Course 2023-2024 in Sustainable Finance
Lecture 9. The Ecosystem of Climate Change

Thierry Roncalli*

*Amundi Asset Management[1]

*University of Paris-Saclay

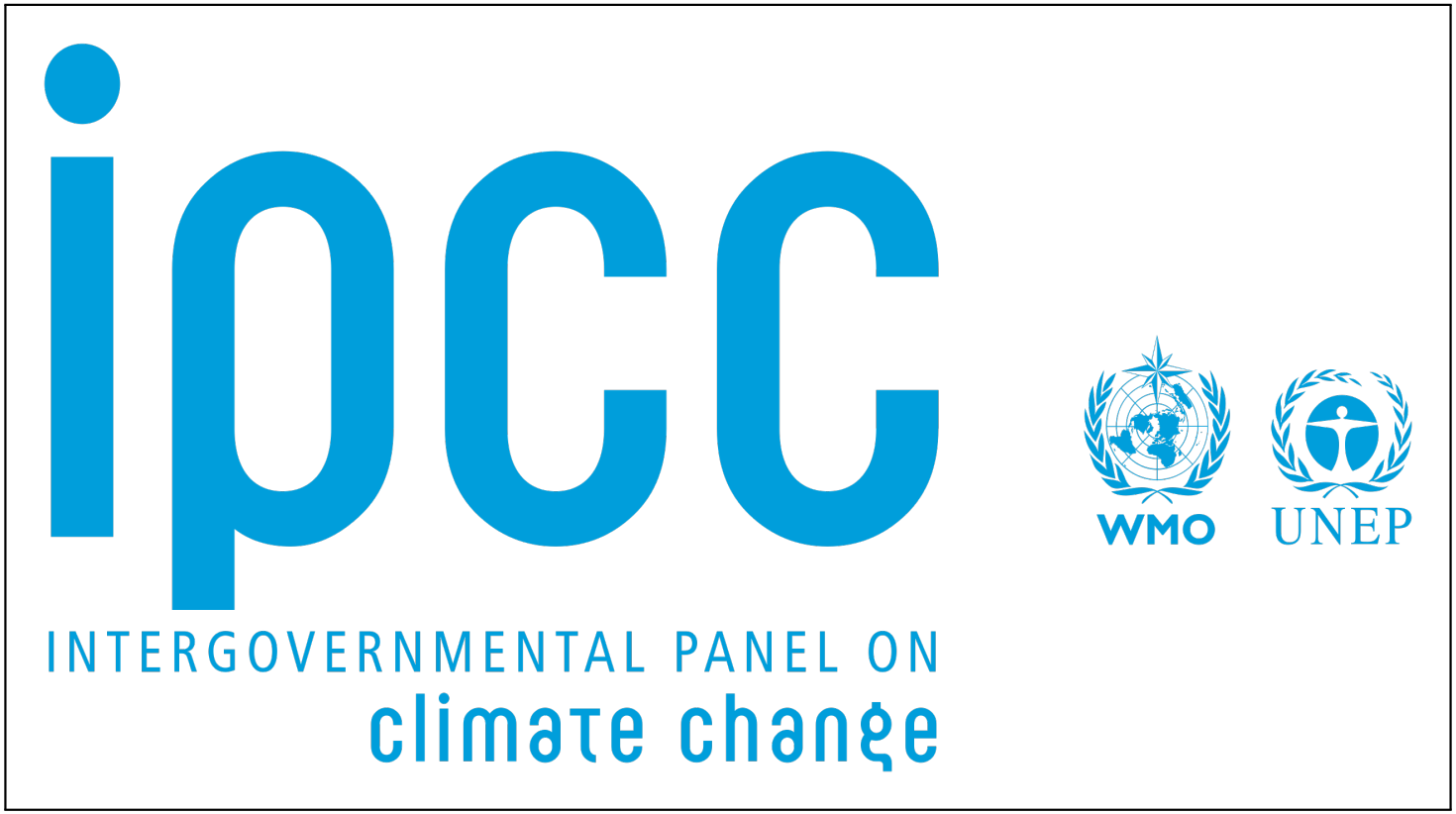
March 2024

[1] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Agenda

- Lecture 1: Introduction
- Lecture 2: ESG Scoring
- Lecture 3: Impact of ESG Investing on Asset Prices and Portfolio Returns
- Lecture 4: Sustainable Financial Products
- Lecture 5: Impact Investing
- Lecture 6: Engagement & Voting Policy
- Lecture 7: Extra-financial Accounting
- Lecture 8: Awareness of Climate Change Impacts
- **Lecture 9: The Ecosystem of Climate Change**
- Lecture 10: Economic Models & Climate Change
- Lecture 11: Climate Risk Measures
- Lecture 12: Transition Risk Modeling
- Lecture 13: Climate Portfolio Construction
- Lecture 14: Physical Risk Modeling
- Lecture 15: Climate Stress Testing & Risk Management

Intergovernmental Panel on Climate Change



Intergovernmental Panel on Climate Change

- The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change in 1988
- The members of the IPCC are then governments (95 as of January 2024), not scientists, academic institutions, or NGOs
- Its original mandate was to "*prepare a comprehensive review and recommendations on the state of knowledge of the science of climate change, the social and economic impacts of climate change, and possible response strategies and elements for inclusion in a possible future international climate convention*"

Intergovernmental Panel on Climate Change

- Working Group I (WGI)
  Assesses the scientific aspects of the climate system that underpin past, present and future climate change.
- Working Group II (WGII)
  Assesses climate change impacts, adaptation options and vulnerabilities on human and natural systems.
- Working Group III (WGIII)
  Focuses on mitigation of climate change, assessment of methods to limit and reduce greenhouse gas emissions, and removal of greenhouse gases from the atmosphere.

Intergovernmental Panel on Climate Change

Table 1: List of IPCC Assessment Reports

Date	Symbol	Title of the report
1990	FAR/AR1	First IPCC Assessment Report
1995	SAR/AR2	Second Assessment Report
2001	TAR/AR3	Third Assessment Report
2007	AR4	Fourth Assessment Report
2014	AR5	Fifth Assessment Report
2023	AR6	Sixth Assessment Report

Intergovernmental Panel on Climate Change

The three main conclusions of the AR6 Synthesis Report are:

1. Unequivocal human influence
   The report reaffirms that human activities are unequivocally causing climate change. The report states that global surface temperatures have reached $1.1°\mathrm{C}$ above pre-industrial levels.
2. Widespread and intensifying impacts
   The report emphasizes that climate change is already having a profound impact on the planet, affecting ecosystems, human health, and infrastructure. These impacts are projected to worsen in the future, even with moderate warming.
3. Urgency of mitigation and adaptation
   The report underscores the urgency of taking action to address climate change. Limiting global warming to $1.5°\mathrm{C}$ will require rapid and far-reaching changes in energy systems, food production and land management. These changes are possible and would bring significant environmental and human health benefits.

Climate research institutions

Table 2: Some well-known climate research institutions

Symbol	Climate research institutions	Country
AARI	Arctic and Antarctic Research Institute	Russia
AWI	Alfred Wegener Institute for Polar and Marine Research	Germany
CICERO	Center for International Climate and Environmental Research	Norway
CIMA	Centro de Investigaciones del Mar y la Atmósfera	Argentina
CIRED	Centre international de recherche sur l'environnement et le développement	France
CMCC	Euro-Mediterranean Center on Climate Change	Italy
GISS	NASA Goddard Institute for Space Studies	US
IAP	Institute of Atmospheric Physics Chinese Academy of Sciences	China
IIASA	International Institute for Applied Systems Analysis	Austria
IPSL	Institut Pierre-Simon Laplace (LSCE)	France
INECC	National Institute of Ecology and Climate Change	Mexico
JAMSTEC	Japan Agency for Marine-Earth Science and Technology	Japan
MOHC	Met Office Hadley Centre for Climate Science and Services	UK
NCAR	National Center for Atmospheric Research	US
NERC	Natural Environment Research Council	UK
NIES	National Institute for Environmental Studies	Japan
NOAA	National Oceanic and Atmospheric Administration	US
PBL	PBL Netherlands Environmental Assessment Agency	Netherlands
PCMDI	Program for Climate Model Diagnosis & Intercomparison (LLNL)	US
PIK	Potsdam Institute for Climate Impact Research	Germany
PNNL	Pacific Northwest National Laboratory	US
REKLIM	Helmholtz Climate Initiative Regional Climate	Germany
SEI	Stockholm Environment Institute	Sweden
SIO	Scripps Institution of Oceanography	US

Climate research institutions

National Center for Atmospheric Research (NCAR)

The National Center for Atmospheric Research is a federally funded research and development center managed by the University Corporation for Atmospheric Research (UCAR) and funded by the National Science Foundation (NSF). NCAR was established in 1960, and its founding director was Walter Orr Roberts. Its headquarters are located in Boulder, Colorado. NCAR's annual budget was $173 million in 2017. The center is organized into eight laboratories with approximately 1 500 members. Notable scientists include or were Guy Brasseur, Clara Deser, Brant Foote, Marika M. Holland, Paul R. Julian, Jean-Francois Lamarque, David M. Lawrence, Gerald A. Meehl, Joanne Simpson, Kevin E. Trenberth, Warren M. Washington, and Tom M. L. Wigley.

Climate research institutions

Potsdam Institute for Climate Impact Research (PIK)

The Potsdam Institute for Climate Impact Research is a government-funded research institute in Potsdam, Germany. It was founded in 1991 by Hans Joachim Schellnhuber, who is now Director of IIASA. With a network of about 400 researchers, PIK's mission is to address scientific issues in the fields of climate risks and sustainable development. The current directors of the institute are Ottmar Edenhofer, who also serves as chief economist, and Johan Rockström, former director of the Stockholm Resilience Center. In 2022, the Institute received about 13.3 million euros in institutional funding. Additional project funding from external sources amounted to approximately 18.2 million euros. The institute boasts many renowned researchers, including Elmar Kriegler, Christoph Müller, Ottmar Edenhofer, Alexander Popp, Stefan Rahmstorf and Johan Rockström.

Climate research institutions

International Institute for Applied Systems Analysis (IIASA)

The International Institute for Applied Systems Analysis is an independent international research institute located in Laxenburg near Vienna, Austria. IIASA was founded by a charter signed on October 4, 1972 by representatives of the Soviet Union, the United States, and ten other countries from the Eastern and Western blocs. IIASA brings together experts from various fields to study complex issues such as climate change, energy, and sustainable development. In 2022, IIASA's annual budget was 24.4 million euros, of which just under half came from the Institute's national and regional member organizations (Austria, Brazil, China, Egypt, Finland, Germany, India, Iran, Israel, Japan, South Korea, Norway, Russia, Slovakia, Sub-Saharan Africa, Sweden, Ukraine, United Kingdom, United States, Vietnam). IIASA has about 500 researchers from 50 countries. Since December 2023, the Director General is Hans Joachim Schellnhuber. Among the researchers who work, have worked or have visited the research center, we can mention George Dantzig, Shinichiro Fujimori, Petr Havlìk, Leonid Kantorovich, Tjalling Koopmans, Nebojsa Nakicenovic, William D. Nordhaus, Michael Obersteiner, Howard Raiffa, Keywan Riahi, Joeri Rogelj and Thomas Schelling.

Climate research institutions

National Oceanic and Atmospheric Administration (NOAA)

The National Oceanic and Atmospheric Administration is an agency of the United States Department of Commerce (DOC) responsible for monitoring and managing the nation's weather, climate, and oceans. NOAA was established in 1970. The scope of NOAA is vast: weather forecasting, oceanography, fisheries management, satellite operations. As a result, it employs 12 000 people worldwide, while the number of NOAA scientists and engineers is about 6 500. The Office of Oceanic and Atmospheric Research (OAR) is the primary research arm of NOAA. It is responsible for conducting a wide range of research on the Earth's atmosphere, oceans, and coasts. One of OAR's goals is to understand the causes and effects of climate change. The most prominent affiliated research center is the Geophysical Fluid Dynamics Laboratory (GFDL), a joint program of Princeton University and NOAA. GFDL researchers include Thomas L. Delworth, Larry W. Horowitz, Thomas R. Knutson, Vaishali Naik, and Venkatachalam Ramaswamy.

Climate research institutions

Institut Pierre-Simon Laplace (IPSL)

The Institut Pierre-Simon Laplace is a French university research institute that brings together 10 laboratories with about 1 500 members. The institute was founded in 1991 by Gérard Mégie, and one of its directors was Jean Jouzel from 2001 to 2008. The 10 laboratories are (1) the Centre d'Enseignement et de Recherche en Environnement Atmosphérique (CEREA), (2) Géosciences Paris-Sud (GEOPS), (3) the Laboratoire Atmosphères, Milieux, Observations spatiales (LATMOS), (4) the team TASQ of the Laboratoire d'Études du Rayonnement et de la Matière en Astrophysique et Atmosphères (LERMA), (5) the Laboratoire Inter-universitaire des Systèmes Atmosphériques (LISA), (6) the Laboratoire de Météorologie Dynamique (LMD), (7) the Laboratoire d'Océanographie et du Climat Expérimentation et Approches Numériques (LOCEAN), (8) the Laboratoire des Sciences du Climat et de l'Environnement (LSCE), (9) the research center Milieux Environnementaux, Transferts et Interactions dans les hydrosystèmes et les Sols (METIS), and (10) the team Surface & Réservoirs of the Laboratoire de Géologie de l'ENS. IPSL is placed under the supervision of Centre National de la Recherche Scientifique (CNRS), Sorbonne Université (SU), Université Versailles Saint-Quentin (UVSQ), École Polytechnique, Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), Institut de Recherche pour le Développement (IRD) and École Nationale des Ponts et Chausses (ENPC). Researchers include Sandrine Bony, Laurent Bopp, Olivier Boucher, Pascale Braconnot, Philippe Ciais, Jean Jouzel, Pierre Friedlingstein, Valérie Masson-Delmotte, Robert Vautard, and Nicolas Viovy.

Reuters Hot List

Table 3: Top 30 climate scientists on the Reuters Hot List

Rank	Name	Gender	Institution	Location
1	Keywan Riahi	M	International Institute for Applied Systems Analysis	Austria
2	Anthony A. Leiserowitz	M	Yale University	United States
3	Pierre Friedlingstein	M	University of Exeter	United Kingdom
4	Detlef Peter Van Vuuren	M	Utrecht University	Netherlands
5	James E. Hansen	M	Columbia University	United States
6	Petr Havlìk	M	International Institute for Applied Systems Analysis	Austria
7	Edward Wile Maibach	M	George Mason University	United States
8	Josep G. Canadell	M	Commonwealth Scientific and Industrial Research Organisation	Australia
9	Sonia Isabelle Seneviratne	F	ETH Zurich	Switzerland
10	Mario Herrero	M	Commonwealth Scientific and Industrial Research Organisation	Australia
11	David B. Lobell	M	Stanford University	United States
12	Carlos Manuel Duarte	M	King Abdullah University of Science and Technology	Saudi Arabia
13	Kevin E. Trenberth	M	National Center for Atmospheric Research	United States
14	Stephen A. Sitch	M	University of Exeter	United Kingdom
14	Glen P. Peters	M	Center for International Climate and Environmental Research	Norway
16	Ove I. Hoegh-Guldberg	M	University of Queensland	Australia
17	Richard Arthur Betts	M	Met Office	United Kingdom
18	Michael G. Oppenheimer	M	Princeton University	United States
18	William Neil Adger	M	University of Exeter	United Kingdom
20	William Wai Lung Cheung	M	University of British Columbia	Canada

Reuters Hot List

Table 4: Top 30 climate scientists on the Reuters Hot List

Rank	Name	Gender	Institution	Location
21	Christopher B. Field	M	Stanford University	United States
23	Shinichiro Fujimori	M	Kyoto University	Japan
23	Elmar Kriegler	M	Potsdam Institute for Climate Impact Research	Germany
25	Yadvinder Singh Malhi	M	University of Oxford	United Kingdom
26	Ken Caldeira	M	Carnegie Institution for Science's Department of Global Ecology	United States
27	Chris D. Thomas	M	University of York	United Kingdom
28	Stéphane Hallegatte	M	World Bank	United States
28	Andy P. Haines	M	London School of Hygiene & Tropical Medicine	United Kingdom
30	Michael Obersteiner	M	International Institute for Applied Systems Analysis	Austria
40	Philippe Ciais	M	Laboratoire des Sciences du Climat et de l'Environnement	France
75	Pete Smith	M	University of Aberdeen	United Kingdom
164	Richard S. J. Tol	M	VU Amsterdam	Netherlands
173	William D. Nordhaus	M	Yale University	United States
240	Phil D. Jones	M	University of East Anglia	United Kingdom
338	Filippo Giorgi	M	International Centre for Theoretical Physics	Italy
639	Klaus Hasselmann	M	Max Planck Institute for Meteorology	Germany
755	Syukuro Manabe	M	Princeton University	United States

Source: Reuters (2021), `www.reuters.com/investigates/special-report/climate-change-scientists-list`.

Reuters Hot List

The top five names of the Reuters Hot List are:

- **Keywan Riahi**, Director of the Energy, Climate and Environment (ECE) Program at IIASA and one of the principal developers of the Representative Concentration Pathway (RCP) and Shared Socio-economic Pathway (SSP) concepts
- **Anthony A. Leiserowitz**, Professor at Yale University, who studies public perceptions of climate change
- **Pierre Friedlingstein**, Chair in Mathematical Modeling of the Climate System at the University of Exeter, coordinator of the annual publication of the Global Carbon Budget
- **Detlef P. Van Vuuren**: Professor at Utrecht University, Project Leader of the IMAGE Integrated Assessment Team at PBL Netherlands Environmental Assessment Agency, one of the main developers of the RCP and SSP concepts
- **James E. Hansen**: one of the world's most influential climate scientists and the director of NASA Goddard Institute for Space Studies from 1981 to 2013

Reuters Hot List

Table 5: Top 20 climate research institutions on the Reuters Hot List

Institution	Count	Location
Potsdam Institute for Climate Impact Research (PIK)	14	Germany
University of Reading	13	United Kingdom
Institute of Atmospheric Physics (CAS)	13	China
Utrecht University	12	Netherlands
Met Office (MOHC)	12	United Kingdom
National Center for Atmospheric Research (NCAR)	11	United States
Columbia University	10	United States
ETH Zurich	10	Switzerland
Laboratoire des Sciences du Climat et de l'Environnement (IPSL)	10	France
International Institute for Applied Systems Analysis (IIASA)	9	Austria
University of Melbourne	9	Australia
University of Leeds	9	United Kingdom
Geophysical Fluid Dynamics Laboratory (NOAA)	9	United States
Max Planck Institute for Meteorology (MPIM)	9	Germany
Pacific Northwest National Laboratory (PNNL)	8	United States
Lamont-Doherty Earth Observatory (Columbia University)	8	United States
Massachusetts Institute of Technology	8	United States
University of Washington	8	United States
Wageningen University & Research	8	Netherlands
University of Tokyo	8	Japan
University of Bremen	8	Germany

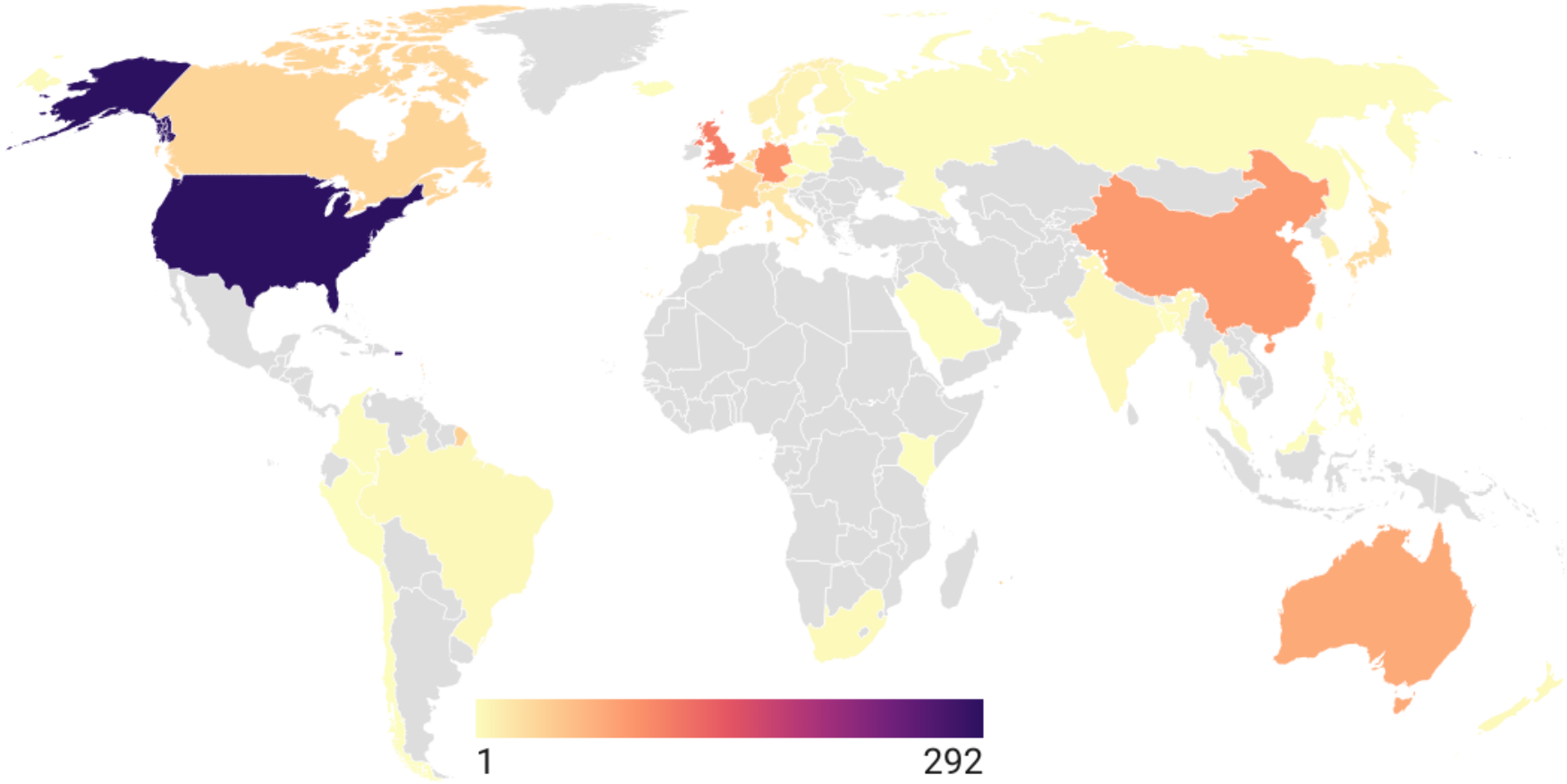
Reuters Hot List

Table 6: Top 15 country on the Reuters Hot List

Country	Count	Frequency	Cumulative
United States	292	29.3%	29.3%
United Kingdom	112	11.3%	40.6%
Germany	91	9.1%	49.7%
China	87	8.7%	58.5%
Australia	74	7.4%	65.9%
France	40	4.0%	69.9%
Netherlands	39	3.9%	73.9%
Canada	37	3.7%	77.6%
Japan	30	3.0%	80.6%
Switzerland	28	2.8%	83.4%
Spain	22	2.2%	85.6%
Italy	20	2.0%	87.6%
Norway	13	1.3%	88.9%
Denmark	12	1.2%	90.2%
South Korea	12	1.2%	91.4%
Austria	10	1.0%	92.4%

Reuters Hot List

Figure 1: Location of the top 1000 climate scientists



Nature index

Table 7: Top 30 leading institutions (Nature index, 2016 ranking)

Institution	2016	2017	2018	2019	2020	2021	2022	2023
Chinese Academy of Sciences (CAS), China	1	1	1	1	1	1	1	1
Helmholtz Association of German Research Centres, Germany	2	2	2	2	2	2	2	3
French National Centre for Scientific Research (CNRS), France	3	4	4	3	3	3	3	6
National Aeronautics and Space Administration (NASA), United States of America (USA)	4	3	3	5	4	6	6	9
Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland	5	5	6	4	5	5	5	10
U.S. Geological Survey (USGS), United States of America (USA)	6	9	8	12	7	9	17	31
University of Colorado Boulder (CU-Boulder), United States of America (USA)	7	10	9	7	14	20	22	26
University of California, Berkeley (UC Berkeley), United States of America (USA)	8	19	12	9	17	18	15	24
Stanford University, United States of America (USA)	9	8	13	22	9	15	14	20
California Institute of Technology (Caltech), United States of America (USA)	10	6	5	8	12	7	8	15
National Oceanic and Atmospheric Administration (NOAA), United States of America (USA)	11	7	7	14	8	8	18	17
Columbia University in the City of New York (CU), United States of America (USA)	12	12	16	11	11	13	23	22
University of Washington (UW), United States of America (USA)	13	11	10	10	10	17	21	21
University of California, San Diego (UC San Diego), United States of America (USA)	14	14	18	26	32	24	10	29
The University of Tokyo (UTokyo), Japan	15	15	20	23	20	31	29	50
Peking University (PKU), China	16	16	19	13	19	11	7	4
The University of Texas at Austin (UT Austin), United States of America (USA)	17	13	14	15	21	27	32	27
The University of Queensland (UQ), Australia	18	57	62	37	43	26	35	36
Nanjing University (NJU), China	19	18	11	6	6	4	4	2
Massachusetts Institute of Technology (MIT), United States of America (USA)	20	21	17	20	22	23	24	32
University of Minnesota (UMN), United States of America (USA)	21	45	22	47	39	41	68	52
University of California, Los Angeles (UCLA), United States of America (USA)	22	17	15	21	29	28	26	23
University of Maryland, College Park (UMCP), United States of America (USA)	23	32	55	40	53	66	77	80
Woods Hole Oceanographic Institution (WHOI), United States of America (USA)	24	34	50	30	37	51	56	67
The Pennsylvania State University (Penn State), United States of America (USA)	25	27	29	25	25	30	28	56
University of Michigan (U-M), United States of America (USA)	26	20	23	35	27	35	50	73
University of Toronto (U of T), Canada	27	38	34	29	34	34	40	40
Georgia Institute of Technology (Georgia Tech), United States of America (USA)	28	50	27	72	55	76	36	
National Institute of Geophysics and Volcanology (INGV), Italy	29	35	45	69		97	88	77
Princeton University, United States of America (USA)	30	67	42	44	46	47	52	43

Source: Nature (2023), `www.nature.com/nature-index/annual-tables`.

Nature index

Table 8: Top 30 leading institutions (Nature index, 2023 ranking)

Institution	2016	2017	2018	2019	2020	2021	2022	2023
Chinese Academy of Sciences (CAS), China	1	1	1	1	1	1	1	1
Nanjing University (NJU), China	19	18	11	6	6	4	4	2
Helmholtz Association of German Research Centres, Germany	2	2	2	2	2	2	2	3
Peking University (PKU), China	16	16	19	13	19	11	7	4
University of Chinese Academy of Sciences (UCAS), China		77	24	18	13	10	9	5
French National Centre for Scientific Research (CNRS), France	3	4	4	3	3	3	3	6
Sun Yat-sen University (SYSU), China				65	42	19	13	7
Tongji University, China	60	43	43	17	15	12	16	8
National Aeronautics and Space Administration (NASA), United States of America (USA)	4	3	3	5	4	6	6	9
Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland	5	5	6	4	5	5	5	10
Zhejiang University (ZJU), China		75	73	53	36	40	25	11
University of Science and Technology of China (USTC), China	74	39	31	16	16	16	20	12
China University of Geosciences (CUG), China		44	37	31	18	14	19	13
China Meteorological Administration (CMA), China	100	95	70	54	23	25	27	14
California Institute of Technology (Caltech), United States of America (USA)	10	6	5	8	12	7	8	15
Ministry of Natural Resources (MNR), China				75	59	44	38	16
National Oceanic and Atmospheric Administration (NOAA), United States of America (USA)	11	7	7	14	8	8	18	17
Tsinghua University, China	53	36	30	28	26	21	12	18
Southern University of Science and Technology (SUSTech), China						72	47	19
Stanford University, United States of America (USA)	9	8	13	22	9	15	14	20
University of Washington (UW), United States of America (USA)	13	11	10	10	10	17	21	21
Columbia University in the City of New York (CU), United States of America (USA)	12	12	16	11	11	13	23	22
University of California, Los Angeles (UCLA), United States of America (USA)	22	17	15	21	29	28	26	23
University of California, Berkeley (UC Berkeley), United States of America (USA)	8	19	12	9	17	18	15	24
Wuhan University (WHU), China			95	55	58	67	42	25
University of Colorado Boulder (CU-Boulder), United States of America (USA)	7	10	9	7	14	20	22	26
The University of Texas at Austin (UT Austin), United States of America (USA)	17	13	14	15	21	27	32	27
Harbin Institute of Technology (HIT), China			67	48	54	45	49	28
University of California, San Diego (UC San Diego), United States of America (USA)	14	14	18	26	32	24	10	29
Nanjing University of Information Science and Technology (NUIST), China				100	77	49	46	30

Source: Nature (2023), `www.nature.com/nature-index/annual-tables`.

Scientific journals

General scientific journals

- Nature
- Nature Communications
- Science
- Science Advances
- American Economic Journal
- Proceedings of the National Academy of Sciences

Figure 2: Volume 626, Issue 7999, 15 February 2024

Scientific journals

Specialized journals

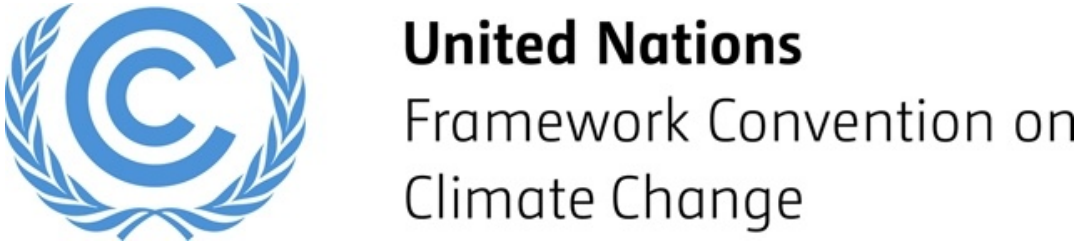
- Atmospheric and Environmental Sciences
  Atmospheric Chemistry and Physics; Bulletin of the American Meteorological Society; Climate Dynamics; Climate in the Past; Earth System Dynamics; Earth System Science Data; Earth's Future; Environmental Research Letters; Journal of Advances in Modeling Earth Systems; Journal of Climate; Journal of Geophysical Research: Atmospheres; Geophysical Research Letters; Geoscientific Model Development; Global Change Biology; Journal of the Atmospheric Sciences; npj Climate and Atmospheric Science; Quarterly Journal of the Royal Meteorological Society; Reviews of Geophysics; Tellus.
- Climate change
  WIREs Climate Change; Climatic Change; Current Climate Change Reports; Global Environmental Change; Global and Planetary Change; Nature Climate Change; Nature Sustainability.
- Economics
  Climate Change Economics; Climate Policy; Ecological Economics; Environmental and Resource Economics; Environmental Modeling & Assessment; Journal of Environmental Economics and Management; Resource and Energy Economics; Review of Environmental Economics and Policy.
- Energy
  Energy and Environmental Science; Energy Economics; Energy Journal; Energy Policy; Energy Studies Review; Journal of Cleaner Production.
- Specialized topics
  Arctic, Antarctic, and Alpine Research; Artic Ice Journal; Cryosphere; Frontiers in Earth Science: Cryospheric Science; Polar Science; Quaternary Science Reviews; Water Research.

Earth Summit

- June 1972: United Nations Conference on the Human Environment or Stockholm conference
- Creation of the United Nations Environment Programme (UNEP)
- June 1992: United Nations Conference on Environment and Development (UNCED) or the Earth Summit (Rio de Janeiro, Brazil)

Earth Summit

- Rio Declaration on Environment and Development signed by 170 countries
- Forest Principles (also known as the Rio Forest Principles)
- Agenda 21 $\Rightarrow$ Sustainable Development Goals (SDGs)
  1. Social and economic dimensions.
  2. Conservation and management of resources for development
  3. Strengthening the role of major groups
  4. Means of implementation
- The so-called Rio Conventions
  - UN Framework Convention on Climate Change (UNFCCC)



  - Convention on Biological Diversity (CBD)
  - United Nations Convention to Combat Desertification (UNCCD
- Launch of the UNEP Finance Initiative (UNEP-FI)

UNFCCC


nited

ations


ramework

onvention

on

limate

hange

UNFCCC

The UNFCCC is the international treaty (or a convention) adopted at the Earth Summit. It consists of 26 articles and two annexes. The objective of the UNFCCC is defined in Article 2:

> *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."*

UNFCCC

Three types of Parties:

- Annex I Parties[2]
- Annex II Parties (subset of Annex I Parties corresponding to developed countries)
- Non-Annex I Parties

$\Rightarrow$ All Parties (including Non-Annex I Parties) must publish national inventories of anthropogenic emissions and implement climate change mitigation programs

[2] In 1992, Annex I Parties were Australia, Austria, Belarus*, Belgium, Bulgaria*, Canada, Czechoslovakia*, Denmark, European Economic Community, Estonia*, Finland, France, Germany, Greece, Hungary*, Iceland, Ireland, Italy, Japan, Latvia*, Lithuania*, Luxembourg, Netherlands, New Zealand, Norway, Poland*, Portugal, Romania*, Russian Federation*, Spain, Sweden, Switzerland, Turkey, Ukraine*, United Kingdom of Great Britain and Northern Ireland, United States of America. The symbol * indicated countries in transition.

Conference of the Parties (COP)

Table 9: Chronological list of the meetings of the Conference of the Parties

Year	COP	CMP	CMA	City	Country	Treaty
1992				Rio de Janero	Brazil	Convention
1995	1			Berlin	Germany	
1996	2			Geneva	Switzerland	
1997	3			Kyoto	Japan	Kyoto Protocol
1998	4			Buenos Aires	Argentina	
1999	5			Bonn	Germany	
2000	6-1			The Hague	Netherlands	
2001	6-2			Bonn	Germany	
2001	7			Marrakech	Morocco	
2002	8			New Delhi	India	
2003	9			Milan	Italy	
2004	10			Buenos Aires	Argentina	
2005	11	1		Montreal	Canada	
2006	12	2		Nairobi	Kenya	
2007	13	3		Bali	Indonesia	
2008	14	4		Poznań	Poland	
2009	15	5		Copenhagen	Denmark	

Conference of the Parties (COP)

Table 10: Chronological list of the meetings of the Conference of the Parties

Year	COP	CMP	CMA	City	Country	Treaty
2010	16	6		Cancún	Mexico	
2011	17	7		Durban	South Africa	
2012	18	8		Doha	Qatar	
2013	19	9		Warsaw	Poland	
2014	20	10		Lima	Peru	
2015	21	11		Paris	France	Paris Agreement
2016	22	12	1-1	Marrakech	Morocco	
2017	23	13	1-2	Bonn	Germany	
2018	24	14	1-3	Katowice	Poland	
2019	25	15	2	Madrid	Spain	
2021	26	16	3	Glasgow	United Kingdom	
2022	27	17	4	Sharm El Sheikh	Egypt	
2023	28	18	5	Dubai	United Arab Emirates	
2024	29	19	6	Baku	Azerbaijan	

Conference of the Parties (COP)

Important COPs

- COP1: Berlin (1995)
- COP3: Kyoto (1997) $\Rightarrow$ Kyoto Protocol (CMP)
- COP18: Doha (2012) $\Rightarrow$ Second commitment of the Kyoto Protocol
- COP21: Paris (2015) $\Rightarrow$ Paris Agreement (CMA)
- COP26: Glasgow (2021) $\Rightarrow$ GFANZ & Net Zero
- COP28: Dubai (2023) $\Rightarrow$ "*Beginning of the end*" of the fossil fuel era

Kyoto Protocol

- Berlin Mandate
- IPCC published the Synthesis Report of the Second Assessment Report (SAR/AR2) in October 1995
- IPCC published the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories
- COP3 (Kyoto, 1997)
- The Kyoto Protocol entered into force on 16 February 2005
- The Protocol's first commitment period started in 2008 and ended in 2012
- At COP18 in Doha, a second commitment extended the first one from 2013 to 2020

$\Rightarrow$ Launch of the EU ETS in 2005

Kyoto Protocol

Table 11: Quantified first commitment under the Kyoto Protocol to limit or reduce emissions (% of base year)

$\mathcal{R}$	Country
+10%	Iceland
+8%	Australia
+1%	Norway
0%	New Zealand, Russian Federation, Ukraine
−5%	Croatia
−6%	Canada, Hungary, Japan, Poland
−7%	United States of America
−8%	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland

Kyoto Protocol

Table 12: List of greenhouse gases under the Kyoto Protocol and the Doha Amendment

Greenhouse gas	Symbol	Kyoto Protocol	Doha Amendment
Carbon dioxide	CO_2	✓	✓
Methane	CH_4	✓	✓
Nitrous oxide	N_2O	✓	✓
Hydrofluorocarbons	HFCs	✓	✓
Perfluorocarbons	PFCs	✓	✓
Sulphur hexafluoride	SF_6	✓	✓
Nitrogen trifluoride	NF_3		✓

Kyoto Protocol

Table 13: Quantified second commitment under the Kyoto Protocol (Doha Amendment) to limit or reduce emissions (% of base year)

$\mathcal{R}$	Country
−0.5%	Australia
−5%	Kazakhstan
−12%	Belarus
−16%	Liechtenstein, Norway, Switzerland
−20%	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, European Union, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland
−22%	Monaco
−24%	Ukraine

Kyoto Protocol

What is the track record of the Kyoto Protocol?

- Nordhaus and Boyer (1999) wrote that "*[...] the benefit-cost ratio of the Kyoto Protocol is 1/7. Additionally, the emissions strategy is highly cost-ineffective, with the global temperature reduction achieved at a cost almost 8 times the cost of a strategy which is cost-effective in terms of where and when efficiency.*"
- Tol (1999) concluded concluded that "*[...] the agreements of the Kyoto Protocol are not readily reconciled with economic rationality.*"
- Etc.
- BUT...

Total EU emissions have been reduced about 19% below base year levels

Paris Agreement

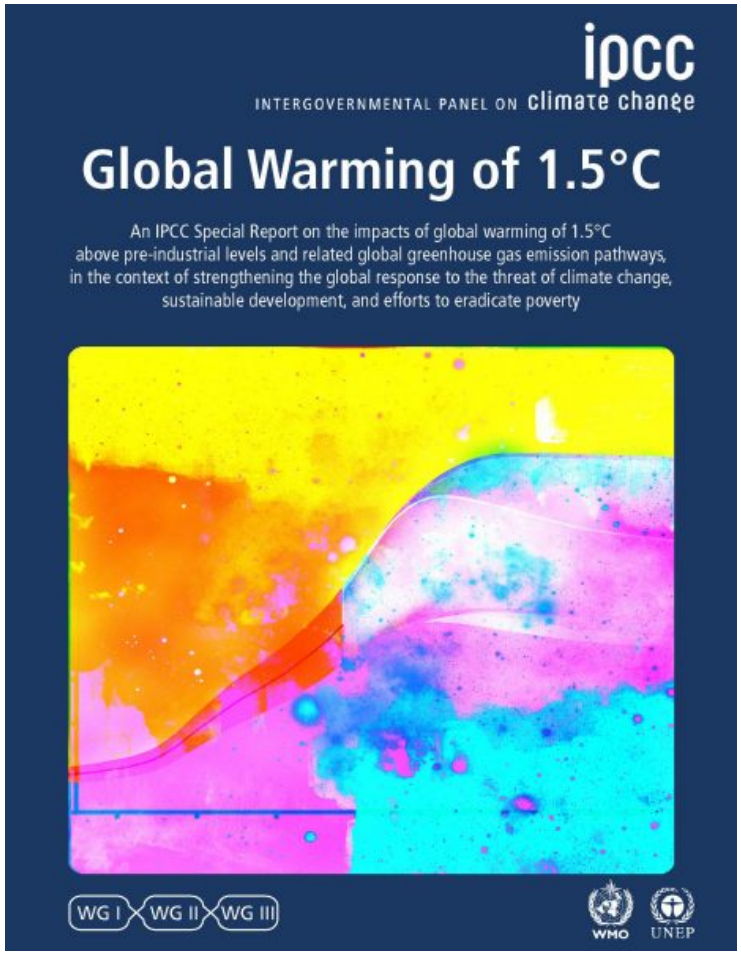
The **Paris Agreement** is an international treaty with the following goals:

1. Keep a global temperature rise this century well below $2°\mathrm{C}$ above the pre-industrial levels
2. Pursue efforts to limit the temperature increase to $1.5°\mathrm{C}$
3. Increase the ability of countries to deal with the impacts of climate change
4. Make finance flows consistent with low GHG emissions and climate-resilient pathways

$\Rightarrow$ Nationally determined contribution (NDC)

Paris Agreement

Figure 3: IPCC Special Report on Global Warming of 1.5°C (SR15)



Paris Agreement

Figure 4: The Economist, Say goodbye to 1.5°C, November 5, 2022

Nationally determined contribution

NDC Registry: `https://unfccc.int/NDCREG`

Nationally determined contribution

First Party: Afghanistan

Base year	2005
Target years	2020 to 2030
Contribution type	Conditional
Sectors	Energy, natural resource management, agriculture, waste management and mining
Gases covered	Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
Target	There will be a 13.6% reduction in GHG emissions by 2030 compared to a business-as-usualgeneral]Business-as-usual (BAU) 2030 scenario, conditional on external support
Financial needs	Total: \$17.405 bn Adaptation: \$10.785 bn + Mitigation: \$6.62 bn (2020-2030)

Nationally determined contribution

Last Part: Zimbabwe (2015 INDC)

- Business-as-usual (BAU) scenario
  "*The INDC BAU baseline focused solely on per capita energy emissions. Zimbabwean per capita energy emissions were projected to be* $1.06\,\mathrm{tCO_2e}$ *in 2020,* $2.57\,\mathrm{tCO_2e}$ *in 2025 and* $3.31\,\mathrm{tCO_2e}$ *in 2030 under business-as-usual.*"
- Emission reduction target
  "*The INDC emission reduction target was a 33% reduction in energy-related emissions per capita compared to BAU by 2030, conditional on international support. In the mitigation scenario, energy-related emissions per capita were projected to be* $2.21\,\mathrm{tCO_2e}$ *in 2030.*"

Nationally determined contribution

Last Part: Zimbabwe (2021 Revised NDC)

- Business-as-usual (BAU) scenario
  "*Updated to include all IPCC sectors. National total emissions in the base data period ranged between* 25.24 $\mathrm{MtCO_2e}$ *in 2011 and* 41.66 $\mathrm{MtCO_2e}$ *in 2015. Emissions in 2017 were* 35.84 $\mathrm{MtCO_2e}$. *National total emissions per capita in the base data period ranged between* 2.03 $\mathrm{tCO_2e}$ *in 2011 and* 2.98 $\mathrm{tCO_2e}$ *in 2015. Emissions per capita in 2017 were* 2.45 $\mathrm{tCO_2e}$. *The NDC revision process incorporated impacts of COVID-19 on emissions trends and macroeconomic parameters, including GDP, which fed into the updated baseline.*"
- Emission reduction target
  "*The updated target is a* 40% *reduction in economy-wide GHG emissions per capita compared to BAU by 2030, conditional on international support. In the mitigation scenario, economy-wide emissions per capita are projected to be* 2.3 $\mathrm{tCO_2e}$ *in 2030.*"

Nationally determined contribution

(1) GHG emissions in 2022 in $\mathrm{MtCO_2e}$, (2) share in %, (3) cumulative share in %, (4) GHG emissions per capita in 2022 in $\mathrm{tCO_2e}$, (5) GHG emissions per GDP in 2022 in $\mathrm{kgCO_2e}$, (6) GHG emissions growth between 2010 and 2022 in %, (7) NDC reduction rate, (8) base year (BAU = business-as-usual), (9) target year, (10) mitigation type (AER = absolute emissions reduction, CIR = carbon intensity reduction, RER = relative emissions reduction).

Table 14: 2022 GHG emissions and NDCs of top emitting countries

Rank	Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	China	15 685	29.16	29.16	10.95	0.61	35.62	65	2005	2030	CIR
2	United States	6 017	11.19	40.35	17.90	0.28	−10.01	50	2005	2030	AER
3	India	3 943	7.33	47.68	2.79	0.39	38.85	45	2005	2030	CIR
4	Russia	2 580	4.80	52.48	17.99	0.64	14.90	30	1990	2030	AER
5	Brazil	1 310	2.44	54.91	6.05	0.40	11.27	50	2005	2030	AER
6	Indonesia	1 241	2.31	57.22	4.47	0.36	50.00	32	BAU	2030	RER
7	Japan	1 183	2.20	59.42	9.41	0.23	−10.85	46	2013	2030	AER
8	Iran	952	1.77	61.19	11.20	0.70	17.94				
9	Mexico	820	1.52	62.71	5.99	0.33	6.64	22	BAU	2030	RER
10	Saudi Arabia	811	1.51	64.22	22.64	0.45	30.84	34	2020	2030	RER

Nationally determined contribution

Table 15: 2022 GHG emissions and NDCs of top emitting countries

Rank	Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11	Germany	784	1.46	65.68	9.49	0.17	−16.68	55	1990	2030	AER
12	Canada	757	1.41	67.09	19.79	0.40	4.22	40	2005	2030	AER
13	International Shipping	751	1.40	68.48			7.17				
14	South Korea	726	1.35	69.83	14.01	0.31	7.79	40	2018	2030	AER
15	Turkey	688	1.28	71.11	8.09	0.24	61.73	21	BAU	2030	RER
16	Australia	571	1.06	72.17	21.98	0.43	−5.06	43	2005	2030	AER
17	Pakistan	546	1.02	73.19	2.53	0.42	36.49	15	BAU	2030	RER
18	South Africa	535	0.99	74.18	8.91	0.66	−9.11	40	2020	2030	RER
19	Vietnam	489	0.91	75.09	4.88	0.44	58.37	9	BAU	2030	RER
20	Thailand	464	0.86	75.95	6.67	0.37	8.76	20	BAU	2030	RER
21	France	430	0.80	76.75	6.50	0.14	−16.37	55	1990	2030	AER
22	United Kingdom	427	0.79	77.54	6.27	0.14	−28.29	68	1990	2030	AER
23	International Aviation	426	0.79	78.34			−8.38				
24	Nigeria	408	0.76	79.09	1.88	0.38	11.08	20	BAU	2030	RER
25	Poland	401	0.75	79.84	10.62	0.29	−4.13	55	1990	2030	AER
26	Italy	395	0.73	80.57	6.70	0.15	−21.62	55	1990	2030	AER
27	Argentina	383	0.71	81.29	8.27	0.37	10.60	10	2020	2030	RER
28	Egypt	378	0.70	81.99	3.55	0.27	19.16	33	BAU	2030	RER
29	Iraq	368	0.68	82.67	8.41	0.90	75.42				
30	Malaysia	354	0.66	83.33	10.50	0.37	26.48	45	2005	2030	CIR

Nationally determined contribution

Table 16: 2022 GHG emissions and NDCs of top emitting countries

Rank	Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
31	Kazakhstan	332	0.62	83.95	17.33	0.65	3.50	15	1990	2030	AER
32	Spain	329	0.61	84.56	7.08	0.17	−13.07	55	1990	2030	AER
33	Taiwan	308	0.57	85.13	12.86	0.19	1.57				
34	United Arab Emirates	295	0.55	85.68	29.33	0.42	31.21	31	BAU	2030	RER
35	Algeria	284	0.53	86.21	6.38	0.57	36.01	7	BAU	2030	RER
36	Bangladesh	281	0.52	86.73	1.62	0.26	29.87	7	BAU	2030	RER
37	Philippines	265	0.49	87.22	2.35	0.27	50.56	3	BAU	2030	RER
38	Uzbekistan	227	0.42	87.65	6.67	0.79	9.25	35	2010	2030	CIR
39	Colombia	216	0.40	88.05	4.23	0.27	18.88	51	BAU	2030	RER
40	Ukraine	209	0.39	88.43	4.84	0.55	−47.32	65	1990	2030	AER
41	Qatar	195	0.36	88.80	67.38	0.74	41.86	25	BAU	2030	RER
42	Ethiopia	192	0.36	89.15	1.63	0.66	53.40	14	BAU	2030	RER
43	Venezuela	170	0.32	89.47	4.99	1.02	−35.03	20	BAU	2030	RER
44	Myanmar	169	0.31	89.78	3.04	0.76	42.10				
45	Kuwait	168	0.31	90.10	37.96	0.80	35.24	7	BAU	2035	RER
	Total	53 786			6.76	0.39	14.46				

Paris Agreement

Kaya decomposition

- Population-based decomposition

$$\text{GHG emissions} = \text{Population} \times \frac{\text{GHG emissions}}{\text{Population}}$$

- GDP-based decomposition

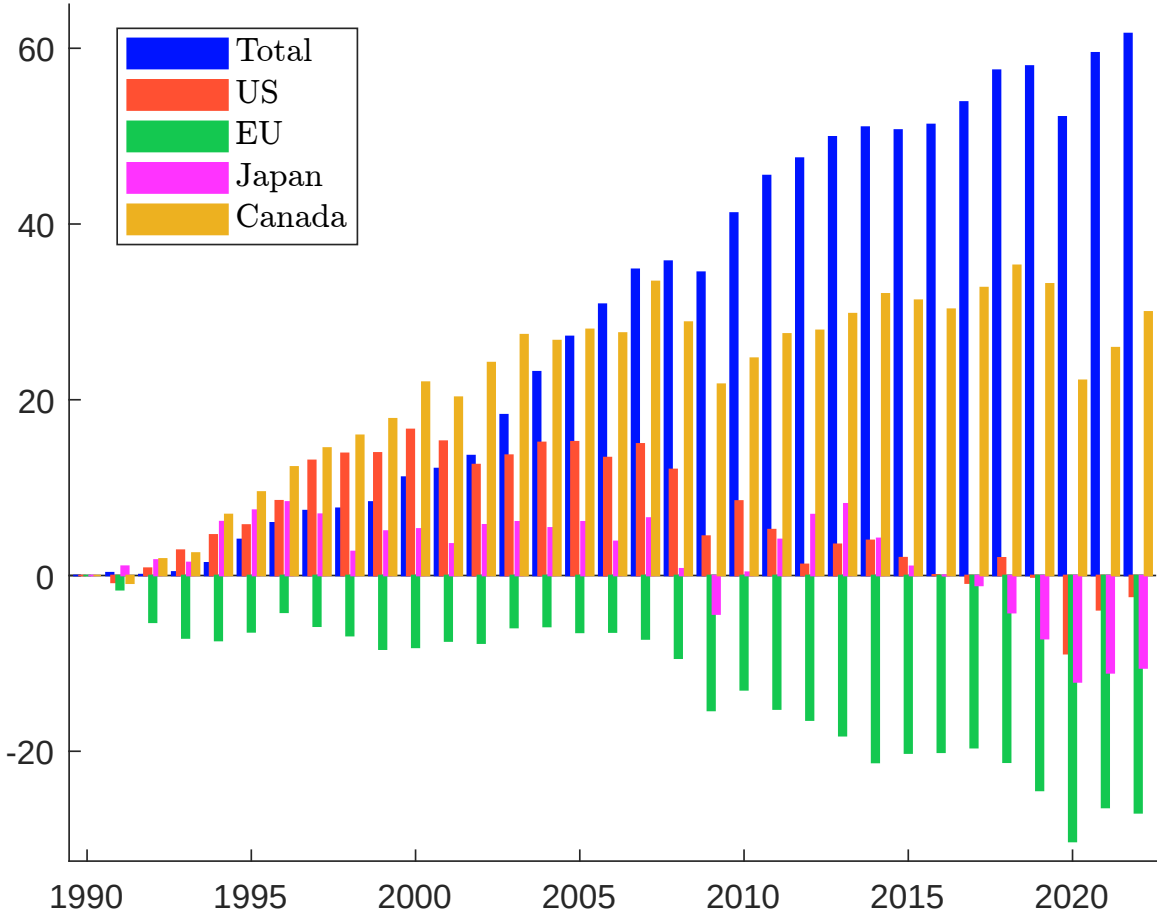
$$\text{GHG emissions} = \text{GDP} \times \frac{\text{GHG emissions}}{\text{GDP}}$$

- Simplified Kaya idensity:

$$\text{GHG emissions} = \text{GDP} \times \frac{\text{Energy}}{\text{GDP}} \times \frac{\text{GHG emissions}}{\text{Energy}}$$

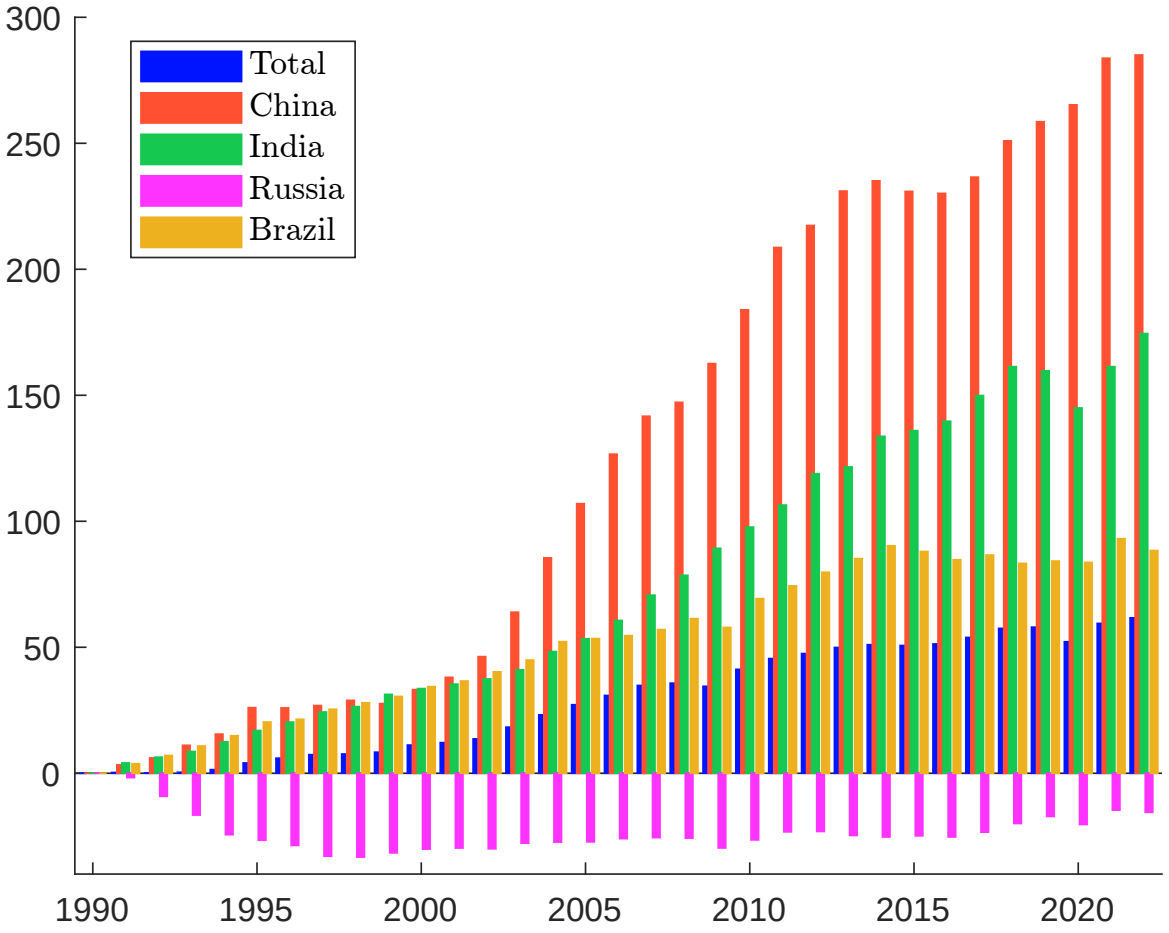
Paris Agreement

Figure 5: Growth of greenhouse gas emissions in % for developed countries (base year = 1990)



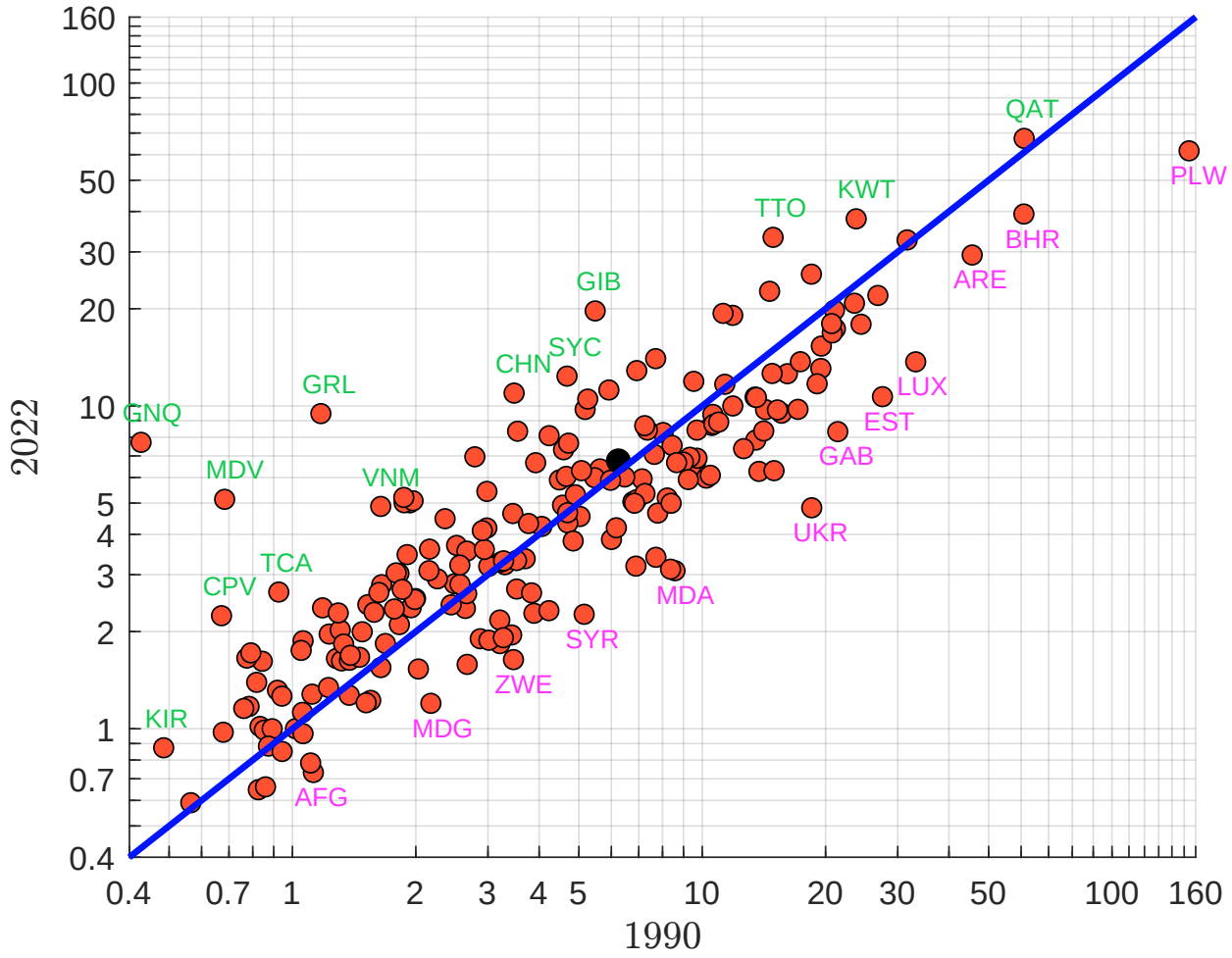
Paris Agreement

Figure 6: Growth of greenhouse gas emissions in % for developing countries (base year = 1990)



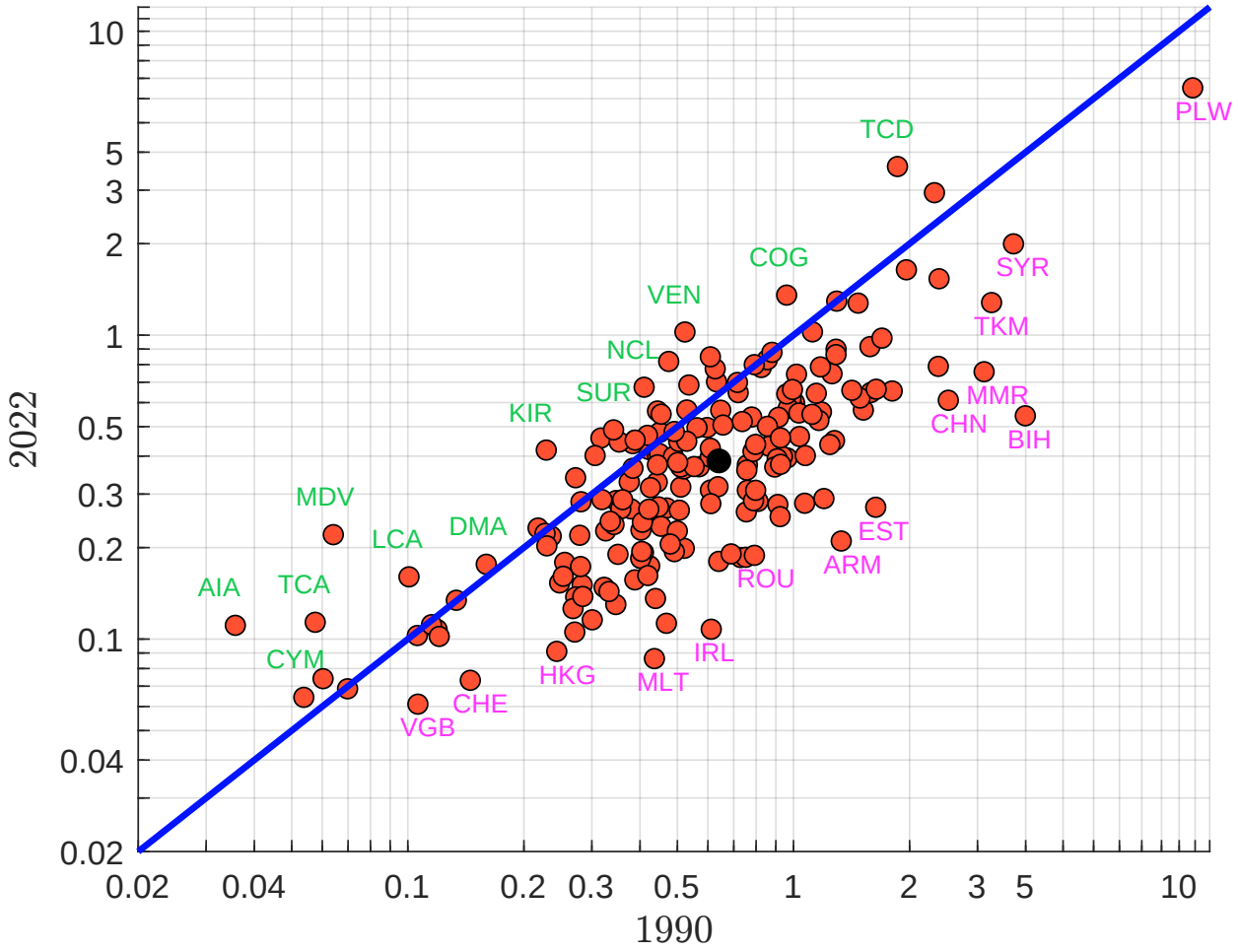
Paris Agreement

Figure 7: Per capita GHG emissions (1990 vs. 2022)



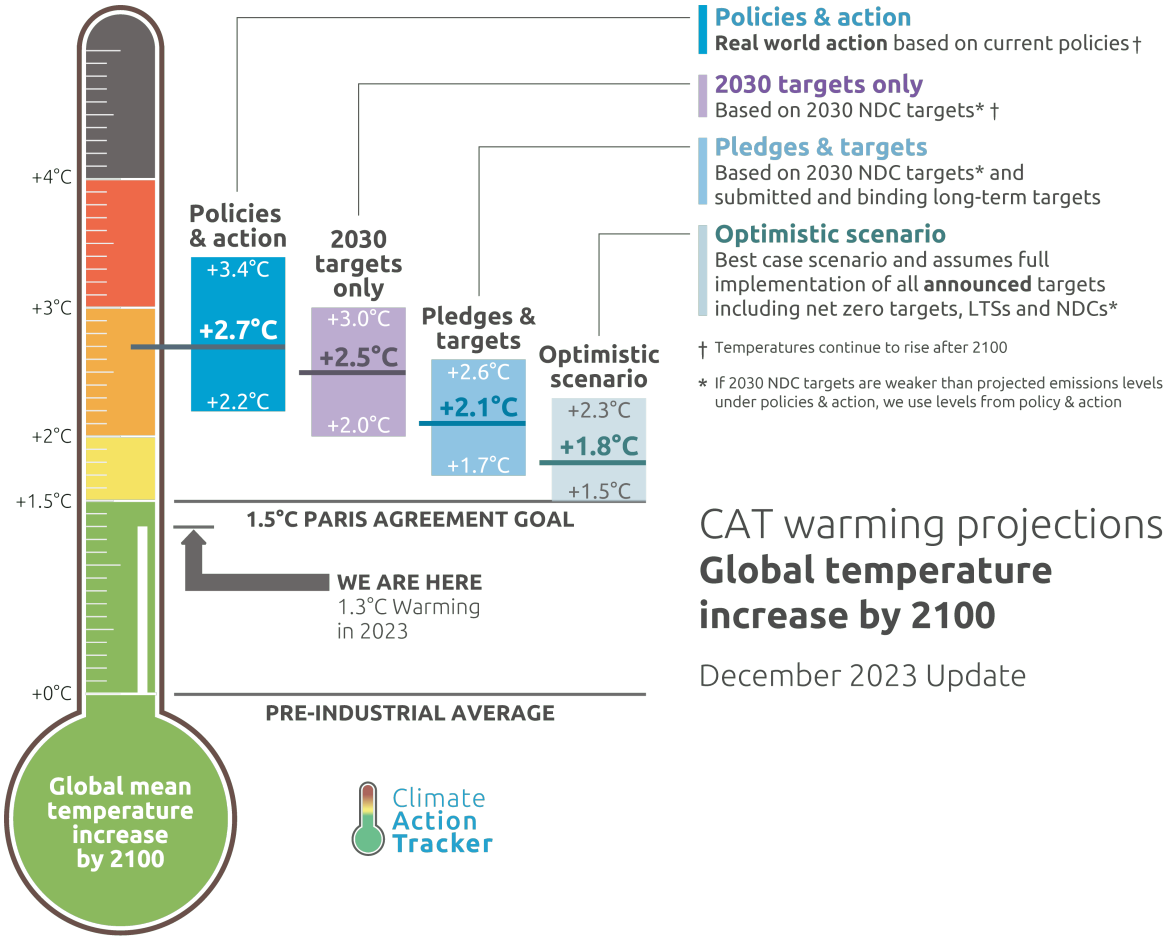
Paris Agreement

Figure 8: GHG emissions per GDP (1990 vs. 2022)



Paris Agreement

Figure 9: The CAT thermometer



Source: Climate Action Tracker (2023), `https://climateactiontracker.org`.

European Union

European Green Deal (December 2019)

Adopted by the EU Council in June 2021, the European Climate Law includes the following components:

- Set a 2030 target to reduce net greenhouse gas emissions by at least 55% compared to 1990 levels;
- Establish a system to monitor progress and take further action if necessary;
- Establish the European Scientific Advisory Board on Climate Change to provide independent scientific advice;
- Define the EU-wide greenhouse gas emission reduction path for 2030-2050;
- Provide predictability for investors and other economic actors;
- Ensure that the transition to climate neutrality is irreversible;
- Commit to negative emissions after 2050.

Communication on the European Green Deal, 14 July 2021

Source: `https://twitter.com/EU_Commission/status/1415289818565816321`.

Communication on the European Green Deal, 14 July 2021

- In July 2021, the European Commission presented the Fit for 55 package
- First quantitative target of the European Climate Change Law, namely to reduce Europe's net greenhouse gas emissions by at least 55% by 2030
- The package consists of several legislative proposals
- As of 1 January 2024, 12 proposals have been adopted

Fit for 55 package

1. Reform of the emissions trading system (ETS, April 2023)
2. New emissions trading system for building and road transport fuels (April 2023)
3. Social climate fund (April 2023)
4. Revision of the effort sharing regulation (ESR, March 2023)
5. Revision of the regulation on land use, forestry and agriculture (LULUCF, March 2023)
6. Revised regulation on CO_2 emissions from new cars and vans (March 2023)
7. Carbon border adjustment mechanism (CBAM, April 2023)
8. Renewable energy directive (RED III, October 2023)
9. Energy efficiency directive (EED, July 2023)
10. Alternative fuels infrastructure regulation (AFIR)
11. ReFuelEU aviation regulation
12. FuelEU maritime regulation

Fit for 55 package

Table 17: National reduction targets under the ESR (revised 2023 vs. original 2018)

Country	2018	2023	Country	2018	2023	Country	2018	2023
Austria	36.0%	48.0%	France	37.0%	47.5%	Malta	19.0%	19.0%
Belgium	35.0%	47.0%	Germany	38.0%	50.0%	Netherlands	36.0%	48.0%
Bulgaria	0.0%	10.0%	Greece	16.0%	22.7%	Poland	7.0%	17.7%
Croatia	7.0%	16.7%	Hungary	7.0%	17.7%	Portugal	17.0%	28.7%
Cyprus	24.0%	32.0%	Ireland	30.0%	42.0%	Romania	2.0%	12.7%
Czechia	14.0%	26.0%	Italy	33.0%	43.7%	Slovakia	12.0%	22.7%
Denmark	39.0%	50.0%	Latvia	6.0%	17.0%	Slovenia	15.0%	27.0%
Estonia	13.0%	24.0%	Lithuania	9.0%	21.0%	Spain	26.0%	37.7%
Finland	39.0%	50.0%	Luxembourg	40.0%	50.0%	Sweden	40.0%	50.0%

Source: European Commission (2023), `https://climate.ec.europa.eu/eu-action/effort-sharing-member-states-emission-targets`.

Fit for 55 package

In addition to the previous 12 adopted proposals, three new proposals have already been provisionally agreed by the co-legislators:

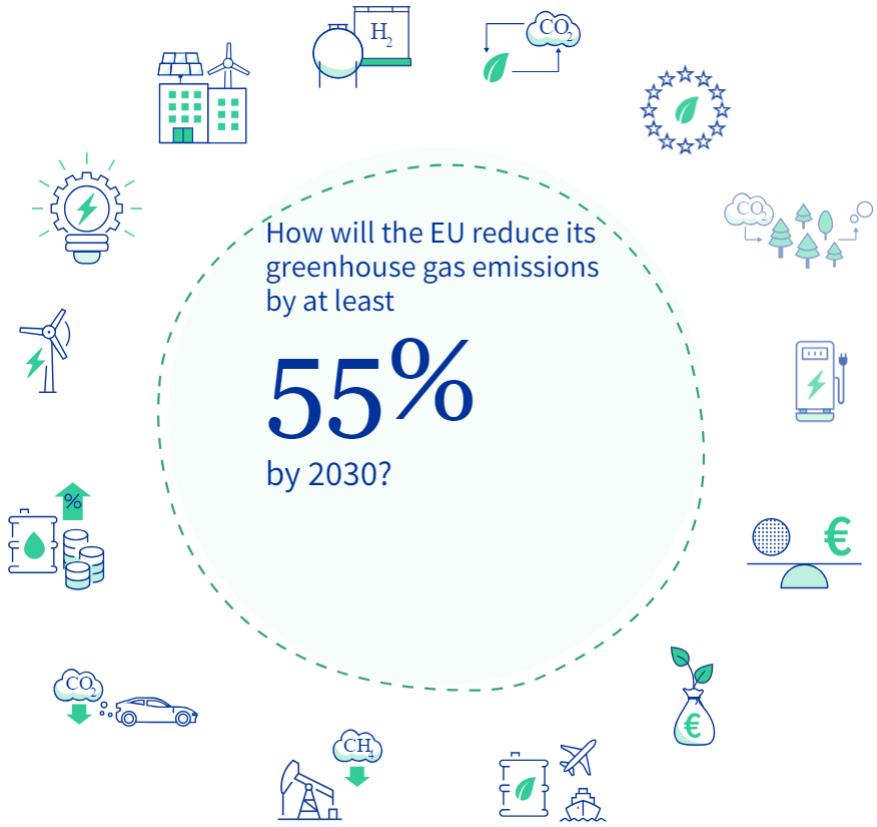
- Energy performance of buildings directive (EPBD)
- EU methane regulation for the energy sector
- Updated EU rules to decarbonise gas markets and promote hydrogen

Remark

One proposal did not materialise: revision of the Energy Taxation Directive (ETD)

Fit for 55 package

Figure 10: What is included in the Fit for 55 package?



Source: European Council (2024), https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition.

United States

The US Environmental Protection Agency (EPA) has implemented the following regulations since 2020:

- An 85% reduction in the production and consumption of hydrofluorocarbons over the next 15 years, beginning in 2021
- Vehicle emissions standards, including stricter GHG emissions standards for cars and light trucks beginning in 2023
- Aviation GHG standards for commercial aircraft and large business jets
- Renewable Fuel Standard (RFS) program, a federal program that requires a certain amount of renewable fuel to be blended into transportation fuel each year
- Regulation of power plant emissions through the Acid Rain Program (ARP) and Mercury and Air Toxics Standards (MATS)

These new regulations complement existing regulations such as the Clean Air Act (CAA) of 1970, the federal law that regulates air emissions from stationary and mobile sources, including power plants, factories, and vehicles

United States

- In August 2022, the United States passed the Inflation Reduction Act (IRA)
- In December 2023, the EPA issued a new methane rule to reduce methane emissions from oil and natural gas operations
- In 2022 and 2023, some states also increased their renewable portfolio standards (RPS)

France

- Energy Transition Act of 2015 (Loi relative à la transition énergétique pour la croissance verte du 17 août 2015)
- Energy and Climate Act of 2019 (Loi relative à l'énergie et au climat du 8 novembre 2019)
- Mobility Orientation Act of 2019 (Loi d'orientation des mobilités du 24 décembre 2019)
- Anti-Waste Act for a Circular Economy of 2020 (Loi relative à la lutte contre le gaspillage et à l'économie circulaire du 10 février 2020)
- National low carbon strategy (Stratégie nationale bas-carbone du 21 avril 2020 or SNBC)
- Climate and Resilience Act of 2021 (Loi climat et résilience du 22 août 2021)
- Environnemental Regulation (Réglementation environnementale RE2020)

Germany

- Klimaschutzgesetz (climate change act)
- Klimaschutzprogramm 2030 (climate action programme 2030)
- Erneuerbare-Energien-Gesetz (EEG or renewable energy sources act)
- Energieeinsparverordnung (EnEV or energy saving ordinance)
- Energiewirtschaftsgesetz (EnWG or energy industry act)

United Kingdom

- Climate Change Act 2008
- UK ETS
- UK CBAM

Other countries

- Australia: national greenhouse and energy reporting scheme (2007), emissions reduction fund (2014), safeguard mechanism (2015), renewable energy target scheme (2021), national climate resilience and adaptation strategy (2021-2025)
- Canada: Canadian environmental protection act (1999), pan-Canadian framework on clean growth and climate change (2016), greenhouse gas pollution pricing act (2018), Canadian net-zero emissions accountability act (2021), clean fuel standard (2022)
- China: renewable energy law (2005), energy conservation law (2007), carbon emissions trading management regulations (2021), 14th five-year plan for green development (2021-2025)

Other countries

- India: national action plan on climate change (2008), energy conservation act (2001), renewable energy sources act (2015), national programme on climate change & human health (2019), green hydrogen/ammonia policy (2022)
- Japan: act on promotion of global warming countermeasures (1998), energy conservation act (1979), climate change adaptation act (2018), green growth strategy through achieving carbon neutrality in 2050 (2021), renewable energy act (2022)