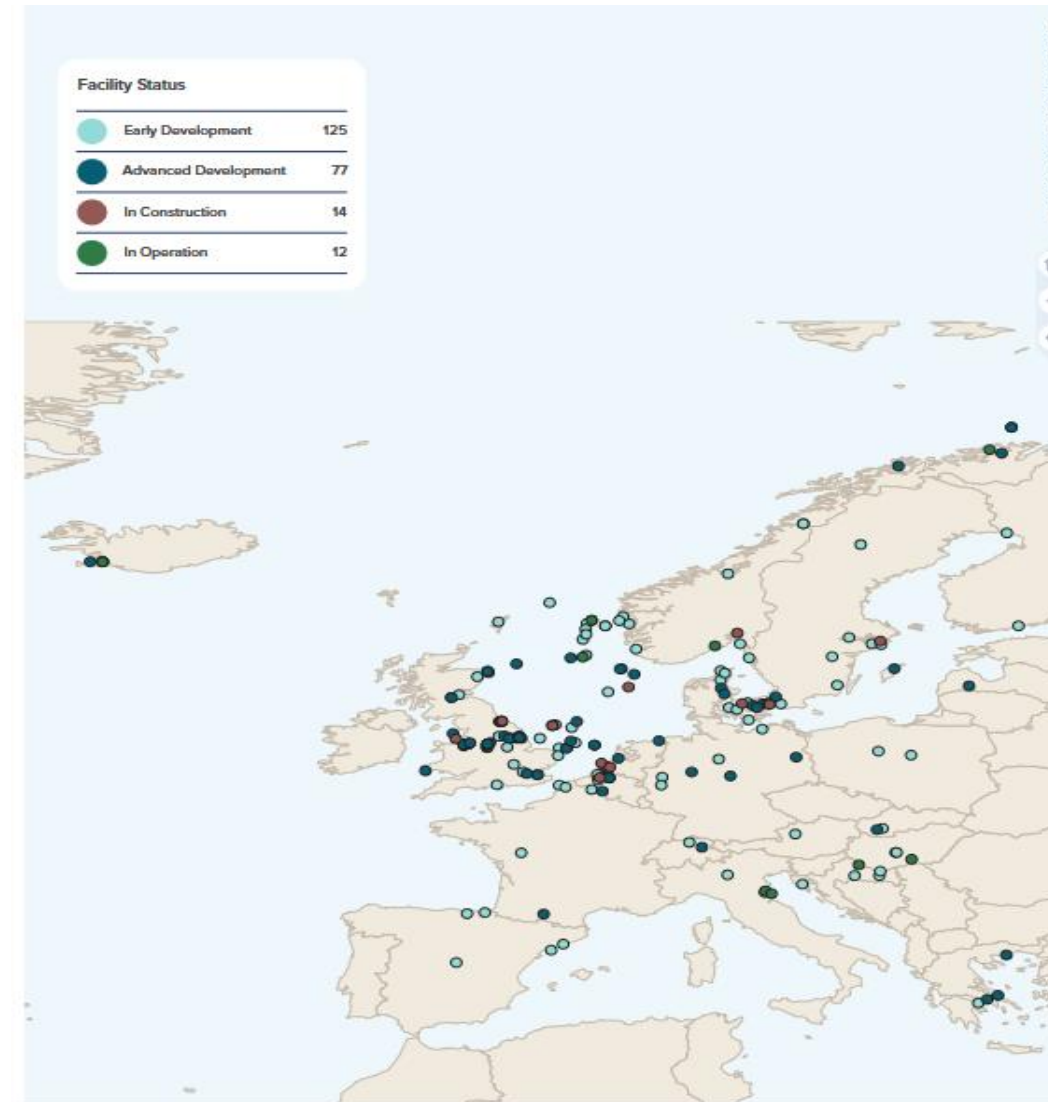


Some large operational CCUS Projects 2015 – 2025 (2)

Facility Name	Country	Operational Year	Industry	Capture Capacity (Mtpa CO ₂)	Storage Type
CNOOC Enping Storage Demonstration	China	2023	Natural Gas / LNG	0.3	Deep Saline Formation
Guanghui Energy Methanol Plant Phase 1	China	2023	Chemical	0.1	Enhanced Oil Recovery
Harvestone Blue Flint Ethanol	USA	2023	Ethanol / Biomass Fermentation	0.2	Deep Saline Formation
Huaneng Yangpu Gas-fired Carbon Capture Demo Project	China	2023	Natural Gas Power Generation and Heat	0.002	N/A
Ngawha Geothermal Reinjection	New Zealand	2023	Geothermal Power Generation and Heat	0.1	Deep Saline Formation
Sinopec Jinling Petrochemical (Nanjing Refinery)	China	2023	Oil Extraction / Refining	0.3	Enhanced Oil Recovery
Climeworks Mammoth	Iceland	2024	Direct Air Capture	0.036	N/A
Eni Casalborgorsetti Natural Gas Plant	Italy	2024	Natural Gas Power Generation and Heat	0.02	N/A
Bantam DAC	USA	2024	Direct Air Capture	0.005	Enhanced Oil Recovery
Eni Ravenna Phase 1	Italy	2024	CO ₂ Transport / Storage	N/A (CO ₂ Transport / Storage)	Depleted Oil and Gas Field
Beijing BBMG Cement	China	2024	Cement and Concrete	0.1	Not Specified
China National Energy Ningxia Phase 1	China	2024	Chemical	3	Enhanced Oil Recovery
Qingzhou Oxy-Fuel Combustion Carbon Capture Project	China	2024	Cement and Concrete	0.2	N/A
Santos Moomba CCS	Australia	2024	Natural Gas / LNG	1.7	Depleted Oil and Gas Field
Xinjiang Jinlong Shenwu	China	2024	Coal Power Generation and Heat	0.2	Enhanced Oil Recovery
Northern Lights Transport and Storage	Norway	2024	CO ₂ Transport / Storage	N/A (CO ₂ Transport / Storage)	Deep Saline Formation
On Power Silverstone Geothermal Plant	Iceland	2025	Geothermal Power Generation and Heat	0.03	N/A
CF Industries Donaldsonville	USA	2025	Hydrogen / Ammonia / Fertiliser	2	N/A
Heidelberg Materials Brevik Cement Plant	Norway	2025	Cement and Concrete	0.4	N/A
CNOOC Bozhong 26-6	China	2025	Oil Extraction / Refining	Not Specified	Enhanced Oil Recovery
CNOOC Enping CCUS Project	China	2025	Natural Gas / LNG	0.1	Deep Saline Formation

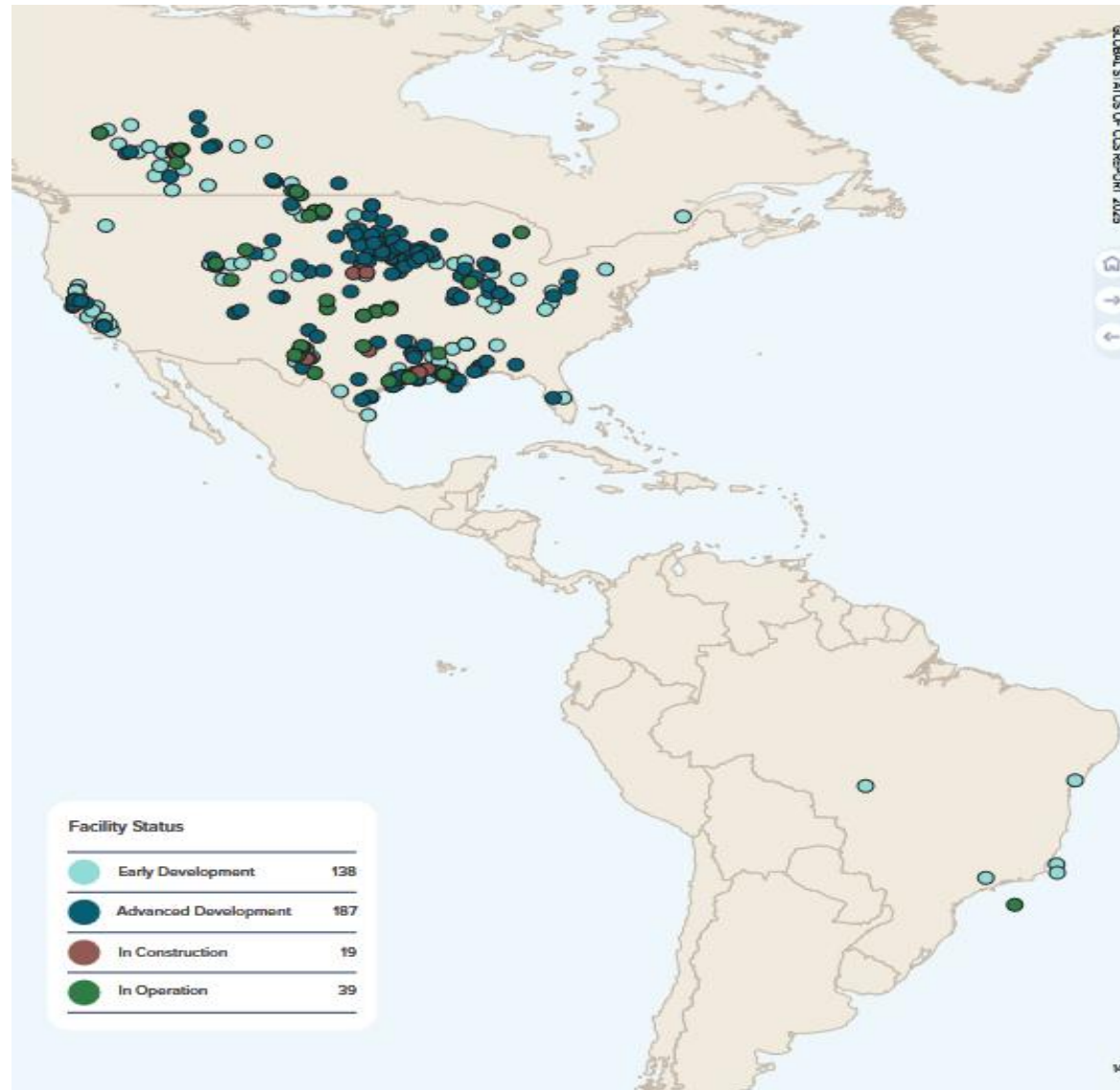


CCS projects – Europe 2025



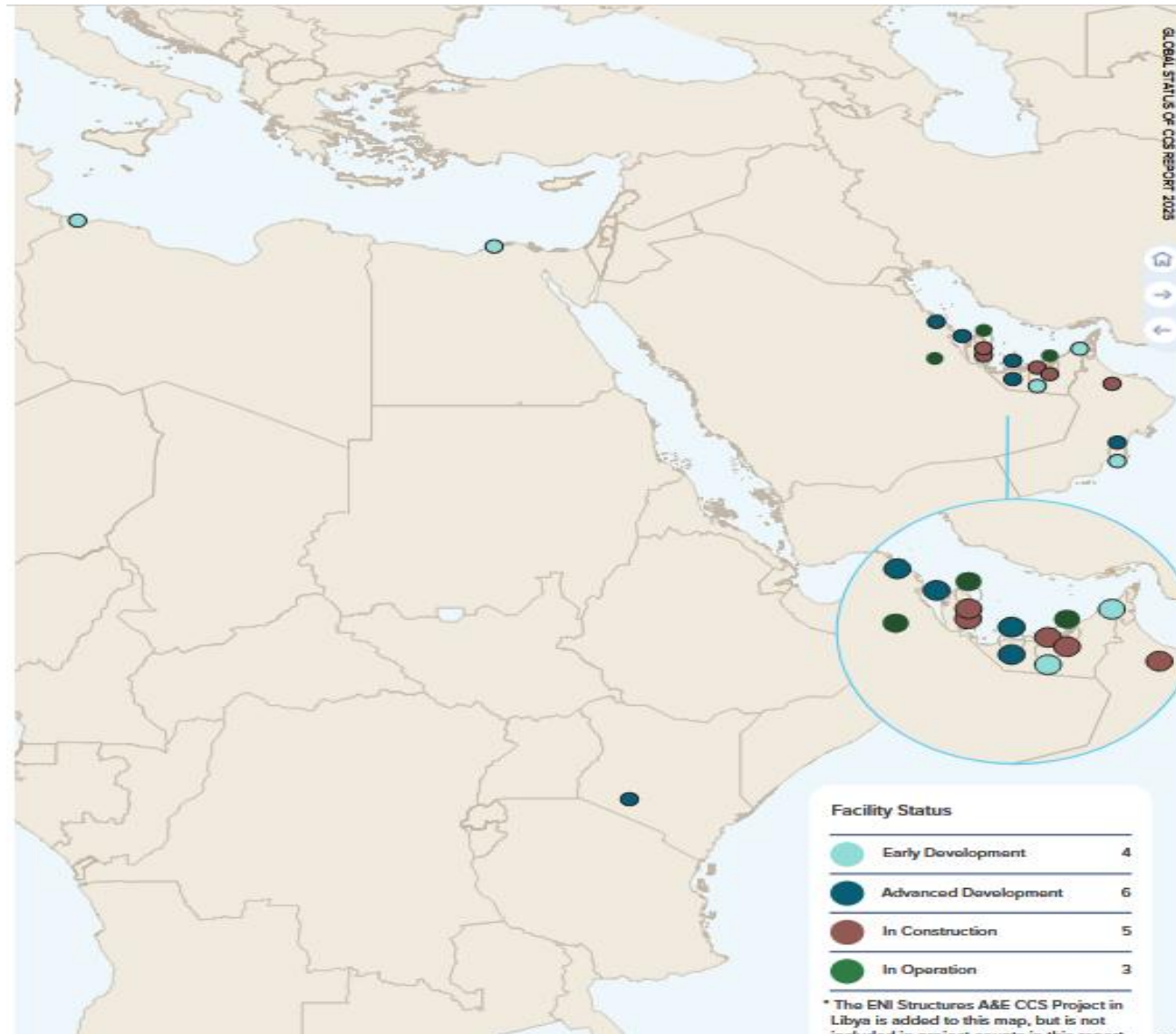
Source Global CCS Institute Global Status Report 2025

CCS projects – US & America 2025



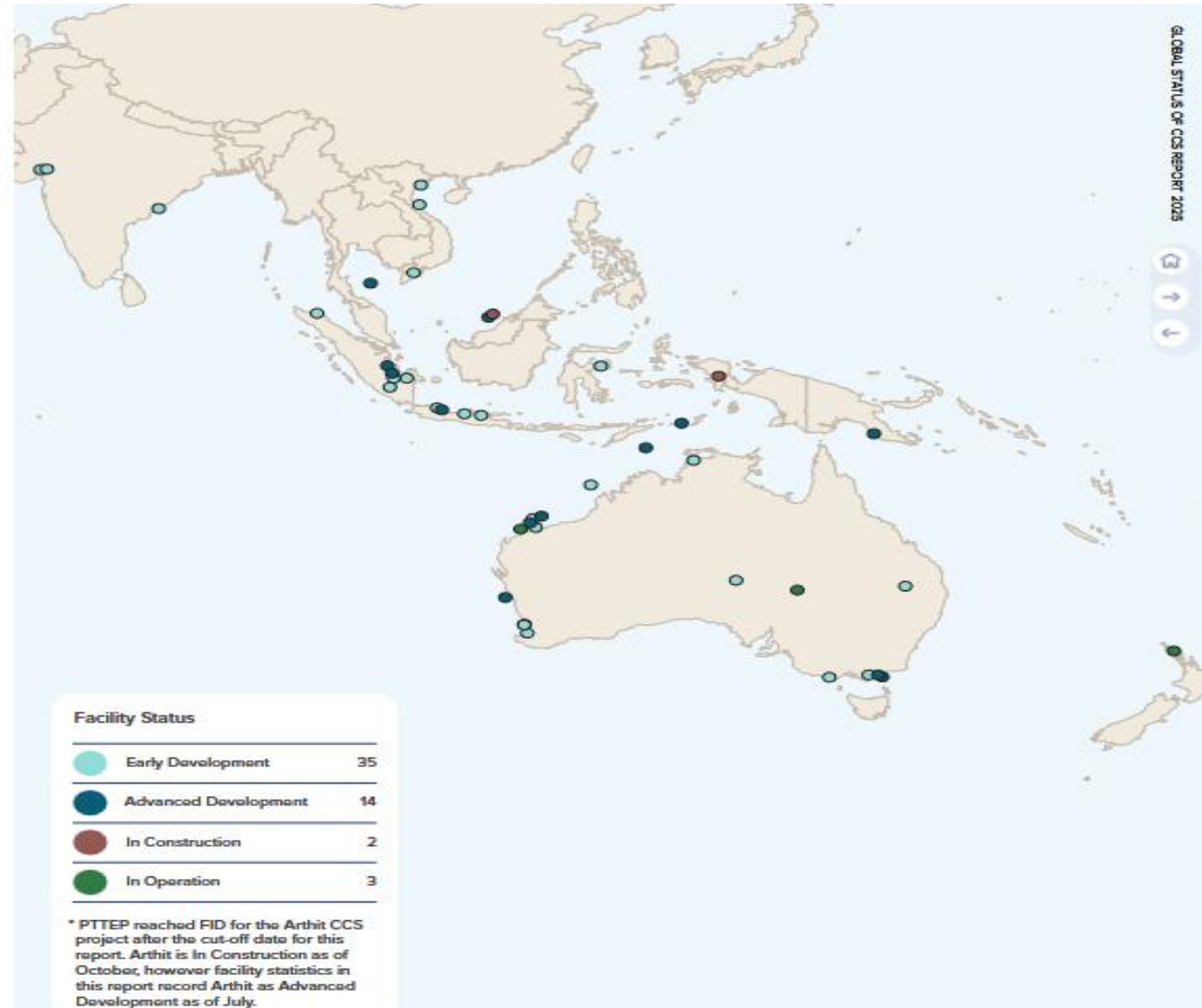
Source Global CCS Institute Global Status Report 2025

CCS projects – Middle East & Africa 2025



Source Global CCS Institute Global Status Report 2025

CCS projects – Asia/Pacific 2025



Source Global CCS Institute Global Status Report 2025

CCS projects – Europe 2025

CCS projects reaching FID or financial close in Europe (July 2024–July 2025)

Project name	Country	Project type	FID /Financial close date
Net Zero Teesside Power	United Kingdom	Natural Gas Power Generation and Heat	Dec-24
Northern Endurance	United Kingdom	CO ₂ Transport / Storage	Dec-24
Project Greensand	Denmark	CO ₂ Transport / Storage	Dec-24
Hafslund Oslo Celsio	Norway	Waste-to-Energy	Jan-25
Beccs Stockholm	Sweden	Bioenergy Power Generation and Heat	Mar-25
Eni Hynet North West	United Kingdom	CO ₂ Transport / Storage	Apr-25
Fluys c-grid Antwerp Pipeline	Belgium	CO ₂ Transport / Storage	May-25

National carbon management strategies and roadmaps for CCS or CDR development



State aid schemes supporting CCS developed by EU Member States

EU Member State	Legal framework	Type of projects	Aid instrument	Amount	Scheme duration	Commission decision
The Netherlands	Energy and Environmental Aid Guidelines (EEAGs)	Renewable electricity, gas and heat, use of industrial waste heat and heat pumps, electrification, waste incineration, CCS, and hydrogen	Direct grant	€30 billion	Until 31 December 2025	Dec-20
Denmark	CEEAGs	CCS	Direct grant	€11 billion	January-April 2023	Jan-23
Denmark	CEEAGs	BECCS	Direct grant	€350 million	Until 31 December 2024	Dec-23
Sweden	CEEAGs	BECCS	Direct grant	€3 billion	July 2024-December 2028	Jul-24
Greece	CEEAGs	Onshore and offshore infrastructure part of the Prinos project	Direct grant	€150 million	From October 2024	Oct-24
France	CEEAGs	Electrification, CCS, CCU and energy efficiency	CCfD	€3 billion	15-year contract	Dec-24
Germany	CEEAGs	Electrification, CCS, CCU, energy efficiency and hydrogen	Other, direct grant	€5 billion	Until 31 December 2026	Mar-25

Nota:

EEAGs: Energy and Environment Aid Guidelines

BECCS: Bioenergy with Carbon Capture and Storage

CCfD: Carbon Contract for Difference

Source Global CCS Institute Global Status Report 2025

CCS projects in Europe - Status as of 01/03/2023

Country	Project Name	Sponsor	Capacity	Projected Start of Operation	Notes
Norway					
	Northern Lights CCS . "Providing carbon storage as a service." The master project comprises the following four components:				
	Errai (formerly Polaris)	Neptune Energy Horisont Energi Vår Energi	4-8mtpa Phase 1: 1.5mtpa	2024-2026	To make blue ammonia from gas sourced from adjacent Hammerfest LNG site. Integrated with CO ₂ -receiving terminal that blends received CO ₂ with industrial CO ₂ captured from sites around Norway
	Smeaheia	Equinor	20mtpa	2027-2028	Slated to become Norway's primary CO ₂ storage site
	Luna	Wintershall Dea 60% Cape Omega 40%	5mtpa	Not disclosed	120km offshore from Bergen, awarded by GoN on October 5, 2022
	Langskip (Longship)	Government of Norway (GoN) Norcem AS Fortum Oslo Verne AS	Not applicable		Approved by Parliament on September 21, 2020 . GoN operates project through Gassnova SE ; and provides state sponsorship for design, construction and testing of CO ₂ transport fleet, inclusive of CO ₂ gathering and compression facilities. Cost estimate is NOK17.1bn (US\$1.59bn) for capital expenditure, and NOK8bn (US\$0.75bn) for 10 years of operating expenditure, two-thirds of which would be funded by GoN and one-third from private-sector participants, Fortum and Norcem.
	Trudvang	Sval Energi AS Storegga Geotechnologies Neptune Energy Norge AS	9mtpa	2029	Open-source CO ₂ repository with projected total storage capacity of 225mt
United Kingdom					
	Acorn	Storegga 30% Shell 30% Harbour Energy 30% North Sea Midstream Partners 10%	5-10mtpa	2030	Based in Scotland. To develop CO ₂ gathering network, both onshore and via ship from other parts of UK, consolidating and compressing, then transporting by repurposed gas pipelines to depleted North Sea gas fields
	Viking CCS	Harbor Energy	10mtpa Phase 1: 2mtpa	Phase 1: 2027	

Source: Institute for Energy Economics and Financial Analysis - June 2023



CCS projects in Europe - Status as of 01/03/2023

Country	Project Name	Sponsor	Capacity	Projected Start of Operation	Notes
	Northern Endurance	BP (lead) National Grid Equinor Shell TotalEnergies	20mtpa	2030	Combines two CO ₂ "hubs": Teesside and Humberside. To pump compressed CO ₂ 145km from Teesside and 103km from Humberside to depleted gas fields offshore
	Hynet North West		10mtpa Phase 1: 4.5mtpa	2030 Phase 1: 2025	
Netherlands					
	Porthos	Air Liquide Air Products Shell Exxon Mobil	2.5mtpa	2025	Dutch waters of North Sea Project overview
	L10	Neptune Energy Rosewood Exploration Exxon Mobil EBN (state-owned enterprise)	4-5mtpa	2026	Dutch waters of North Sea Overview presentation
Denmark					
	Project Greensand	INEOS Energy Wintershall Dea	8mtpa Phase 1: 1.5mtpa	2030 Phase 1: 2025	
	Project Bifrost	TotalEnergies Orsted, TUD	3mtpa	2027	
Sweden					
	Slite CCS	Heidelberg Materials	1.8mtpa	2030	Part of a "carbon-neutral" cement plant project undertaken by Heidelberg Materials
Bulgaria					
	ANRAV	Petroceltic Heidelberg Materials	0.8mtpa	2028	Recipient of EU Innovation Fund monies on July 13, 2022, to demonstrate CCUS in Eastern Europe. To sequester CO ₂ in Black Sea fields
France-Spain					
	PYCASSO	Avenia – European Cluster Collaboration Platform	1mtpa	2030	Regional CO ₂ gathering and disposal demonstration project

Source: Institute for Energy Economics and Financial Analysis - June 2023



CCS projects in Europe - Status as of 01/03/2023

Country	Project Name	Sponsor	Capacity	Projected Start of Operation	Notes
Germany					
	Wilhelmshaven LNG terminal		1mtpa	2026	To create a CO ₂ liquefaction facility and use new LNG terminal to load CO ₂ ships for disposal at fields being developed in Norway and elsewhere in the North Sea
Italy					
	CCS Ravenna Hub	ENI	4mtpa Phase 1 testing 0.1mtpa	2027 Phase 1: 2023	To expand to 10mtpa in 2030 if initial commercial operations prove successful
Iceland					
	Project Silverstone	CarbFix	0.025mtpa	2025	EU-funded project to demonstrate CarbFix technology's ability to take externally sourced CO ₂ , process it and create solid-phase underground storage
	Coda Terminal	CarbFix	3mtpa	2031	Commercial-scale terminal for receiving, processing and storing CarbFix-based technology for CO ₂ disposal

Source: Institute for Energy Economics and Financial Analysis - June 2023

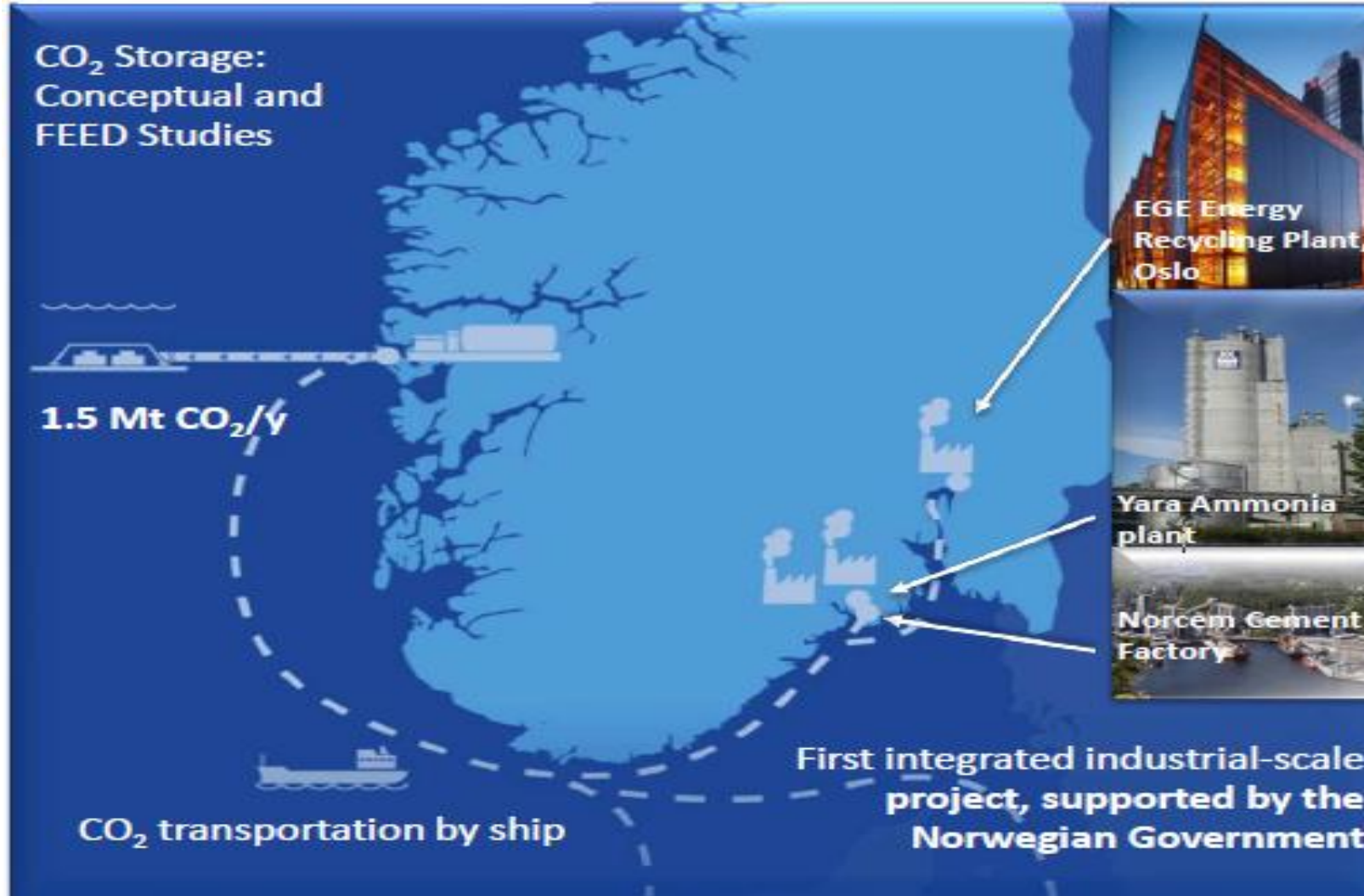


Difficulties to implement CCS in Europe: Past years evolution

- Six potential projects for CCS were scheduled in Europe: in Poland, Netherlands, Italy, Germany, Spain and UK.
- Program NER 300: due to technical and steel market difficulties, Arcelor Mittal decided to put on hold its « Ulcos » project at Florange steel manufacture (France)
- European Commission decided to suspend the financing of CCS 2012 projects in Europe (1,5 G€ were available for that purpose)
- P.m. Rotterdam Climate Initiative Project in the Netherlands: ROAD-CCS Project by E.ON & GdF-Suez: Construction of a Coal Power Plant, 1100 MW equipped with a CO₂ capture facility (1 Mt/year). The CO₂ will be transported in a 16 inches pipeline and injected in a depleted gas field (Total CO₂ storage = 35 Mt). Investment # 400 M€. Project estimated start-up: 2016. Financing not yet completed due to the low price of CO₂. Project redesigned.
- France Nord Project (BRGM, ADEME, Total, EDF, Air Liquide, Engie and others): CO₂ storage in a salt aquifer in the Paris basin. Objective: 200 MtCO₂ injected over 50 years. Project abandoned after negative technical evaluation.
- Cancellation of 2 power plants based CCS program in UK in 2015: White Rose (coal) and Peterhead (natural gas)
- The recent increase of Carbon Price in Europe could reactivate new CCS projects in the area.



October 2017 : Equinor (ex Statoil), Shell and TotalEnergy enters Norway CO₂ Storage Partnership (See also below)



Current contracts with:

Yara (fertilizers)
Orsted ex DONG Energy (Energy)
Heidelberg Material, Norcem shareholder (Cement)

Storage capacity:
1,5 Mt CO₂/year
5,0 Mt in a second phase

Injection in a saline aquifer

1st phase financed by
Norwegian Government (80%):
500 M\$

Second phase: 700 M\$



Global CO₂ Storage Potential Capacities

Type	CO ₂ Storage Capacity (Gt)
Depleted Oil and Gas Reservoirs	675 - 900
Saline Aquifers	400 - 10000
Un-minable Coal Seams	10 - 200
Total	# 1100 - 11000
# Nb of years of emissions 2025: # 35 Gt	31 - 310

Source: IEA 2016 Report on CCS
 IPCC 2005 Special Report on Carbon Dioxide Capture and Storage
 Petrochina

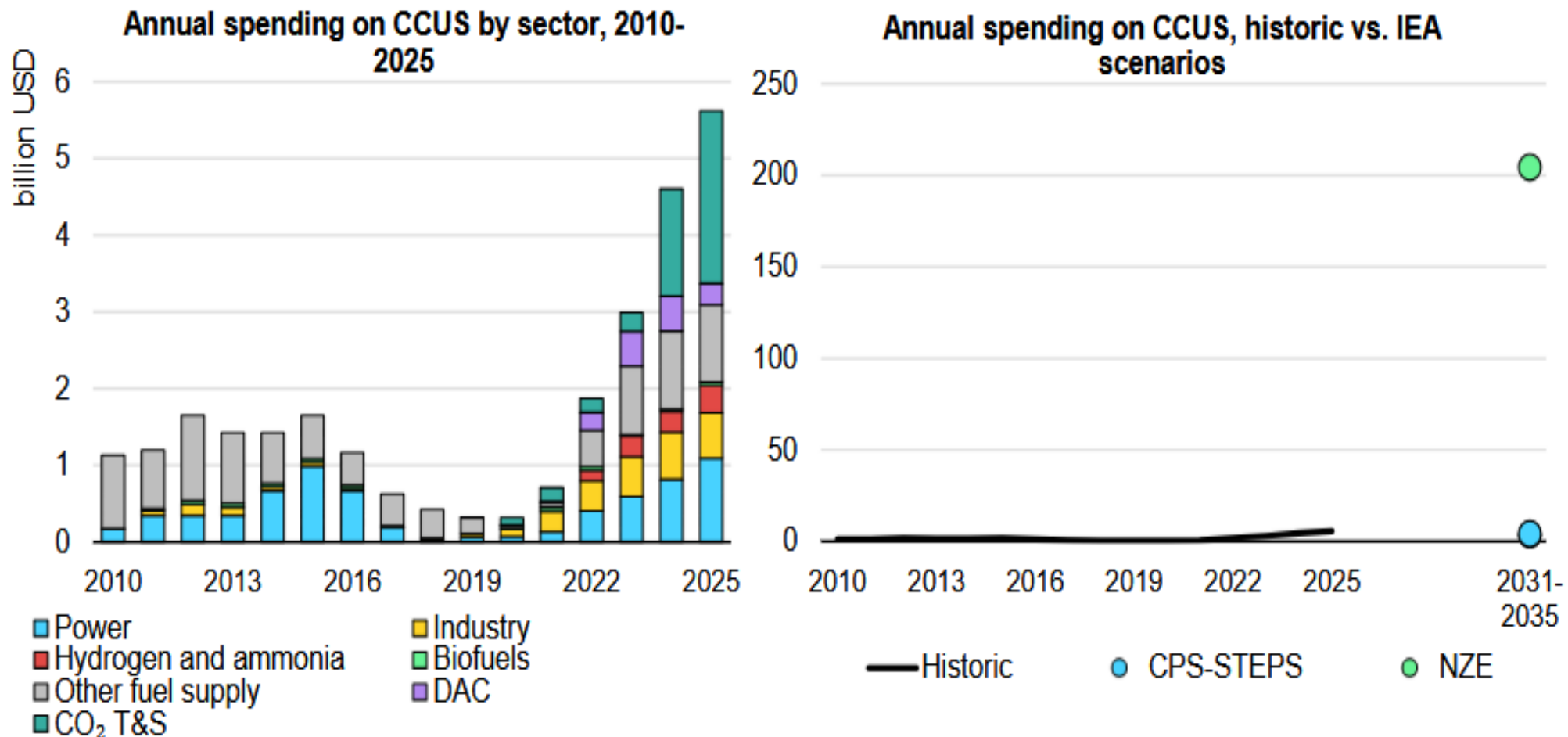


5 G\$ spent in 2025 worldwide for CCUS Projects (Source: IEA)
A relevant price of CO₂ is the must!



5+ G\$ spent in 2025 worldwide for CCUS Projects (Source: IEA)

A relevant price of CO₂ is the must!



Source: IEA Financing CCUS at scale 2026



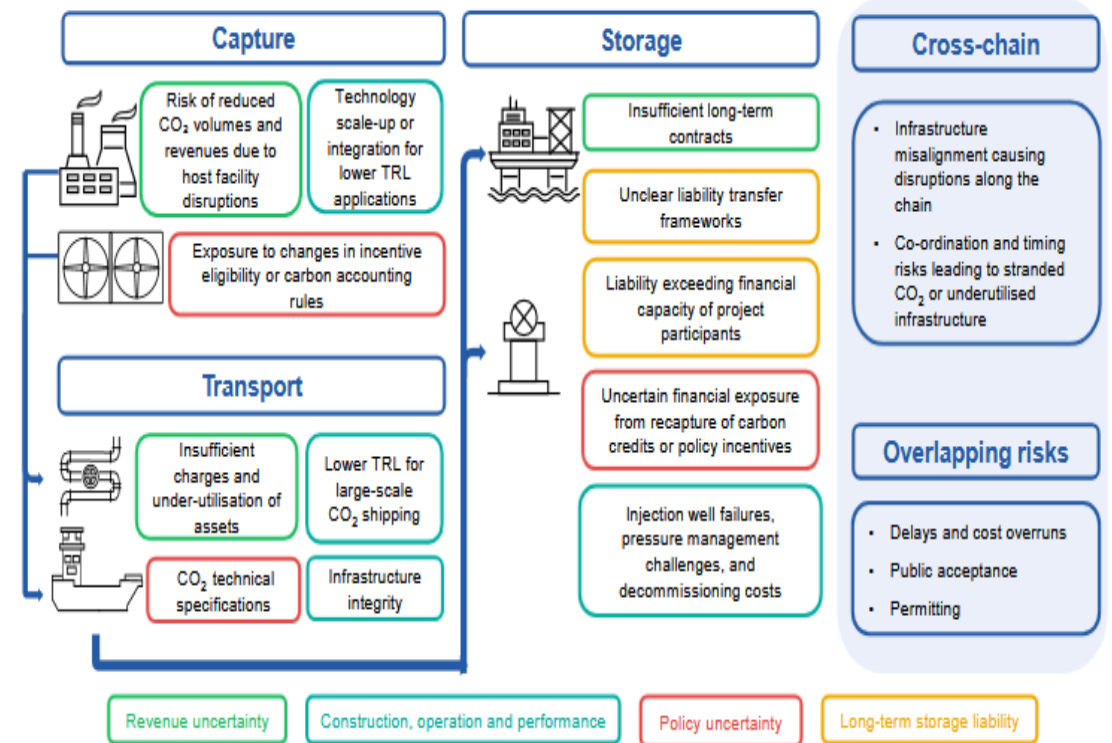
Problematic of Financing CCUS Projects

Public Support vs Risks

Public support mechanisms for CCUS projects

Category	Policy instrument	Public entities	Examples
Enabling conditions	- Legal and regulatory frameworks - International agreements		Frameworks in Europe and parts of the United States, Canada and Australia have provisions for the long-term liability of stored CO₂. Agreements between countries are needed under the London Protocol and Article 6 of the Paris Agreement.
Capital support	- Grants - Equity stakes - Loans	 	The Innovation Fund and Connecting Europe Facility are major grant programmes for CCUS in the European Union. The European Investment Bank and Nordic Investment Bank offered loans to a BECCS project in Sweden.
Risk-sharing mechanisms	- CfDs, reverse auction, regulated tariffs - Public-private partnerships - Offtake agreements - Export guarantees	 	The Canada Growth Fund can provide concessional debt or equity, CfDs, anchor equity and offtake agreements. SOEs in the Netherlands (EBN, Gasunie, Port of Rotterdam), Norway (Gassnova) and United Arab Emirates (ADNOC) help reduce cross-chain and performance risks.
Public entities			
Government	Sovereign wealth fund/ state-owned bank	Multilateral development bank/development finance institution	State-owned enterprise
			Export credit agency

Overview of risks across the value chain for CO₂ capture, transport and storage



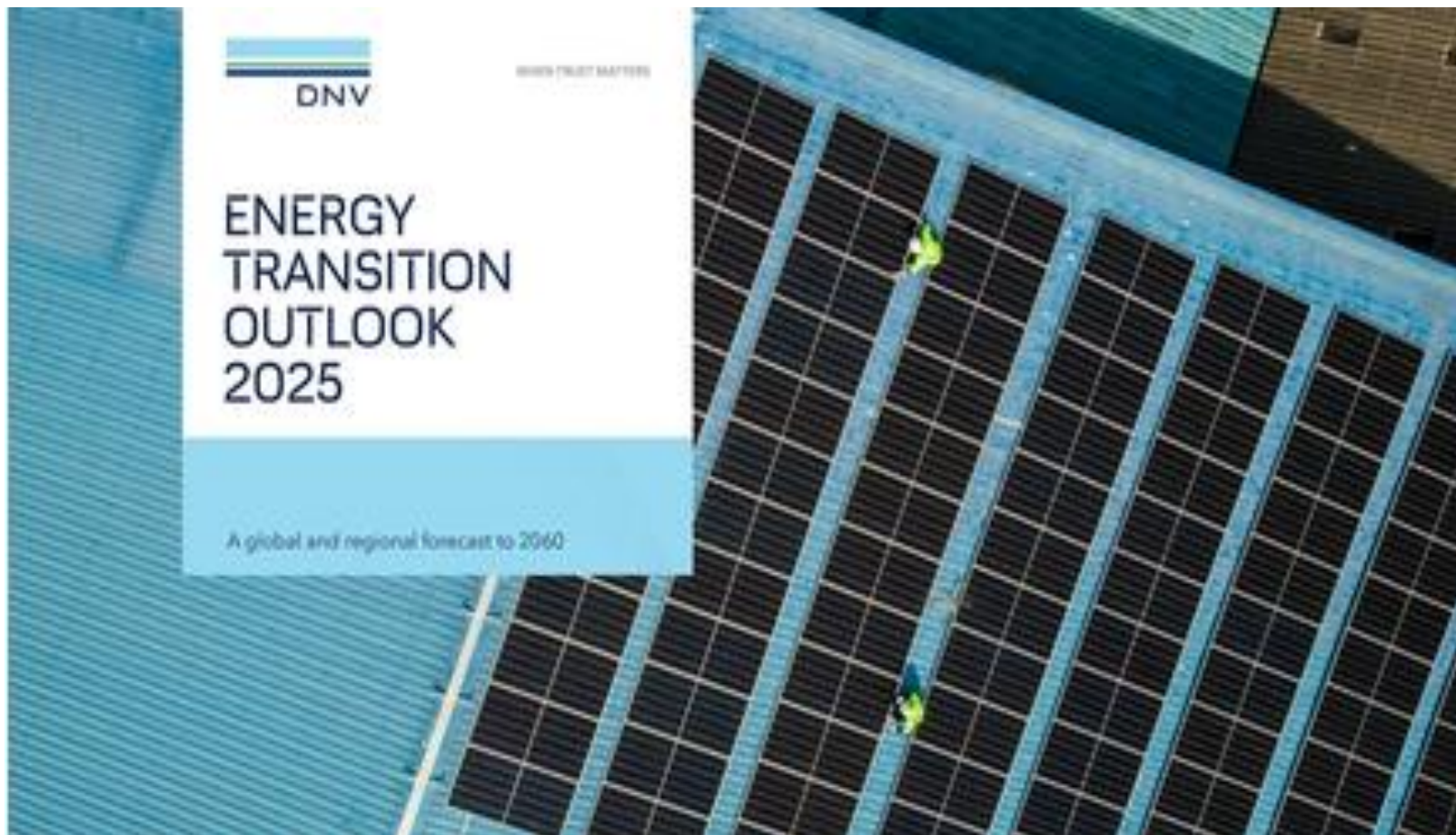
IEA. CC BY 4.0.

Note: TRL = technology readiness level.

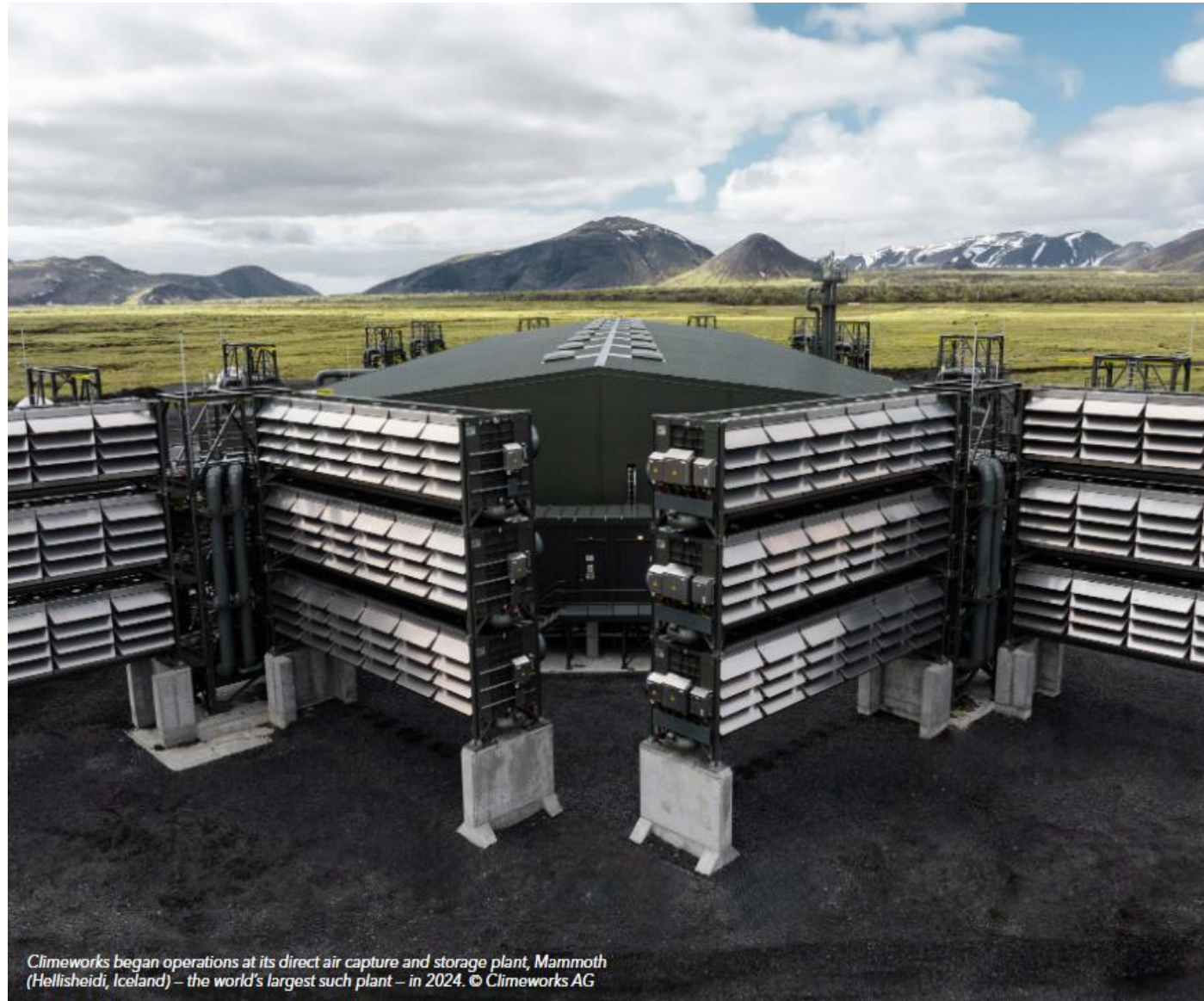
Each segment of the value chain has risks that can affect the viability of other parts of the chain, and investors must consider how these risks interact and spread.



CCS – A view by DNV



CCS – A view by DNV



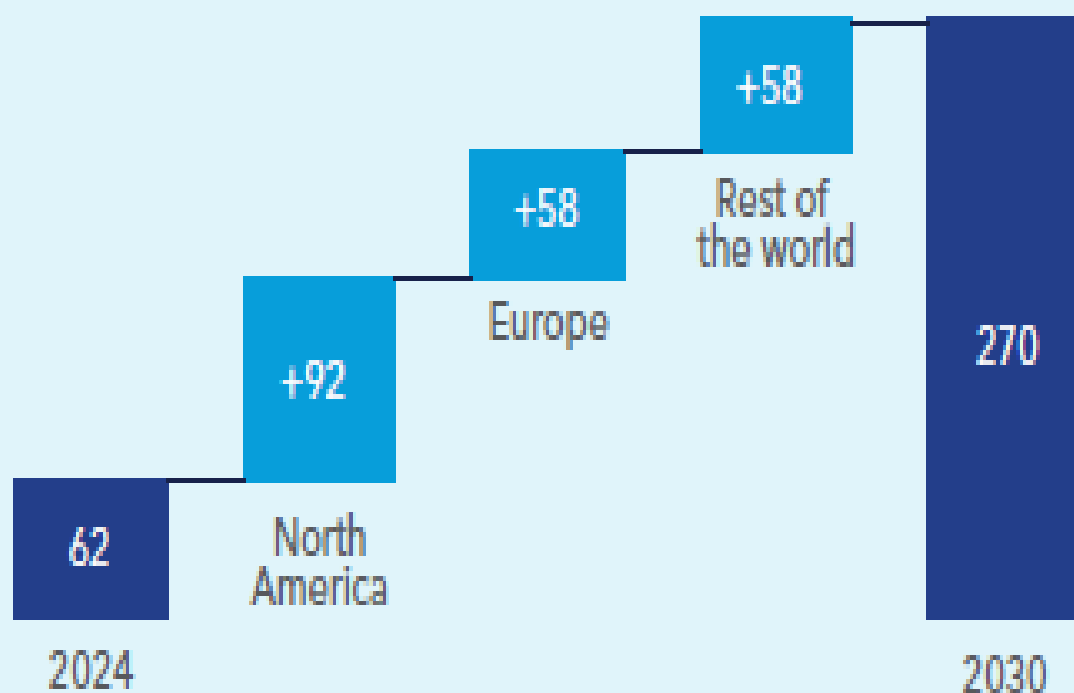
Climeworks began operations at its direct air capture and storage plant, Mammoth (Hellisheidi, Iceland) – the world's largest such plant – in 2024. © Climeworks AG



CCS – A view by DNV – Capacity additions & Uses

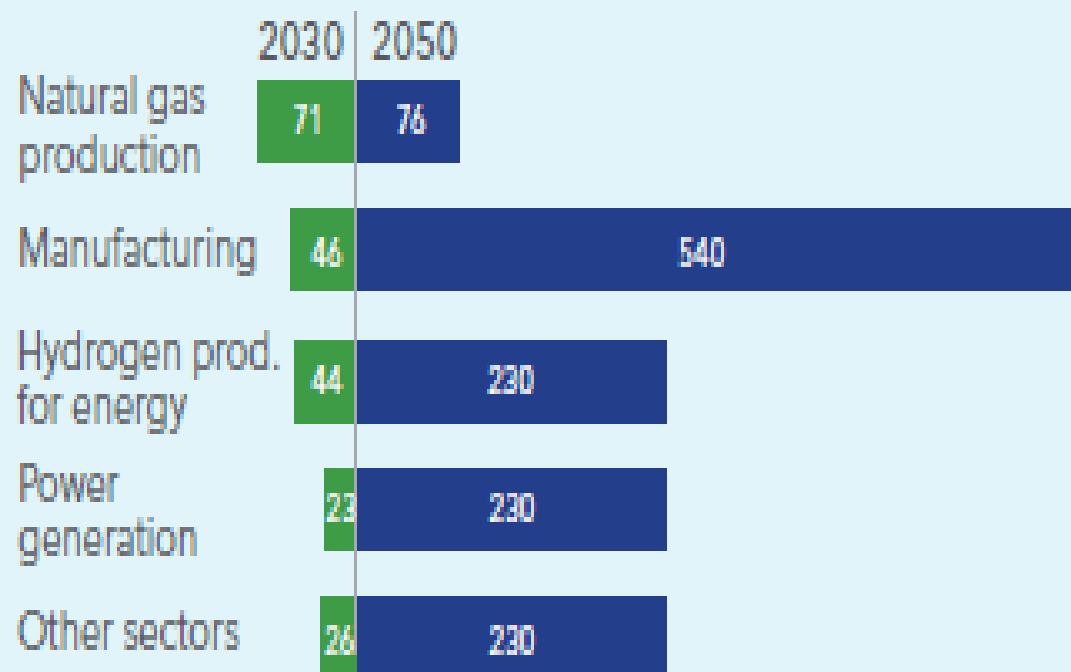
CCS capacity additions to 2030

Units: MtCO₂/yr



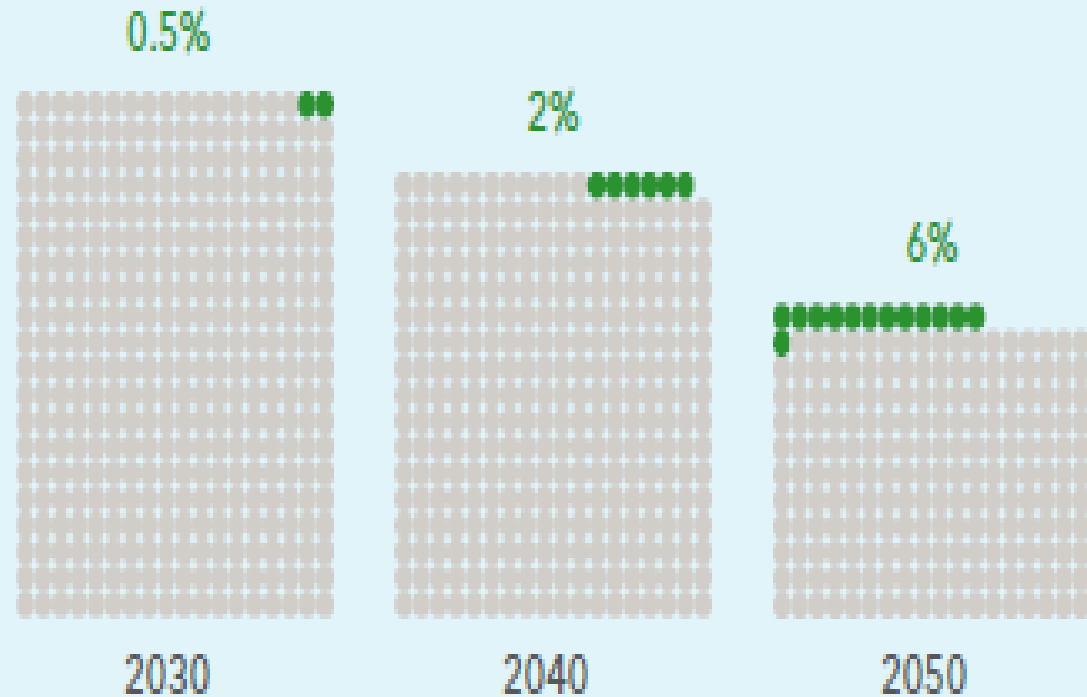
CCS by sector in 2030 and 2050

Units: MtCO₂/yr



CCS – A view by DNV – Captured Emissions

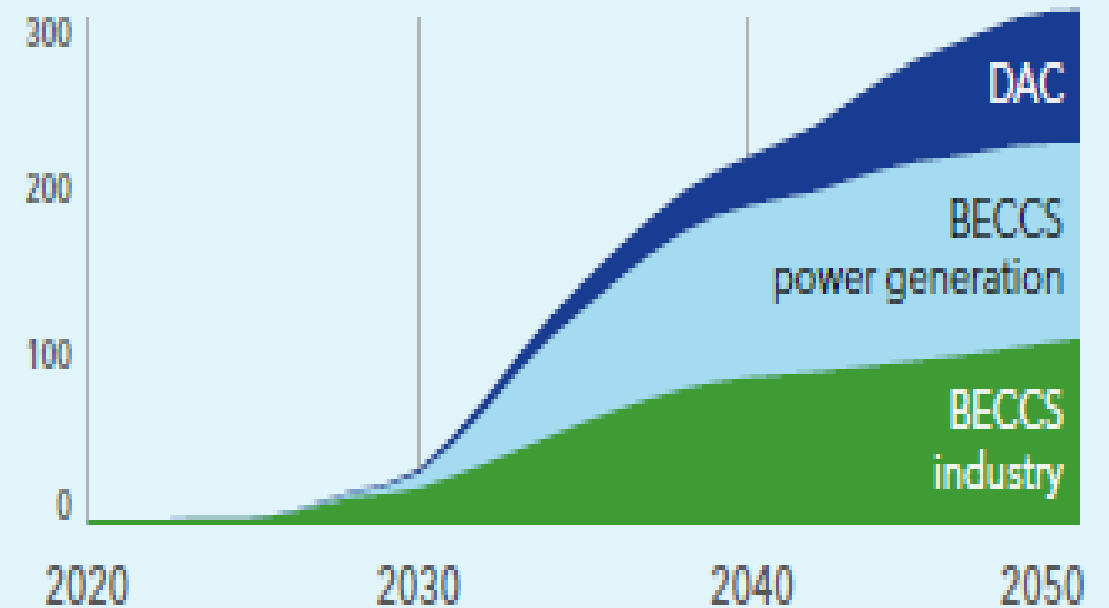
Share of global CO₂ emissions captured with CCS



One circle represents 100 MtCO₂/yr. CCS numbers include carbon removal.

Carbon dioxide removal through 2050 by sector

Units: MtCO₂/yr



CCS – A view by DNV – Selected Projects

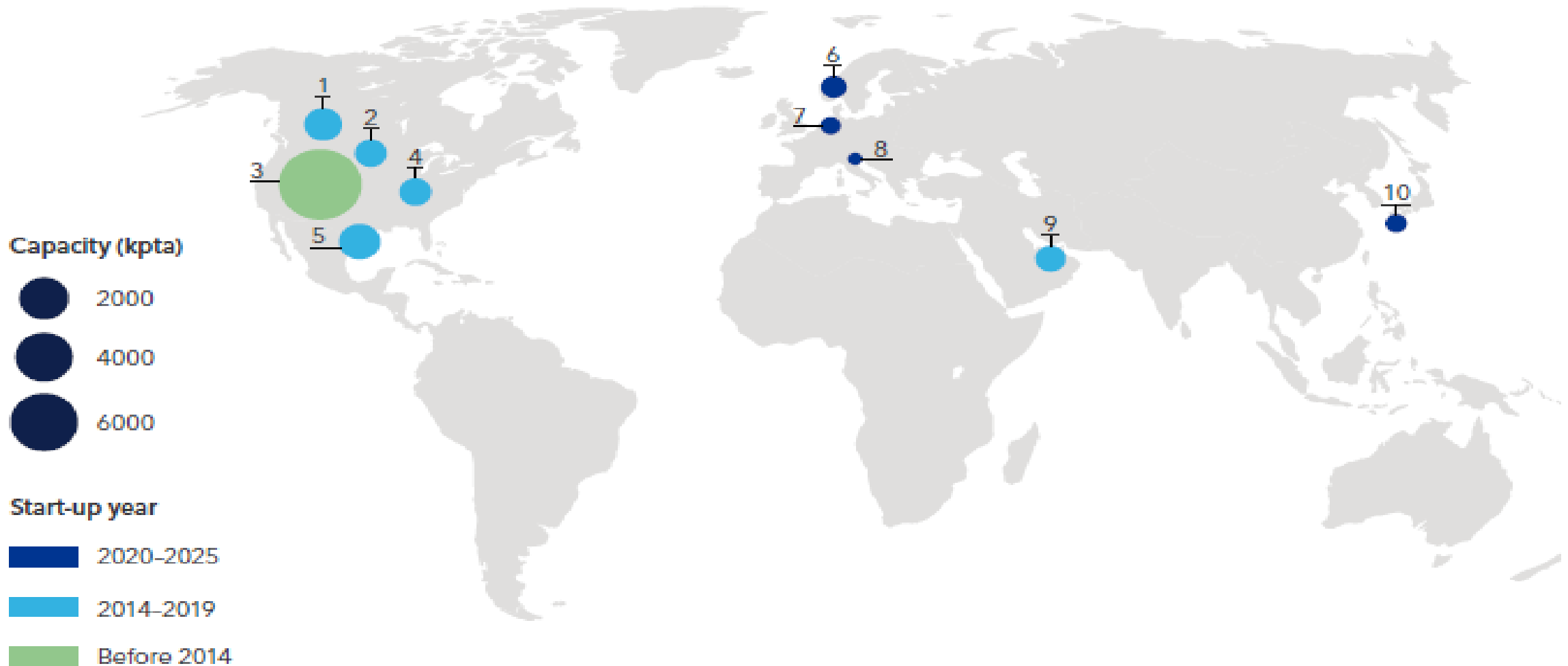
Selected operational capture reference facilities in various industries

Nr	Name and Location	Industry	Design Capacity (ktpa)	Technology	Start-up year
1	Quest, Canada	Hydrogen	1 200	Amine, Shell Adip-X	2015
2	Boundary Dam, Canada	Coal Power	1 000	Amine, Shell Cansolv	2014
3	Shute Creek, US	Natural Gas Processing	9 100	Physical Solvent, Selexol	1986
4	ADM Illinois, US	Ethanol	1 000	Inherent	2017
5	Petra Nova, US	Coal Power	1 700	Amine, MHI	2017
6	Heidelberg Materials Brevik, Norway	Cement	400	Amine, Capturi	2025 (in commissioning)
7	Twence, Netherlands	Waste-to-Energy	100	Amine, Capturi	2025
8	Ravenna, Italy	Gas Turbine	25	Amine, MHI	2024
9	Al Reyadah, UAE	Steel	800	Amine, MEA	2016
10	Mikawa, Japan	Biomass Energy	180	Amine, Toshiba	2020



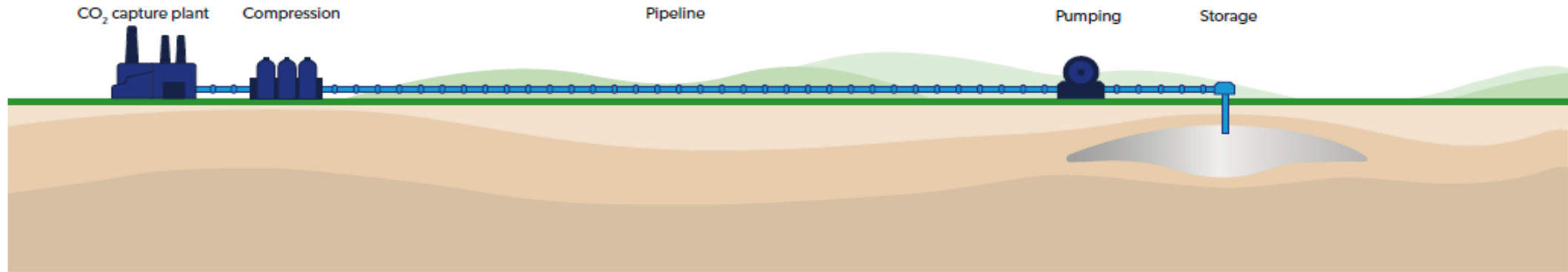
CCS – A view by DNV – Selected Projects

Mature capture technologies have been deployed across various Industries

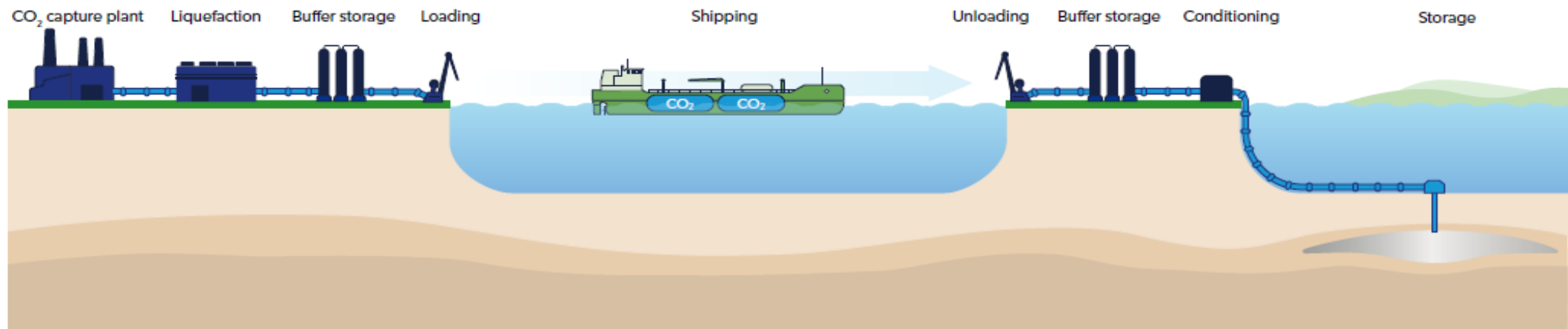


CCS – A view by DNV Pipeline & Shipping Value Chain

Pipeline value chain



Shipping value chain (shore-to-shore configuration)



CCUS Technologies & Costs



Main Technologies for CO₂ Capture

- **Chemical absorption:** Reaction between CO₂ and a chemical solvent (amine,....)
- **Physical separation:** Adsorption, absorption, cryogenic separation, dehydration and compression
- **Oxy-fuel separation:** Combustion of fuel with pure oxygen, capture and dehydration
- **Membrane separation:** Polymeric or inorganic membranes with high CO₂ selectivity from the gas stream
- **Calcium looping:** CO₂ capture at high temperature with CaO used as a sorbent
- **Chemical looping:** Formation of a metal oxide from the air followed by a reaction with fuel generating a concentrated flow of CO₂
- **Direct separation:** In the cement industry, direct CO₂ stripping from the limestone



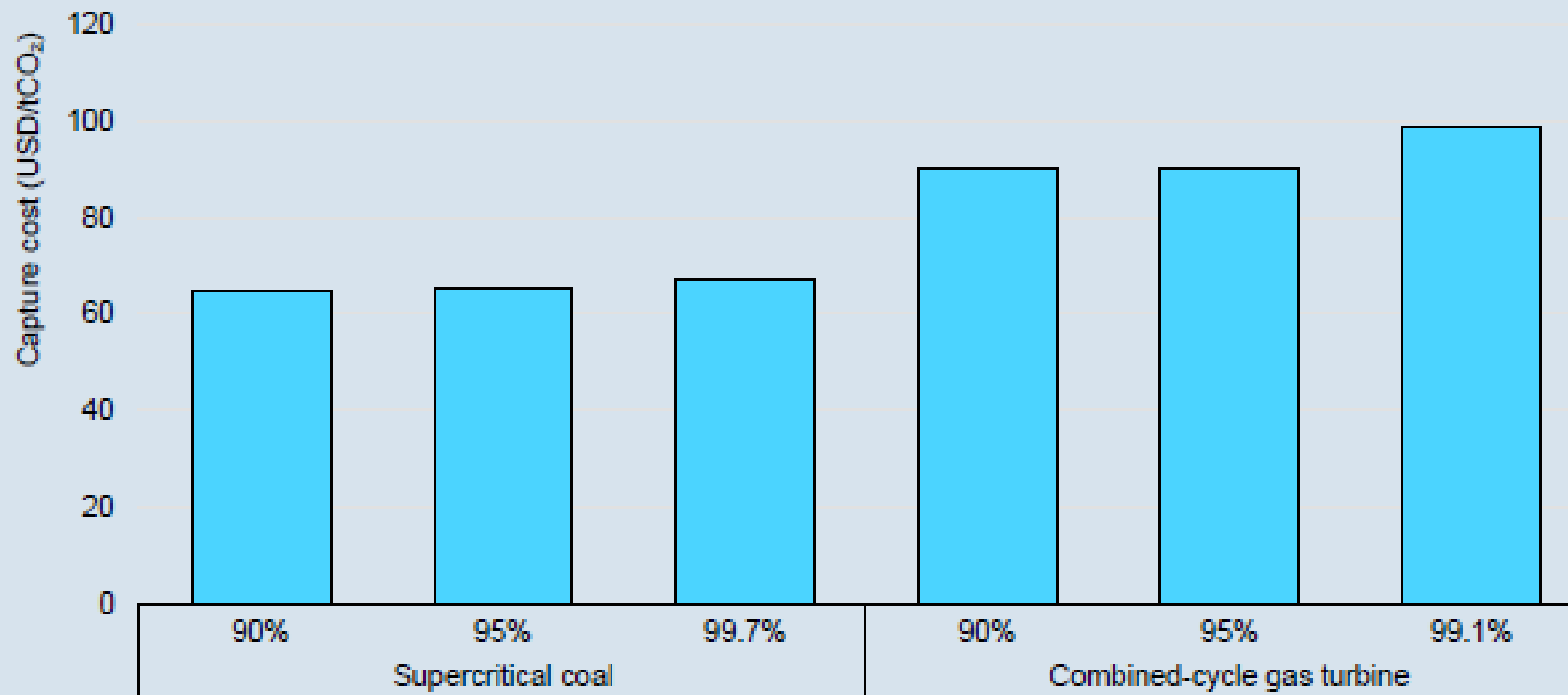
Main Technologies for CCUS Applications

Sector	Key CCS applications	Combustion emissions	Process emissions	Alternative decarbonization pathways
Industry	Chemicals Primarily production of ethanol and methanol, but with various other applications in the future			Green hydrogen and CO2 utilization technologies
	Hydrogen production Production of blue hydrogen from natural gas or coal			Green hydrogen
	Cement Process emissions account for 70% of emissions from cement production, the remaining from combustion			Carbon-free concrete and low carbon fuels
	Iron and Steel Both a high degree of process emissions from iron ore reduction and combustion emissions			Iron electrolysis or direct iron ore reduction with hydrogen
Power generation	Gas Flue gas CO2 separation			Renewables and nuclear Green hydrogen
	Coal Flue gas CO2 separation			Renewables and nuclear Green hydrogen
	Bio energy Bio energy with CCS (BECCS) with potential of being net negative			Carbon free
Energy	Natural gas processing High concentration CO2 from natural gas processing is currently the easiest to abate with CCS			Substitution of end -use consumption
	Oil refining Majority from process emissions, but dependent on refinery setup, feedstock and product composition			Substitution of end -use consumption
Other	Waste incineration Flue gas CO2 separation			
	Direct air capture CO2 extracted from the ambient air. Ideally located close to storage site and with access to cheap, clean electricity			Carbon free

Source: Rystad Energy

CO₂ Capture Costs for current technologies 60 – 100 \$/tCO₂

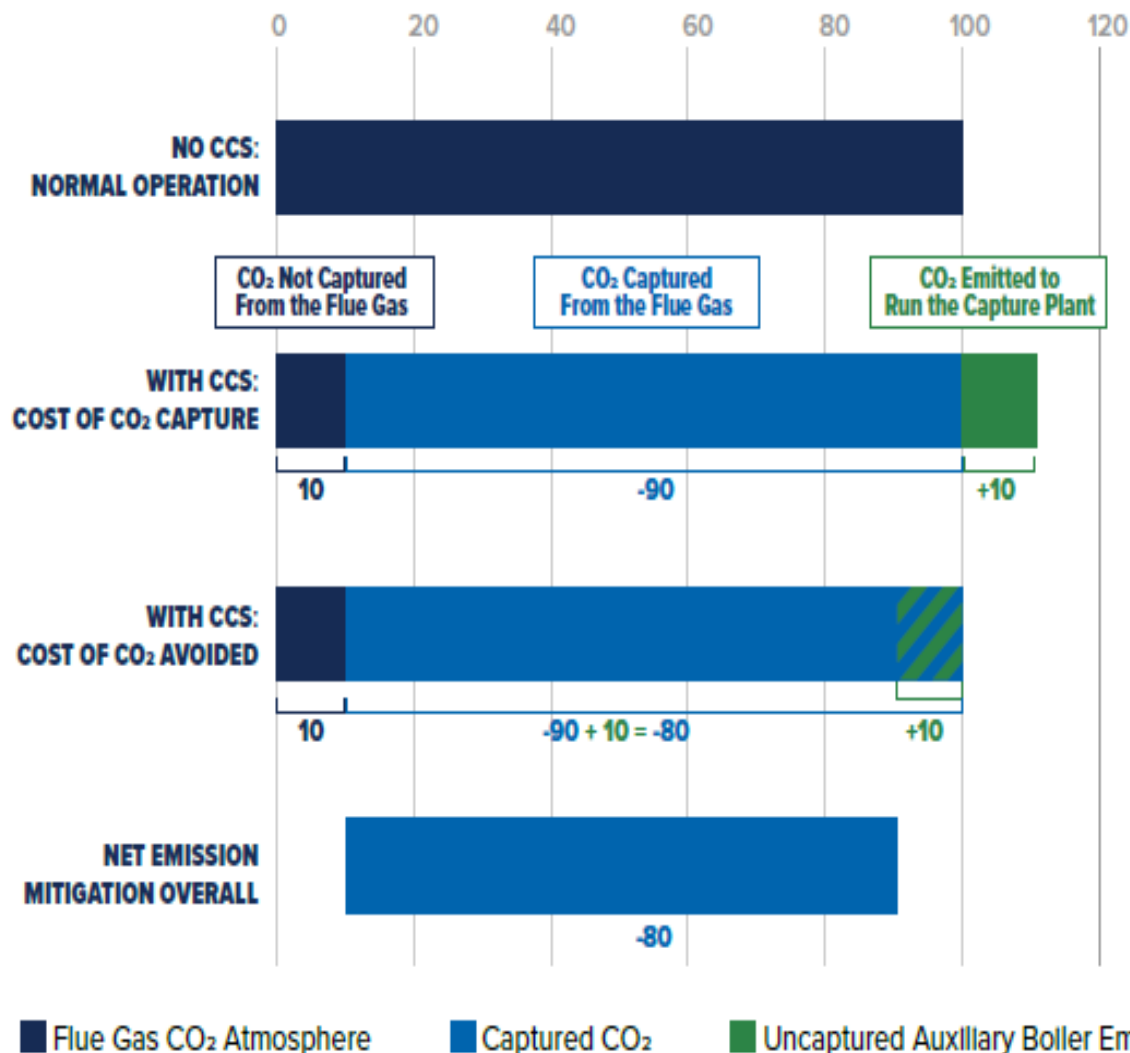
Indicative CO₂ capture costs for coal- and gas-fired power plants by capture rate



Source: IEA analysis based on own estimates and IEAGHG (2019b), Towards Zero Emissions CCS in Power Plants Using Higher Capture Rates or Biomass.



CO₂ Flows and Capture Costs: 110 – 130 \$/t CO₂



Assume a hypothetical plant costs \$10 Million to capture 90,000 tpa of CO₂ out of a 100,000 tpa CO₂ flue gas stream

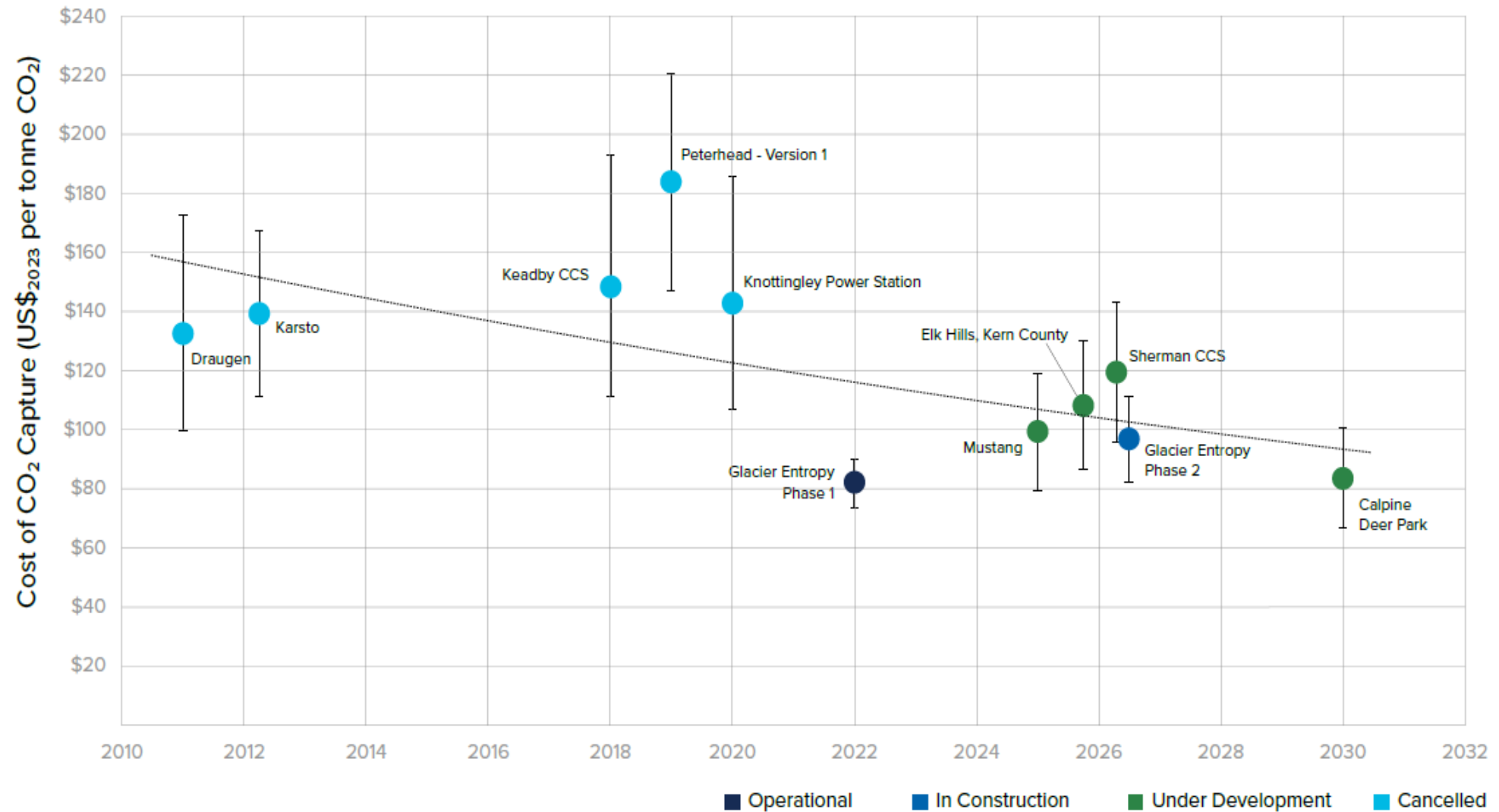
Hypothetical costs of CO₂ Captured
Cost/CO₂ Captured from Flue Gas =
 $\$10,000,000 / 90,000 = \$111.11/\text{tCO}_2$

Hypothetical costs of CO₂ Avoided
Cost/Net Impact =
 $\$10,000,000 / 80,000 = \$125/\text{tCO}_2$

The hypothetical Net Impact to emissions is the same under both calculation methods. A reduction in emissions by 80,000 tpa



CO₂ Capture Costs for a Gas-fired plant – Evolution 2010 - 2030



Source: Global CCS Institute January 2025



Reminder – IEA Special Report on CCUS 2020



Additional Carbon Removal Technologies to get an objective of 0 Net Carbon Emissions

Technology	Current maturity	Carbon removal potential Cumul to 2100 (GtCO ₂)	CO ₂ capture Cost (\$/tCO ₂)
Bioenergy with CCS BECCS	Demonstration	100 - 1200	10 - 90
Direct Air Capture and Storage - DACS	Demonstration	100 - 1000	130 - 350
Land Management and Biochar Production	Early adoption	80 - 1500	30 - 150
Afforestation Reforestation	Early adoption	80 - 300	5 - 50

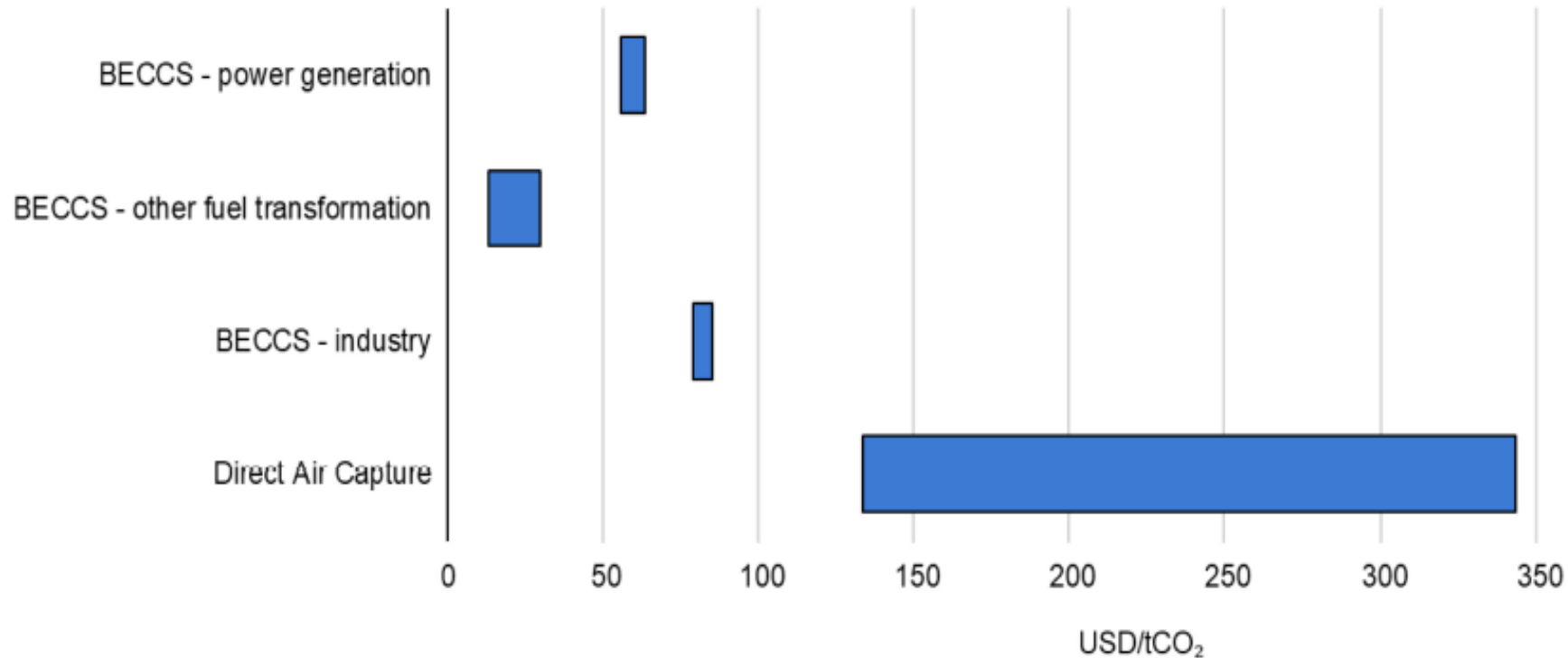
Source: IEA Special Report on CCUS 2020

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TPA Toolbox Energy Book 3 - GHG



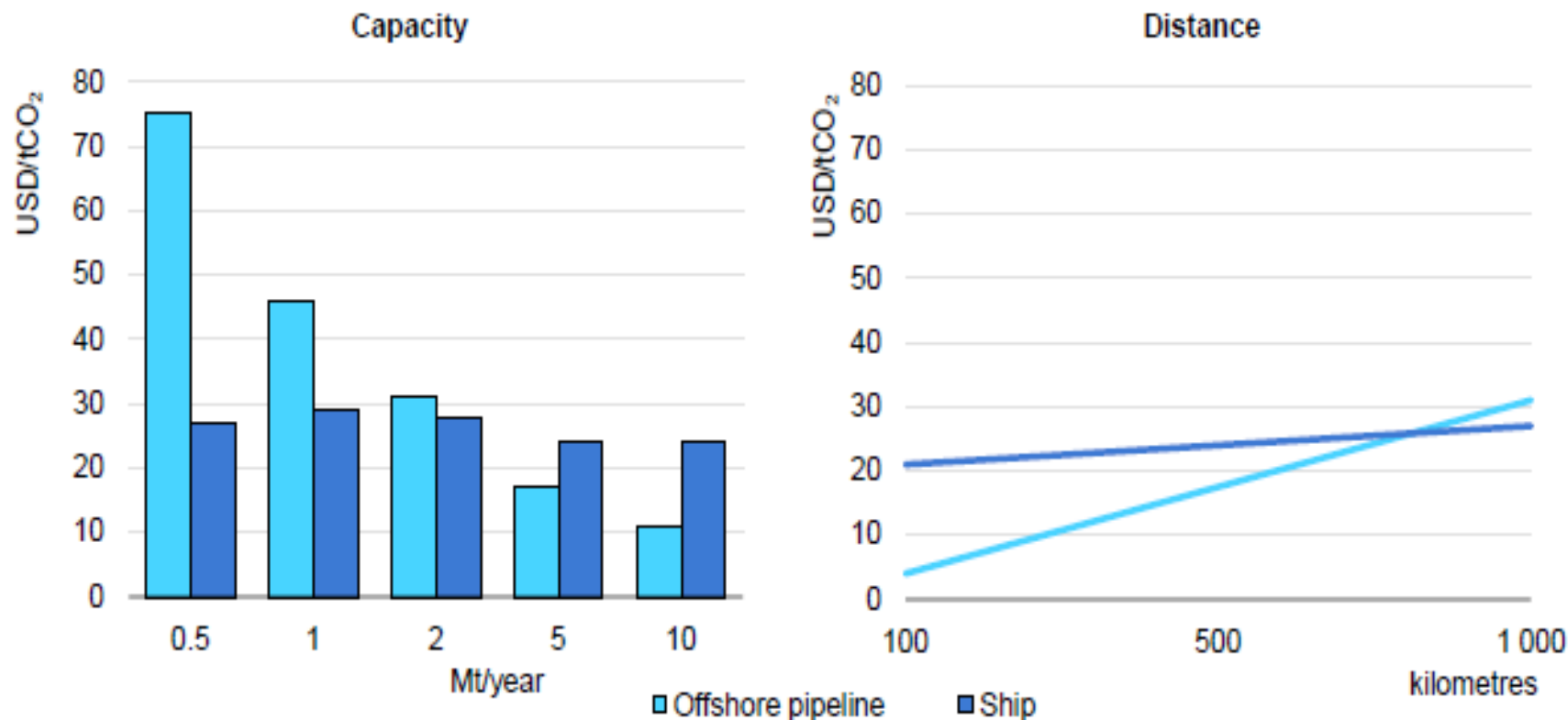
Additional Carbon Removal Technologies to get an objective of 0 Net Carbon Emissions



Notes: CO₂ capture costs are based on the following assumptions: technical lifetime = 25 years; representative discount rate = 8%; the price of fuel = USD 7.50/GJ; the price of electricity = USD 6.7/GJ. BECCS applied to industrial processes is based on chemical absorption.

Sources: EASAC (2018), Fuss et al. (2018), Haszeldine et al. (2018), Keith et al. (2018), Realmonte et al. (2019).

CO₂ Transportation Costs Shipping & Offshore Pipelines Maximum optimized Cost # 30 \$/tCO₂



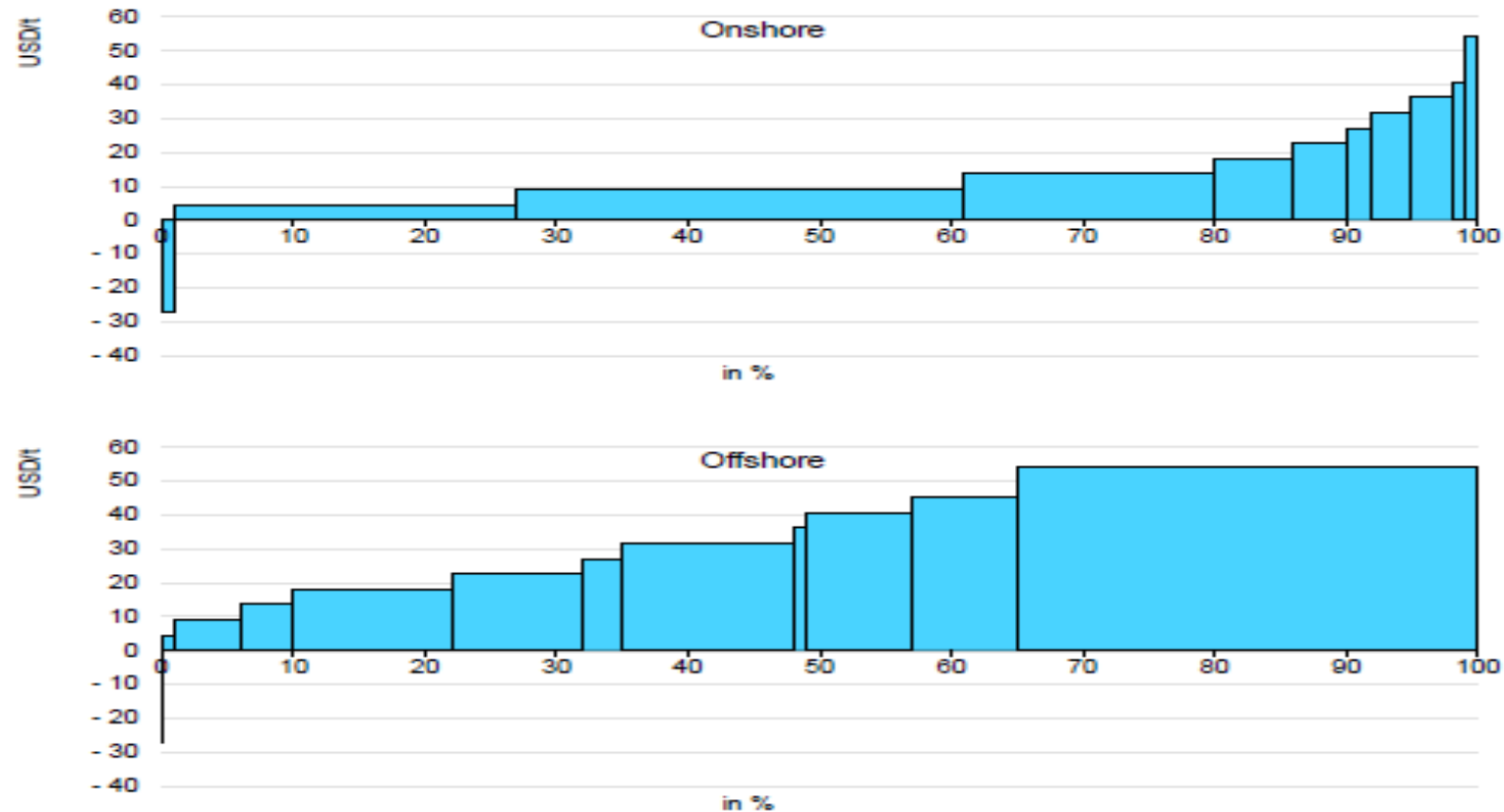
Notes: Left-hand chart assumes a distance of 1 000 km. The right-hand chart assumes a capacity of 2 Mt/year.

Source: IEAGHG (2020b), The Status and challenges of CO₂ Shipping Infrastructure.

CO₂ Storage Costs

Indicative Costs for CO₂ Storage in the US

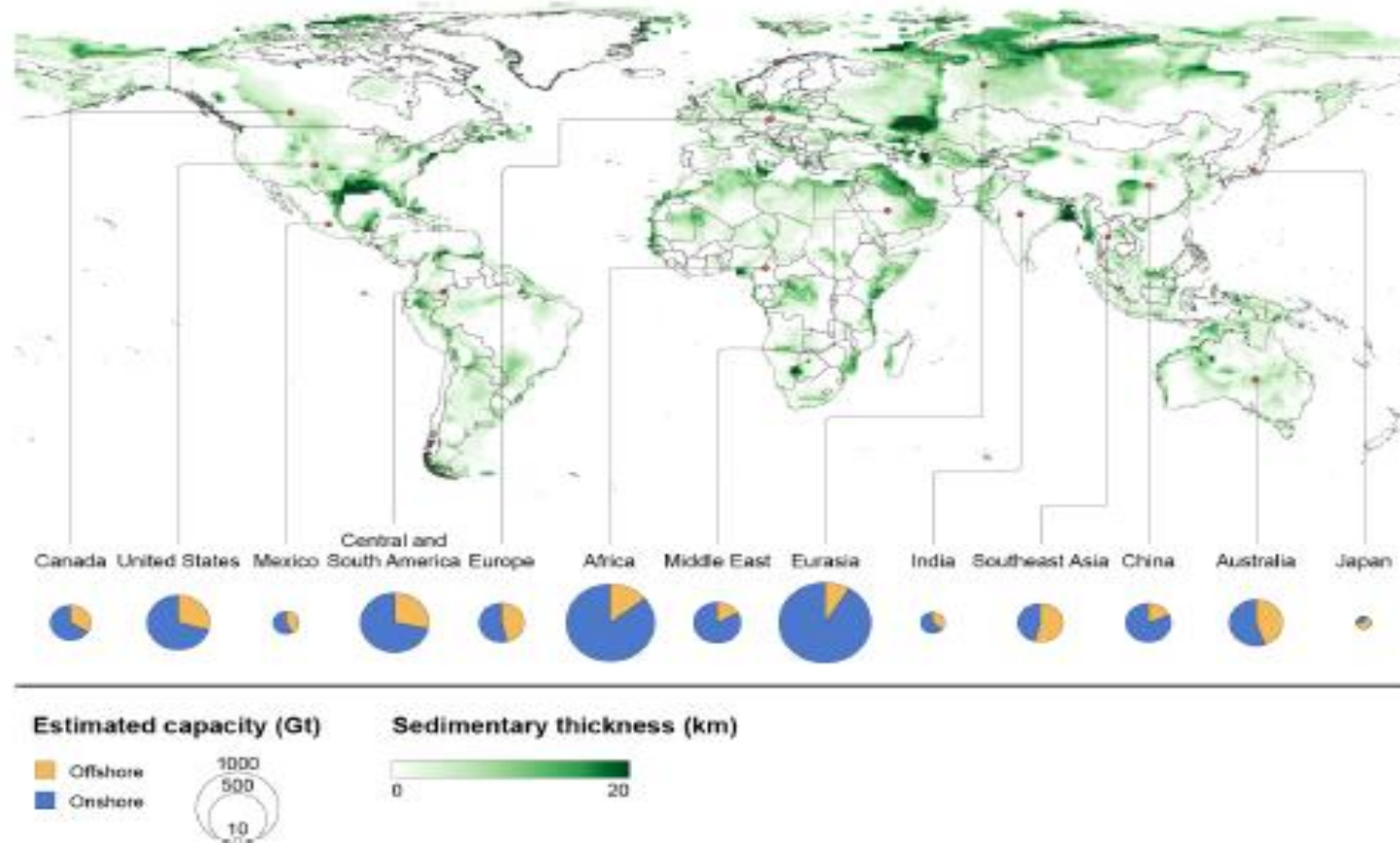
In average from # 10 \$/tCO₂ onshore to # 30 \$/tCO₂ offshore



Source: Based on US EPA (2018), Inventory of U.S Greenhouse Gas Emissions and Sinks 1990-2017.

CO₂ storage costs can vary considerably, with CO₂-EOR at negative costs and the majority of the onshore storage capacity being available at below USD 10/tCO₂.

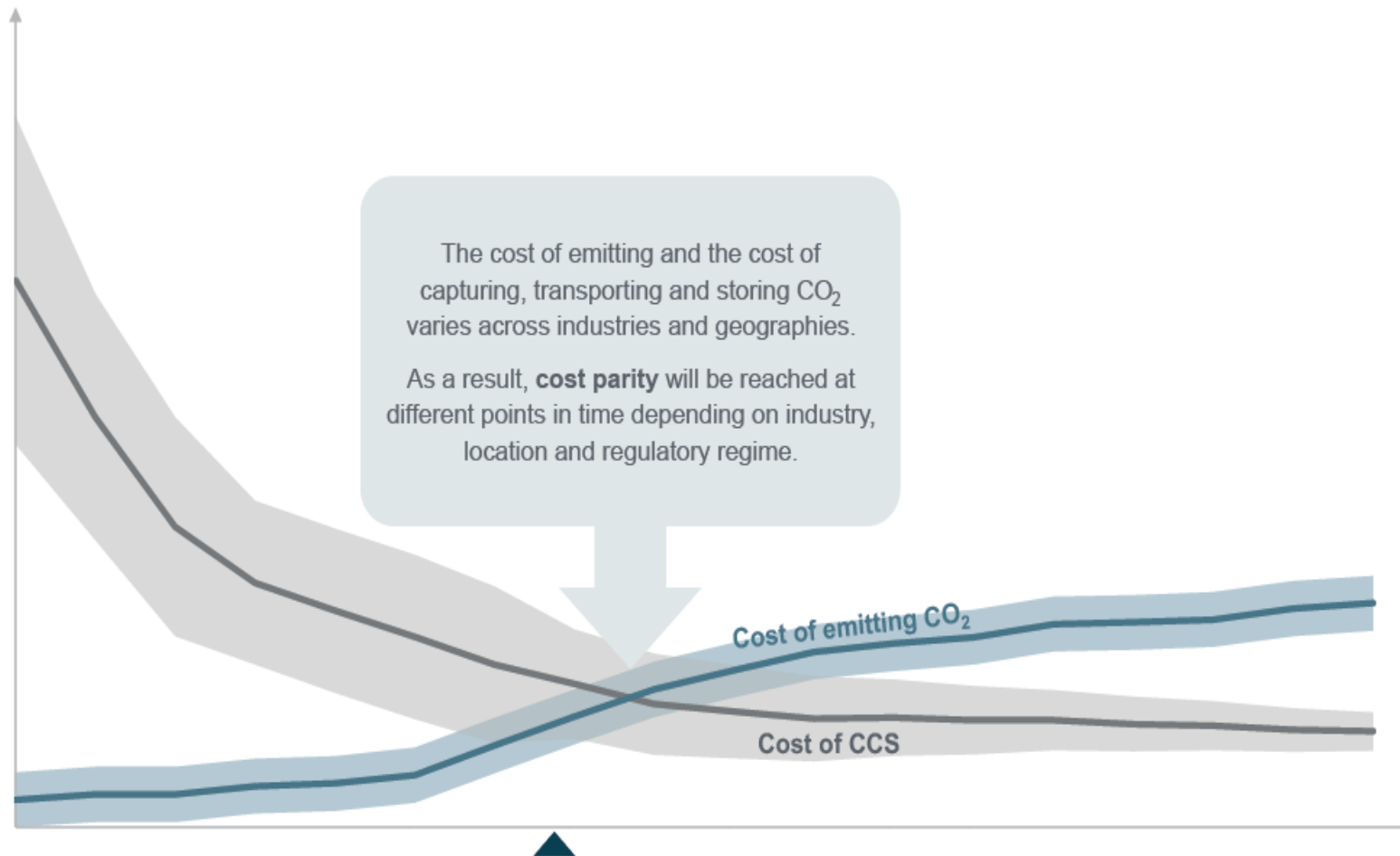
CO₂ Storage Capacity by Regions



Notes: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area. Sedimentary thickness serves as an indicator of the theoretical potential of CO₂ storage sites. The offshore capacity estimates exclude sites in water depths of more than 300 metres and more than 300 kilometres offshore. The Arctic and Antarctic regions are also excluded.

Source: Kearns, J. et al., (2017), Developing a Consistent Database for Regional Geologic CO₂ Storage Capacity Worldwide.

What decision to be taken?



Source: Rystad Energy



Conclusions for CCUS Costs:

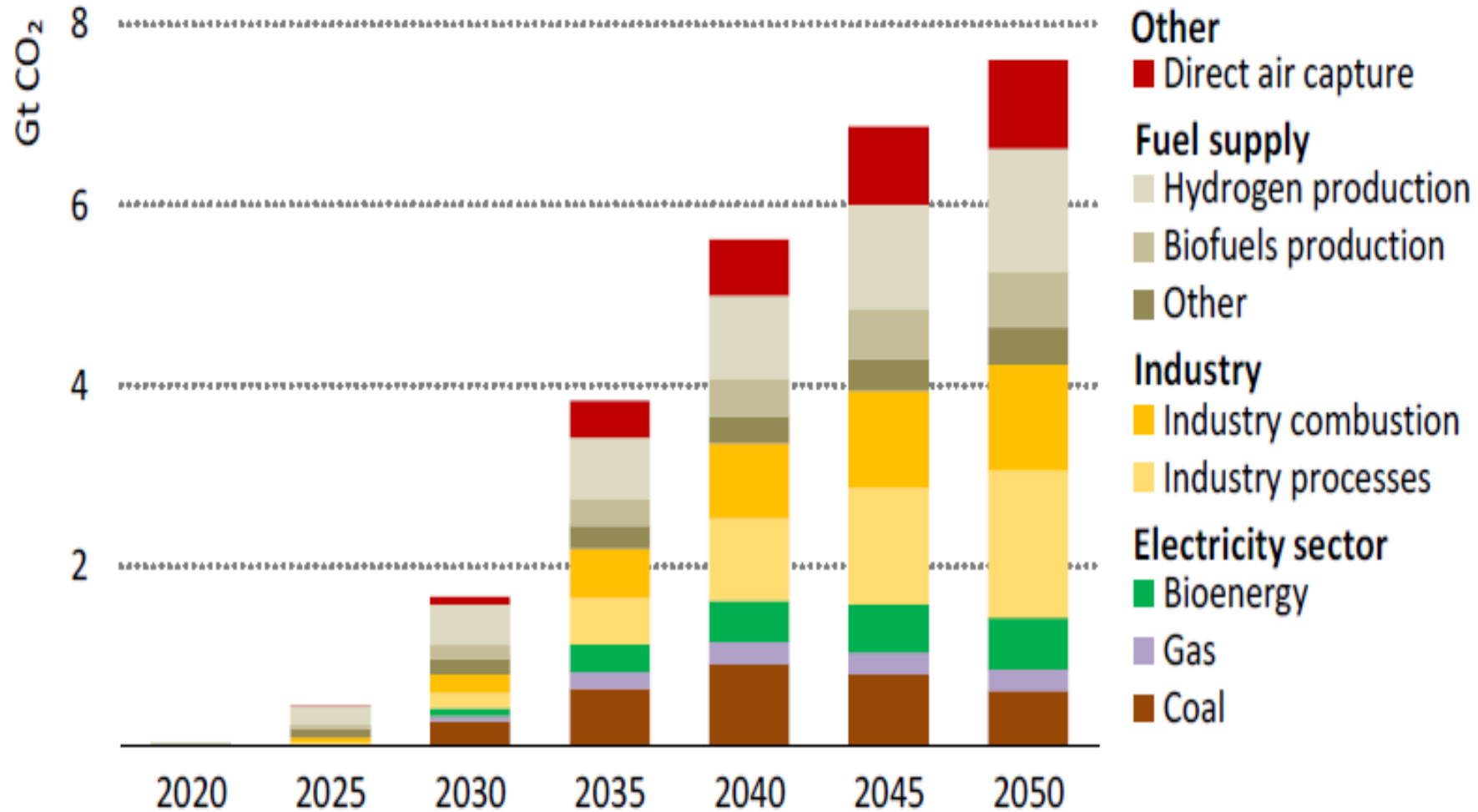
The overall Costs for CCUS including Capture, Transportation & Storage is in the range of 100 to 200 \$/tCO₂ based upon current Technologies

This gives an indication of the level of a potential Carbon Tax to economically justify investments in CCUS

A huge challenge!



Reminder: IEA 2021 Carbene Capture Sources in NZE 2050 Scenario

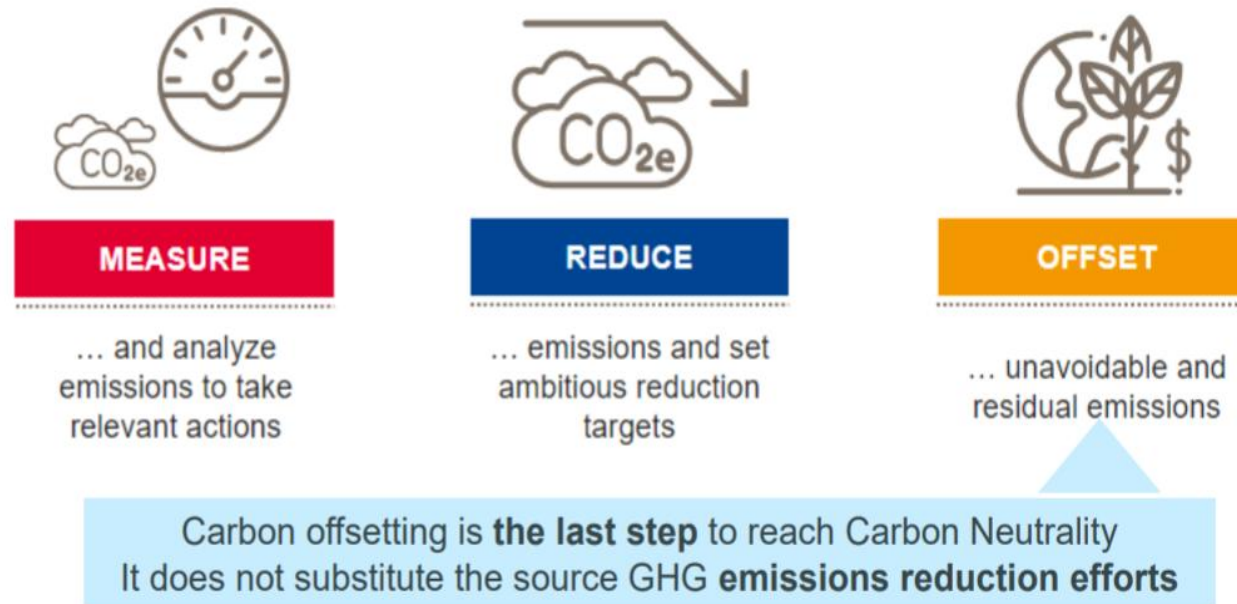


Source: IEA Net Zero by 2050 - October 2021

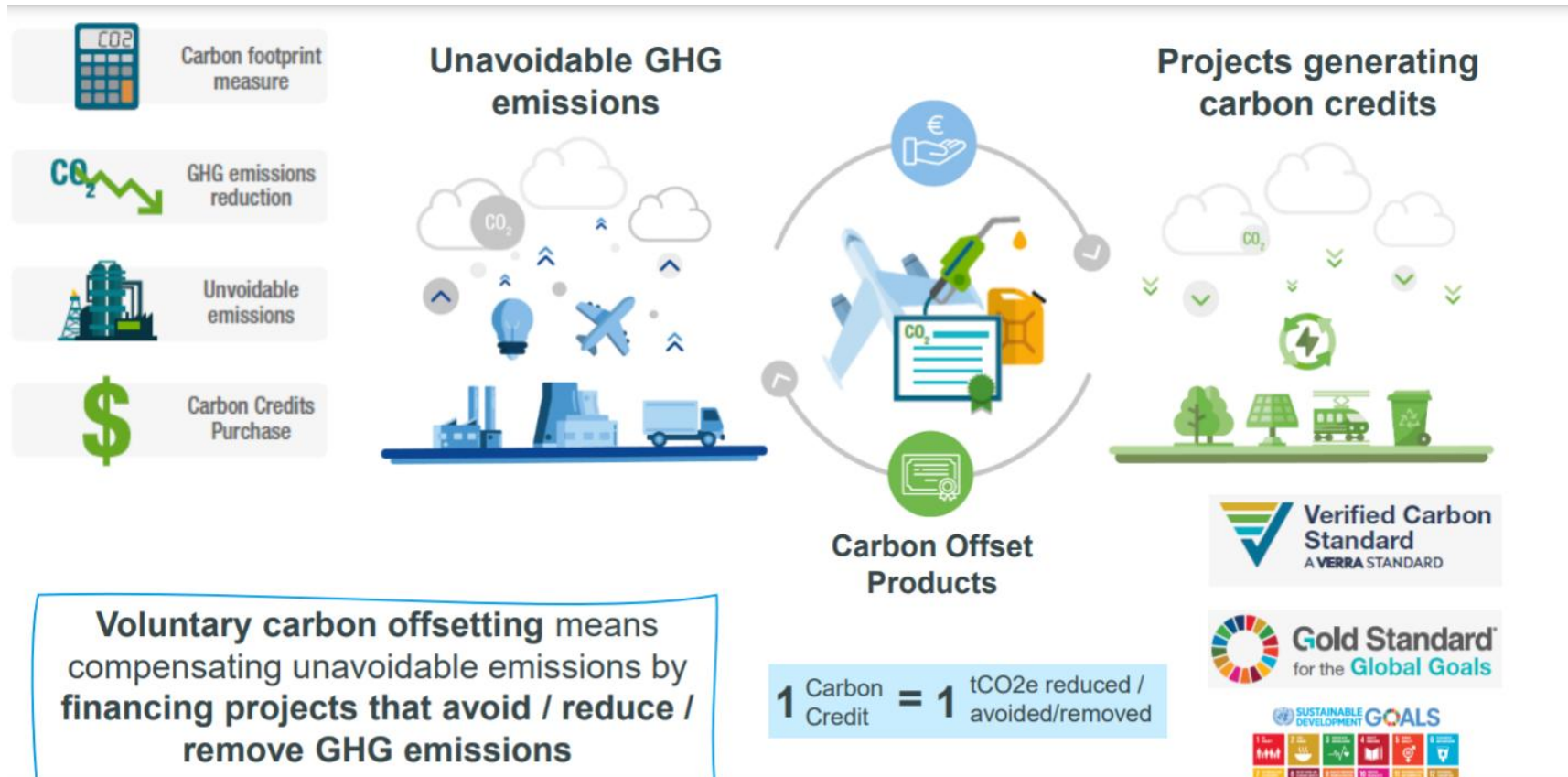


Voluntary Carbon Offsetting

In order to achieve the **1,5°C Paris ambition**, the world needs substantial emission reductions. A clear mitigation hierarchy shall be installed by companies: **reducing emissions comes first, carbon credits are an important complement.**



Ways for remaining Carbon offsettings

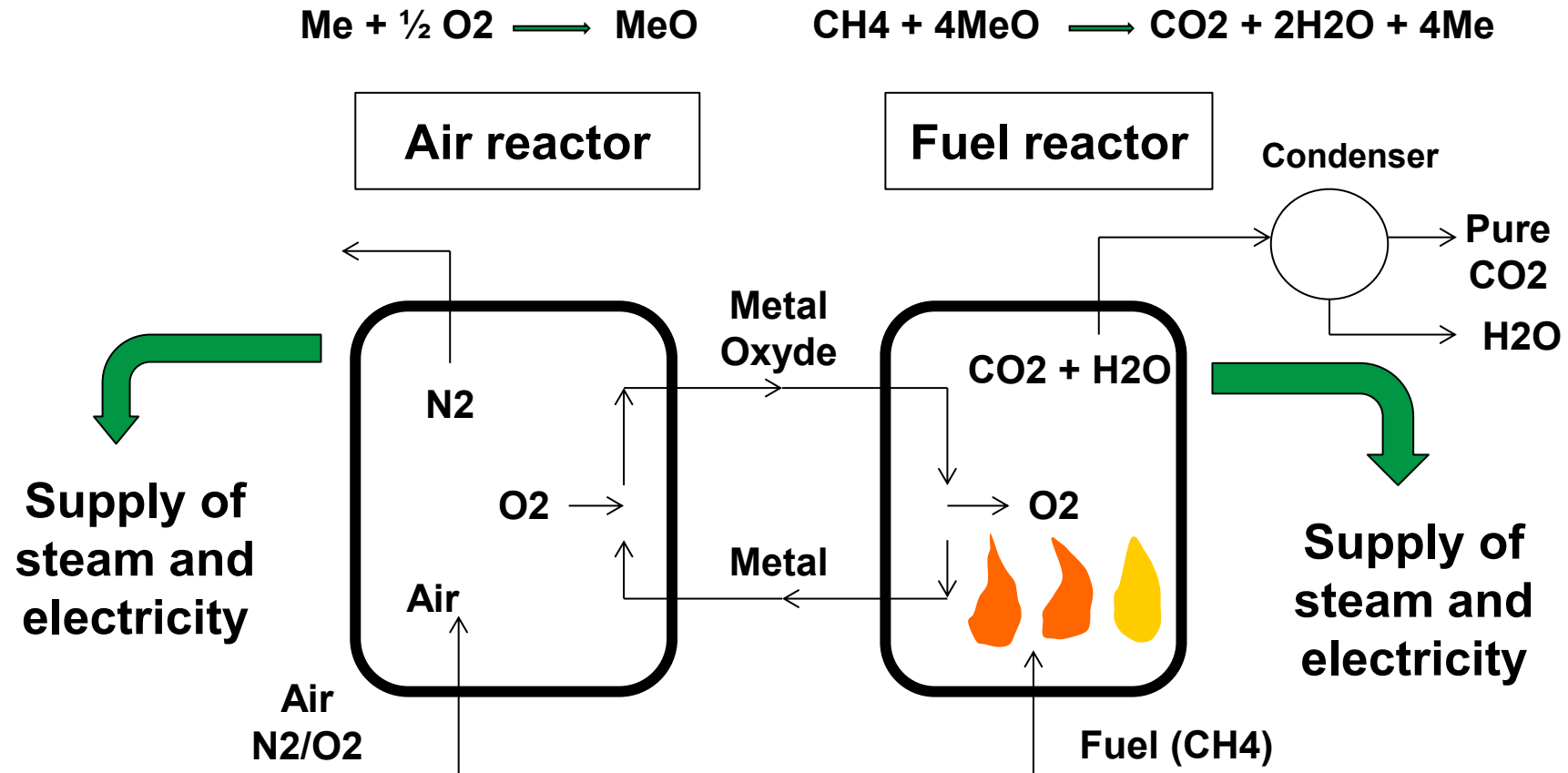


March 2018: Chinese – European Emissions - Reducing Solutions (CHEERS) Project

- **Objective: to develop a plant that will capture virtually all CO₂ and use it to produce electricity and steam.**
- **Capacity of the plant: 3 MWth**
- **Chemical Looping Combustion (CLC) technology will be used**
- **CO₂ produced will be relatively pure and ready for storage or utilization.**
- **The plant will produce electricity and steam that will be used on an industrial site.**
- **The plant will be located at the technical center of the chinese partner: Chinese thermal power equipment manufacturer, Dongfang Boiler**
- **Partnership of the project: Total, Dongfang Boiler, IFP Energies Nouvelles, SINTEF (Norway), Silesian University of Technology (Poland), Bellona (NGO Norway)**



Basic principle of CLC



Air reactor: At high temperature, the metal will absorb air oxygen
Fuel reactor: Combustion of oxygen from metal oxide generates pure CO₂



Chinese – European Emissions - Reducing Solutions (CHEERS) Project

CHEERS PROJECT : CHEMICAL LOOPING COMBUSTION

International pioneer in **retrofitting** an existing unit to CLC
Demonstration of CLC technology with **solid fuel**
In the frame work of **Horizon 2020** Work Program and China MOST
Quality of CO₂ based on **EOR** requirements
Techno-economic evaluation of industrial scale unit



Other CCUS Project

CCUS VALUE CHAIN DEVELOPMENT - STEEL PLANT



3D project : DMX™ Demonstration in Dunkirk



3D project received funding from the European Union's Horizon H2020 research and innovation programme under grant agreement No 838031

CO₂ Cluster :

12 Mt CO₂/y that could be captured in a short term

DMX™ Demonstration Unit in Arcelor Mittal Steel Plant



7

Climate change What implications for oil companies: the case of TotalEnergies



TABLE OF CONTENTS

1. What is science telling us about climate change ?
2. Economic consequences for energy and industries
3. The Kaya Equation
4. Agenda for Climate Change Negotiations
5. CO2 Markets, Pricing and Trading
6. Carbon Capture and Storage technologies
7. What implications for oil companies:
the case of TotalEnergies



Climate Change: what can an oil company do about it ?

- ◆ Promote a better understanding of climate change mechanisms and use it's industrial competences to develop potential solutions
- ◆ Manage a better control greenhouse gas emissions from its own facilities
- ◆ Help its clients to manage their greenhouse gas emissions
- ◆ Promote alternatives: renewable energies non CO₂ or low CO₂ emitting and nuclear energy
- ◆ Imagine and validate efficient and reliable solutions to capture and sequester CO₂ (Lacq Pilot scheme and others)

✓ ... while continuing to meet the world's energy demand
(deep offshore, unconventional oil, mature fields, LNG...)



Climate Change: 5 priorities for TotalEnergies

- **Promote Natural Gas supply. Substitute Coal by Natural Gas in the energy mix (Coal CO₂ emissions = 2 times Natural Gas CO₂ emissions for each kWh produced)**
- **Promote and Develop Renewables: solar energy and biofuels (La Mède: 1st bio refinery in Europe)**
- **Improve energy efficiency in TotalEnergies industrial units and final products consumption. Promote energy efficiency for TotalEnergies clients (Total Eco Solutions)**
- **Promote individual solutions to get access to energy. Example: Africa, more than 1 million individual solar lamps already provided, reaching more than 5 million people in 25 countries.**
- **Stimulate sectorial initiatives, leading to international commitments (Price of CO₂)**



Reminder - Some operational criterias

TotalEnergies performance – From 2011 to 2022

	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011
Oil & Gas Production (Mboe/d) (Mtoe)	2,76 138	2,82 141	2,87 143	3,04 150	2,78 138	2,57 128	2,45 122	2,35 117	2,15 107	2,30 115	2,30 115	2,35 117
Net primary Energy Consumption Operated (TWh) (Mtoe)	166 14,1	148 12,6	147 12,5	160 13,6	143 12,2	142 12,2	150 12,8	153 13,1	153 13,1	157 13,4	159 13,6	158 13,5
GHG emissions O&G* Operated (MtCO2eq) Group share (Direct emissions) (MtCO2eq)	40 56	37 54	36 52	41 55	40 54	38 50	41 51	42 50	44 54	46 51	47 55	46 53
Flaring Total flaring (Mm3/d) Routine flaring (Mm3/d)	3,3 0,5	3,6 0,7	4,2 0,6	5,7 0,9	6,5 2,1	5,4 1,8	7,1 2,3	7,2 2,3	9,8 3,1	10,8 3,4	10,8 3,4	10,0 3,1

Source: TotalEnergies

*Scope 1: Direct GHG emissions

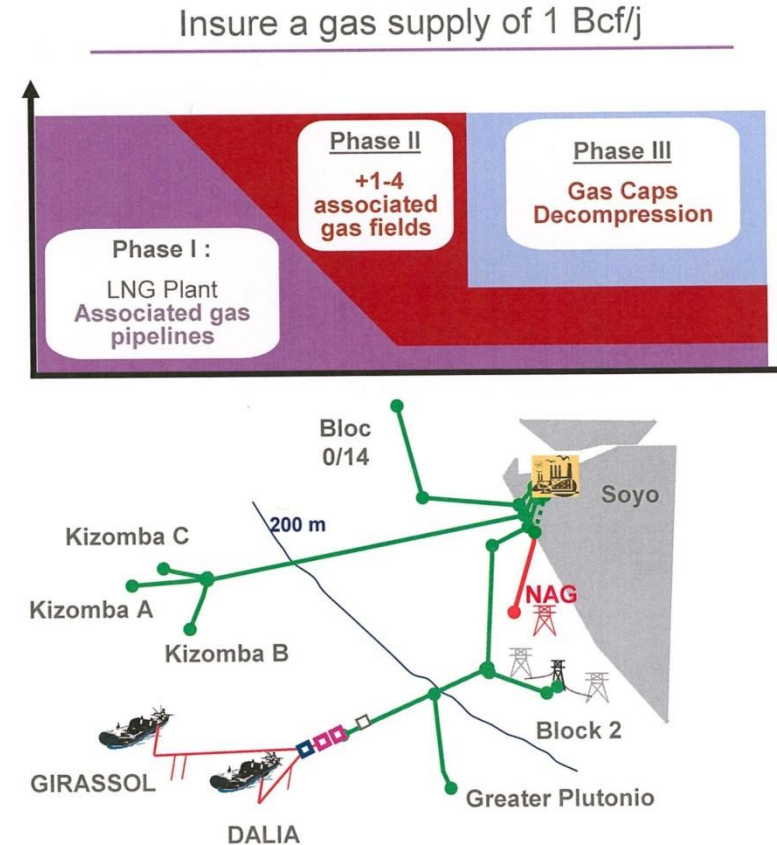
*Scope 1+2 as from 2021 including CCGT



An example: Angola LNG Project

From a flaring issue to gas valorization scheme

- ◆ Common target: to keep developing oil production and value gas to avoid flaring as from 2012.
- ◆ A strong commitment from all stakeholders and a partnership Sonangol – Oil Companies
- ◆ A pool of all gas resources
- ◆ A legal and commercial frame adapted to project characteristics



Carbon Price: 6 European Companies are calling for a CO₂ Price

Mid 2015, 6 European Companies jointly signed a letter addressed to Heads of States, to CCNUCC (Convention - Cadre des Nations Unies sur les Changements Climatiques) Executive Secretary , and to the COP21 President requesting the establishment of mechanisms to build-up an efficient Carbon Pricing.



Oil and Gas Climate Initiative (OGCI)



On 16 october 2015 in Paris, 10 National and International Oil & Gas Companies jointly declared their support for a worldwide agreement to be reached at COP 21 to limit global warming to 2°C



Oil and Gas Climate Initiative (OGCI)



**Creation of the OGCI Climate Investments Fund of 1G\$ over 10 years
Covering CCS, CO₂ valorisation, Methane emissions reduction, Energy efficiency.**



Oil and Gas Climate Initiative (OGCI)



Milestones



OGCI Objective 2025

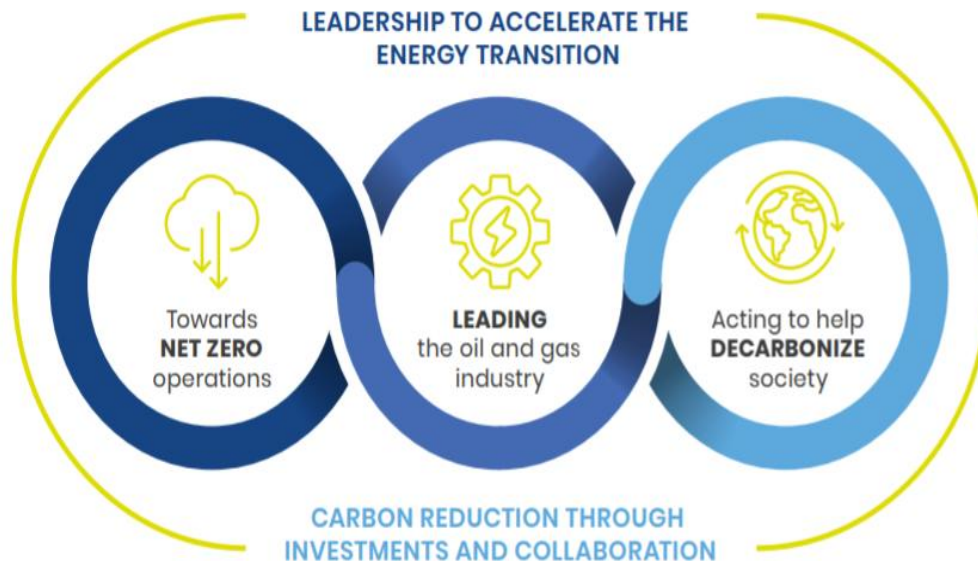
- **To reduce Methane emissions by 22% vs 2017**
- **OGCI Partnership in 2018 - 13 companies:**
BP, Chevron, CNPC, ENI, Equinor, ExxonMobil, Occidental, Pemex, Petrobras, Repsol, Saudi Aramco, Shell, TotalEnergies.
- **2018 activity mainly oriented towards methane emissions reduction and CO₂ recycling & storage.**
- **Agreement signed with CNPC to establish a investment fund dedicated to China.**



OGCI Targets

Commitments of Industry is necessary

1. OGCI'S STRATEGY TOWARDS NET ZERO OPERATIONS



UPSTREAM METHANE INTENSITY TARGET



TotalEnergies: Development of CCS Technology

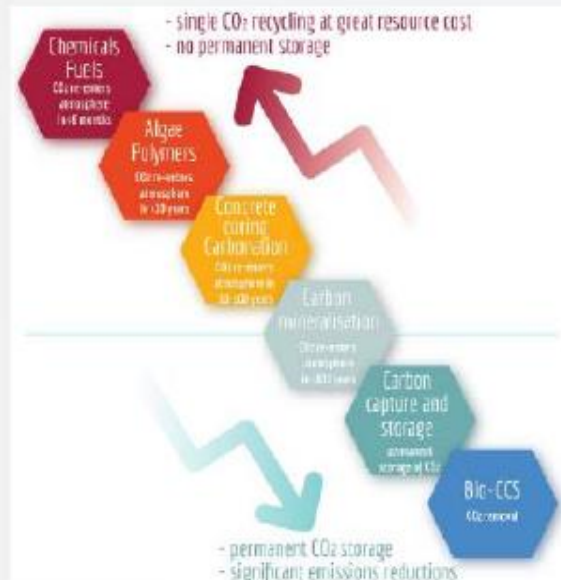


Total's objectives in reducing Carbon Intensity

CCUS – A PRAGMATIC APPROACH



Source: US DOE / NETL (National Energy Technology Laboratory), Cost and Performance Baseline for Fossil Energy Plants, Revision 3, July 2015



Source: ZEP
"Climate solutions for EU industry: interaction between electrification, CO₂ use and CO₂ storage".

- CCU and CCS both contribute to capture technology development and necessary costs reductions
- Storage: necessary for CO₂ sinks, and a permanent solution for large volumes of residual CO₂ (cement, steel, etc.)
- Utilization has far less volume potential (case specific, R&D efforts required)

Source: Total 2020

Total's objectives in reducing Carbon Intensity

OUR CCUS AMBITION

To have CCUS globally recognized leadership by 2035

To provide our customer a CCUS solution towards carbon neutrality.

To prepare for new business opportunities.

- **One R&D strategy for CCUS**

1. **To reduce CCS Cost**

- Optimize mature technologies thought scale-up effect
- Promote technologies competition
- Push disruptive technologies to the market

2. **To evaluate mass market opportunities in CO₂ Utilization**

3. **To be present all along the value chain of CCUS**

- Take part in industrial projects
- Create new business models

4. **To scale-up CCUS impact on Climate**

- Derisk mega CO₂ storage capacities

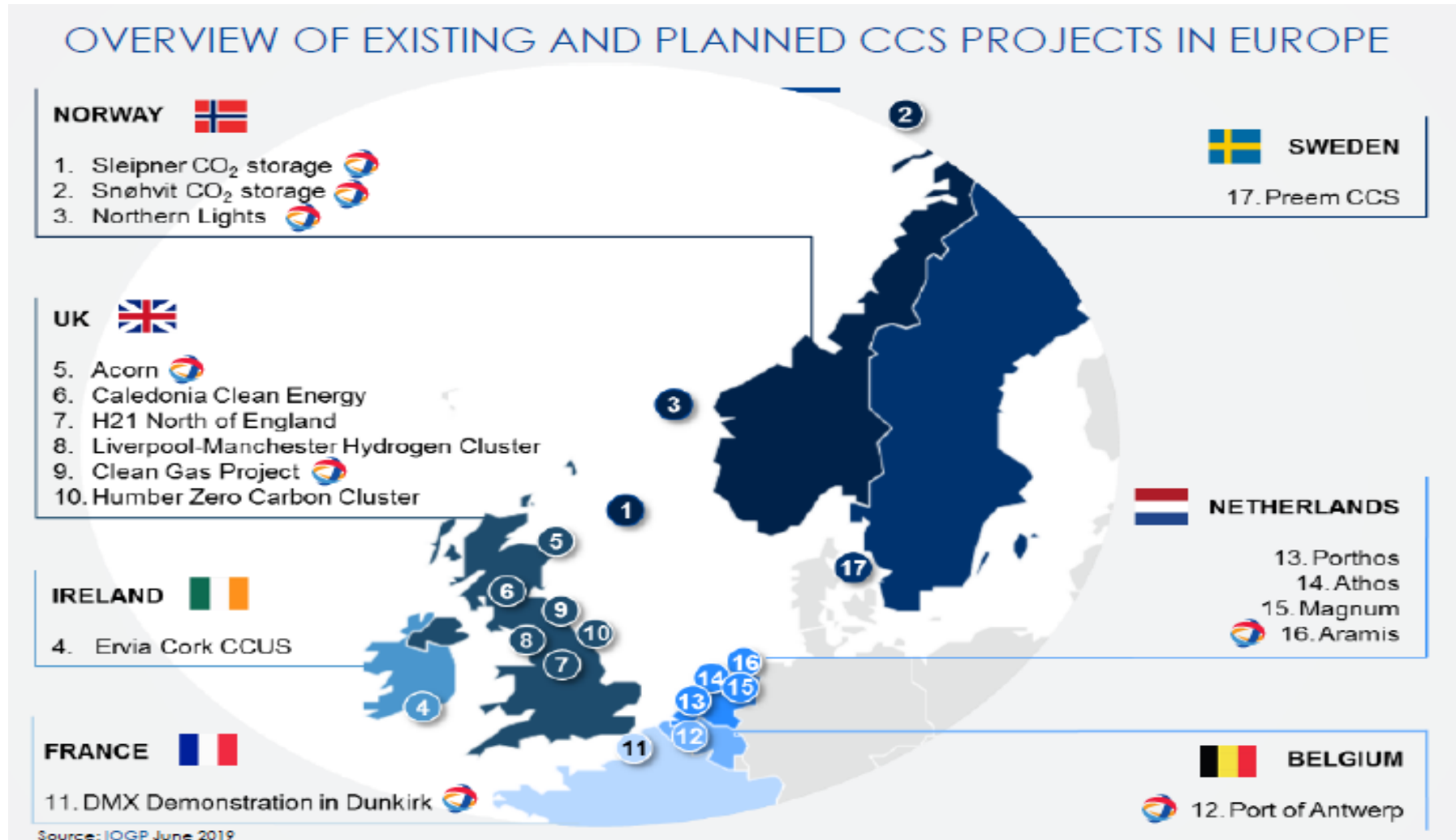
- **R&D key enabling factors**

- Work for CCUS sustainability
- Develop internal expertise
- Leverage our impact through OGCI and through partnership funding

Worldwide involvement :
USA, EU, Asia, Middle East



Total's involvement in CCS projects in Europe



Source: Total 2020

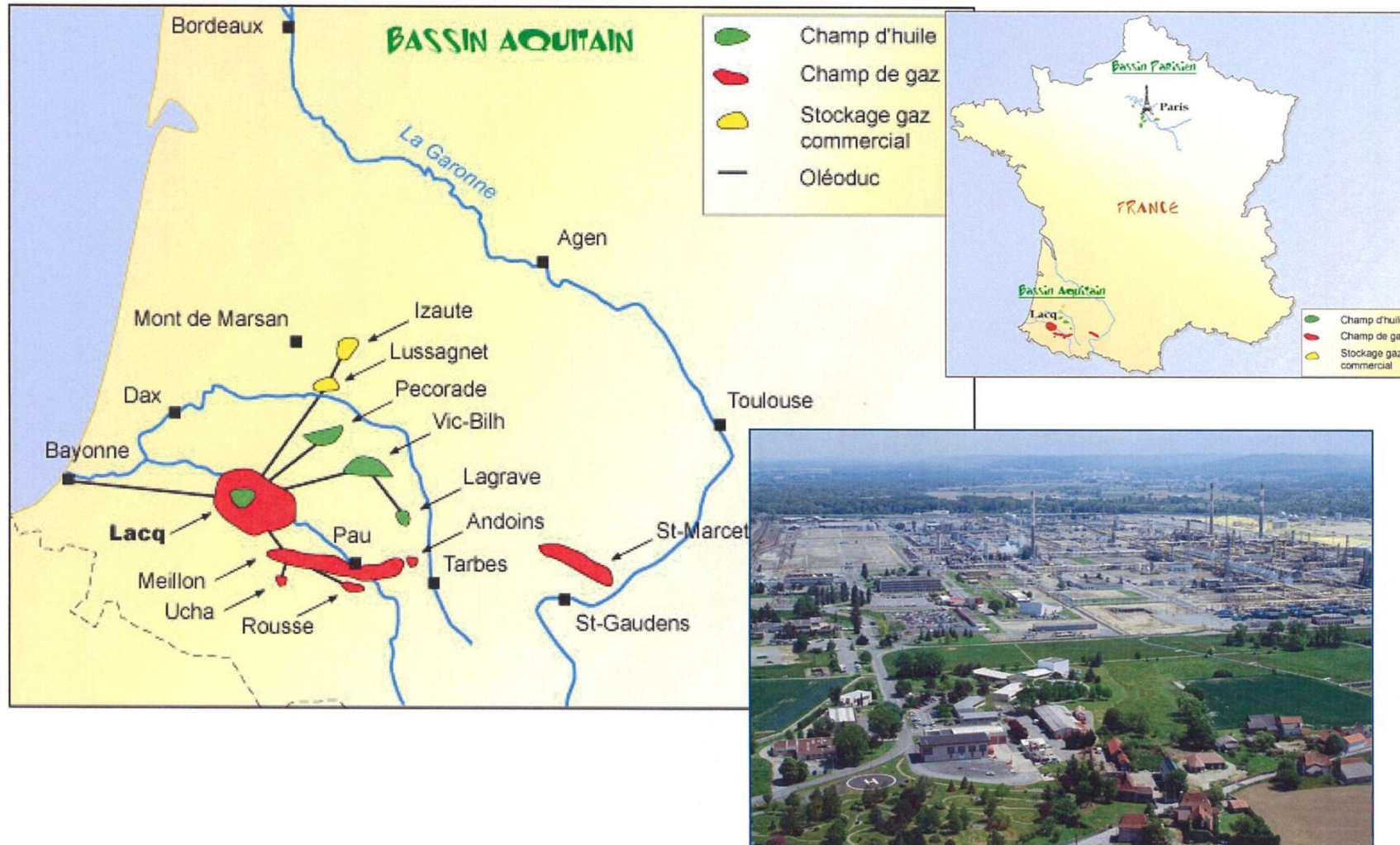
The start-up: A TOTAL Project : CCS pilot project in Lacq - General Objectives.



- 1 - Contribute to a potential climate change mitigation technology
- 2 - A 30 MWth oxycombustion scheme with CCS
- 3 - A pilot to validate industrial size CCS schemes worldwide
- 4 – Total cost = 60 M€, entirely funded by Total



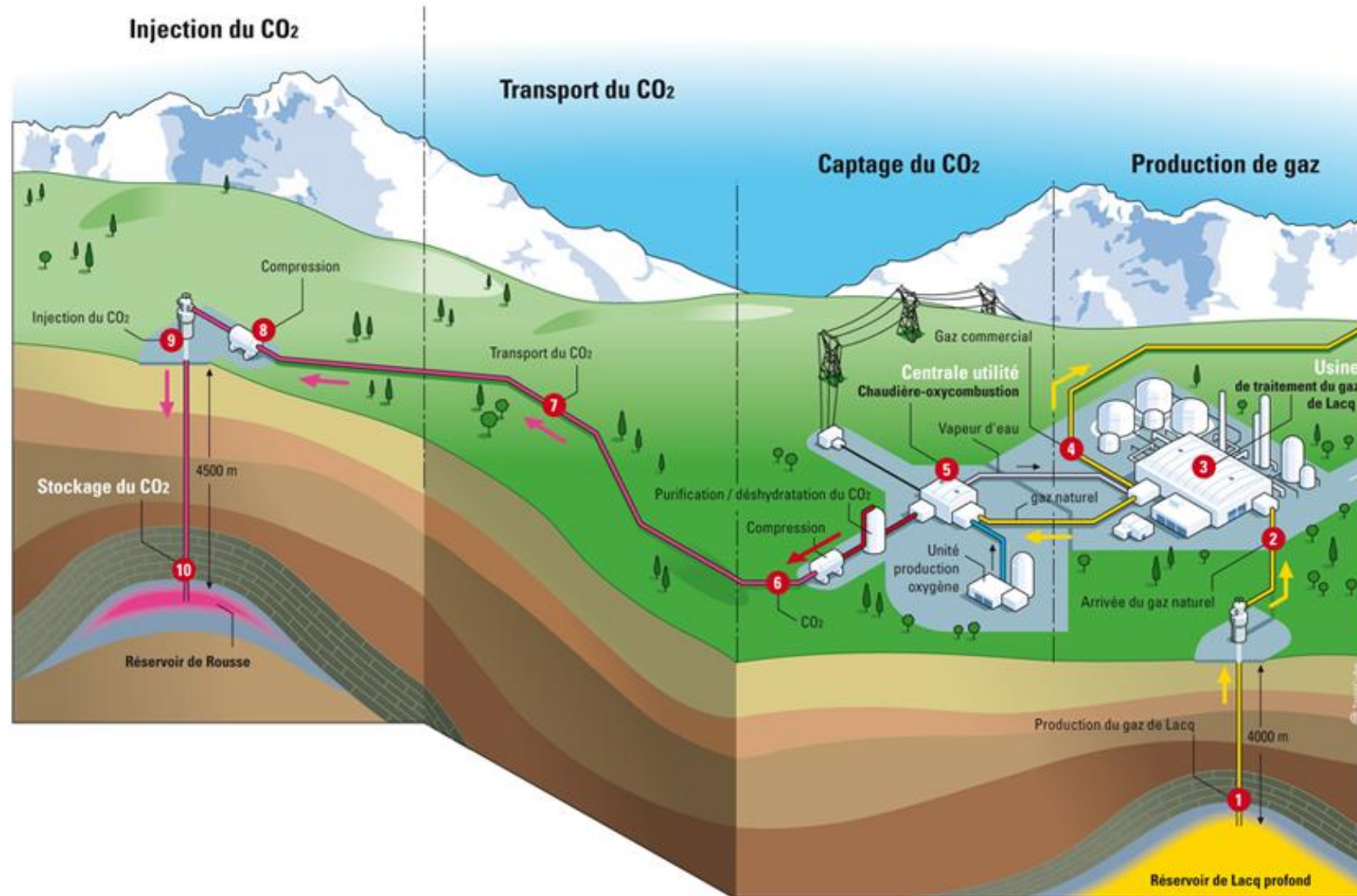
Pilot location: Total Exploration & Production in France



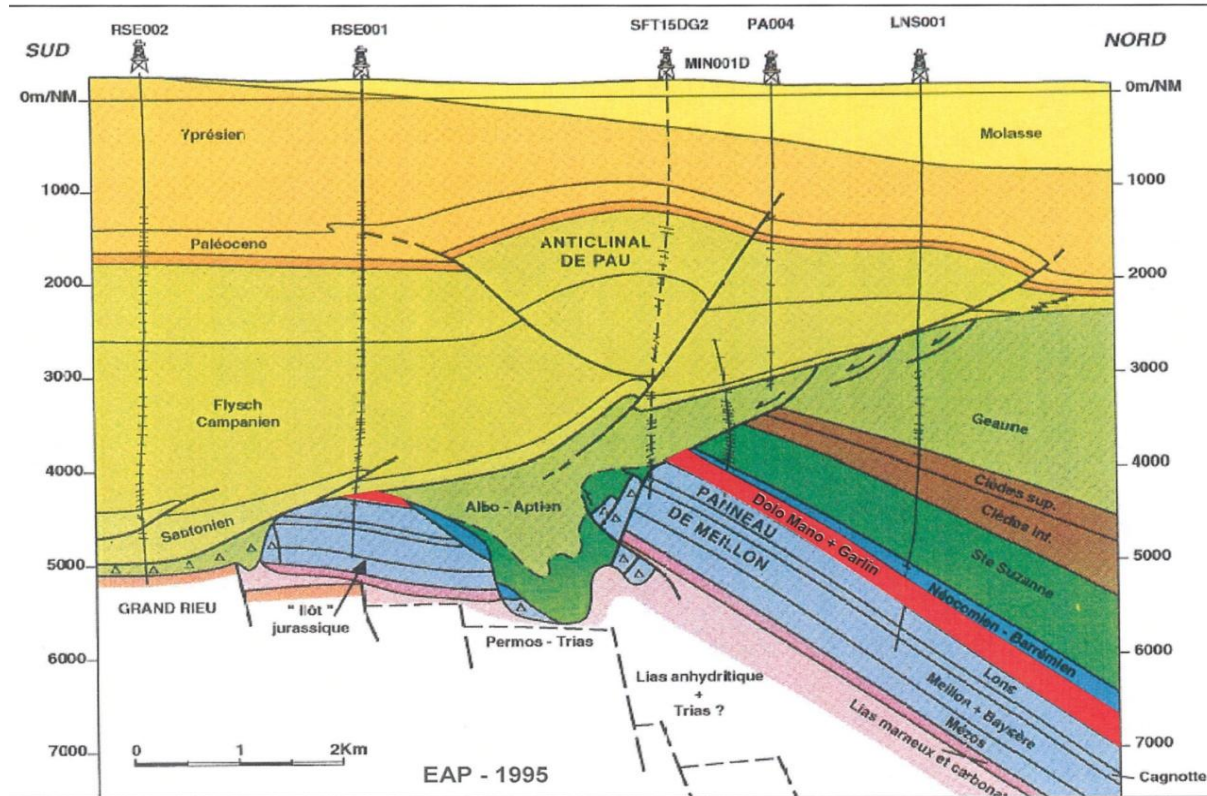
The Lacq plant - South-West of France



Carbon Capture & geological Storage in the Lacq region



CO₂ injection into a depleted gas reservoir



Mano dolomitic fractured reservoir

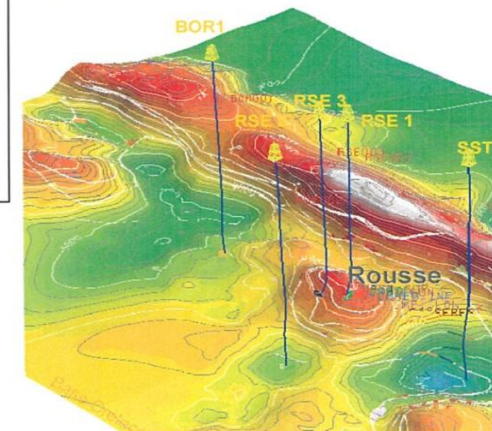
Depth # 4500m

Temp. # 150°C

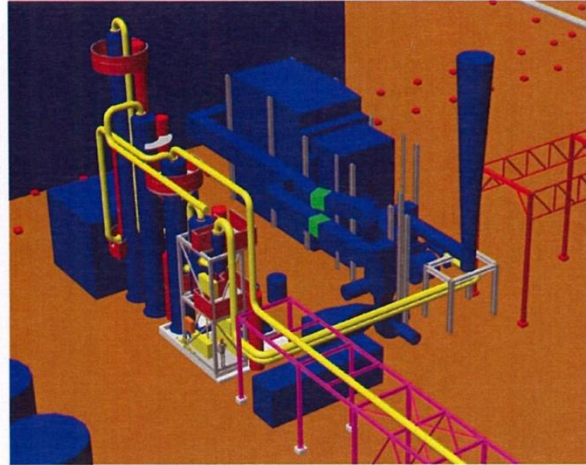
**Initial P = 485 barg
Current P # 30 barg**

Initial CO₂ = 4,6%

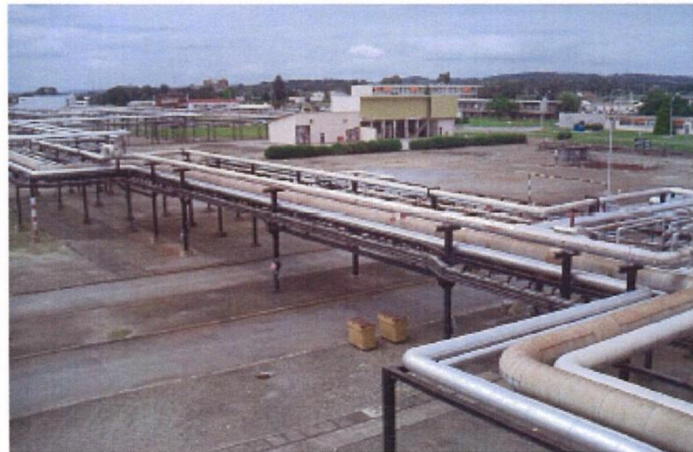
No aquifer



Installations for CO₂ Capture at Lacq



Oxycombustion:
Revamping of
existing boiler
and installation of
CO₂ treatment
installations

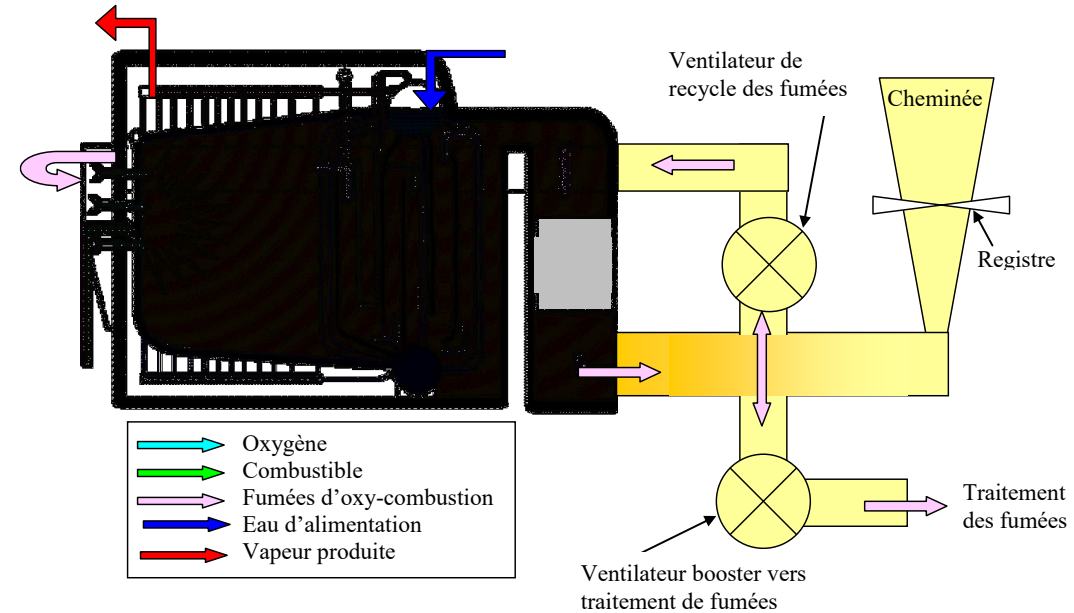


Air separation
unit and
compression of
CO₂



Boiler revamping

- Existing boiler revamping with CO₂ recycling
- 40 t/h of steam 60bar/450°C (30 MW_{th}) to HP steam network



- ALSTOM in charge of boiler revamping study
- Air Liquide developing and providing oxyburners
- 1MW prototype tested
- 4 x 8 MW_{th} required
- 204 t/day oxygen required



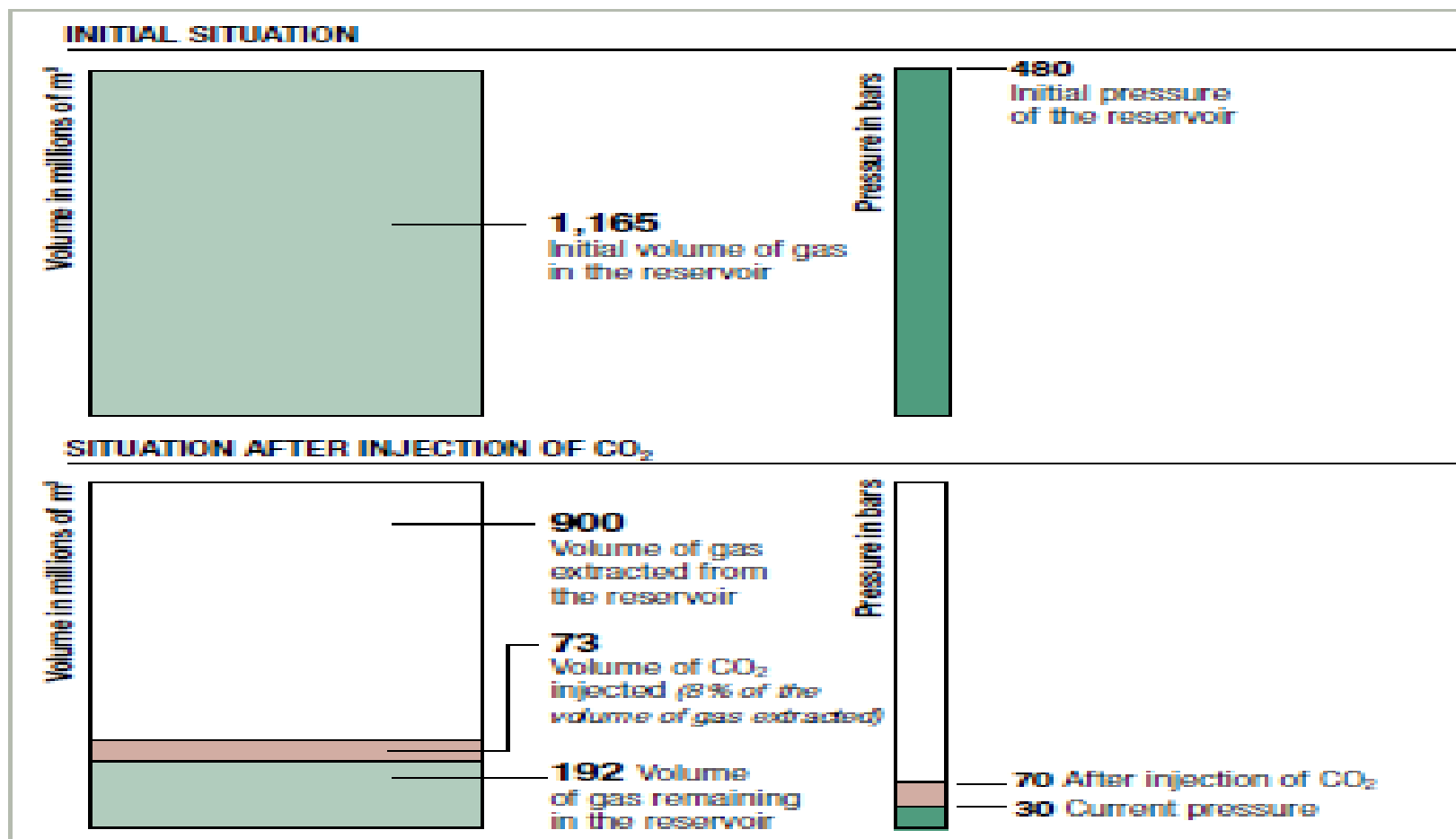
Lacq CCS oxycombustion basic process

- ◆ Combustion using pure oxygen releases flue gas with a high concentration of CO₂ and water vapor
- ◆ The flue gas is purified and dehydrated. The wet CO₂ (concentration of 90 to 93%) is compressed at 27 bar then dried for transport (27 km)
- ◆ The CO₂ is then compressed at a pressure of over 40 bar before being reinjected to a depth of 4500 m into the Rousse reservoir
- ◆ Rousse reservoir has already demonstrated its integrity for several million years

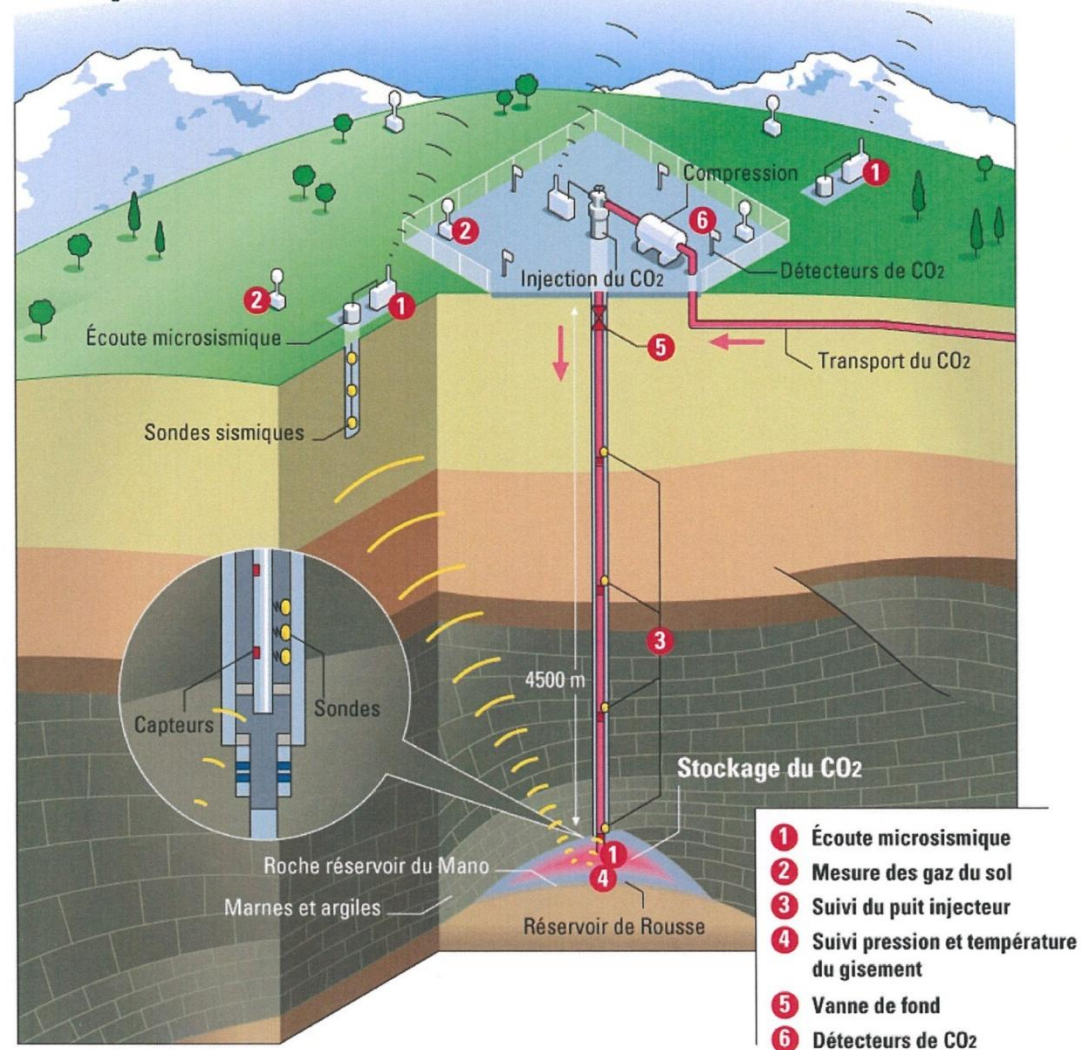


CO₂ injection at Lacq: volume and pressure of CO₂ Pre-project estimates

VOLUME AND PRESSURE OF CO₂ PRODUCED AND INJECTED



Monitoring System of the CO₂ Lacq injection



Monitoring System of the CO₂ Lacq injection

Monitoring System includes:

- ◆ Composition of the injected CO₂ and flow measurement
- ◆ Surface CO₂ detectors
- ◆ Well annulus pressure
- ◆ Pressure and temperature of the injector
- ◆ Pressure and temperature in the reservoir
- ◆ Microseismic equipment
- ◆ Soil gas measurement
- ◆ Groundwater quality
- ◆ Surface water quality
- ◆ Biodiversity-fauna and flora



Project Planning - History

	2006	2007	2008	2009	2010	2011
Site screening and conceptual studies	★					
Basic engineering studies						
Detailed engineering and procurement						
Construction works						
Injection well work over						
Operational Phase and injection/storage				★	★	
Base line surveys and monitoring						
Information to stakeholders						
Public inquiry						
Permitting process with regulatory agencies				★		

Over 3 years, more than 50 000 metric tons of CO₂ have been injected. Injection process ended at mid march 2013. After a 3 years observation period, positive results achieved, paving the way for future full scale implementation.

Source: Total



Other Lacq CCS Project features

- ◆ Independent Scientific Committee
- ◆ Voluntary Public consultation
- ◆ Helping to prepare the future European directive on CO₂ storage
- ◆ Sharing the results with Indonesian authorities (December 2007 Agreement signed in Bali)
- ◆ Many visits of international companies and organisations



Northern Lights, a Major Milestone in the Development of CCUS



October 2017 : Equinor (ex Statoil), Shell and Total enter Norway CO₂ Storage Partnership



Source: Total, Shell, Statoil

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TPA Toolbox Energy Book 3 - GHG

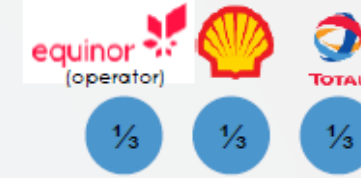
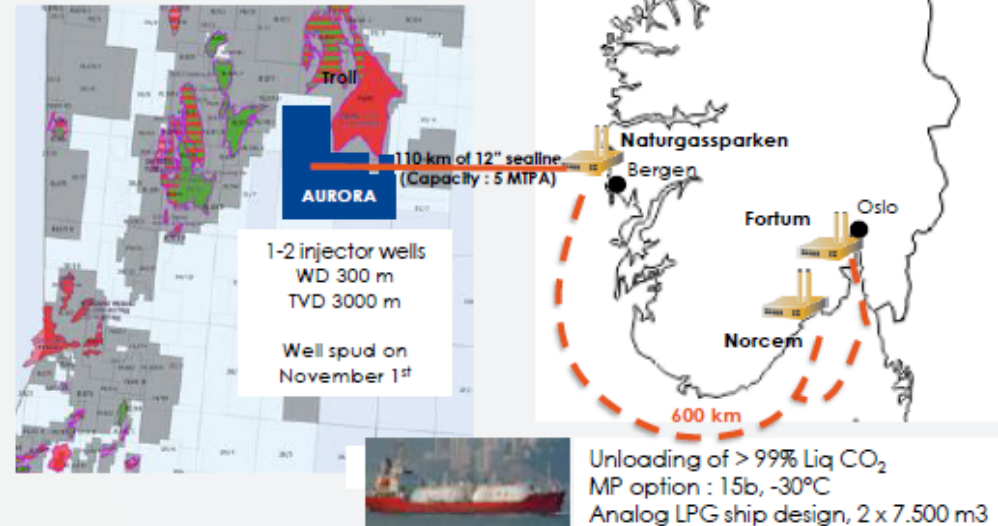
October 2017 : Equinor (ex Statoil), Shell and Total enter Norway CO₂ Storage Partnership



NORTHERN LIGHTS PROJECT

Northern Lights, CO₂ shipping and storage part of the first full-chain CCS commercial project based upon multiple industrial CO₂ emissions.

Project design capacity 1.5 MTPA (1st phase)
Offshore pipeline designed for 5 MTPA



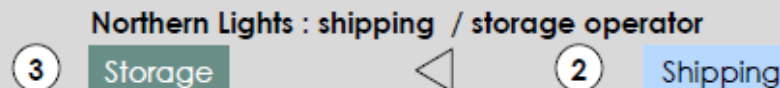
1 Capture

✓ MAX 0.8 MTPA estimated State reserved capacity for volumes from capture sites in the Oslo area :

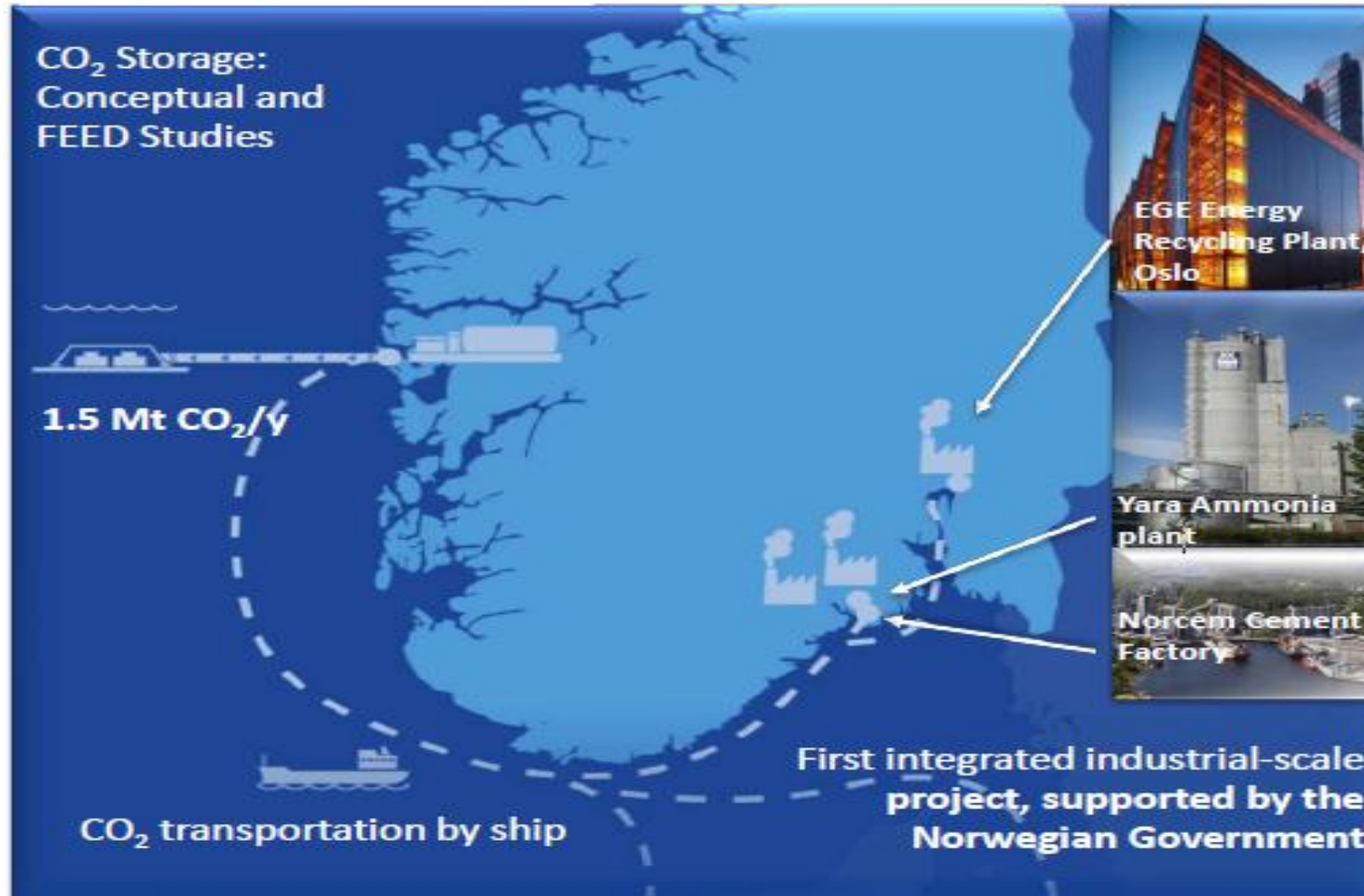
→ Enabling low carbon industry and CO₂ sinks

- Fortum, waste incinerator
FEED phase
CO₂ capture : 0.4 MTPA
- Norcem, cement factory
FEED phase
CO₂ capture : 0.4 MTPA

✓ MIN 0.7 MTPA available capacity to market



October 2017 : Equinor (ex Statoil), Shell and TotalEnergy enters Norway CO₂ Storage Partnership



Current contracts with:

Yara (fertilizers)
Orsted ex DONG Energy
(Energy)
Heidelberg Material, Norcem
shareholder (Cement)

Storage capacity:
1,5 Mt CO₂/year
5,0 Mt in a second phase

Injection in a saline aquifer

1st phase financed by
Norwegian Government (80%):
500 M\$

Second phase: 700 M\$

Northern Lights project – Øygarden Norway





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