2023 Report

The Production Gap

ONLINE APPENDIX

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Appendix A: Methodology for quantifying the fossil fuel production gap and additional details for Chapter 2

The analysis of the global fossil fuel production gap relies on the determination of two key elements. The first is the global level of future fossil fuel production implied by national governments' plans and projections. The second is the pathway of global fossil fuel production consistent with limiting warming to 1.5°C or 2°C, as modelled by the mitigation scenarios assembled for the Working Group III (WGIII) contribution to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6) (IPCC, 2022). This appendix details the methods for deriving these pathways and for estimating the production gap in terms of extraction-based emissions, energy, and physical units, and summarizes how the global production gap has changed compared to the 2021 analysis.

A.1 Estimating global production levels under the "government plans and projections" (GPP) pathway

The 2023 analysis of the GPP pathway is informed by the plans and projections of 19 of the 20 major producer countries profiled in Chapter 3 (data were not available for South Africa; new countries compared to the 2021 production gap assessment are denoted with an asterisk): Australia, Brazil, Canada, China, Colombia*, Germany, India, Indonesia, Kazakhstan, Kuwait*, Mexico, Nigeria*, Norway, Qatar*, the Russian Federation, Saudi Arabia, the United Arab Emirates (UAE), the United Kingdom of Great Britain and Northern Ireland (UK), and the United States of America (US). Together, these 19 countries accounted for around 80% of global fossil fuel production, on a primary energy basis,[1] in 2021. Among these 19 countries, government plans and projections are available for 9 producer countries for coal (accounting for 93% of global production in 2021 on an energy basis), 17 countries for oil (74% of global production), and 18 countries for gas (72% of global production) (IEA, 2023b).

Production data provided by each country's source documents differ in terms of the units (physical versus energy basis as well as actual units specified), the years covered between 2021 and 2050, and fuel subtypes included under liquids (i.e., crude oil only or also including condensate and/or natural gas liquids (NGLs)). Since the IPCC mitigation scenarios provide modelled outputs of coal, oil, and gas supply in units of exajoules (EJ) per year, all original country data are harmonized to units of EJ per year and, where needed, linearly interpolated between available years to derive a complete annual time series for 2021-2050[2]. Conversion factors between physical and energy units for each country and fuel were estimated using 2021 national production statistics from the IEA's World Energy Statistics and Balances (IEA, 2023b). This therefore assumes that coal and liquid subtypes (e.g., anthracite versus bituminous coal, or crude versus condensate oil) stay constant at 2021 ratios. For a given country and fuel for which projections end prior to 2050, values are extrapolated from the last year available based on that country and fuel's projected percent increase or decrease changes as modelled (at 5-year intervals between 2030–2050) under the IEA's Stated Policies Scenario (STEPS). This scenario reflects governments' stated climate policies as of September 2022, as modelled by the International Energy Agency (IEA) in their World Energy Outlook 2022 (IEA, 2022c).[3] Given that global production levels estimated under

[1] Primary energy represents the amount of energy that can be harvested directly from fossil fuels prior to any conversion.

[2] Annual time series are developed for all countries, where needed, so that their aggregate can be scaled up to derive the global GPP pathway with values in 2021, 2025, 2030, 2035, 2040, 2045, and 2050, corresponding to future years (except for 2025) for which their estimated global shares of production are available from the IEA STEPS. This set of years also overlaps with the IPCC model scenario outputs that occur at 5- or 10-year intervals for all scenarios, starting in 2010.

[3] For example, for Australia, where the government's projections end in 2035, the time series of coal, oil, and gas production are extended to 2040, 2045, and 2050 based on the percent changes modelled by IEA STEPS between these years.

our GPP pathway are higher than those under the STEPS (as shown in Figures 2.1–2.2), this is likely a conservative extrapolation approach.

Detailed sources, methods, and conversion factors for each country and fuel are provided in Table A.1 (see next page).

After aggregating the coal, oil, and gas production projections from these 19 countries, their combined production levels are then scaled up to a global estimate by assuming that their future shares of global coal, oil, and gas production follow the values under the IEA STEPS. The STEPS projects that production from these 19 countries continue to account for around 75–80% of global fossil fuel production (in energy terms) through 2050; detailed shares by fuels are shown in Table A.2.

Table A.2 *Estimated percentage shares of global coal, oil, and gas production (on an energy basis) by 19 major producer countries as modelled by the IEA's Stated Policies Scenario (IEA, 2022c).*

	2021	**2030**	**2035**	**2040**	**2045**	**2050**
Coal (Australia, China, Colombia, Germany, India, Indonesia, Kazakhstan, Russian Federation, US)	93%	91%	91%	90%	89%	89%
Oil (Australia, Brazil, Canada, China, Colombia, Germany, Indonesia, Kazakhstan, Kuwait, Mexico, Nigeria, Norway, Russian Federation, Saudi Arabia, UAE, UK, US)	74%	76%	74%	73%	73%	72%
Gas (Australia, Brazil, Canada, China, Colombia, Germany, Indonesia, Kazakhstan, Kuwait, Mexico, Nigeria, Norway, Qatar, Russian Federation, Saudi Arabia, UAE, UK, US)	72%	74%	73%	71%	70%	70%
Total (19 countries)	80%	80%	78%	77%	76%	75%

__Table A.1__ Data sources, methods, and conversion factors used to derive the "government plans and projections" (GPP) pathway from 19 key producer countries. Unit abbreviations are as follows: EJ = exajoules; Mtce = million tonnes of coal equivalent; Mt = million tonnes; Bcm = billion cubic meters; Bf = billion cubic feet; Qbtu = quadrillion British Thermal Units; Mtoe = million tonnes of oil equivalent; Mboe = million barrels of oil equivalent; Mb/d = million barrels per day. Conversion factors are rounded to 2 significant figures in this table.

Country	Fossil fuel	Data sources	Years of projections (annual timeseries unless otherwise specified)	Notes	Units of original data	Conversion factors from physical units to net EJ, where needed
Australia	Coal	Projections are from Australia's emissions projections 2022 (DCCEEW, 2022).	2025, 2030, 2035	Given footnote 35 stating the saleable coal production tends to average 80% of run-of-mine production, the projected black coal production is reduced by 20% for the production gap analysis. Projections are extended to 2040, 2045, and 2050 based on IEA STEPS.	Physical (Mt)	0.025 EJ per Mt
	Oil	Projections are from the Resources and Energy Quarterly, March 2023 (Department of Industry, Science and Resources, 2023).	2022–2028	Crude oil, condensate, and NGLs included. Projections are extended to 2030, 2035, 2040, 2045, and 2050 based on IEA STEPS.	Physical (Mb/d)	1.9 EJ/yr per Mb/d
	Gas	2020-2028 projections are from the Resources and Energy Quarterly, March 2023 (Department of Industry, Science and Resources, 2023); 2030 and 2035 projections for gas are estimated using LNG production projections provided in Australia's emissions projections 2022 (DCCEEW, 2022) combined with IEA statistics (IEA, 2023b).	2022–2028, 2030, 2035	To derive domestic gas production from LNG production projections, assume that: 1) gas liquefaction and export will scale with LNG production; 2) other domestic use and statistical differences will stay constant (a conservative assumption); and 3) other production- and export-related uses scale with LNG production increase. Projections are extended to 2040, 2045, and 2050 based on IEA STEPS.	Physical (Bcm)	0.034 EJ per Bcm
Brazil	Coal	No projections available.				
	Oil	2023–2032 projections are from the 10-Year Energy Expansion Plan 2032 (MME & EPE, 2023); 2033–2050 projections are from the National Energy Plan 2050 (MME & EPE, 2020).	2023–2050	Crude oil and condensate included.	Physical (Mb/d)	2.1 EJ/yr per Mb/d
	Gas			Brazil's reported gas production includes fractions that are re-injected, self-consumed, and flared. Following the IEA's World Energy Statistics and Balances approach, Brazil's gas production projections are reduced by 52% for all years. This is the average fraction of re-injection, self-consumption, and flaring forecasted for 2023–2027 by the Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP, n.d.).	Physical (Bcm)	0.036 EJ per Bcm
Canada	Coal	No projections available.				
	Oil	Projections are from Canada's Energy Future 2023 report (Canada Energy Regulator, 2023).	2020–2050	Crude oil, condensate, and NGLs included. The 2023 edition provided three scenarios: current measures, Canada net-zero, and global net-zero. Given that Canada's 2050 net-zero commitment is enshrined in law (Government of Canada, 2021), the "Canada net-zero"	Physical (Mb/d)	2.1 EJ/yr per Mb/d
	Gas			-	Physical (Bcm)	0.035 EJ per Bcm

					scenario is used in the production gap analysis.		
China	Coal	Coal production projections are not available and instead derived from consumption projections from the Sustainable Transition Scenario in CNPC's 2060 World and China Energy Outlook (2022 Edition) (CNPC ETRI, 2022) and the Coordinated Development Scenario from Sinopec's 2060 China Energy Outlook (Sinopec EDRI, 2022), along with import projections from the latter source.	2020–2060 (at 5-year intervals)	Average of two scenarios used in the production gap analysis.	China's fossil fuel production is dominated by several large SOEs (G20 Peer-review Team, 2016). Since no official government projections of fossil fuel production are publicly available for China, this report relies on outlooks provided by its SOEs, whose energy scenarios are now all aligned with China's 2060 carbon neutrality goal. The Economics and Technology Research Institute (ETRI) and the Economics and Development Research Institute (EDRI) are research subsidiary companies of two SOEs, CNPC and Sinopec, respectively. Both institutes are deeply involved in China's energy research and policymaking.	Physical (Mt)	0.023 EJ per Mt
	Oil	Projections are from the CNPC's 2060 World and China Energy Outlook, Sustainable Transition Scenario (CNPC ETRI, 2022).		Crude oil included. (2021 NGLs make up 0.1% of China's total liquids production.)		Physical (Mt)	0.042 EJ per Mt
	Gas			-		Physical (Bcm)	0.035 EJ per Bcm
Colombia	Coal	Projections are from the draft 2022–2052 National Energy Plan (UPME, 2023).	2022–2052	-	Colombia's draft 2022–2052 National Energy Plan, which was being finalized as of August 2023, presented several scenarios of coal, oil, and gas production based on varying estimates of reserves and resources, with Scenario "1" having the "greatest certainty" (UPME, 2023). These production scenarios are one of many elements that inform five different energy scenarios presented in the plan: Actualización; Modernization; Inflection; Disruption; and Transition. The "Actualización" ("updated") energy scenario featuring fossil fuel production Scenario 1 is used in the production gap analysis.	Energy (EJ)	-
	Oil			Crude oil, condensate, and NGLs included.			
	Gas			-			
Germany	Coal	Projections are from the "climate action plan scenario" from the 2020 Integrated National Energy and Climate Plan (BMWK, 2020).	2020–2030 (at 5-year intervals)	Assume lignite production reaches zero in 2038 according to Germany's Coal Phase-out Act.		Energy (Mtoe)	-
	Oil			Crude oil, condensate, and NGLs included.	Future global shares not available from IEA STEPS. Assume production after 2030 continues declining at the 2025–2030 annual decline rate of 3% and 7% for oil and gas, respectively.		
	Gas			-			

India	Coal	Projections are from India's Ministry of Coal (2022).	2022–2030	Projections are extended to 2035, 2040, 2045, and 2050 based on IEA STEPS.	Physical (Mt)	0.015 EJ per Mt
	Oil	No projections available.				
	Gas					
Indonesia	Coal	Projections are from the business-as-usual scenario of the Indonesia Energy Outlook 2021 by the government's Research Center for Industrial Processing and Energy (PPIPE) and Agency for the Assessment and Application of Technology (BPPT) (PPIPE & BPPT, 2021).	2022–2050	-	Physical (Mt)	0.022 EJ per Mt
	Oil				Energy (Mboe)	-
	Gas				Physical (Bcf)	1.3 EJ per Bcf
Kazakhstan	Coal	Projections are from the National Energy Report 2021 (NER2021) (KAZENERGY, 2021).	2020–2050 (at 5-year intervals)	-	Physical (Mt)	0.018 EJ per Mt
	Oil		2020–2050	Crude oil and condensate included.	Physical (Mt)	0.042 EJ per Mt
	Gas		2020–2024; 2025–2050 (at 5-year intervals)	The reported gas projections include fractions that are re-injected and used by producers, which is expected to account for around 50% of total gas production. These fractions are not included in the production gap analysis.	Physical (Bcm)	0.037 EJ per Bcm
Kuwait	Coal	No production.				
	Oil	Sources: 2025, 2035, and 2040 crude oil production is assumed to scale with the respective increases in crude oil production capacity targets (Gnana, 2022; KPC, n.d.).	2025, 2035, 2040	Scaling factors applied to 2021 crude oil production from IEA statistics. NGL production, which accounted for 6% of 2021 liquids production, is assumed to stay constant (a conservative estimate). Projections are extended to 2045 and 2050 based on IEA STEPS.	Physical (Mb/d)	2.1 EJ/yr per Mb/d
	Gas	2025 and 2035 gas production projections are from the 2019 Kuwait Energy Outlook published by the Kuwait Institute for Scientific Research (KISR, 2019, p. 48).	2025, 2035	Projections are extended to 2040, 2045, and 2050 based on IEA STEPS.	Physical (Bcm)	0.034 EJ per Bcm
Mexico	Coal	No projections available				
	Oil	Crude oil and petroleum products Outlook 2018–2032 ("Prospectiva de Petróleo Crudo y Petrolíferos 2018–2032") (SENER, 2018b, p. 60).	2022–2032	The Ministry of Energy has not updated longer-term oil and gas production projections published in 2018. Given that the 2018–2021 projected values do not match actual production, projections for 2022–2032 are derived by extending actual 2021 production values to 2032 using the annual scaling factors provided in the Outlooks. Values are then extended to 2035, 2040, 2045, and 2050 based on IEA STEPS. Gas projections likely include NGLs, based on comparisons to 2018–2020 actual production values reported by the government and the IEA (Sistema de Información de Hidrocaburos, 2021). Gas projections are	Physical (Mt)	0.043 EJ per Mt
	Gas	Natural Gas Outlook 2018–2032 ("Prospectiva de Gas Natural 2018–2032") (SENER, 2018a, p. 71).			Physical (Bcm)	0.036 EJ per Bcm

				therefore reduced by 20%, the fraction of NGLs between 2016–2021 reported by the government of Mexico (Sistema de Información de Hidrocaburos, 2021). This fraction is instead added to the production projections for liquids.			
Nigeria	Coal	No projections available.					
	Oil	Projections are from the Nigeria Agenda 2050 plan (Federal Government of Nigeria, 2023).	2020–2050 (at 5-year intervals)	Oil constituents unspecified. All liquids assumed.		Physical (Mb/d)	2.0 EJ/yr per Mb/d
	Gas			The reported gas projections include fractions that are re-injected and used by producers and flared, which accounted for around 25% of total production in 2020 and is expected to reduce to 20% by 2050 according to Nigeria Agenda 2050. These fractions are not included in the production gap analysis.		Physical (Bcf)	1.2 EJ per Bcf
Norway	Coal	No projections available.					
	Oil	2023–2027 projections are from the Norwegian Petroleum Directorate (2023); 2028–2050 projections are from the Norwegian Ministry of Finance (2021).	2023–2050	2028–2050 oil and gas projections are estimated from the reported total, assuming the liquids-to-gas ratio remains constant at average 2022–2027 values. Crude oil, condensate, and NGLs included.		Energy (Mboe)	-
	Gas					Physical (Bcm)	0.035 EJ per Bcm
Qatar	Coal	No production.					
	Oil	No projections available.					
	Gas	2027 gas production is estimated from the target increase in LNG production capacity (QatarEnergy, 2022) combined with IEA statistics (IEA, 2023b).	2027	See method notes for Australia-gas.	Values are extended to 2030, 2035, 2040, 2045, and 2050 based on IEA STEPS.	Energy	-
Russian Federation	Coal	Coal projections are from the Energy Strategy and the Development of the Coal Industry until 2035 (Government of the Russian Federation, 2020b, 2020a). Projections contain two scenarios, “High” and “Low”.	2025, 2030, 2035	-	Projections are extended to 2040, 2045, and 2050 based on IEA STEPS. Average of two scenarios used in the production gap analysis.	Physical (Mt)	0.024 EJ per Mt
	Oil	Projections are from the General Scheme for the Development of the Oil and Gas Industries until 2035 (Alifirova, 2021; Central Dispatch Department of the Fuel and Energy Complex, 2021). Projections contain two scenarios, “High” and “Low”.	2030, 2035	Crude oil and condensate included.		Physical (Mt)	0.042 EJ per Mt
	Gas		2035	-		Physical (Bcm)	0.034 EJ per Bcm
Saudi Arabia	Coal	No production.					
	Oil	Projections are from Saudi Aramco’s Base Prospectus 2021 (Aramco, 2021). Two scenarios — “levelling of demand” (LD) and “accelerated transition case” (ATC) — are provided.	2020–2050 (at 5-year intervals)	Crude oil, condensate, and NGLs included. Average of two scenarios used in the production gap analysis.		Physical (Mb/d)	2.0 EJ/yr per Mb/d
	Gas	Projections are from Saudi Aramco’s Base Prospectus 2021 (Aramco, 2021).	2019–2030	Projections are extended to 2035, 2040, 2045, and 2050 based on IEA STEPS.		Physical (Bcm)	0.034 EJ per Bcm

United Arab Emirates	Coal	No production.					
	Oil	2027 oil production is estimated by assuming that it will scale with ADNOC's target increase in oil production capacity (ADNOC, 2022; Di Paola & Ratcliffe, 2022).	2027	Oil constituents unspecified. All liquids assumed.	Projections are extended to 2030, 2035, 2040, 2045, and 2050 based on IEA STEPS.	Physical (mb/d)	2.1 EJ/yr per Mb/d
	Gas	2028 gas production is estimated from ADNOC's target increase in LNG production (ADNOC, 2022; Di Paola & Ratcliffe, 2022) combined with IEA statistics (IEA, 2023b).	2028	See method notes for Australia-gas.		Physical (Bcm)	0.034 EJ/yr per Bcm
United Kingdom of Great Britain and Northern Ireland	Coal	No projections available					
	Oil	Projections are from the North Sea Transition Authority's February 2023 oil and gas production projections (NSTA, 2023).	2023–2050	Crude oil and NGLs included.		Physical (Mb/d) and energy (Mtoe)	(physical units used due to better match with IEA statistics)
	Gas			-		Physical (Bcm) and energy (Mtoe)	
United States of America	Coal	EIA Annual Energy Outlook 2023 (US EIA, 2023),“reference” case	2022–2050	-		Physical (Mt) and energy (gross Qbtu)	0.022 EJ per Mt
	Oil			Crude oil, condensate, and NGLs included.		Physical (Mb/d) and energy (gross Qbtu)	1.8 EJ/yr per Mb/d
	Gas			-		Physical (Bcm) and gross energy (Qbtu)	0.034 EJ per Bcm

A.2 Deriving global fossil fuel production pathways consistent with limiting long-term warming to 1.5°C or 2°C

Pathways of global fossil fuel production that would be consistent with limiting warming to 1.5°C or 2°C are derived from the long-term mitigation scenarios compiled by the Working Group III (WGIII) Contribution to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2022). These scenarios provide cost-optimized pathways for decarbonizing the energy and land-use systems under different emissions pathways with varying probabilistic global warming outcomes. Prior assessments of the production gap relied on the mitigation scenarios compiled for the IPCC's Special Report on Global Warming of 1.5°C (SR1.5) (Huppmann et al., 2019; IPCC, 2018).

Scenarios categorized with the following temperature outcomes are selected: "C1" — which limit warming to 1.5°C in 2100 with a likelihood greater than 50%, with no or limited overshoot throughout the 21st century (and which also limit peak warming to 2°C throughout the 21st century with close to, or more than, 90% likelihood); and "C3" — which limit peak warming throughout the 21st century to 2°C with a likelihood greater than 67%.[4]

The raw timeseries data from all C1 and C3 scenarios, plus metadata, were downloaded from the AR6 scenarios database (release 1.1) maintained by the International Institute for Applied Systems Analysis (IIASA) (Byers et al., 2022).[5] Global annual fossil fuel production values are taken from the "Primary Energy|Coal", "Primary Energy|Oil", and "Primary Energy|Gas" model variables, which are provided in units of exajoules (EJ) per year and at 5- or 10-year intervals between 2010–2100 for all scenarios, and reported by 97% of 97 C1 scenarios and by 100% of 310 C3 scenarios in the database.

According to our knowledge of the COFFEE model and a 2013 survey ran by IIASA,[6] 10 of the 11 model families whose scenarios (406 out of 407 scenarios) are analysed here include non-energy use under their reporting of "Primary Energy|xx": AIM, COFFEE, GCAM, GEM-E3, IMAGE, MESSAGE, POLES, REMIND, TIAM, and WITCH. (It is unknown whether the EPPA model accounts for non-energy use, but there is only one C3 scenario from EPPA.) Thus, the "Primary Energy|xx" variable is interpreted here as representative of total supply for all intended uses (i.e. energy and non-energy uses). However, the level of detail to which non-energy/non-combustion uses are accounted for likely varies between different models. More consistent documentation and reporting of this issue, including by the "Final Energy| Non-Energy Use|xx" output variables (currently reported by 32–49% of the C1 and C3 scenarios), would aid analysis and interpretation. Consequently, in deriving the GPP and 1.5°C- or 2°C-consistent production pathways and in quantifying the resulting production gap, values are not adjusted to exclude non-energy uses and should be interpreted as production intended for all uses.

There are a wide variety of modelling approaches and assumptions underlying different C1 and C3 scenarios, which have important implications for the resulting fossil fuel reduction pathways (Achakulwisut et al., 2023). Consequently, a three-step scenario-selection approach has been developed and applied for the 2023 production gap analysis, similar to the AR6 filtering approach recently developed by Climate Analytics (Grant et al., 2023). (See Box 2.1 in Chapter 2 for carbon dioxide removal (CDR) and carbon capture and storage (CCS) terminology.)

First, the majority of the AR6-assessed scenarios rely on extensive CDR, mostly through bioenergy combined with carbon capture and storage (BECCS) and afforestation/reforestation (A/R) (Creutzig et al., 2021; Fuss et al., 2018). Based on a systematic literature review, Fuss et al. (2018) estimated upper "sustainable" limits of 5 billion tonnes of CO_2 per year ($GtCO_2$/yr) for BECCS and 3.6 $GtCO_2$/yr for A/R by mid-century, due to their negative side-effects such as competition for land and loss of biodiversity. Thus, C1 and C3 scenarios relying on BECCS and A/R exceeding these levels were excluded.

Second, most IAMs do not adequately capture real-world constraints on regional CO_2 storage potential and injection rates, which influence model reliance on CCS coupled to fossil fuel use (fossil-CCS), BECCS, and direct air carbon capture and storage (DACCS) (Grant et al., 2022). Therefore, a mid-century limit of 8.6 $GtCO_2$/yr for total CCS has also been imposed, based on the "investable" CCS potential as estimated by Grant et al. (2022) when accounting for real-world financial, contractual, and institutional constraints.

Finally, scenarios have been selected only if they feature immediate rather than delayed climate action,[7] and if they are compatible with achieving net-zero GHG emissions by 2100. Reaching net-zero GHGs will lead to declining long-term temperatures, which can limit the long-term impacts of climate change (IPCC, 2023).

The selected 36 C1 scenarios are classified as "1.5°C-consistent" and the 64 C3 scenarios as "2°C-consistent", in keeping with previous editions of the Production Gap Report (PGR) to define pathways consistent with two different temperature outcomes (SEI et al., 2019, 2020, 2021). Table A.3 summarizes the scenario-filtering approach of the pathways selected as 1.5°C- or 2°C-consistent in this report. The full list of models and scenarios used in this report are shown in Table A.4.

Table A.3 *Classification of pathways used in the 2023 Production Gap Report (PGR). The "pathway class" and "pathway selection criteria and description" definitions are drawn from Table 2.1 of the IPCC SR1.5 Chapter 2. The same additional CDR constraints are applied to each pathway group.*

AR6 category	Step 1: Avoid excessive CDR reliance	Step 2: Avoid excessive CCS reliance	Step 3: Ensure immediate action and consistency with net-zero GHG emissions	Number of selected scenarios	PGR pathway classification
C1: limit warming to 1.5°C (>50%) with no or limited overshoot	Pathways in which the average 2040-2060 BECCS values ("Carbon Sequestration|CCS|Biomass")[a] are lower than 5.0 $GtCO_2$/yr, and the average 2040-2060 afforestation values[b] are lower than 3.6 $GtCO_2$/yr.	Pathways in which the average 2040-2060 CCS values ("Carbon Sequestration|CCS")[c] are lower than 8.6 $GtCO_2$/yr.	1. Does not feature delayed action (i.e. "Policy_category" P3a, P3b, and P3c excluded). 2. Achieves (set "a") or is on track to achieve (set "b")[d] net-zero GHG emissions by 2100. (To apply this step, the median pathway for "AR6 climate diagnostics|Infilled|Emissions|Kyoto Gases (AR6-GWP100)" from set "a" is first calculated. C1 or C3 scenarios in set "b" with 2030 and 2050 values lower than the respective median values are added to those in set "a". This step is applied last so that the median pathways are sufficiently stringent after all other constraints are applied.)	36 (out of 97)	"1.5°C-consistent"
C3: limit warming to 2°C (>67%)				64 (out of 310)	"2°C-consistent"

[a] Pathways with missing values for this variable are excluded.
[b] Given the limited variable reporting, to increase the number of scenarios that can be analysed, the variable "Carbon Sequestration|Land Use|Afforestation" is used if reported. If not, "Carbon Sequestration|Land Use" is used as a proxy. If both of these variables are not report, "Emissions|CO2|AFOLU" is used as a proxy.
[c] i.e. representative of total CCS coupled to fossil fuels, bioenergy, and direct air capture.
[d] While the scenarios in set "b" do not explicitly achieve net-zero GHG emissions by 2100, they can provide valuable information. Many of them were produced as part of the ENGAGE project, which explored how to avoid overshoot of the carbon budget through rapid action (Riahi et al., 2021). They therefore represent a precautionary approach to limiting warming to 1.5°C or 2°C with particularly rapid action in the near-term. The selected "b" pathways exhibit rapid reductions towards net-zero, and could reach net-zero GHGs in the second half of the century under different pathway design choices after peak warming.

Table A.4 *Full list of models and scenarios identified as 1.5°C- or 2°C-consistent in this report. An asterisk denotes three C1 scenarios that do not rely on CDR beyond their cumulative "feasible potential" based on expert consensus (Grant et al., 2021) (see Section 2.4).*

[4] Although the "IMP-Neg" scenario ("EN_NPi2020_400f_lowBECC") from the COFFEE 1.1 model is technically categorized as a C3 in the database, it is categorized as a C2 scenario here, following the IPCC AR6 WGIII Chapter 3, Table 3.2 (i.e. "The warming profile of Neg peaks around 2060 and declines to below 1.5 °C (50% likelihood) shortly after 2100. Whilst technically classified as a C3, it strongly exhibits the characteristics of C2 high overshoot scenarios").
[5] Available at https://data.ece.iiasa.ac.at/ar6/
[6] Source: Volker Krey, IIASA, personal communication to Roberto Schaeffer, October 27, 2019.
[7] Some scenarios in the AR6 database are designed to follow current policies or NDCs out to 2030 before starting globally coordinated mitigation. These scenarios therefore do not truly explore cost-effective pathways to limit warming to a given temperature with action starting as soon as possible. Such "delayed action" scenarios are therefore excluded, leaving only scenarios that give the models full flexibility on the timing and extent of reductions in fossil fuel production.

PGR classification	Model	Scenario	AR6 category
1.5C-consistent	COFFEE 1.1	EN_NPi2020_400	C1
1.5C-consistent	MESSAGE-GLOBIOM 1.0	SSP2-19	C1
1.5C-consistent	MESSAGEix-GLOBIOM 1.0	LowEnergyDemand_1.3_IPCC	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_450	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_500	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_COV	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR1p	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR2p	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR3p	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR4p	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	NGFS2_Divergent Net Zero Policies	C1
1.5C-consistent	MESSAGEix-GLOBIOM_1.1	NGFS2_Net-Zero 2050	C1
1.5C-consistent	POLES EMF33	EMF33_WB2C_nofuel	C1
1.5C-consistent	REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50	C1
1.5C-consistent	REMIND 2.1	R2p1_SSP1-PkBudg900	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-fullCDR	C1
1.5C-consistent*	REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-minCDR	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_200f	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_300f	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400f	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_500	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Divergent Net Zero Policies	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-95th	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-median	C1
1.5C-consistent*	REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000	C1
1.5C-consistent	REMIND-MAgPIE 2.1-4.2	SusDev_SSP1-PkBudg900	C1
1.5C-consistent*	REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_ HighRE_Budg900	C1
1.5C-consistent	WITCH 5.0	EN_NPi2020_400f	C1
1.5C-consistent	WITCH 5.0	EN_NPi2020_450	C1
1.5C-consistent	WITCH 5.0	EN_NPi2020_450f	C1
1.5C-consistent	WITCH 5.0	EN_NPi2020_500	C1
1.5C-consistent	WITCH 5.0	EN_NPi2020_500f	C1
1.5C-consistent	WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_1000	C1
1.5C-consistent	WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_400	C1
2C-consistent	COFFEE 1.1	EN_NPi2020_400_lowBECCS	C3
2C-consistent	IMAGE 3.0.1	SSP1-26	C3
2C-consistent	IMAGE 3.0.1	SSP4-26	C3
2C-consistent	IMAGE 3.2	SSP1_SPA1_26I_RE	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000_DR1p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000_DR2p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000_DR3p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000_DR4p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f_DR1p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f_DR2p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f_DR3p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_1000f_DR4p	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_800	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_800_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_800f	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_800f_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_900	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_900_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_900f	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	EN_NPi2020_900f_COV	C3
2C-consistent	MESSAGEix-GLOBIOM_1.1	NGFS2_Below 2°C	C3
2C-consistent	MESSAGEix-GLOBIOM_1.2	COV_GreenPush_1000	C3
2C-consistent	MESSAGEix-GLOBIOM_1.2	COV_NoPolicyNoCOVID_1000	C3
2C-consistent	MESSAGEix-GLOBIOM_1.2	COV_Restore_1000	C3
2C-consistent	MESSAGEix-GLOBIOM_1.2	COV_SelfReliance_1000	C3
2C-consistent	MESSAGEix-GLOBIOM_1.2	COV_SmartUse_1000	C3

PGR classification	Model	Scenario	AR6 category
2C-consistent	POLES EMF33	EMF33_Med2C_nobeccs	C3
2C-consistent	POLES EMF33	EMF33_Med2C_none	C3
2C-consistent	REMIND 2.1	LeastTotalCost_CBA_brkLR15_SSP2_P50	C3
2C-consistent	REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP2_P50	C3
2C-consistent	REMIND-MAgPIE 1.5	SSP2-26	C3
2C-consistent	REMIND-MAgPIE 1.7-3.0	EMF33_WB2C_cost100	C3
2C-consistent	REMIND-MAgPIE 1.7-3.0	EMF33_WB2C_nobeccs	C3
2C-consistent	REMIND-MAgPIE 1.7-3.0	EMF33_WB2C_none	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_700	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_700f	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_800	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	EN_NPi2020_800f	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Below 2°C - IPD-95th	C3
2C-consistent	REMIND-MAgPIE 2.1-4.2	NGFS2_Below 2°C - IPD-median	C3
2C-consistent	REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_ HighRE_Budg1100	C3
2C-consistent	REMIND-Transport 2.1	Transport_Budg1100_Conv	C3
2C-consistent	REMIND-Transport 2.1	Transport_Budg1100_Conv-LowD	C3
2C-consistent	REMIND-Transport 2.1	Transport_Budg1100_ElecPush	C3
2C-consistent	REMIND-Transport 2.1	Transport_Budg1100_ElecPush-LowD	C3
2C-consistent	REMIND-Transport 2.1	Transport_Budg1100_H2Push	C3
2C-consistent	TIAM-ECN 1.1	EN_NPi2020_1000f	C3
2C-consistent	TIAM-ECN 1.1	EN_NPi2020_1000f_COV	C3
2C-consistent	TIAM-ECN 1.1	EN_NPi2020_900f	C3
2C-consistent	WITCH 5.0	CO_2Deg2020	C3
2C-consistent	WITCH 5.0	EN_NPi2020_1000	C3
2C-consistent	WITCH 5.0	EN_NPi2020_1000f	C3
2C-consistent	WITCH 5.0	EN_NPi2020_600	C3
2C-consistent	WITCH 5.0	EN_NPi2020_600f	C3
2C-consistent	WITCH 5.0	EN_NPi2020_700	C3
2C-consistent	WITCH 5.0	EN_NPi2020_700f	C3
2C-consistent	WITCH 5.0	EN_NPi2020_800	C3
2C-consistent	WITCH 5.0	EN_NPi2020_800f	C3
2C-consistent	WITCH 5.0	EN_NPi2020_900	C3
2C-consistent	WITCH 5.0	EN_NPi2020_900f	C3

A.3 Estimating the global production gap in terms of extraction-based GHG emissions, energy, and physical units

Quantities of fossil fuel production — and thus the size of the production gap — can be expressed in three different units: physical units, energy units, or units of extraction-based emissions. Figure 2.2 shows the production gaps in terms of its component fuels in energy (primary axis) and physical (secondary axis) units. Quantifying the coal, oil, and gas production gaps in energy terms (i.e., exajoules per year) allows for a direct comparison to the modelled outputs of primary energy supply as reported in the AR6-assessed mitigation scenarios, as well as by other parties, such as the IEA in their World Energy Outlooks. In order to translate the gap from energy to physical terms, a constant conversion factor for each fuel is applied to all future years, derived from 2021 global production statistics from the IEA's World Energy Statistics and Balances (IEA, 2023b): 0.022 exajoules per million tonnes for coal; 1.9 exajoules per year per million barrels per day for oil (crude oil plus natural gas liquids (NGLs)); and 0.035 exajoules per billion cubic meters for gas.

In Figure 2.1, the fossil fuels are aggregated to represent the production gap in terms of extraction-based emissions, an accounting method that reflects the amount of GHG emissions expected to be released from production activities and from the combustion of extracted coal, oil, and gas (Davis et al., 2011). Here, top-down emission factors for each fuel are calculated as the ratio of the global annual sum of GHG emissions from fuel production and combustion to the global annual sum of fuel production based on IEA statistics for 2016–2020 (the most recent five years of data available) (IEA, 2023b, 2023a). These factors account for total GHG emissions from fuel combustion plus CO_2, CH_4, and N_2O emissions from production processes; the IEA uses 100-year Global Warming Potentials (GWPs) from the IPCC's Fourth Assessment Report to calculate CO_2-

equivalent emissions. The following emission factors are applied to all five pathways in Figure 2.1 for all years (2021–2050): 0.098 billion tonnes of carbon dioxide equivalent ($GtCO_2eq$) per exajoules (EJ) for coal, 0.069 for oil, and 0.058 for gas. These values all assume, implicitly, that some coal, oil, and gas are not combusted, according to IEA's estimates of what fossil fuels go to other, non-energy uses, such as the use of metallurgical coal as a feedstock for making iron, or the use of oil as a feedstock for making petrochemicals.

This top-down approach to convert each fossil fuel production pathway from energy-based to extraction-based units has two main limitations:

1) It implicitly assumes that globally averaged emission rates per unit of coal, oil, and gas produced remains the same in all future years, though this could vary as coal and liquid subtype ratios (e.g., anthracite versus bituminous) change.
2) Only a limited number of AR6-assessed scenarios report what fraction of coal, oil, or gas primary energy goes towards non-combustion uses in future years. The approach applied here implicitly assumes that these fractions remain constant at recent levels (i.e., 2016–2020, as specified above) for each fuel for all future years.

However, since the same factors are applied to all global pathways in Figure 2.1 for each given fuel, these limitations do not affect the quantification of the total production gap itself.

For a detailed discussion of other methodological approaches for estimating extraction-based emissions, please refer to Appendix B of the 2019 Production Gap Report (SEI et al., 2019).

A.4 Changes in the production gap compared to the 2021 assessment

Compared to the 2021 assessment, both the GPP and low-carbon pathways have changed in this year's assessment. As briefly discussed in Chapter 2, it is challenging to directly compare the 2023 production gap to the 2021 assessment for several reasons:

1. This year's assessment of global GPP pathways is more comprehensive, since it is informed by the plans and projections of four additional countries and now extends out to 2050 compared to 2040 previously (see Tables A.1–A.2). The 2021 assessment relied on the plans and projections of 15 countries. On an energy basis, these 15 producer countries accounted for 75% of global fossil fuel production in 2020 — around 90% for coal (8 countries), 70% for oil (14 countries), and 65% for gas (13 countries). The source documents used in the 2021 assessment can be found in Table B.1 of the 2021 report's Online Appendix B.
2. The lack of regular, standardized reporting of fossil fuel production projections by countries is another confounding factor. For example, some governments issue long-term national energy outlooks annually, which enables a direct year-to-year comparison of their projections. However, many countries do not. In some cases, countries provide projections in different government documents and/or create new scenarios, which makes comparison over time difficult.
3. The mitigation scenarios assessed in AR6 represent a largely different ensemble and are therefore not directly comparable to those assessed in the SR1.5, which were used in previous production gap analyses. This year, additional scenario-selection criteria (steps 2–3) have also been applied (see Table A.3). These have implications for the resulting median 1.5°C- and 2°C-consistent pathways, especially for the latter when scenarios designed to feature delayed action are excluded.
4. The total production gap shown in Figure 2.1 is aggregated in terms of extraction-based emissions in units of $GtCO_2eq$/yr), which account for GHG emissions from production activities as well as from the combustion of extracted fuels. In prior assessments, the total production gap was quantified in units of $GtCO_2$/yr, representing the expected emissions from the combustion of extracted fuels only.

5. Further research on the additional countries currently modelled in the “rest-of-the-world” bloc in the global GPP pathway (see Figure 2.3) — though difficult since government plans and projections for future fossil fuel production are not readily available from these countries — would help constrain changes and uncertainties in the GPP pathways of each report.

Given these considerations, only broad comparisons are drawn below for changes in the production gap with respect to the 1.5°C-consistent pathway and in Figures A.1–A.2.

Compared with the 2021 assessment, the global production gap with respect to the median 1.5°C-consistent pathway for coal is wider by 2030 and remains roughly the same for 2040. Almost half of the increase in the 2030 gap is due to an increase in the underlying government projections (primarily those of China, and partly of India and Indonesia). The remaining increase can be explained by a reduction in the modelled level of coal supply under the median 1.5°C-consistent pathway due to a faster coal phase-out in the selected AR6 versus SR1.5 mitigation scenarios. For 2040, the coal production gap has remained almost the same due to almost equivalent reductions in both the GPP and median 1.5°C-consistent levels. Decreases in the underlying government projections for 2040 are observed for China and the US.

For oil, the production gap in the 2023 assessment is narrower in both 2030 and 2040 under the 2023 assessment. This is mainly due to the median 1.5°C-consistent pathway allowing a slightly slower oil decline, which is balanced by a much faster phase-out for coal and a slightly faster near-term reduction for gas under 1.5°C-consistent pathways.

Meanwhile, the gas production gap widens for 2030 and slightly decreases for 2040. The small increase in the 2030 gap is mainly because of the larger near-term gas reduction modelled in the median 1.5°C-consistent pathway. The small decline for 2040 is mainly due to a decrease in the underlying government projections (primarily Saudi Arabia and Canada; however, the former reflects a change in the underlying source document and the latter reflects a change in the available scenarios). In sum, these changes largely cancel each other out to leave the overall production gap largely unchanged for both 2030 and 2040 (i.e. differing by no more than 1–3 $GtCO_2eq/yr$ when the 2021 gap analysis is re-calculated in units of $GtCO_2eq/yr$).

Nevertheless, since the purpose of our Production Gap Report series is to track the discrepancy between global coal, oil, and gas levels implied by governments’ plans and projections and those consistent with the Paris Agreement’s goals, Figures A.1–A.2 show how the size of the production gap for the GPP relative to the 1.5°C-consistent pathways have changed between the 2021 and 2023 assessments.

Figure A.1 *Global fossil fuel production under the GPP and 1.5°C-consistent pathways estimated in the 2021 and 2023 Production Gap Reports, denominated in extraction-based GHG emissions.*

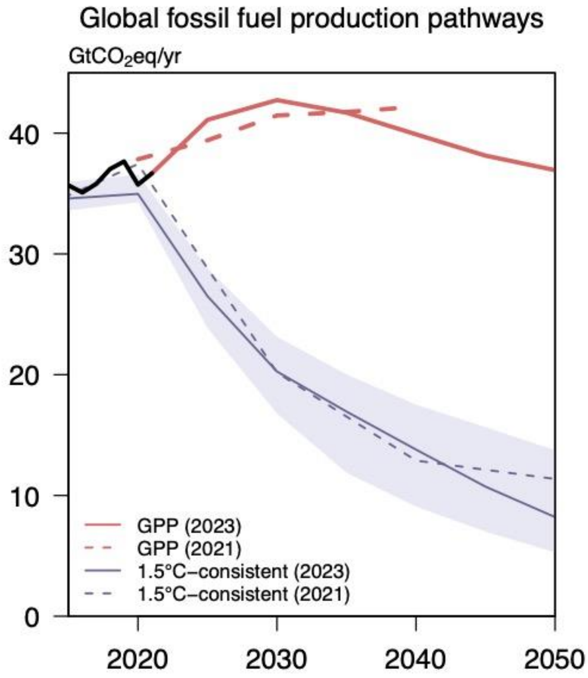
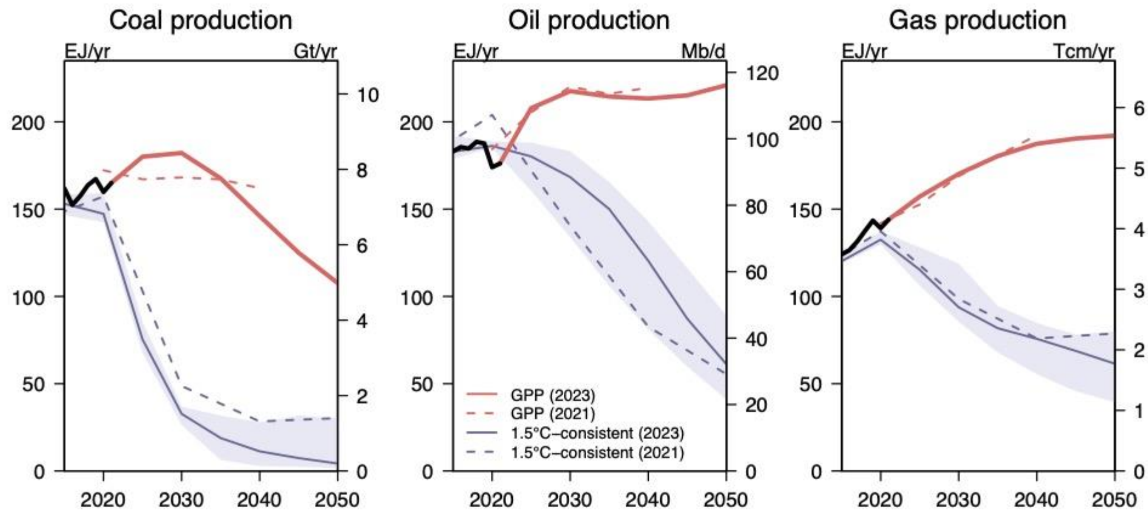


Figure A.2 *Global coal, oil, and gas production under the GPP and 1.5°C-consistent pathways estimated in the 2021 and 2023 Production Gap Reports, denominated in energy units (exajoules per year). Physical units are displayed as secondary axes: billion tonnes per year for coal, million barrels per day for oil, and trillion cubic meters per year for gas.*



A.5 Additional details for Section 2.3

Table A.5 *Additional variables and scenarios not shown in Table 2.2. Values are rounded to two significant figures.*

	2030						2040						2050					
Variable	**Median pathway**	**Median low-CDR pathway**	**IMP-LD**	**IMP-Ren**	**IMP-SP**	**IEA NZE**	**Median pathway**	**Median low-CDR pathway**	**IMP-LD**	**IMP-Ren**	**IMP-SP**	**IEA NZE**	**Median pathway**	**Median low-CDR pathway**	**IMP-LD**	**IMP-Ren**	**IMP-SP**	**IEA NZE**
Percent change relative to 2020																		
Coal production	-78%	-83%	-75%	-90%	-76%	-39%	-92%	-99%	-90%	-99%	-99%	-83%	-97%	-99%	-98%	-99%	-99%	-90%
Oil production	-10%	-2%	-47%	-3%	-4%	-14%	-35%	-37%	-75%	-47%	-21%	-54%	-67%	-76%	-90%	-77%	-51%	-76%
Gas production	-29%	-19%	-47%	-33%	-2%	-15%	-43%	-57%	-75%	-58%	-38%	-62%	-54%	-77%	-85%	-78%	-68%	-77%
Combined oil and gas production[a]	-18%	-9%	-47%	-15%	-4%	-15%	-38%	-46%	-75%	-52%	-28%	-58%	-62%	-77%	-88%	-77%	-58%	-76%
Non-biomass renewable energy supply	220%	240%	250%	320%	230%	210%	490%	600%	410%	740%	510%	590%	690%	910%	500%	1000%	700%	840%
Energy CO_2 emissions	-47%	-40%	No data	-50%	-34%	-31%	-70%	-74%	No data	-79%	-60%	-81%	-89%	-93%	No data	-95%	-79%	-100%
Energy CH_4 emissions	-63%	-65%	No data	-70%	-58%	-73%	-79%	-85%	No data	-87%	-79%	-93%	-90%	-95%	No data	-95%	-91%	-98%
CH_4 emissions from all sources[a]	-37%	-39%	-34%	-36%	-42%	No data	-49%	-50%	-48%	-46%	-62%	No data	-58%	-58%	-58%	-51%	-77%	No data
Annual value																		
Percent (%) electricity generation from non-biomass renewables[a]	75%	79%	No data	86%	78%	56%	81%	89%	No data	90%	87%	81%	88%	89%	No data	90%	89%	85%
Fossil-CCS ($GtCO_2$/yr)	0.51	0.41	0	0.41	0.24	0.45	1.6	0.70	0	0.93	0.62	1.3	2.1	0.56	0	0.56	0.49	1.6
BECCS ($GtCO_2$/yr)	0.31	0.22	0	0.31	0.14	0.067	1.6	0.46	0	1.44	0.46	0.47	2.8	0.91	0	2.4	0.91	0.78
DACCS ($GtCO_2$/yr)[a]	0.0029	0	0	0.0040	0	0.069	0.043	0	0	0.0045	0	0.30	0.25	0	0	0.0050	0	0.62
Land use sequestration ($GtCO_2$/yr)	0.73	0.23	1.3	0.20	0.28	N/A[b]	1.4	0.30	2.2	0.24	0.52	N/A[b]	2.2	0.23	3.2	0.22	0.79	N/A[b]

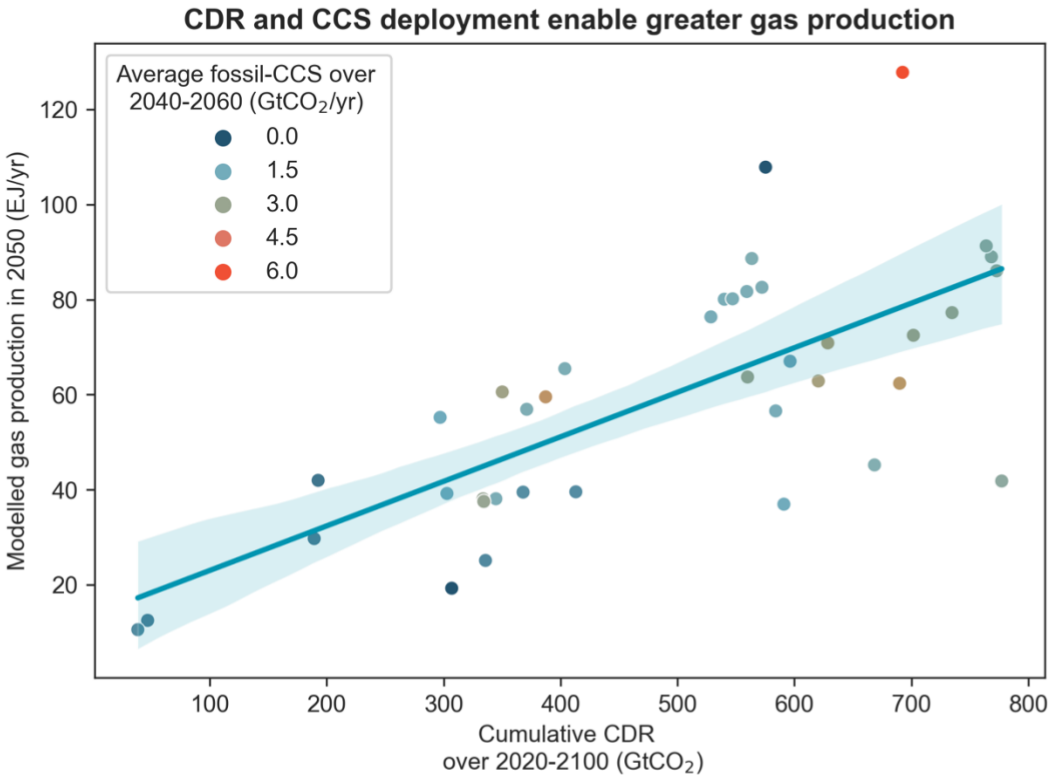
[a] Not plotted in Figure 2.4.

[b] The IEA NZE does not model land-use systems, focusing only on energy. As such, it does not incorporate carbon sequestration via conventional land-based methods.

A.6 Additional details for Section 2.4

An analysis of the IPCC AR6-assessed C1 scenarios by Achakulwisut et al. (2023) found that higher-gas pathways are typically associated with higher reliance on fossil-CCS and CDR. For example, as illustrated in Figure A.3, this relationship can be seen for the modelled values of annual global gas supply in 2050 across the 36 C1 scenarios selected within the 1.5°C-consistent set in this report.

Figure A.3 *Modelled gas production in 2050 (exajoules per year) versus cumulative 2020–2100 carbon dioxide removal (CDR; billion tonnes of CO_2) in the selected 36 C1 scenarios. Symbol colours reflect the annual average 2040–2060 level of fossil-CCS (billion tonnes of CO_2 per year).*



A.7 Additional details for Figure 2.5

In Figure 2.5, the trajectories of future coal, oil, and gas production derived from governments' plans and projections from the 19 countries analysed in the production gap analysis are aggregated into different groups according to two indicators: (1) a country's income level; and (2) a country's relative economic dependence on fossil fuel production. While simplified, these two indicators nonetheless capture the broad challenge that an equitable global transition will require, and recognizes that countries' transitional challenges differ widely depending on their level of dependence on fossil fuel production and their capacity to diversify and support a transition, as explored in detail in Chapter 4 of the 2020 Production Gap Report (SEI et al., 2020).

As shown in Table A.6, countries are assigned an income level based on their 2022–2023 World Bank classification (World Bank, 2022). Relative economic dependence for coal follows the IEA's Coal Transition Exposure Index categorization, which is based on the share of coal in national goods exports and the degree of coal self-sufficiency (IEA, 2022, table 5.1). For oil and gas, relative dependence is categorized based on the percentage of national gross domestic product (GDP) from the oil and gas sector based on data from Calverley

& Anderson (2022, table 7) for 88 oil- and gas-producing countries. (Some researchers have suggested that gross national income (GNI) might provide a better metric given that a non-trivial share of fossil fuel revenues could be expatriated in some countries. However, recent data on fossil fuel rents as % of GNI are not readily available for all countries.) In this analysis, countries are grouped into "low" (less than 25th percentile; i.e. 3% or lower), "medium low" (25th–50th percentile; 4–13%), "medium high" (50th–75th percentile; 14–36%), "high" (75th–95th percentile; 37–60%), or "very high" (more than 95th percentile; 61% or higher) dependence based on how their values compare to all other countries for a given fuel. This is a simplistic approach that only represents the dependence of a given country relative to other producer countries for each fuel. For a summary of approaches to evaluating the extractives (including oil and gas) dependence of countries, see Hailu and Kipgen (2017).

Table A.6 *Categorization of income level and relative economic dependence on fossil fuel production for the 19 countries whose plans and projections are aggregated in Figure 2.5.*

	Indicator for transition capacity	**Indicators for economic dependence**		
Country	**Income level**	**Coal economic dependence**	**Percent share of GDP from oil and gas production (%)**	**Assigned level of oil and gas dependence**
Australia	High	Very high	3%	Low
Brazil	Upper-middle	No data	10%	Medium low
Canada	High	Medium low	10%	Medium low
China	Upper-middle	Medium high	3%	Low
Colombia	Upper-middle	Very high	5%	Medium low
Germany	High	Medium low	No data	No data
India	Lower-middle	Medium high	2%	Low
Indonesia	Lower-middle	Very high	12%	Medium low
Kazakhstan	Upper-middle	High	13%	Medium low
Kuwait	High	N/A	40%	High
Mexico	Upper-middle	No data	04%	Low
Nigeria	Lower-middle	No data	10%	Medium low
Norway	High	No data	14%	Medium high
Qatar	High	N/A	40%	High
Russia	Upper-middle	Medium high	19%	Medium high
Saudi Arabia	High	N/A	50%	High
South Africa	Upper-middle	High	No data	No data
UAE	High	N/A	27%	Medium high
UK	High	No data	1%	Low
US	High	High	8%	Medium low

Appendix B. Data sources and details for Chapter 3

In Figure 3.1, data on 2021 annual primary fuel production for coal, oil, and gas for each country are downloaded from the IEA's World Energy Balances and Statistics (2022 edition) (IEA, 2023b). The globally averaged, fuel-specific, extraction-based GHG emission factors described in Section A.3 above are then applied to a given country's fossil fuel production shown in the stacked bar charts. This is a simplified approach, given limited data on country-specific GHG emissions from fossil fuel production activities. A more accurate quantification would account for the variations in the GHG-emissions-intensity of fossil fuel production among countries.

In Table 3.1, data on 2021 annual production, import, and export of primary fossil fuels are downloaded from the IEA's World Energy Balances and Statistics (2022 edition) (IEA, 2023b). For some countries in which 2021 oil import and export data are missing from this dataset (China, India, Indonesia, Kazakhstan, Kuwait, Nigeria, Qatar, Russian Federation, Saudi Arabia, South Africa, the UAE), data from the IEA's World Oil Statistics (2023 edition) are used (IEA, 2023c). The net supply for domestic consumption for each country is calculated as the sum of production + import – export without accounting for other transfers or statistical differences.

Table B.1 Data and sources for the infographics shown in each country profile.

	COAL PRODUCTION			OIL PRODUCTION			GAS PRODUCTION			Indicators for economic dependence			Indicator for transition capacity
Country	**Global ranking[a]**	**Share of global production (%)[a]**	**Net trade status[b]**	**Global ranking[a]**	**Share of global production (%)[a]**	**Net trade status[b]**	**Global ranking[a]**	**Share of global production (%)[a]**	**Net trade status[b]**	**Share of direct employment (coal miners per 1000 workers)[c]**	**Coal economic dependence[d]**	**% share of GDP from oil and gas production[e]**	**World Bank Income level[f]**
Australia	5	6.9	Exporter	30	0.4	Importer	7	3.6	Exporter	3.8	Very high	3%	HI
Brazil	29	0.1	Importer	8	3.7	Exporter	27	0.6	Importer	No data	No data	10%	UMI
Canada	13	0.6	Exporter	4	5.1	Exporter	5	4.6	Exporter	0.4	Medium low	10%	HI
China	1	52.7	Importer	6	4.7	Importer	4	4.9	Importer	3.9	Medium high	3%	UMI
Colombia	10	0.9	Exporter	21	0.9	Exporter	40	0.3	Importer	1.7	Very high	5%	UMI
Germany	12	0.7	Importer	57	0.0	Importer	48	0.1	Importer	0.3	Medium low	No data	HI
India	2	7.6	Importer	24	0.8	Importer	22	0.8	Importer	0.9	Medium high	2%	LMI
Indonesia	3	7.6	Exporter	25	0.8	Importer	14	1.5	Exporter	1.8	Very high	12%	LMI
Kazakhstan	9	1.0	Exporter	13	2.1	Exporter	24	0.7	Exporter	3.2	High	13%	UMI
Kuwait	N/A	N/A	N/A	10	3.2	Exporter	30	0.5	Importer	N/A	N/A	40%	HI
Mexico	23	0.1	Importer	11	2.3	Exporter	23	0.8	Importer	No data	No data	4%	UMI
Nigeria	60	0.0	N/A	15	1.7	Exporter	17	1.1	Exporter	No data	No data	10%	LMI
Norway	55	0.0	Importer	12	2.3	Exporter	8	2.9	Exporter	No data	No data	14%	HI
Qatar	N/A	N/A	N/A	14	1.8	Exporter	6	4.4	Exporter	N/A	N/A	40%	HI
Russian Federation	6	6.4	Exporter	2	12.6	Exporter	2	18.9	Exporter	2.0	Medium high	19%	UMI
Saudi Arabia	N/A	N/A	N/A	3	12.4	Exporter	10	2.4	N/A	N/A	N/A	50%	HI
South Africa	7	3.3	Exporter	84	0.0	Importer	63	0.0	Importer	3.3	High	No data	UMI
UAE	N/A	N/A	Importer	7	4.1	Exporter	15	1.3	Importer	N/A	N/A	27%	HI
UK	42	0.0	Importer	20	1.0	Importer	20	0.8	Importer	0.0	No data	1%	HI
US	4	7.1	Exporter	1	17.2	Importer	1	23.2	Exporter	0.3	High	8%	HI

[a] 2021 estimate (IEA, 2023b).
[b] 2017-2021 average (IEA, 2023b).
[c] 2019 estimate for all countries except India (2017). Sources: World Bank (2021, p. 36) and International Labour Organization (2019).
[d] Based on IEA's Coal Transition Exposure Index (IEA, 2022b).
[e] Data from Calverley & Anderson (2022, tbl. 7).
[f] 2022-2023 classification: HI = High Income; UMI = Upper Middle Income; and LMI = Lower Middle Income (World Bank, 2022).

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