The role of nuclear energy in energy system transitions

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IPCC Vice-Chair

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INTERGOVERNMENTAL PANEL ON climate change

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IPCC Sixth Assessment (AR6)

Some overarching preliminary aspects for the Synthesis Report

- *Global Stocktake*
- *Interaction among emissions, climate, risks and development pathways*
- *Economic and social costs and benefits of mitigation and adaptation in the context of development pathways*
- *Adaptation and mitigation actions in the context of sustainable development*
- *Finance and means of support*

May 2019
Emission inventories

Oct. 2018
Global warming of 1.5 °C

Sept. 2019
Oceans and cryosphere

April 2021
The Physical Science Basis

October 2021
Climate Change Impacts, Adaptation and Vulnerability

April 2022
The Synthesis Report

Talanoa dialogue UNFCCC

Land
Aug. 2019

Mitigation of Climate Change
July 2021

Global stocktake 2023 UNFCCC

March 2018 — Cities and Climate Change Science Conference

May 2018 — Expert Meeting on Assessing Climate Information for Regions

May 2018 — Expert Meeting on Short Lived Climate Forcers

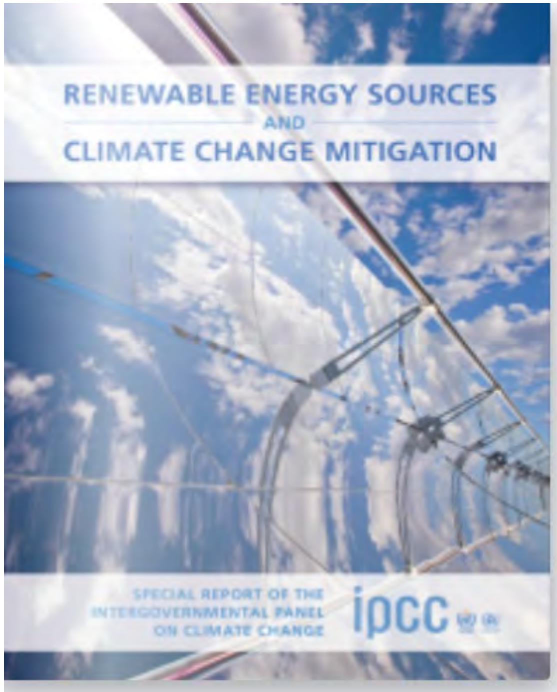
**** Dates are subject to change***

Paris Agreement

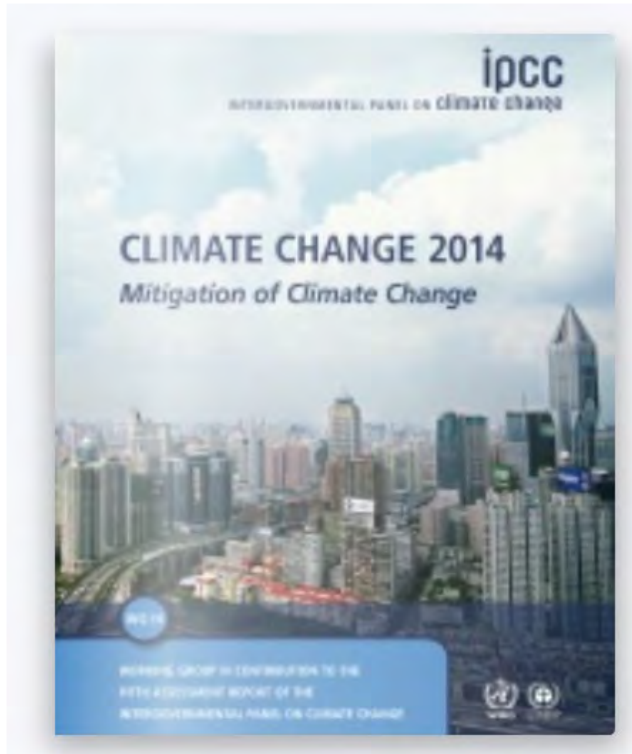
"… holding the increase in the global average temperature to well below 2ºC above pre-industrial levels, while pursuing efforts to limit the temperature increase to 1.5ºC above these levels, recognizing that this would significantly reduce the risks and impacts o climate change."

Global Warming of 1.5°C

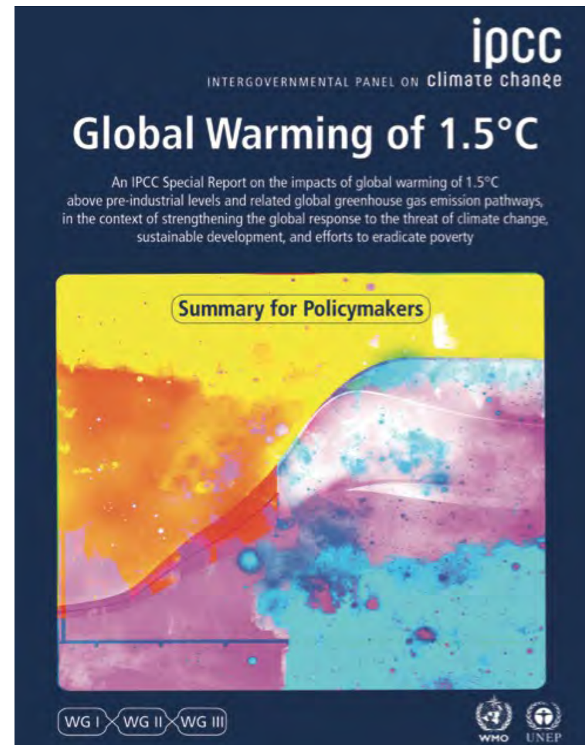
An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.



IPCC , 2011



IPCC , 2014



IPCC , 2018

Where are we?

Ashley Cooper / Aurora Photos

Where are we?

- Since pre-industrial times, human activities have caused approximately 1.0°C of global warming [0.8 – 1.2]ºC
- Already seeing consequences for people, nature and livelihoods
- At current rate, would reach 1.5°C between 2030 and 2050
- Past emissions alone do not commit the world to 1.5°C
- ***So there is a window of action to limit warming to 1.5ºC by reducing greenhouse gas emissions across all sectors***
- ***Mitigation actions would have to be large-scale and rapid*** **actions would have to be large-scale and rapid**

Emergence and intensity of regional climate change hot spots

Warming of 1.5°C or less
Warming of 1.5°C-2°C
Warming > 2°C

L, likely
VL, very likely
LC, low confidence
MC, medium confidence
HC, high confidence

Southeast Asia

- Increased flooding related to sea-level rise: risks; higher risks *(MC)*; substantial increases in risk
- Asian monsoon : *LC*; *LC;* *L* increase in precipitation intensity
- Heavy precipitation: increase; stronger increase *(MC)*; substantial increase
- Crop yield reductions: -; one third decline per capita *(MC)*; substantial reduction

Warming of 1.5°C or less
Warming of 1.5°C - 2°C
Warming > 2°C

L, likely
VL, very likely
LC, low confidence
MC, medium confidence
HC, high confidence

Small islands

- **Inundation risk** : land exposed; tens of thousands displaced ; substantial, widespread impacts
- **Coastal flooding** : risks; high risks ; substantial and widespread impacts
- **Fresh water stress** : increased; projected aridity; substantial and widespread impacts
- **Number of warm days** : increase; further increase (70 warm days/year), persistent heat stress in cattle ; persistent heat stress
- **Loss of coral reefs**: 70-90%; most coral reefs ; loss of most coral reefs *(VL)*

Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

Where are we now?

- Stabilizing global warming at 1.5°C requires CO_2 emissions to reach net zero by mid-century
- Decline of other non-CO_2 human emissions
- Energy sector can substantially reduce greenhouse emissions in developed and developing nations
- Examples of actions :
  - shifting to low- or zero-emission power generation such as renewables, nuclear and fossil fuel with Carbon Capture and Storage (CCS)
  - electrifying transport and industry
  - improving energy efficiency

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Decarbonization in the IPCC AR5


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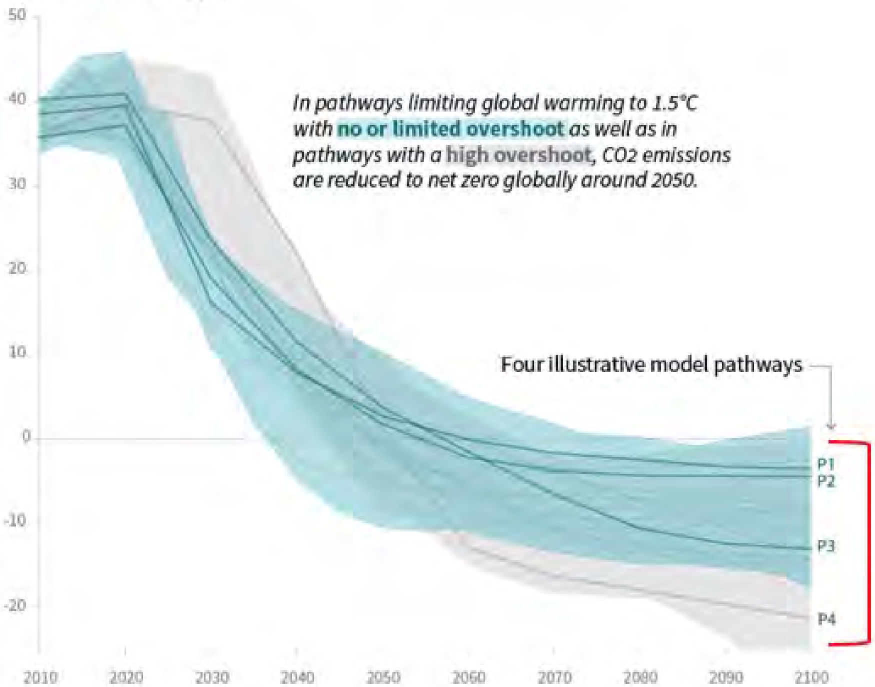
- Decarbonizing (reducing the carbon intensity of electricity generation)
  - key component in achieving low-stabilization levels that would lead to a warming of approximately **2ºC**
- In most low-stabilization scenarios, share of low-carbon electricity supply
  - renewables, nuclear and CCS
    - increases from 30% in 2012/2013 to more than 80% by 2050
  - fossil fuel power generation without CCS is phased out almost entirely by 2100

SPM3a | Global emissions pathway characteristics

Global total net CO_2 emissions

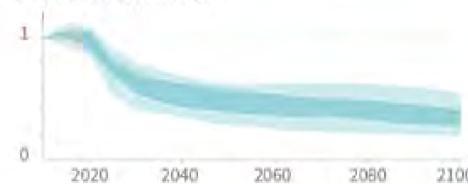


Timing of net zero CO_2
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

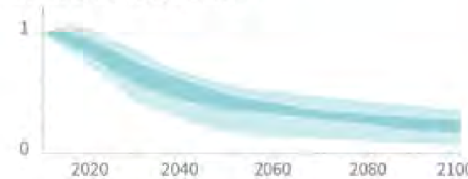
Non-CO_2 emissions relative to 2010

Emissions of non-CO_2 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.

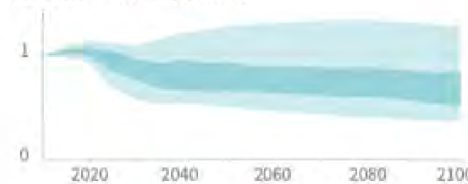
Methane emissions



Black carbon emissions



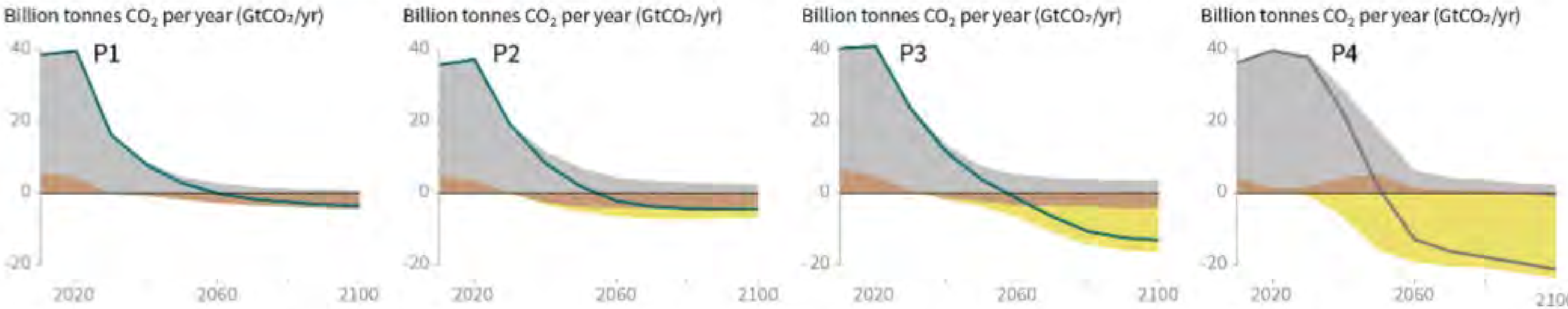
Nitrous oxide emissions



SPM3b | Characteristics of four illustrative model pathways

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways

Fossil fuel and industry · AFOLU · BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

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System transitions consistent with 1.5°C warming

By 2050:

- renewables supply a share of 49–67% of primary energy
- share from coal decreases to 1–7% (large fraction with CCS)

From 2020 to 2050:

- primary energy supplied by oil declines in most pathways
    - –32 to –74%
- Deployment of CCS varies widely across the pathways
- Primary energy supplied by bioenergy
    - 40–310 EJ yr^{-1} in 2050
- Nuclear
    - 3–120 EJ yr^{-1} in 2050


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System transitions consistent with 1.5°C warming

Nuclear power increases its share in most 1.5°C pathways by 2050

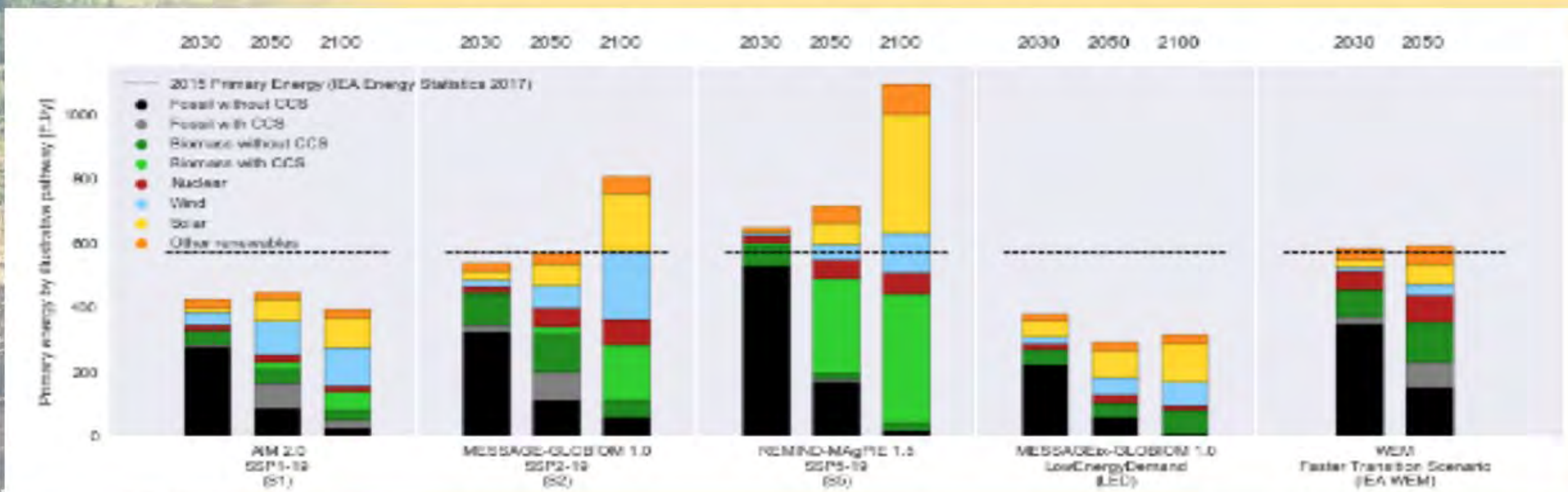
Large differences in nuclear power between models and across pathways

- future deployment can be constrained by societal preferences assumed in narratives underlying the pathways.

Some 1.5°C pathways see no role for nuclear fission by the end of the century,

- others project over 200 EJ yr^{-1} of nuclear power in 2100.

Contribution of Different Energy Sources to Primary Energy Supply in 2030, 2050, 2100 from different models



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Barriers to Nuclear and Advances

Nuclear energy could make an increasing contribution to low-carbon energy supply, but a variety of barriers and risks exist

- operational risks
- concerns with safety
- uranium mining risks
- financial and regulatory risks
- unresolved waste management issues
- nuclear weapon proliferation concerns
- adverse public opinion

Development of new fuel cycles and reactor technologies under way and progress concerning safety and waste disposal

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Nuclear evolution

- 17% of the world's electricity generation in 1993 from nuclear
- 11% in 2012

Contribution to global total primary energy supply declining since 2002

- Growing nuclear contribution to the total primary energy supply after 2000 in economies in transition and Asia (mostly in Russia and China).

Top five countries in installed nuclear capacity

- United States, France, Japan, Russia, and Republic of Korea — with 99, 63, 44, 24, and 21 GWe of nuclear power
- 68 % of total global nuclear capacity as of September 2013

SPM3b | Characteristics of four illustrative model pathways

Global indicators	P1	P2	P3	P4	Interquartile range
Pathway classification	No or low overshoot	No or low overshoot	No or low overshoot	High overshoot	No or low overshoot
Temperature and emissions					
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-59,-40)
in 2050 (% rel to 2010)	-93	-95	-91	-97	(-104,-91)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-55,-38)
in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
Energy systems					
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12, 7)
in 2050 (% rel to 2010)	-32	2	21	44	(-11, 22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47, 65)
in 2050 (%)	77	81	63	70	(69, 87)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(243,438)
in 2050 (% rel to 2010)	833	1327	878	1137	(675,1300)
Carbon dioxide removal					
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550, 1017)
of which BECCS ($GtCO_2$)	0	151	414	1191	(364, 662)
Agriculture					
Land area of bioenergy crops in 2050 (million hectare)	22	93	283	724	(151, 320)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-46,-23)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,4)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on SAR GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

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Table 2.6: Global primary energy supply of 1.5°C pathways from the scenario database (Supplementary Material 2.SM.1.3). Values given for the median (maximum, minimum) across the full range of 85 available 1.5°C pathways. Growth Factor = [(primary energy supply in 2050)/(primary energy supply in 2020) – 1].

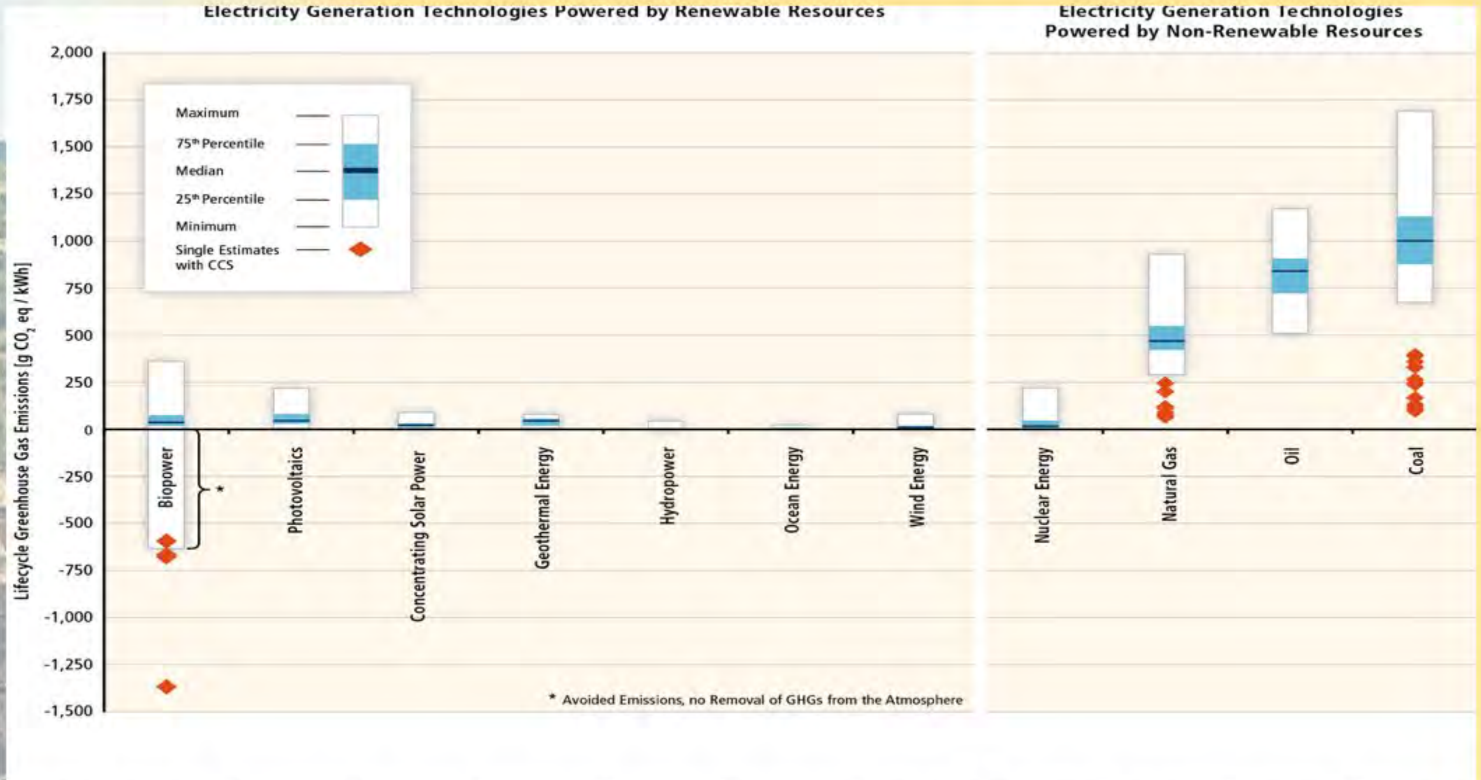
	Primary energy supply [EJ]			Share of primary energy [%]		Growth Factor
	2020	2030	2050	2020	2050	2020-2050
total primary	582.12 (636.98, 483.22)	502.81 (749.05, 237.37)	580.78 (1012.50, 289.02)			0.03 (0.59, -0.51)
renewables	87.70 (101.60, 60.16)	139.48 (203.90, 87.75)	293.80 (584.78, 176.77)	15.03 (20.39, 10.60)	60.80 (87.89, 28.47)	2.62 (6.71, 0.91)
biomass	61.35 (73.03, 40.54)	75.28 (113.02, 44.42)	154.13 (311.72, 40.36)	10.27 (14.23, 7.14)	26.38 (54.10, 10.29)	1.71 (5.56, -0.42)
non-biomass	26.35 (36.58, 17.60)	61.60 (114.41, 25.79)	157.37 (409.94, 53.79)	4.40 (7.19, 2.84)	28.60 (61.61, 9.87)	4.63 (13.46, 1.38)
nuclear	10.93 (18.55, 8.52)	16.22 (41.73, 6.80)	24.48 (115.80, 3.09)	1.97 (3.37, 1.45)	4.22 (13.60, 0.43)	1.34 (7.22, -0.64)
fossil	493.44 (638.04, 376.30)	347.62 (605.68, 70.14)	199.63 (608.39, 43.87)	83.56 (114.75, 77.73)	33.58 (74.63, 7.70)	-0.58 (0.12, -0.91)
coal	147.09 (193.55, 83.23)	49.46 (176.99, 5.97)	23.84 (134.69, 0.36)	25.72 (30.82, 17.19)	4.99 (13.30, 0.05)	-0.85 (-0.30, -1.00)
gas	135.58 (169.50, 105.01)	127.99 (208.55, 17.30)	88.97 (265.66, 14.92)	23.28 (28.39, 18.09)	13.46 (34.83, 2.80)	-0.37 (0.99, -0.88)
oil	195.02 (245.15, 151.02)	175.69 (319.80, 38.94)	93.48 (208.04, 15.07)	33.79 (42.24, 28.07)	16.22 (27.30, 2.89)	-0.54 (0.06, -0.93)

Table 2.7: Global electricity generation of 1.5°C pathways from the scenarios database (Supplementary Material 2.SM.1.3). Values given for the median (maximum, minimum) values across the full range across 89 available 1.5°C pathways. Growth Factor = [(primary energy supply in 2050)/(primary energy supply in 2020) – 1].

	Electricty generation [EJ]			Share of electricity generation [%]		Growth Factor
	2020	2030	2050	2020	2050	2020-2050
total electricity	100.09 (113.98, 83.53)	120.01 (177.51, 81.28)	224.78 (363.10, 126.96)			1.31 (2.55, 0.28)
renewables	26.38 (41.80, 18.26)	59.50 (111.70, 30.06)	153.72 (324.26, 84.69)	27.95 (41.84, 17.38)	77.52 (96.65, 35.58)	5.08 (10.88, 2.37)
biomass	1.52 (7.00, 0.66)	3.55 (11.96, 0.79)	16.32 (40.32, 0.21)	1.55 (7.30, 0.63)	8.02 (30.28, 0.08)	6.53 (38.14, -0.93)
non-biomass	24.48 (35.72, 17.60)	55.68 (101.90, 25.79)	136.40 (323.91, 53.79)	25.00 (40.43, 16.75)	66.75 (96.46, 27.51)	4.75 (10.64, 1.38)
nuclear	10.84 (18.55, 8.52)	15.49 (41.73, 6.80)	22.64 (115.80, 3.09)	10.91 (18.34, 8.62)	8.87 (39.61, 1.02)	1.21 (7.22, -0.64)
fossil	61.35 (76.76, 39.48)	38.41 (87.54, 2.25)	14.10 (118.12, 0.00)	61.55 (71.03, 47.26)	8.05 (33.19, 0.00)	-0.76 (0.54, -1.00)
coal	32.37 (46.20, 14.40)	10.41 (43.12, 0.00)	1.29 (46.72, 0.00)	32.39 (40.88, 17.23)	0.59 (12.87, 0.00)	-0.96 (0.01, -1.00)
gas	24.70 (41.20, 13.44)	25.00 (51.99, 2.01)	11.92 (67.94, 0.00)	24.71 (39.20, 11.80)	6.78 (32.59, 0.00)	-0.52 (1.63, -1.00)
oil	1.82 (13.36, 1.12)	0.92 (7.56, 0.24)	0.08 (8.78, 0.00)	2.04 (11.73, 1.01)	0.04 (3.80, 0.00)	-0.97 (0.98, -1.00)

Estimates of lifecycle GHG emissions for broad categories of electricity generation technologies

Source : Figure SPM.8 (IPCC SR Renewable Energy Sources and Climate Change Mitigation, 2011)



	Biopower	Photovoltaics	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

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Feasibility assessment of examples of 1.5°C-relevant mitigation options with **dark shading** signifying the absence of barriers in the feasibility dimension, moderate shading that on average, the dimension does not have a positive not a negative effect on the feasibility of the option, and faint shading the presence of potentially blocking barriers. Feasibility assessment of examples of 1.5°C-relevant mitigation options with **dark shading** signifying the absence of barriers in the feasibility dimension, moderate shading that on average, the dimension does not have a positive not a negative effect on the feasibility of the option, and faint shading the presence of potentially blocking barriers.

Ec = Economic ; Tec = Technical ; Inst = Institutional ; Soc = Social and Cultural; Env = Environmental ; Geo = Geophysical

System	Mitigation option	Evidence	Agreement	Ec	Tec	Inst	Soc	Env	Geo	Context
Energy system transitions	Wind energy (on-shore & off-shore)	Robust	Medium							Wind regime, economic status, space for windfarms and enhanced by legal framework for independent power producers affect uptake; cost-effectiveness affected by incentive regime.
	Solar PV	Robust	High							Cost-effectiveness affected by solar irradiation and incentive regime. Also enhanced by legal framework for independent power producers affect uptake.
	Bioenergy	Robust	Medium							Depends on availability of biomass and land and capability to manage sustainable land use. Distributional effects depend on the agrarian (or other) system used to produce feedstock.
	Electricity storage	Robust	High							Batteries universal but grid flexible resources vary with area's level of development
	Power sector CCS	Robust	High							Varies with local CO2 storage capacity, presence of legal framework, level of development and quality of public engagement
	Nuclear energy	Robust	High							Electricity market organisation, legal framework, standardisation & know-how, country's 'democratic fabric', institutional and technical capacity, and safety culture of public and private institutions

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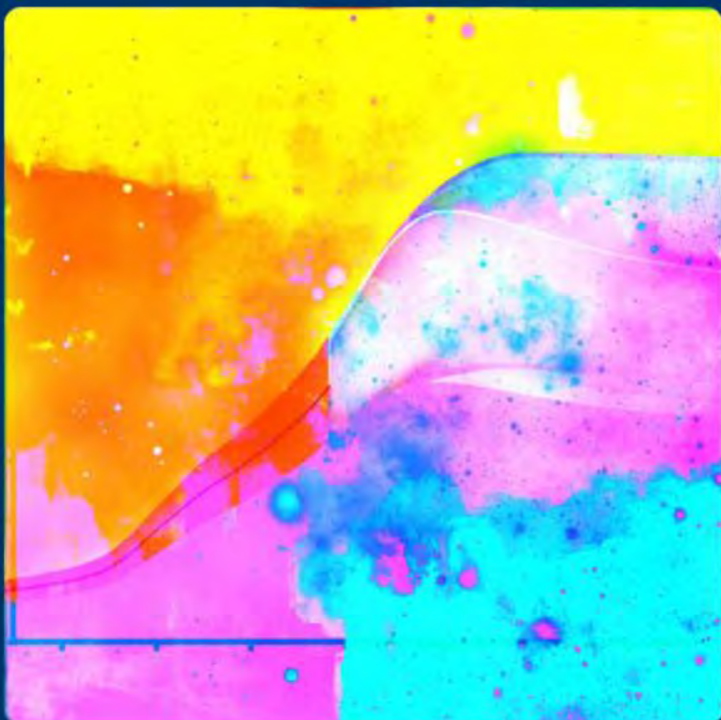
Concluding Remarks

Nuclear power plants have low lifecycle emission and low operating costs

However investments in nuclear power are characterized by:

- very large up-front investment costs
- significant technical, market, and regulatory risks

Without support from governments, investments in new nuclear power plants are currently generally not economically attractive



Thank you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System transitions consistent with 1.5°C warming

Rapid, far-reaching and unprecedented changes in all systems

- A range of technologies and behavioural changes
- Renewables supply 70-85% of electricity in 2050
- Coal declines steeply, ~zero in electricity by 2050
- Oil and especially gas persist longer – gas use rises by 2050 in some pathways
- Deep emissions cuts in transport and buildings
- Transitions in global and regional land use in all pathways, but their scale depends on the mitigation portfolio
- Urban and infrastructure system transitions imply changes in land and urban planning practices

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Carbon Dioxide Removal (CDR)

- All pathways that limit global warming to 1.5°C with limited or no overshoot use CDR
- The larger and longer the overshoot, the greater the reliance on CDR later in the century
- BECCS (bioenergy with carbon capture and storage) features in most scenarios but is avoided in a few
- CDR at large scale could have significant impacts on land, food and water security, ecosystems and biodiversity
- Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could improve biodiversity, soil quality, and local food security