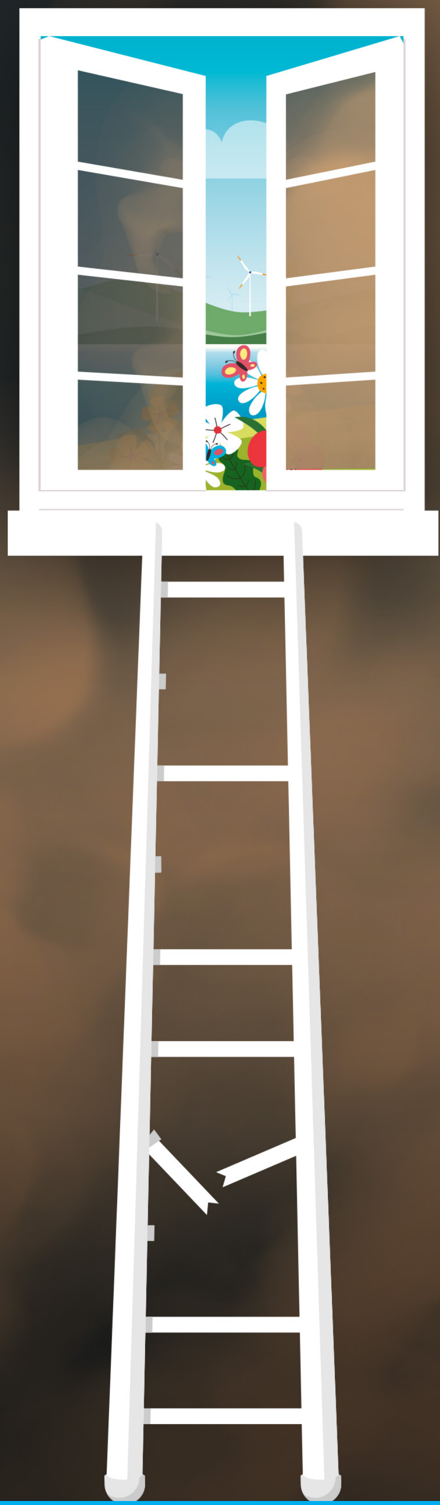
UN environment programme

The Closing Window

Climate crisis calls for rapid transformation of societies



Appendices

Emissions Gap Report 2022

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Appendix A

Supplementary material for chapter 2: Global emissions trends

A.1 Methods and data

A.1.1 Growth rates

Growth rates are calculated following the Global Carbon Budget convention (Friedlingstein *et al.* 2022). For growth rates over time periods longer than 1 year, a linear trend is fitted to the logarithm of greenhouse gas (GHG) emissions. Where growth rates are calculated over periods including leap years, emissions are multiplied by (365/366) in these years to adjust for the additional day of data.

A.1.2 Uncertainties

Uncertainty estimates follow the ranges established in the IPCC 6th Assessment Report (Dhakal *et al.* 2022) and Minx *et al*. (2021). These are based on a synthesis of the literature and expert judgement. Uncertainties at the 90 per cent confidence interval by gas are ±8 per cent for CO_2 FFI, ±70 per cent for CO_2 land use, land use change and forestry (LULUCF) (bookkeeping models), ±30 per cent for CH_4, ±60 per cent for N_2O and ±30 per cent for F-gases. Where emissions estimates are summed across gases using global warming potentials, the aggregate uncertainty is calculated as the square root of the sum of the squared uncertainties by gas, as in Minx *et al.* (2021). Note that such uncertainties are only assessed for global totals by individual gases and are not necessarily applicable for smaller aggregates reported in the chapter, such as total emissions by sector or country.

A.1.3 Land use, land use change, and forestry data from national inventories

The country LULUCF CO_2 data used in this study is from Grassi, Conchedda *et al.* (2022). For Annex I (AI) countries, data are from annual GHG inventories (complete time series 1990-2020). For non-Annex I (NAI) countries, the most recent and complete information was compiled from different sources, including National Communications, Biennial Update Reports, submissions to the framework REDD+ (Reducing Emissions from Deforestation and Forest Degradation), and NDCs. To ensure a complete time series since 1990, which is often not yet available in NAI countries, gap-filling was applied through linear interpolation between two points and/or through extrapolation backward (until 1990) and forward (until 2020) using the single closest available data. Overall, while the quality and quantity of the LULUCF data submitted by countries to the UNFCCC significantly improved in recent years, important gaps remain.

Note that non-CO_2 LULUCF data from countries are not included in this report, consistently with bookkeeping models (Friedlingstein *et al.* 2022). Based on information available from AI countries and the largest NAI countries, non-CO_2 emissions represent a relatively small contribution, equal to about 6-7 per cent of the total CO_2-equivalent LULUCF flux (Grassi, Conchedda *et al.* 2022).

A.1.4 Differences in land use, land use change, and forestry between global models and countries: causes and reconciliation

Previous studies (Grassi *et al*. 2021; Grassi, Schwingshackl *et al.* 2022) suggested that most of the discrepancies between the national GHG inventories and bookkeeping models reflect different system boundaries between anthropogenic and natural fluxes. In practice, countries consider 'anthropogenic' part of the sink that global models consider 'natural' (Figure A.1). The IPCC Guidelines for national GHG inventories (IPCC 2006; IPCC 2019) distinguish three types of effects that can drive the fluxes between land and the atmosphere: (1) direct human-induced effects, i.e. land-use changes and management practices; (2) indirect human-induced effects, i.e. human-induced environmental changes (e.g., changes in atmospheric CO_2 concentration, nitrogen deposition, temperature, or precipitation) that affect growth, mortality, decomposition rates, and natural disturbances regimes; and (3) natural effects, including climate variability and a background natural disturbance regime.

Due to differences in purpose and scope, the largely independent scientific communities that support the IPCC Guidelines (reflected in national inventories) and those that support the IPCC assessment reports (based on global bookkeeping models) have developed different approaches to identify anthropogenic GHG fluxes, as illustrated in Figure A.3. The main conceptual difference is that bookkeeping models consider as anthropogenic only the fluxes that are due to direct human-induced effects, such as land-use change, shifting cultivation, harvest, and regrowth. By contrast, national inventories generally consider as anthropogenic all the fluxes occurring on a larger area of managed forest than the one used by models and include most of indirect human-induced effects on this area that models consider natural (i.e., the natural response to human-induced environmental changes such as increased CO_2 atmospheric concentration and nitrogen deposition, which enhance tree growth). Both approaches are broadly valid in their specific contexts but are not directly comparable. If the differences in global land-use CO_2 fluxes between bookkeeping models and national inventories are not reconciled or transparently explained, they may hamper an accurate assessment of the collective progress under the Paris Agreement's Global Stocktake.

Grassi *et al.* (2021) proposed a simple approach to reconciling these conceptual differences, building on a post-processing of global model results. Specifically, the natural sink occurring on forest areas considered managed by countries (estimated by Dynamic Global Vegetation Models, DGVMs) is used to derive an 'adjustment.' This adjustment - equal to about 5.5 $GtCO_2$/yr globally in the last decade (Grassi, Schwingshackl *et al.* 2022) - may be added to the anthropogenic fluxes from bookkeeping models to make them conceptually and quantitatively more comparable to national GHG inventories (Friedlingstein *et al.* 2022; Grassi, Schwingshackl *et al.* 2022). The need of an adjustment whenever a comparison between LULUCF fluxes reported by countries and the global emission estimates of the IPCC is attempted is recommended also in the UNFCCC Synthesis report for the technical assessment component of the first Global Stocktake (UNFCCC 2022). In the absence of these adjustments, collective progress under the Global Stocktake, based on national inventories, would appear better than it actually is.

It should be noted that the adjustment described above should be seen as a short-term and pragmatic fix based on existing data, rather than a definitive solution to bridge the differences between global models and national inventories. Additional steps are needed to understand and reconcile the remaining differences, some of which are relevant at the country level, and to operationalize future comparisons between global models and national inventories (Grassi, Schwingshackl *et al.* 2022).

A.1.5 Consumption-based greenhouse gas emissions of households

Individual emissions footprint are modeled estimates based on the systematic combination of household surveys, tax and administrative data as well as environmental input-output estimates. These footprints include emissions associated to household consumption as well as governments and capital formation in the national accounts sense. Household consumption emissions are allocated to households on the basis of country-level elasticities of expenditure to emissions, using latest available country-by-country micro-data studies. Investment-related emissions are allocated to households as a function of their share in national wealth. Government related emissions are allocated equally to all individuals. Alternative scenarios are presented and discussed in Chancel (2022).

A.2 Additional figures

Figure A.1 Net CO_2 LULUCF emissions in bookkeeping models and inventories, 1990-2020. Data from Friedlingstein *et al.* (2022) and Grassi *et al.* (2022)

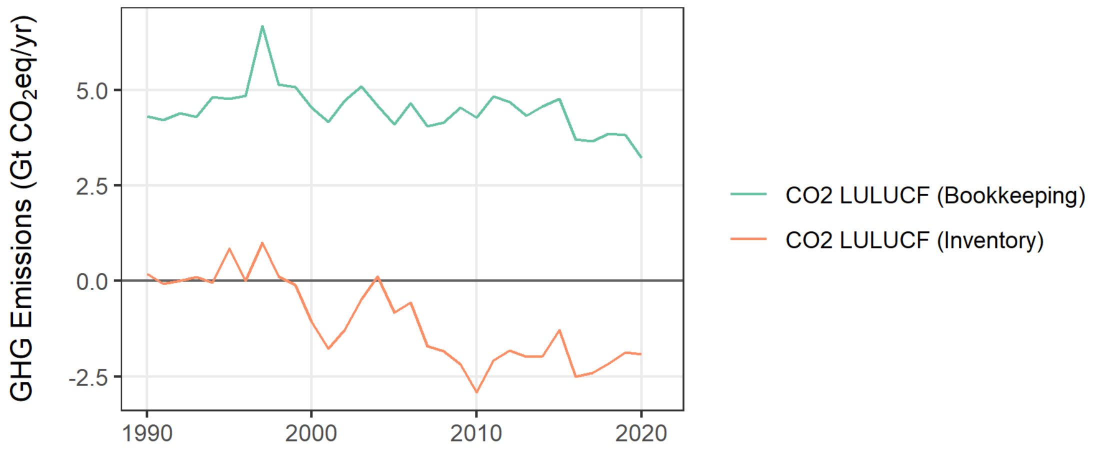


Figure A.2 Total net anthropogenic GHG emissions by sector and subsector, 1990-2021. The upper panel shows trends and totals by 5 sectors, the lower panel shows emissions in 2020 for the ten largest subsectors. Emissions for the CO_2 LULUCF sector are depicted using the bookkeeping approach from the 2022 Global Carbon Budget. Data from Crippa *et al.* (2022) and Friedlingstein *et al.* (2022).

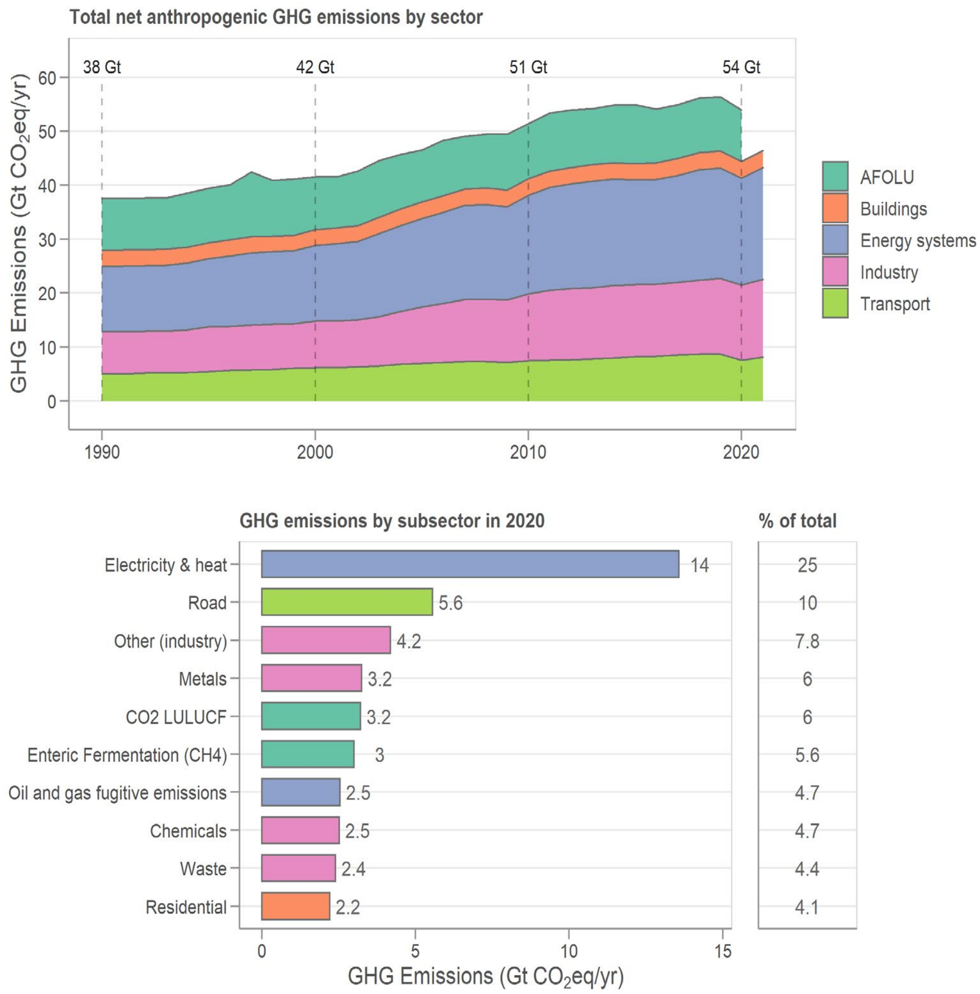
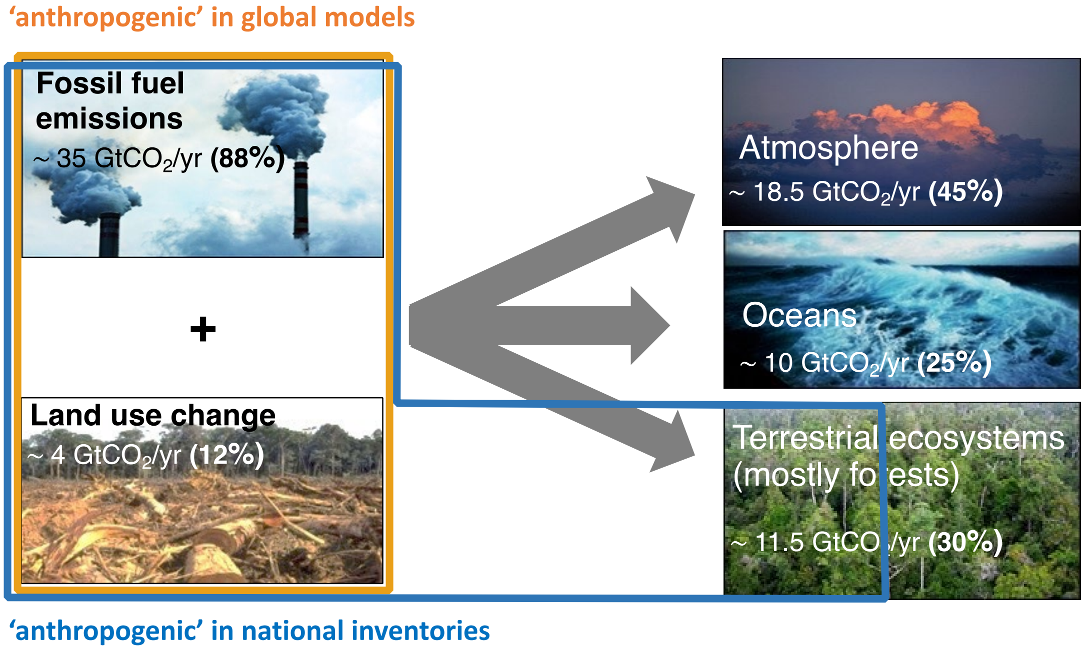
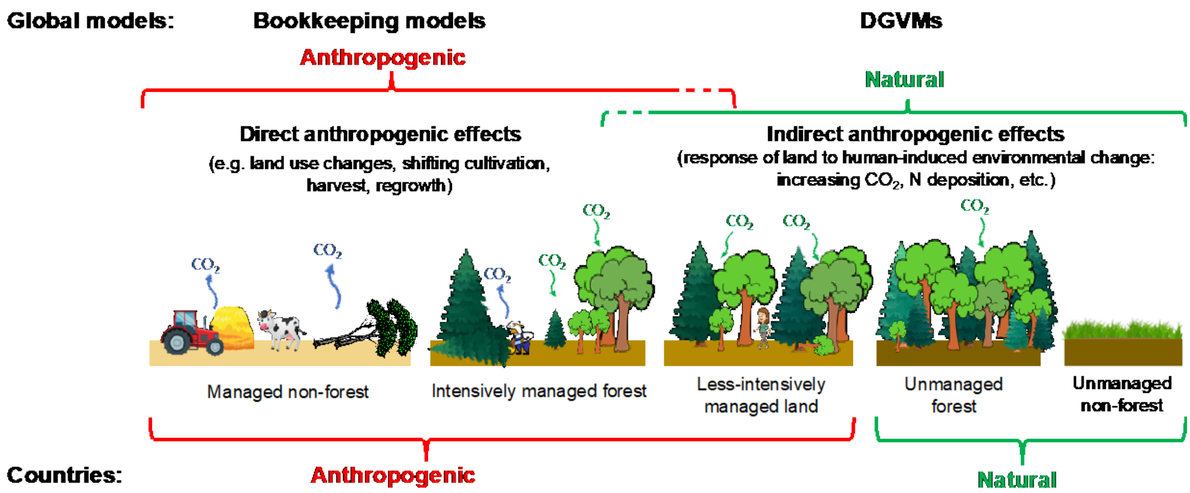


Figure A.3 Illustration of the different system boundaries between global bookkeeping models and national GHG inventories for estimating the anthropogenic fluxes. Numbers are an approximation based on Friedlingstein *et al.* (2022).



Source: Global Carbon Project (2010)

Figure A.4 Conceptual illustration of the different approaches for estimating the anthropogenic and natural land CO_2 fluxes by global models used in the IPCC Assessment Reports (bookkeeping models and Dynamic Global Vegetation Models, DGVMs) and by country GHG inventories. Note that, beyond the differences illustrated in this figure, other methodological differences exist between global models and country inventories. Based on Grassi, Schwingshackl *et al.* (2022).



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Appendix B

Supplementary material for chapter 3: Nationally determined contributions and long-term pledges: The global landscape and G20 member progress

B.1 Data sources for nationally determined contributions and country-level emissions projections

Official and independent sources for emissions data in 2030 under the NDC and current policies scenarios for G20 members are presented in Table B.1.

We excluded a number of pre-2020 studies when their emissions estimates for 2020 were already more than 10 per cent higher than the highest of the estimates by the three studies published in 2021 that considered the impact of COVID-19 and recent policies implemented in 2020 and 2021 (Keramidas *et al.* 2021; Nascimento *et al.* 2021; Climate Action Tracker 2022).

Three main considerations informed the selection of studies projecting 2030 emissions: 1) taking into account of the most recent societal, economic and policy developments, 2) including peer-reviewed studies to the extent possible, 3) including studies published by national experts, and 4) covering all GHGs and sectors. On the first point, to take account of the most recent emission trends, the potential impact of recently implemented policies, and other global social and economic circumstances, we considered studies that were published in 2020 or later. Exceptions were made when external reviewers suggested national studies published before 2020, the emission projections of which are considered to be relevant for this assessment. Policy cut-off dates ranged from 2019 to mid-2022 across studies, meaning that recently adopted policies including those presented later in Section 3.4.3 are fully reflected in some of the scenario studies reviewed here.

Recent independent studies added to the assessment include three studies on the United States of America that quantified the potential impact of the recently adopted Inflation Reduction Act (Jenkins *et al.* 2022; Larsen *et al.* 2022; Mahajan *et al.* 2022), national model scenario projections for Brazil (Baptista *et al.* 2022) and India (Swamy *et al.* 2021), global model scenario projections of Fujimori *et al*. (2021) for China and India. Up-to-date official emissions projections published since October 2021 were collected from, e.g., G20 members' recently published National Communications and Biennial Update Reports as well as other national government reports. These include annually updated projections by the Australian and Canadian governments (Australia, Department of Industry, Science, Energy and Resources 2021; Environment and Climate Change Canada 2022b). Due to the literature cut-off date, emission projections reported in the 4th Biennial Reports to the UNFCCC were not considered.

Table B.1 Official and independent sources for emissions data in 2030 under the NDC and current policies scenarios for the assessment of G20 members.

Member	Updated or new NDC and other announced 2030 target: official data sources (cut-off date: 1 August, 2022)[1]	Current policies scenario: Official data sources [2]	Current policies scenario and NDC scenario: Independent sources (1. global models and 2. national models)
Argentina	UNFCCC (2021a)	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), Meinshausen *et al.* (2022) (NDC only) 2. Keesler and Blanco (2022)
Australia	Calculated by the authors based on the base year emissions data reported in the official annual report (Australia, Department of Industry, Science, Energy and Resources 2021)	Australia, Department of Industry, Science, Energy and Resources (2021)	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al.* (2022) (NDC only) 2. TIMES (Fragkos *et al.* 2021) [3]
Brazil	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al.* (2022) (NDC only) 2. Baptista *et al.* (2022) [3]
Canada	Environment and Climate Change Canada (2022b)	Environment and Climate Change Canada (2022b)	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al.* (2022) (NDC only) 2. Canadian Climate Institute (Sawyer *et al.* 2022) (legislated / developing policies scenario)
China	N/A	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), CD-LINKS (Roelfsema *et al.* 2020), Fujimori *et al.* (2021); Meinshausen *et al.* (2022) (NDC only) 2. PECE (Fragkos *et al.* 2021),[4] National Center for Climate Change Strategy and International Cooperation (NCSC), Energy Research Institute (ERI) – Integrated Policy Assessment Model for China (IPAC). NCSC and ERI scenarios are published in the COMMIT scenario database (IIASA 2021; van Soest *et al.* 2021)

EU27	N/A [5]	European Commission (2021b)	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only) [6]
India	N/A	N/A	1. Climate Action Tracker (2022), Joint Research Centre (2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), CD-LINKS (Roelfsema *et al.* 2020), Meinshausen *et al*. (2022) (NDC only) 2. Indian Institute of Management (IIM) – Asian-Pacific Integrated Model (AIM) India (Roelfsema *et al.* 2020), AIM/Hub (Fujimori *et al*. 2021), WRI and Energy Innovation (Swamy *et al.* 2021)
Indonesia	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only)
Japan	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.*, 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only) 2. [6]
Mexico	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022)
Republic of Korea	N/A	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only) [6]
Russian Federation	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), CD-LINKS (Roelfsema *et al.* 2020), Meinshausen *et al*. (2022) (NDC only) 2. HSE – TIMES model (Roelfsema *et al.* 2020)
Saudi Arabia	UNFCCC	N/A	1. Climate Action Tracker (2021), Joint Research Centre (Keramidas *et al.* 2021)
South Africa	UNFCCC	N/A	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only)
Türkiye	UNFCCC	UNFCCC Biennial Reports data portal (BR4)	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only)
United Kingdom	Climate Change Committee (2020)	United Kingdom, Department for Business, Energy & Industrial Strategy (2020)	1. Climate Action Tracker (2022), Meinshausen *et al*. (2022) (NDC only)

United States of America	UNFCCC	N/A [To be updated with 7th NC 3rd 4th BR final of April 2021]	1. Climate Action Tracker (2022), Joint Research Centre (Keramidas *et al.* 2021), PBL (Nascimento *et al.* 2021; den Elzen *et al.* 2022), Meinshausen *et al*. (2022) (NDC only) 2. Rhodium Group (Larsen *et al.* 2022), REPEAT (Jenkins *et al.* 2022), Energy Innovation (Mahajan *et al.* 2022)

Notes: N/A: not available.

[1] References provided only when the NDC emission levels are available in absolute terms.

[2] In this year's report, we did not consider any projections in the fourth biennial reports submitted to UNFCCC in 2019 (and the USA's published in 2021), as explained in Section 3.4.1.

[3] NDC target emission levels are recalculated to reflect the current NDCs.

[4] Augmented with historical non-CO_2 GHG emissions data from China's First Biennial Update Report on Climate Change (China, 2016), combined with the median estimate of the 2010–2030 non-CO_2 emissions growth rates for China from five integrated assessment models (Tavoni *et al.*, 2014), to produce economy-wide figures.

[5] EEA (2020) quantified NDC emissions target levels, which include international aviation but exclude land use, land-use change and forestry (LULUCF) and international shipping. In this table, we present figures excluding international transport, in line with national GHG inventories submitted to the UNFCCC.

[6] For the EU27, Fragkos *et al*. (2021) was excluded because it provided emissions projections only for the EU28. For Japan, projections in Roelfsema *et al.* (2020), Fragkos *et al.* (2021) and Fujimori *et al.* (2021) were excluded because their trajectories deviate substantially already in 2020 compared to the estimate reported in the 2022 national GHG inventory report (UNFCCC 2022). For the Republic of Korea, the projections by Fragkos *et al.* (2021) were excluded due to similar reasons as for Japan.

B.2 Summary of GHG mitigation pledges in previous and new or updated NDCs by G20 members

Table B.2 Summary of GHG mitigation pledges in previous and new or updated NDCs by G20 members.

G20 member	Previous NDC	New or updated 2030 pledge	Change in 2030 emissions relative to previous NDC Based on modeling studies* (median and range)
G20 members that have submitted new or updated NDCs			
Argentina	Cap 2030 net emissions at 483 $MtCO_2e$ (unconditional) and 369 $MtCO_2e$ (conditional)	Cap 2030 net emissions at 349 $MtCO_2e$ (unconditional)	-0.12 $GtCO_2e$ (range: -0.1 – -0.13)
Australia	Reduce GHG emissions by 26-28% from 2005 levels by 2030**	Reduce GHG emissions by 43% from 2005 levels by 2030	-0.12 $GtCO_2e$ (range: -0.1 – -0.14)
Brazil	Reduce GHG emissions by 37% from 2005 levels by 2025 and (indicatively) 43% from 2005 levels by 2030	Reduce GHG emissions by 50% from 2005 levels by 2030[2]	0.1 $GtCO_2e$ (range: 0 – 0.2)[1]
Canada	Reduce GHG emissions by 30% from 2005 levels by 2030	40-45% below 2005 levels by 2030	-0.07 to -0.11, with median staying at -0.09 $GtCO_2e$
China	Peak CO_2 emissions around 2030 Reduce CO_2/GDP by 60%-65% from 2005 levels by 2030 Share of non-fossil fuels in primary energy consumption to around 20% in 2030 Increase forest stock volume by around 4.5 billion cubic metres in 2030	Achieve CO_2 emissions peak before 2030 and carbon neutrality before 2060 Reduce CO_2/GDP by 65% from 2005 levels by 2030 Share of non-fossil fuels in primary energy consumption to around 25% in 2030* Increase forest stock volume by around 6 billion cubic metres in 2030 Total installed capacity of wind and solar power will reach above 1,200 GW by 2030	-0.8 $GtCO_2e$ (range: 0.0 – -1.4)
EU27	Reduce GHG emissions by at least 40% from 1990 levels by 2030 (applied to EU28 collectively)	Reduce net GHG emissions by at least 55% from 1990 levels by 2030	-0.7 $GtCO_2e$ (range: -0.5 – -0.8)
India	Reduce emissions/GDP by 33-35% from 2005 levels by 2030 Increase in share of non-fossil fuel in primary electricity production to 40% (conditional) additional (cumulative) carbon sink of 2.5–3 $GtCO_2e$ by 2030.	Reduce emissions/GDP by 45% from 2005 levels by 2030 Increase in share of non-fossil fuel in primary electricity production to 50% (conditional) additional (cumulative) carbon sink of 2.5–3 $GtCO_2e$ by 2030.	Reduced, but target still results in higher emissions than Current Policies scenario projections[2]
Indonesia	Reduce GHG emissions by 31.89% (unconditional) and 44.2%	Reduce GHG emissions by 29% (unconditional) and 41%	-0.08 $GtCO_2e$

	(conditional) relative to BAU by 2030	(conditional) relative to BAU by 2030	
Japan	Reduce GHG emissions by 26% from 2013 levels by 2030	Reduce GHG emissions by 46% from fiscal year 2013 levels in fiscal year 2030, with efforts to reduce by 50%	-0.27 $GtCO_2e$ (range: -0.25 – -0.3)
Mexico	Reduce GHG emissions by 22% (unconditional) and 36% (conditional) from BAU by 2030	Reduce GHG emissions by 22% (unconditional) and 36% (conditional) from BAU by 2030	Marginal increase due to change in BAU scenario
Republic of Korea	Reduce GHG emissions by 37% from BAU by 2030	Reduce GHG emissions by 40% from 2018 levels by 2030	-0.1 $GtCO_2e$ (range: -0.1 – -0.11)
Russian Federation	Limit 2030 emissions to 70-75% of 1990 level	Limit 2030 emissions to 70% of 1990 level	Reduced, but target still results in higher emissions than Current Policies scenario projections -0.05 $GtCO_2e$ (range: 0.0 – -0.15)
Saudi Arabia	Annually abate up to 130 $MtCO_2e$ by 2030	Annually abate up to 278 $MtCO_2e$ by 2030	-0.2 $GtCO_2e$ (range: 0 – -0.37)
South Africa	Limit 2025-2030 emissions to 398 - 614 $MtCO_2e$ (conditional)	Limit 2030 emissions to 350 - 420 MtCO2e (conditional)	-0.1 $GtCO_2e$ (range: -0.05 – -0.2)
United Kingdom	Contribution to EU-28-wide at least -40% target	Reduce GHG emissions by at least 68% from 1990 levels by 2030	-0.17 $GtCO_2e$ (range: -0.1 – -0.2)
United States of America	Reduce GHG emissions by 26-28% from 2005 levels by 2025	Reduce GHG emissions by 50-52% from 2005 levels by 2030	-0.8 to -0.9, with median staying at -0.85 $GtCO_2e$
G20 members that have not yet submitted new or updated NDCs			
Türkiye	Reduce GHG emissions by up to 21% from BAU by 2030	N/A	N/A

Sources: ClimateWatch, Climate Action Tracker (Date: July 2022) and reduction estimates based on this study

* Three model groups (Keramidas *et al.* 2021; den Elzen *et al.* 2022; Meinshausen *et al.* 2022) and two open-source tools : Climate Action Tracker (2021); and WRI's ClimateWatch (2021).

** Australia's previous NDC of December 2020 provided an indicative emissions budget of 4832-4764 $MtCO_2e$ over the period 2021-2030. Its updated NDC, submitted to the UNFCCC on 16 June 2022, revised the commitment to both a single-year target to reduce emissions 43 per cent below 2005 levels by 2030 and a multi-year emissions budget from 2021-2030. The indicative multi-year emissions budget is 4381 $MtCO_2e$ over the period 2021-2030.

[1] This was only quantified by PBL and WRI.

[2] This was only quantified by PBL and Climate Action Tracker.

B.3 Limitations of the analysis of G20 economies toward their NDCs

The most important caveats are similar to those of previous Emissions Gap Reports (adapted from den Elzen *et al.* 2019).

First, whether a country is projected to achieve or miss its Cancun Pledge or NDC targets with existing policies depends on both the strength and stringency of the existing climate policy packages and the ambition level of the targets given structural factors (such as demographic and macroeconomic trends) that shape how easy or difficult a target is to achieve. Although targets have been assessed as diverging in ambition, this report does not assess the degree of each country's efforts to achieve a certain mitigation projection, and does not assess the ambition of the targets in the context of equity principles. Countries that are projected to achieve their NDCs with existing policies are therefore not necessarily undertaking more mitigation actions than countries that are projected to miss them, and vice versa.

Second, current policy scenario projections are subject to the uncertainty associated with macroeconomic trends, such as gross domestic product (GDP), population growth and technology developments, as well as the impact of policies. Some pledges are also subject to the uncertainty of future GDP growth and other underlying assumptions. These all add to the fundamental uncertainty resulting from COVID-19.

B.4 Recent G20 member state policy updates

The table below shows examples of recent climate policies and plans adopted by G20 member states that are expected to influence the member states' GHG emissions and possibilities for achieving their NDC targets for 2030.

Table B.3 Overview of recent climate policy updates by G20 member states

Argentina	- Since 2016, Argentina has had an electricity supply programme for renewable energy sources (RenovAr) that seeks to encourage investment projects in renewable energy. By law, Argentina is committed to generating at least 20% of its electricity from renewable sources by the end of 2025. In 2021, renewables met an average of 13% of total demand, up from 10% in 2020 (Argentina, 2021; Argentina 2022) - creates the integrated non-motorized mobility programme, which seeks to discourage car use, and promote more efficient public transport (Argentina, Ministry of Transport 2022). However, Argentina does not yet have a long-term strategy for decarbonization of the transport sector and has not yet set national targets for the phase out of fossil-fuel cars, heavy-duty vehicles, and the share of EVs in the national fleet (Climate Transparency Initiative 2021a).
Australia	- On 16 June 2022, Australia submitted an updated NDC, which includes an increased 2030 target, a reaffirmed net zero 2050 target, and a suite of new policies across the economy to drive the transition. This includes a $20 billion investment in Australia's electricity grid to unlock greater penetration of renewable energy and accelerate decarbonization of the grid and the introduction of declining emissions baselines for Australia's major emitters, under the existing Safeguard Mechanism, providing a predictable policy framework for industry, consistent with a national trajectory to net zero and supporting international competitiveness (Australia, Department of Industry, Science, Energy and Resources 2022). - In September 2022, the Parliament passed the Climate Change Bill, which outlines Australia's GHG emissions reduction targets of a 43% reduction from 2005 levels by 2030 and net zero emissions by 2050; requires the minister to prepare and table an annual climate change statement; requires the Climate Change Authority to give the minister

	advice in relation to the annual statement and future greenhouse gas emissions reduction targets; and provides for periodic reviews of the operation of the Act (Australia 2022). - The Australian Government's Powering Australia plan is focused on creating jobs, cutting power bills and reducing emissions by boosting renewable energy. Key focus areas include backing industry, agriculture and carbon farming; transport, and electricity and gas (Australian Labor Party 2021).
Brazil	- In its updated NDC, Brazil commits to reducing its GHG emissions by 37 per cent in 2025 and by 50 percent in 2030 relative to 2005 levels. It has also committed to eliminating illegal deforestation by 2028 (Brazil 2022a). - In May 2022, Brazil adopted a federal decree establishing the procedures for setting up a national system for reducing GHG emissions as well as sectoral plans for climate change mitigation. The decree also establishes a single register of carbon and methane credits and classifies carbon credits as financial assets. The decree is expected to become a management mechanism and an operational instrument for the sectoral plans, which should establish gradual sectoral targets for emission reductions. These sectoral plans must be approved by the Interministerial Committee on Climate Change and Green Growth. Deadlines and specific rules are not yet specified under the decree (Brazil 2022b).
Canada	- In March 2022, the Government of Canada introduced Canada's 2030 Emissions Reduction Plan as a key first deliverable under the Canadian Net-Zero Emissions Accountability Act adopted in June 2021. This plan provides a sector-by-sector roadmap for the Canadian economy to achieve 40-45% emissions reductions below 2005 levels by 2030 (Environment and Climate Change Canada 2022a) - At COP26, Canada announced the goal to achieve a net-zero electricity grid by 2035. To this end, Canada's Emission Reduction Plan includes CAN 850m in investments for clean electricity and the government is working to develop the Clean Electricity Regulations (CER), expected by the end of 2022 (discussed under coal phase out) (Environment and Climate Change Canada 2021; Environment and Climate Change Canada 2022a; Carss 2022; Canada 2022b). - In June 2021, the federal government strengthened its target to reach 100% of sales of passenger vehicles to be zero emissions vehicles (ZEVs) by 2035, rather than 2040. In Canada's Emissions Reduction Plan, the government indicated it is developing a regulated sales mandate to support this target, with interim targets of at least 20% by 2026 and at least 60% by 2030 (Environment and Climate Change Canada 2022a; Task Force for a Resilient Recovery 2020; Environment and Climate Change Canada, 2022c). To reduce emissions from medium- and heavy-duty vehicles (MHDVs), the Government of Canada will aim to achieve 35 percent of total MHDV sales being ZEVs by 2030. In addition, the Government will develop a MHDV ZEV regulation to require 100 percent MHDV sales to be ZEVs by 2040 for a subset of vehicle types based on feasibility, with interim 2030 regulated sales requirements that would vary for different vehicle categories based on feasibility, and explore interim targets for the mid-2020s (Environment and Climate Change Canada 2022a).
China	- The renewable energy development in China has continued its strong growth. By the end of 2021, the installed solar photovoltaics (PV) and wind capacity was more than 300 gigawatts (GW). Since 1996, the annual newly installed solar PV and wind capacity has accounted for about 55 per cent of new energy capacity (Statista 2022). - In April 2022, China announced that it would increase coal production by 300 million tons in 2022 through coal mining capacity increase, expanded and new production, and other measures. This comes despite China's pledge to strictly control coal-fired power generation projects, limit the increase in coal consumption over the 14th Five-Year Plan

	period (2021–2025) and phase down coal consumption during the 15th Five-Year Plan period (2026–2030). The transformation away from coal infrastructures is challenged by energy security concerns (China, National Development and Reform Commission [NDRC] 2022; China, National Energy Administration 2022; Xinhua 2022). - To peak CO2 emissions and achieve carbon neutrality, China has released an Action Plan for Carbon Dioxide Peaking before 2030 and a Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality. Specific objectives and implementing plans are published at the regional level and across all sectors covering energy, industry, urban-rural development, transportation, carbon sink, technology development, carbon market, climate and green finance, climate adaptation and social awareness (China, NDRC 2021a; China, NDRC 2021b).
European Union	- In December 2021, the European Commission proposed legislation to boost the renovation and decarbonization of buildings and reduce methane emissions in the energy sector by 80 per cent in 2030 (European Commission 2021a; European Commission 2021c). New requirements to promote sustainable products and construction were proposed in March 2022, which could lead to 132 million tons of oil equivalent (Mtoe) of primary energy savings (European Commission 2022a). - In May 2022, the European Commission presented its REPowerEU Plan in order to phase out Russian fossil fuels. Among others, the plan includes proposals to invest €210 billion mostly in clean energy and industry, speed up permitting procedures for renewable energy projects, and increase ambitions for renewable energy and energy efficiency. The plan would bring the EU's total renewable energy generation to 1236 GW by 2030 if adopted (European Commission 2022b; European Commission 2022c). - The EU's revision and update of legislation under the "Fit for 55" package to implement its 2030 climate target is in its final phase. The European Commission, European Parliament and member states have already supported a ban on the sale of new fossil fuel cars and vans by 2035, an EU Carbon Border Adjustment Mechanism (CBAM), and an expansion of emissions trading to new sectors (European Council 2022a; European Council 2022b; European Parliament 2022).
India	- In August 2022, the Cabinet approved an update of India's NDC. The updated NDC has led to major polices being pushed forward, including 1) electric vehicles (EVs), 2) co-firing of biomass pellets in thermal power plants by 7 per cent, 3) ethanol blending in petrol by 20 per cent, 4) inclusion of agroforestry and private forestry, 5) solarization of agricultural pumps, 6) clean cooking (by shifting to liquefied petroleum gas [LPG]), and 7) rooftop solar PV. The Government of India is considering coal gasification, conversion of coal into chemical projects, ammonia, and hydrogen as future fuels. Energy storage is supported through a production linked scheme to promote renewable energy (India, Press Information Bureau 2022). - In recognition of the role of lifestyles, the movement Lifestyle for Environment has been proposed to foster a citizen-centric approach to combat climate change (Bhaskar 2022; India, Press Information Bureau 2022). The Lok Sabha passed the Energy Conservation (Amendment) Bill on 9 August 2022, aiming to facilitate the establishment and development of domestic carbon markets. The markets' objective is to incentivize actions for emission reduction expected to result in increased investments in clean energy and energy efficiency areas, especially in the private sector (PRS Legislative Research 2022).
Indonesia	- In February 2022, the Ministry of Environment and Forestry released Ministerial Decree No. 168/2022 on Forestry and Other Land Use (FOLU) Net Sink 2030 along with its operational plan. This regulation is expected to remove GHG emissions while implementing the energy transition and decarbonization. The FOLU Net Sink commitment

	was introduced in the last Long-Term Strategy to Low-Carbon and Climate Resilience 2050 published in 2021 (Forest Hints 2022). - The Ministry of Energy and Mineral Resources has announced a net-zero emission road map for the energy sector, which indicates that Indonesia will no longer build new fossil fuel power plants, with the exception of the 35 GW power capacity addition plan, and begin to retire subcritical coal power plants from 2030 onwards. In the period of 2031–2060, 45 GW of coal power plants will be retired and shut down. In addition, the Indonesian State-owned electricity company Perusahaan Listrik Negara seeks to cancel some coal plants under construction. However, despite the verbal statement and political decision, no regulation to phase out coal has been issued yet (International Energy Agency [IEA] 2022a; Indonesia, Ministry of Energy and Mineral Resources 2022; Organization for Economic Co-operation and Development [OECD] Clean Energy Finance and Investment Mobilization Programme 2021). - The Electricity Supply Business Plan 2021–2030, published in October 2021, aims to achieve renewable energy capacity to account for 51.6 per cent of total power addition until 2030. Hydropower dominates the upcoming renewable plan by around 25.6 per cent, followed by solar (11.5 per cent), geothermal and other renewables (Indonesia, Ministry of Energy and Mineral Resources 2021; OECD Clean Energy Finance and Investment Mobilization Programme 2021)
Japan	- In May 2022 the energy related bundled bill was enacted, including the revisions of the Energy Conservation Act and the Sophisticated Energy Supply Act. The bundled bill aims to change the structure of energy supply and demand to achieve of carbon neutrality in 2050 and a 46% reduction in GHG emissions by 2030. With the revision of the Energy Conservation Act, the definition of energy, which previously focused on only fossil energy, has changed to include non-fossil energy. Business operators of a certain scale are now mandated to submit the mid- to long-term plan and periodic report on their non-fossil energy transition. The revised Energy Conservation Act also encourages rationalization of demand in response to variable renewable power generation with a view to minimizing renewable power curtailment. With the revision of the Sophisticated Energy Supply Act hydrogen and ammonia is not considered a non-fossil energy source, regardless of their production method. The intension is to boost the demand and supply of hydrogen and ammonia and to accelerate infrastructure development. Thermal power stations equipped with carbon dioxide capture and storage (CCS) are also included in the act. Most of the detailed implementation plans will be determined in due course. Environmental NGOs have criticized the categorization of hydrogen and ammonia as non-fossil energy regardless of the production method (Japan 1979) - The building-related bundled law was enacted in April 2022. As part of the bundled law, the Building Energy Conservation Law was revised to make conformity to energy conservation standards for all new buildings from 2025. As part of the bundled law, a low-interest financing system by the Japan Housing Finance Agency is established to support energy-efficiency renovations for the existing residential buildings. Combining the mandate for all new buildings' conformity to energy conservation standards with the promotion of energy-efficiency renovations for the existing buildings aims to secure ZEH/ZEB (Zero Energy House/Building) levels of energy efficiency on the stock average in 2050 (Japan, Agency for Natural Resources and Energy 2021)
Mexico	- Mexico updated the Program for the Development of the National Electric System, which reaffirms the Energy Transition Law's commitment to achieving 35% of clean energy in the power sector by 2024. Analysis shows that the renewable energy penetration plan is inconsistent with the goal. To illustrate, under the current energy policies, a 30.5% share of clean energy will be reached by 2024, and new private renewable energy capacity will not be added until 2027 (Mexico, Secretaría de Energía 2022).

	- In 2022, Mexico committed to joining the global effort to produce 50% of vehicles with zero polluting emissions by 2030. However, current public policy does not encourage a reduction of light internal combustion vehicles, and EV penetration is limited (4.6% of motor vehicles sold in the country in 2021). The consumption of gasoline is also encouraged with high subsidies to fossil fuels that keep it cheap, as well as the inauguration of a new refinery and the rehabilitation of the existing ones. Furthermore, the fuel vehicle emissions standards to reduce emissions in the new light and heavy fleet are still pending being published. (Grados, Martínez and Villarreal 2020; Climate Transparency Initiative 2021b; Instituto Nacional de Ecología y Cambio Climático 2022; Mexico, Secretaría de Energía 2022). - Mexico signed the COP26 Global Methane Pledge, and the government committed to reducing methane gas emissions in exploration and production processes in the oil industry by up to 98 percent. Nevertheless, methane emissions have increased in recent years, and according to independent assessments, onshore oil and gas production emits more than 10 times the amount of methane reported in official inventories (UNFCCC 2021b; Zavala-Araiza *et al.* 2021; Instituto Nacional de Ecología y Cambio Climático 2022).
Republic of Korea	- The government of the Republic of Korea announced an increase in the nuclear power in the generation mix to more than 30% by 2030 from 27.4% of 2021, while the share of renewables will be adjusted from 30% to a "feasible and reasonable level". The civic society and renewables industries have been raising concerns on the backsliding of energy policy (Republic of Korea, Ministry of Trade, Industry and Energy 2022). - In April 2022, the government's energy policy direction was launched, with the aim of normalizing energy policy. It included a plan to change the current power market structure to gradually improve Korea Electric Power Corporation's (KEPCO) monopoly status and introducing more market-based competition based on market principles. The plan will make up for the current situation where renewable energy development is held back due to a flawed energy market system (Republic of Korea, Ministry of Trade, Industry and Energy 2022). - In June 2022, the government of the Republic of Korea set a new goal to increase energy efficiency by 25% by 2027. Accordingly, it has mandated Energy Efficiency Resource Standards and promoted Korea Energy Efficiency Partnership 30 by supporting corporates to set energy efficiency targets policy (Republic of Korea, Inter-ministerial Energy Committee 2022).
Russian Federation	- In November 2021, the Russian Federation released the newest version of their Transport Strategy until 2030. The strategy outlines measures including energy-efficient or electric vehicles, low-carbon infrastructure and alternative fuels intended to reduce transport emissions by 1.2 per cent relative to total emissions in 2017 by 2030 (Russian Federation 2021a). - The Concept for the Development of Electric Vehicle Production was approved by the Russian Federation in August 2021, setting a target for EVs to make up at least 10 per cent of the Russian market by 2030. In addition to measures promoting EV production, the Government plans to stimulate demand by providing subsidies covering up to 25% of the price of domestically produced EVs (Russian Federation 2021b; Reuters 2021). - In August 2021, the Russian Government approved the concept for the Development of Hydrogen Energy. The plan presents strategic initiatives towards the development, use and export of low-carbon hydrogen energy (Russian Federation 2021a).
Saudi Arabia	- Saudi Arabia formally launched the Saudi Green Initiative in October 2021. It includes an updated mitigation target by 2030 and a goal to reach net zero emissions by 2060. Five initiatives will contribute to emissions reductions (Saudi Arabia 2021): 1) Enhance Saudi

	Arabia's Energy Efficiency Program by 2025 by implementing new energy efficiency standards, 2) changing the energy mix towards generating 50% of electricity from renewable energy by 2030, 3) Produce three million tons of blue hydrogen and one million ton of green hydrogen by 2030, 4) Use new technologies to capture carbon and produce 12 tons of green methanol daily by 2030, and 5) Improve waste management in the city of Riyadh by 2035. - Saudi Arabia launched the Circular Carbon Economy National Program in 2021, which aims to support new technologies and policies to "reduce, reuse, recycle and remove" CO_2 emissions (Saudi & Middle East Green Initiatives 2021)
South Africa	- The Climate Change Bill was introduced to the Parliament in February 2022. It aims 'to enable the development of an effective climate change response and a long-term, just transition to a low-carbon and climate-resilient economy and society' (South Africa 2022). The Bill is currently under consideration by the National Assembly and members of the public had until 27 May 2022 to submit any comments on the Bill to the Portfolio Committee on Environment, Forestry and Fisheries. - Legal action against gas ships for the Risk Mitigation Independent Power Producer Procurement Programme: The application from DNG Power Holdings to set aside the appointment of Preferred Bidders under the Risk Mitigation Independent Power Producer Procurement Programme was dismissed by South Africa's High Court. The court decision will enable the South African government and Eskom to finalize its governance and regulatory approval process to conclude a financial close with the bidders for the programme. The programme comprises eleven projects totaling 1,996MW. Of this, some 1,220MW, or 60%, is made up of three floating power plants (power ships) and associated floating storage and regasification units (FSRUs) from Türkiye company Karpowership. The balance comprises eight projects, ranging from 75MW to 200MW, incorporating various combinations of wind, solar photovoltaic (PV), battery energy storage and diesel/gas engines (IPP Risk Mitigation 2020). - The Just Energy Transition Partnership (JETP) was announced last year during COP26. JETP aims to reduce emissions in the energy sector and accelerate the coal phase-out process. South Africa is to receive US$8.5 billion in grants and loans from the EU, France, Germany, the UK and the US to support its transition from coal-fired power plants to cleaner energy sources. The JETP identifies concrete areas to support South Africa's energy transition and it addresses vital questions about how African countries can use international climate finance. In doing so, it provides a framework for negotiating support for African and other developing countries through flexible fora like the G7 (Messetchkova, 2022).
Türkiye	- Türkiye ratified the Paris Agreement 5 years later than it was put into force and a national Climate Council has been organized. The council has drafted policy recommendations which are yet to be declared official (Şahin 2022). - The Government of Türkiye has declared a net-zero emissions target for 2053. A roadmap for the long-term decarbonization still needs to be developed (Şahin 2022).
United Kingdom	- In 2021, the UK government confirmed it will bring forward the date of its planned coal phase-out from 2025 to 2024. Ending coal generation by the end of 2024 will mean the UK will have gone from generating a third of its electricity from coal to none in the space of just 10 years. However, as a result of the war in Ukraine and the energy crisis, the government of the United Kingdom has delayed the closure of several coal-fired power plants (Environment and Climate Change Canada 2017; United Kingdom, Department for Business, Energy & Industrial Strategy, Trevelyan and Sharma 2021; IEA 2022b; United Kingdom 2022b).

	- The UK continues to lead the G20 in power sector decarbonization. It has committed to 100% clean electricity by 2035, and renewables deployment is accelerating. There is a target of 50GW offshore wind by 2030, and solar capacity is projected to grow five-fold by 2035. The latest Contracts for Difference auction secured almost 11GW of renewables, including 7GW of offshore wind at a record low strike price of £37.35/MWh (2021 prices) (United Kingdom 2021a; United Kingdom 2022a; United Kingdom, Department for Business, Energy & Industrial Strategy, Hands and Kwarteng 2022). - The UK will end the sale of new petrol and diesel cars and vans by 2030. Only hybrids with 'significant zero emissions capacity' will be sold post-2030, with all hybrid sales banned by 2035. This policy is supported by a zero emissions vehicle (ZEV) mandate, which will set legally binding targets for sales of ZEVs from 2024. The UK has also set out a strategy to achieve 300,000 public charging points by 2030. However, accompanying policies to reduce emissions from fossil fueled vehicles are too weak and need strengthening (United Kingdom, Department for Transport 2021; United Kingdom 2021b; Climate Change Committee 2022).
United States of America	- In August 2022, the United States of America enacted the Inflation Reduction Act, projected to reduce GHG emissions by 1 Gt. The law makes major investments in clean energy technologies including utility-scale and distributed solar, wind and other renewable resources, existing zero-emitting nuclear plants, carbon capture facilities in the power and industrial sectors, light, medium and heavy-duty clean vehicles as well as heat pumps and other energy-efficient upgrades for homes and businesses. The Act also provides tax credits for emerging clean technologies like clean hydrogen production, direct air capture facilities and clean fuel production (United States of America, Congress 2022a; United States of America, Department of Energy 2022; Jenkins *et al*. 2022; Larsen *et al*. 2022; Mahajan *et al*. 2022). - The United States of America also enacted the Infrastructure Investment and Jobs Act in November 2021, which makes US$27 billion in power grid and transmission investments, creates a new US$7.5 billion grant programme for EVs and alternative fuel infrastructure deployment, and provides US$3.5 billion and US$8 billion for direct air capture and clean hydrogen hubs, respectively, among other key investments (United States of America, Congress 2022b). - In 2021 and 2022, the Environmental Protection Agency and National Highway Traffic Safety Administration adopted standards for light-duty vehicles through model year 2026. The Environmental Protection Agency estimates that the standards will avoid more than 3 billion tons of GHG emissions through 2050 (United States of America, Department of Transportation undated; United States of America, Environmental Protection Agency 2021; United States of America, Environmental Protection Agency 2022).

B.5 Complementary explanation of the indicators and coding criteria used for table 3.4

Green checkmarks indicate the criterion is fulfilled; yellow checkmarks indicate the criterion is partially fulfilled or fulfilled to a lower level of robustness; red X indicates the criterion is not fulfilled; The question mark sign (”?”) indicates the member has not provided information on the criterion (where relevant); *inconclusive* indicates inconsistency across data sources consulted; *no data* indicates the data sources consulted do not track data on the member.

Reference to fairness is based on consideration of whether the G20 member addresses how the net-zero target aligns with its fair share contribution to the global goal of limiting warming to 1.5°C above pre-industrial levels (as opposed to how fairness and related concepts in the domestic context). It receives a green check if CAT codes it as containing a "statement explaining why fair share in advisory (but not government) document" and the Net Zero Tracker codes its equity indicator as "yes", and a red X if CAT codes it as containing "no reference to fairness / equity" or “no information provided" and the Net Zero Tracker codes its equity indicator as "no".

Covers all sectors and *covers all gases* receive a green check if the target covers all IPCC inventory sectors and all 7 baskets of gases (CO_2, CH_4, N2O, HFCs, PFCs, SF_6, and NF_3), and a red X otherwise.

Excludes international offsets receives a green check if the G20 member states it will not use offsets, and a yellow check if the member states that at this time it does not anticipate using offsets. *Separate removals targets* receive a green check if the G20 member has set separate targets for gross emissions and gross removals, in addition to the net emissions target, and a red X otherwise.

Removals transparency refers to how transparent the G20 member is regarding the role of removals in achieving its net-zero target, and receives a green check if CAT codes it as containing "transparent assumptions for domestic LULUCF and separately for domestic removals and storage" and if the Net Zero Tracker codes its CDR indicator as "yes,” specifying what is included, or as "no," a yellow check if CAT codes it as containing "non-transparent assumptions for domestic LULUCF and domestic removals and storage" and NZT codes its CDR indicator as "yes (unspecified)," and a red X if CAT codes it as "no information provided" and NZT as "not specified."

Published plan receives a green check if CAT codes it as "underlying [government or government-endorsed] analysis identifies pathway and key measures for reaching net zero, with sector-specific detail" or "some information on anticipated pathway or measures for achieving net zero is available, but with limited detail" and the Net-Zero Tracker codes its plan indicator as "yes” and a red X if CAT codes it as "no information provided" and the Net-Zero Tracker codes its plan indicator as “no”; for members not covered by CAT, the coding is based on the Net-Zero Tracker alone.

Review process receives a green check if CAT codes it as “yes,” a yellow check if CAT codes it as “yes, but non-legally binding or in the process of establishing a review cycle," and a red X otherwise.

Annual reporting receives a green check if the Net-Zero Tracker codes as “annual reporting” and a red X otherwise. Members are designed as “inconclusive” if different trackers reach differing conclusions.

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Appendix C

Supplementary material for chapter 4: The emissions gap

C.1 Data sources for NDCs and current policies emissions projections

Table C.1 Projected global GHG emissions of current policies for the four selected studies by 2030 (Original data). Source: based on IPCC AR6.

Studies	Kyoto GHGs[a] [GtCO_2-eq]			References
	2015	2019	2030 median (min - max)[b]	
Climate Action Tracker	51	53	54 (52–55)	Climate Action Tracker (2021)
PBL	52	54	58	den Elzen *et al.* (2022)
JRC GECO	51	53	57	Keramidas *et al.* (2021)
ENGAGE[c]			57 (52–60)	Riahi *et al.* (2021)
Total	52	53	57 (52–60)	

Notes: [a] GHG emissions expressed in CO_2-eq emission using AR6 100-year GWPs. [b] If a range is available from a study, a median is provided in addition to the range. [c] range includes estimates from four models GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE based on sensitivity analysis.

Table C.2 Projected global GHG emissions by 2030 of new and updated NDCs for the four selected studies by 2030. (Original data) Source: updated from IPCC AR6.

Studies	Kyoto GHGs[a] [GtCO_2-eq]		References
	Unconditional NDCs	Conditional NDCs	
Climate Action Tracker	49	46	Climate Action Tracker (2021)
PBL	53 (51–55)	51 (49–53)	den Elzen *et al.* (2022)
JRC GECO		48	Keramidas *et al.* (2021)
Meinshausen *et al.*	57 (56–57)	54 (53–55)	Meinshausen *et al.* (2022)
Total (Median estimate)	53 (49–57)	50 (46–55)	

Notes: [a] GHG emissions expressed in CO_2-eq emission using AR6 100-year GWPs.

Table C.3 Projected global GHG emissions of current policies by 2030 for the four selected studies after harmonization and adjusted to include the impact of Inflation Reduction Act in the USA.

Studies	Kyoto GHGs[a] [GtCO_2e]			References
	2015	2019	2030 median (min - max)[b]	
Climate Action Tracker	54	56	56 (54–58)	Climate Action Tracker (2021)
PBL	54	56	59	den Elzen *et al.* (2022); Roelfsema *et al.* (2022)
JRC GECO	54	56	60	Keramidas *et al.* (2021)
ENGAGE[c]	54	56	57 (52–60)	Riahi *et al.* (2021)
Median estimate	54	56	58 (52–60)	

Notes: [a] GHG emissions expressed in CO_2e emission using AR6 100-year GWPs (Forster *et al.* 2021). [b] If a range is available from a study, a median is provided in addition to the range. [c] range includes estimates from four models GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE based on sensitivity analysis.

Table C.4 Projected global GHG emissions by 2030 of new and updated NDCs for the four selected studies after harmonization, and adjusted to include the impact of the recent updated NDCs of certain G20 members (as of July 2022) after the cut-off date for five studies.

Studies	Kyoto GHGs[a] [$GtCO_2e$]		References
	Unconditional NDCs	Conditional NDCs	
Climate Action Tracker	52	49	Climate Action Tracker (2021)
PBL	55 (53–57)	54 (51–55)	den Elzen *et al.* (2022)
JRC GECO		51	Keramidas *et al.* (2021)
University of Melbourne	57 (56–58)	54 (53–54)	Meinshausen *et al.* (2022)
Median	55 (52–57)	52 (49–54)	

Notes: [a] GHG emissions expressed in CO_2e emission using AR6 100-year GWPs.

C.2 Net zero targets considered in global warming projections

Table C.5 Net-zero targets considered in temperature projections. If it is 'unclear' to which greenhouse gases the net-zero target is applicable to, the conservative assumption that it applies to CO_2 only is made. NZT = Net-Zero Target.

Country	*Net zero target*	
	Year	**Net zero target applicable to**
Argentina	2050	UNCLEAR
Australia	2050	GHG
Brazil	2050	UNCLEAR
Canada	2050	GHG
China	2060	UNCLEAR
European Union	2050	GHG
France	2050	GHG
Germany	2045	GHG
India	2070	UNCLEAR
Indonesia	2060	UNCLEAR
Italy	2050	GHG
Japan	2050	GHG
Mexico	No NZT	N/A
Republic of Korea	2050	GHG
Russian Federation	2060	UNCLEAR
Saudi Arabia	2060	UNCLEAR
South Africa	2050	CO_2
Türkiye	2053	UNCLEAR
United Kingdom	2050	GHG
USA	2050	GHG
Malaysia	2050	UNCLEAR
Nigeria	2060	GHG
Thailand	2050*	CO_2
Kazakhstan	2060	UNCLEAR
Ukraine	2060	CO_2
Vietnam	2050	UNCLEAR
Colombia	2050	GHG
UAE	2050	UNCLEAR
Chile	2050	GHG

Notes:

* Thailand's Long-Term Strategy (LTS) indicates net zero CO2 to be achieved by 2065 and net zero GHG emissions "as early as possible within the second half of this century". The COP26 announcement made by Thailand's PM overrides this LTS information and is used here instead.

* Some specifications in this table differ from table 3.4 but this does not result in a material difference in the findings.

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Appendix D

Supplementary material for chapter 5: Transformations needed to achieve the Paris Agreement in electricity supply, industry, buildings and transportation

D.1 Electricity supply

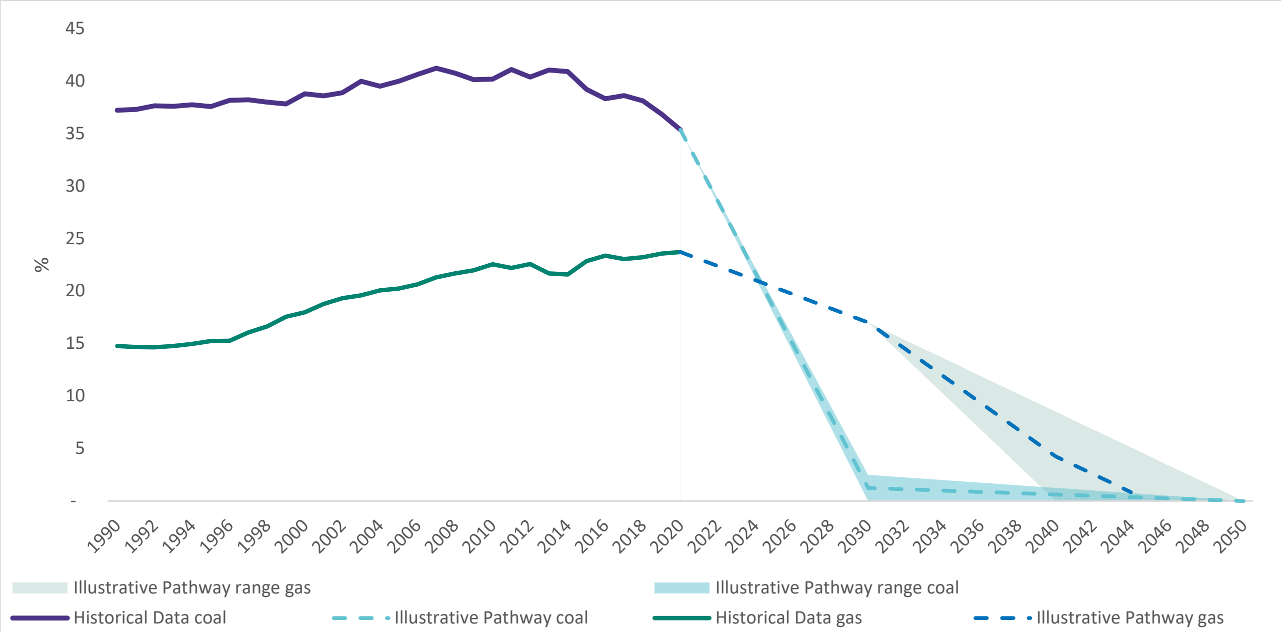
Limiting global warming to 1.5°C requires rapid global transformation of the power system, which is the single largest source of energy-related CO_2 emissions globally, covering 42 per cent of total energy-related emissions (IEA 2021c). At least four shifts need to occur to decarbonize power: (1) steeply accelerate the share of zero-carbon power in electricity generation; (2) phase out unabated coal and gas generation; (3) adapt grid/storage and demand management; and (4) ensure reliable energy access for all (Boehm *et al.* 2022).

(1) Steeply accelerate the share of zero-carbon power in electricity generation: To be aligned with 1.5°C, the literature suggests that the share of zero carbon power in electricity generation should be between 65 per cent and 92 per cent by 2030 and between 98 per cent and 100 per cent by 2050 (Monteith and Menon 2020; IEA 2021d; IRENA 2021; Boehm *et al.* 2022). . Renewable energy technologies like wind and solar are now the cheapest form of power generation in many places and are cheaper than running existing fossil fuel power plants in roughly half the world (Mathis 2021), regularly exceeding analysts' predictions (Way *et al.* 2022). Yet, far greater levels of investment and capacity are needed now and over the coming decades given the primary role renewables will play in achieving a zero-carbon power sector.

(2) Phase out unabated coal and gas generation: The literature suggests that the share of generation from unabated coal needs to fall to or near zero in 2030, requiring the pace of change to accelerate by about 6 times in the next 8 years (IEA 2021d; IRENA 2021; Boehm *et al.* 2022). The share of unabated coal in electricity generation increased from 37 per cent in 1990 to a peak of 41 per cent in 2011 and has since declined to 35 per cent in 2020, down slightly from 38 per cent in 2018. COVID-19 hit coal particularly hard—from 2019 to 2020, coal generation dropped 4.4 per cent, more than any other electricity source that year (IEA 2021b). However, data shows that coal generation rebounded quickly and already exceeded 2019-levels in 2021. While the International Energy Agency and the International Renewable Energy Agency have indicated that a 1.5°C pathway requires no new coal plants as of today, 457 gigawatts of new capacity is planned around the world (IEA 2021d; Global Energy Monitor *et al.* 2022).

Natural gas emits less CO_2 when burned than coal, but methane is released during production and distribution. The share of electricity generation from unabated gas has increased steadily from 15 per cent to 24 per cent between 1990 and 2020 (IEA 2021b; IEA 2022b). Gas-fired power generation only fell by 2 per cent in 2020 and has mostly recovered (IEA 2021b). Several governments have accelerated new gas infrastructure as a response to the war in Ukraine (Climate Action Tracker 2022). But to be aligned with 1.5°C, the share of generation from unabated natural gas needs to fall to 17 per cent in 2030 before being phased out by 2040-2050, requiring a turnaround from its current upward trend (IEA 2021b; IRENA 2021; Boehm *et al.* 2022).

Figure D.1 Share of unabated coal and fossil gas in electricity generation



Sources: Historical Data: IEA (2022b); Targets: Climate Action Tracker (2020), IEA (2021d); IEA (2021c); IRENA (2021); Boehm *et al.* (2022)

(3) Adapt grid/storage and demand management: A decarbonized power system relying primarily on renewables will require different grid systems than we have today. Flexibility will be key in decentralized supply, storage and demand, given the characteristics of wind and solar (IRENA and IEA Energy Technology Systems Analysis Programme 2015).

(4) Ensure reliable energy access for all: Currently, 10 per cent of the world's population has no access to electricity and over 40 per cent has unreliable access (Ayaburi *et al.* 2020; World Bank 2022). Ensuring universal energy access must be part of the shift to a global clean energy system. The health impacts of using dirty fuels for cooking and lighting the home is felt particularly by women and young children.

D.2 Industry

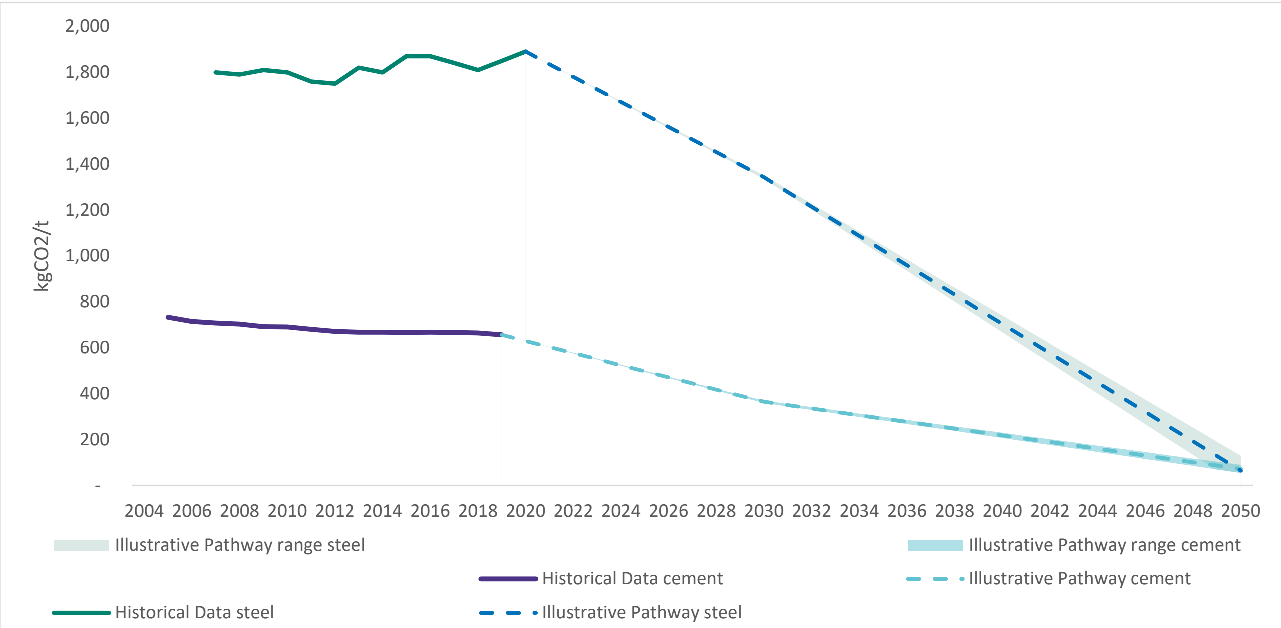
The industry sector is the largest contributor to global emissions when including direct and indirect emissions, and the second largest contributor when only considering direct emissions (IPCC 2022). To date, efforts to decrease emissions have mainly focused on improved energy efficiency and application of best available technologies. As most industrial processes have already reached maximum theoretically attainable energy efficiency, the key transformations needed to bring the industry sector to a 1.5°C-compatible pathway include (1) electrify industry, transform production processes using (2) new fuels and (3) solutions for hard-to-abate sectors, (4) accelerate material efficiency and scale up energy efficiency everywhere and (5) promote circular material flow.

(1) Electrify industry: To get on track to the Paris Agreement, the share of electricity in industry's final energy demand needs to increase to 35 per cent in 2030 and 50-55 percent in 2050 (Climate Action Tracker 2020). The share of electricity reached 28.5 per cent in 2019 but decreased slightly to 28.4 in 2020 (IEA 2021b). Historically, electrification in the industry sector has targeted machine drives, but there is room for more electrification in the near term if efforts are placed on low- to medium temperature heat, of which only small shares globally have been electrified to date (Wei, McMillan and de la Rue du Can 2019).

(2) Reduce demand for and decrease carbon intensity of global cement and steel production: Demand reduction, substitution and carbon management are crucial to decarbonize the industrial sector. The carbon intensity of global cement production needs to be reduced by 40 per cent from 2015 levels by 2030 and at least 85-91 per cent by 2050 (Climate Action Tracker 2020). Although the intensity has declined historically, the decline slowed down in recent years, reaching near stagnation (Global Cement and Concrete Association [GCCA] 2021; IEA 2021a). To reach the 2030 target the pace of decline needs to increase by a factor of 11. Demand reduction can be achieved through more intensive use of products, extending manufactured product service lifetime, lifestyle choice for less building space, cars, among other interventions. Emissions related to cement production could be reduced faster by improving the clinker-to-cement ratio, switching to low-carbon fuels and by increasing the rate of supplementary cementitious materials. However, more innovative solutions must be developed to reduce emissions to zero in the longer term as demand is projected to increase in some parts of the world (Teske, Niklas and Talwar 2019).

The carbon intensity of global steel production needs to be reduced by 25-30 per cent from 2015 levels by 2030 and 93-100 per cent by 2050 (Climate Action Tracker 2020). The carbon intensity of steel production has fluctuated in recent years and even increased from 2018-2020 (World Steel Association 2021) to levels above those of 2015. The ramping up of coal-based blast furnace-produced steel, mainly in China in 2020, was a major driver behind recent increased emissions. To decrease steel production-related emissions, the growth in blast furnace capacities needs to be stopped and development of new innovative production methods for primary steel without CO_2 emissions, such as Hydrogen Direct Reduction or electrolytic reduction of ores, needs to be accelerated. Steel demand can be reduced by new light weight equipment, vehicles, long lived appliances /infrastructure design, by promoting sharing economy both steel and cement demand can be reduced (IPCC 2022) as nearly half of the steel produced is used in transport equipment manufacturing, and domestic appliances (Teske and Pregger 2022).

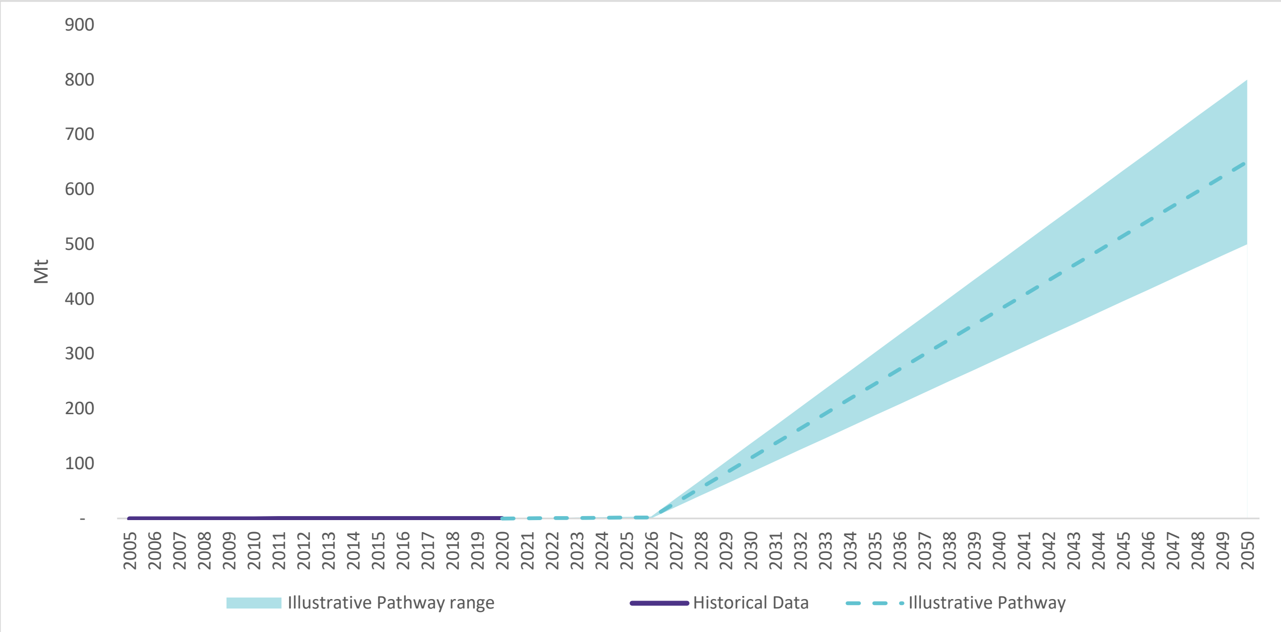
Figure D.2 Carbon intensity of global cement and steel production



Source Historical Data: GCCA (2021); IEA (2021b); World Steel Association (2021); Targets: CAT (2020)

(3) Grow and integrate green hydrogen production capacity: There is vast potential for green hydrogen to help decarbonize several sectors, especially the hard-to-abate energy-intensive industry sectors that cannot use electricity. Green hydrogen production capacity needs to grow to 0.23-3.5 Mt (25 GW cumulative electrolyze capacity) by 2026 (in order to achieve costs below US$2/kg) and then massively scale up to 500-800 Mt (2,630 - 20,000 GW cumulative electrolyser capacity) by 2050 (UNFCCC 2021), up from almost zero today (IEA 2022a). Green hydrogen production is still an emerging technology and based on electrolyser capacity already under construction, global installed electrolyser capacity fed by renewable-based power generation could reach 26.6 GW in 2026, which would be in line with the 2026 benchmark.

Figure D.3 Green hydrogen production



Sources: Historical Data: IEA (2022a); Targets: UNFCCC (2021)

(4) Accelerate and scale up material and energy efficiency: Demand for materials has grown 2.5-3.5 fold over the past 25 years (Bashmakov *et al.* 2022). Use of manufactured materials like steel, cement, plastics, glass, aluminum, and copper is rising in all regions globally. Material processing and rising demand are the main drivers of industrial emissions. Extraction of basic materials in this century is 13 times higher than in the beginning of the last century (IPCC 2022). Basic materials production leads to increases in both direct and indirect emissions. Supply side interventions include changing the material intensity of the product used. While energy efficiency contributed substantially towards decoupling GHG emissions from industrial output production on energy use for over a century (Saunders *et al.* 2021) , material efficiency has not contributed much but has potential to accelerate in coming decades (Bashmakov *et al.* 2022).

(5) Promote circular material flow: Recycling of waste materials helps to reduce emissions but the growing complexity of product design and functionality increases the demand for materials. There are still huge gaps and regional variations in recycling. The rate of recycling across various metals vary from 20 to 85 per cent, and the recycling rate of end of life waste from industrial material produced is very low at ~10 per cent (IPCC 2022; Teske and Pregger 2022).

D.3 Transportation

Transportation is the second-largest source of energy-related CO_2 emissions globally, contributing 25 per cent of total energy-related CO_2 emissions (IEA 2021c). Transformation of the transportation system requires a number of shifts: (1) shift to low-emitting modes, (2) accelerate the move to zero-carbon cars and trucks, and (3) prepare the move to zero-carbon aviation and shipping. In addition, car and plane use by frequent travelers should be abated. These shifts should be promoted simultaneously, and many actions can address more than one shift.

(1) Shift to low-emitting modes of transport: A significant shift to lower emitting modes, including public transport, walking and cycling is required alongside electrification of transport modes to align with a 1.5°C pathway (Institute for Transportation and Development Policy and University of California Davis 2021). Currently, private light-duty vehicles make up 53.2 per cent of all trips (International Transport Forum 2021). To align with a 1.5°C pathway, the number of trips made by private light-duty vehicles need to decrease by 4-14 per cent below business-as-usual levels by 2030. The number of kilometers of public transit per 1,000 inhabitants must be doubled 2030, while the number of kilometers of high-quality bike lanes per 1,000 inhabitants should be increased five-fold by 2030 (Transformative Urban Mobility Initiative 2021; Boehm *et al.* 2022). Increased spending on alternative modes can help incentivize a mode shift, as it is tied to infrastructure availability (Graham-Rowe *et al.* 2011). Alongside increasing access to public transport, parking fees, penalties for polluting vehicles, and road fees that internalize the negative externalities imposed by fossil fuel-powered cars encourage more efficient and healthier travel.

It is important to note that increasing fees and penalties can disproportionately burden low-income groups who do not have other options and have a harder time shouldering the increases. For this reason, it is key that active transportation modes such as walking or cycling and public transportation such as buses and trains are available, convenient, and affordable so that travelers can choose these options and not be overburdened by increasing costs.

(2) Accelerate the move to zero-carbon cars and trucks: Light-duty electric vehicles (EVs) sales reached 8.3 per cent of total sales in 2021 (Irle 2021). The literature suggests that this needs to increase to between 35 per cent and 95 per cent by 2030[1] and reach 100 per cent by 2035, requiring an increase in the rate of change by 1.8 to 6 times in the next 8 years (ICCT, 2021; IEA 2021d; IRENA 2021; Boehm *et al.* 2022). The share of light-duty EVs on the road need to increase from current levels of only 0.55 per cent to (BloombergNEF 2022) between 20 and 40 per cent in 2030 and between 75 and 100 per cent by 2050 (IEA 2021d; Boehm *et al.* 2022; Cheung and O'Donovan 2022) An increasing number of countries and auto companies have set goals to reach 100 per cent zero-emission cars and vans, including a major commitment at COP26 (BloombergNEF 2018; Austria *et al.* 2021).

While cars and trucks contribute almost 75 per cent of transportation emissions (IEA 2020a) they do not dominate personal travel across the world. In some parts of the world, especially in Asia, two- and three-wheelers are much more prominent than cars and vans. These vehicles do not contribute as much to greenhouse gas emissions, but they contribute to local air pollution. Countries such as India have made progress electrifying their two- and three-wheeler markets in recent years (Express Drives Desk 2022).

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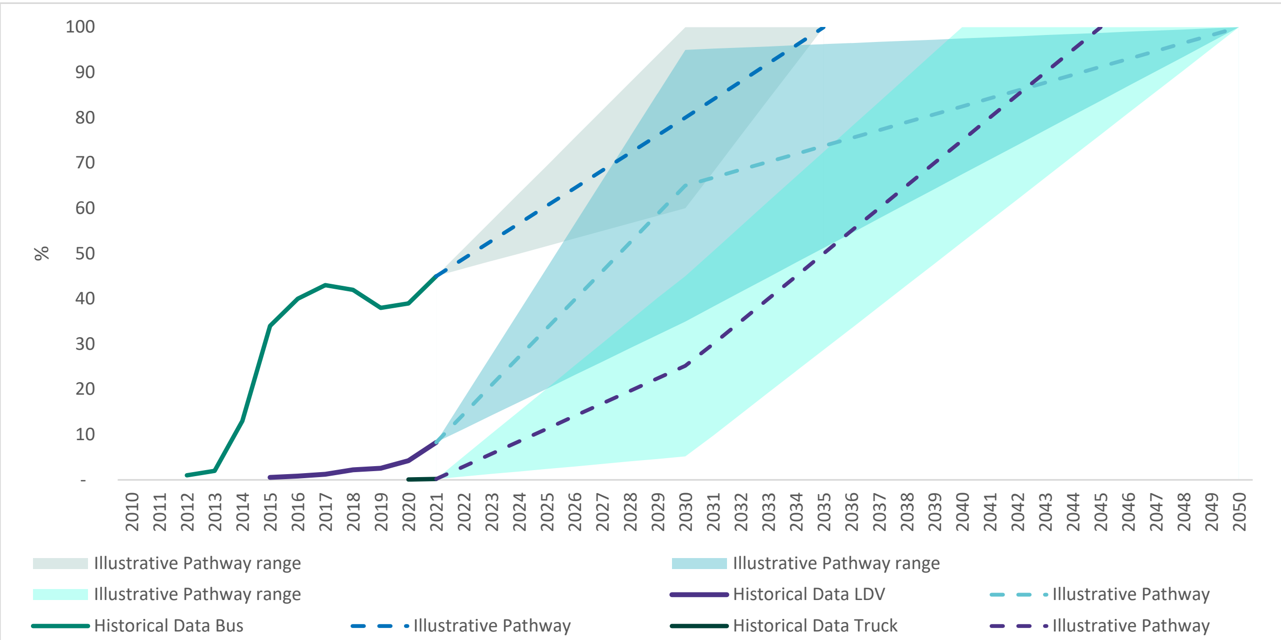
[1] There is a wide range of 2030 targets in the literature: 33 per cent (IRENA), 35 per cent (ICCT), 64 per cent (IEA), 75-95 per cent (WRI, NewClimate, and Climate Analytics, 2022).

Heavier vehicles including buses and medium- and heavy-duty vehicles should be decarbonized too. Buses have proven to be a success story for vehicle electrification, reaching a high of 43 per cent of bus sales in 2017, driven largely by demand in China (BloombergNEF 2021). However, sales have slowed since then, falling to 39 per cent in 2020. The literature suggests that a 1.5°C-aligned pathway demands increasing the share to 60-100 per cent in 2030 and 100 per cent in 2050 (International Council on Clean Transportation 2021; IEA 2021d; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022). Zero-carbon options in the medium- and heavy-duty vehicles (MHDVs) segment have only just begun to hit the market, reaching 0.2 per cent of sales in 2020 (BloombergNEF 2021). The literature suggests that alignment with a 1.5°C pathway requires electric and fuel cell MHDVs to reach between 5 per cent and 45 per cent of sales in 2030 and 100 per cent between 2040 and 2050 (IEA 2021d; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022; Xie, Dallmann and Muncrief 2022). Heavier vehicles face upfront cost barriers but are set to be just as cheap to own and operate as their fossil fuel powered counterparts over the next few years in some parts of the world (Basma, Saboori and Rodriguez 2021). Zero-emission buses face several challenges, including upfront cost premiums and decision makers lacking sufficient information (Li *et al.* 2019). Fortunately, the economics of zero-emission buses are expected to reach price parity with diesel buses in some parts of the world by 2030 (BloombergNEF 2018), and as adoption is increasing, cities are sharing their learnings about the procurement process and the operational performance of their zero-emission buses (Li *et al.* 2019).

Figure D.4 Share of electric vehicles in light-duty vehicle, bus, and medium- and heavy-duty vehicles sales



Sources: Historical Data: Bloomberg NEF (2022); Targets: CAT (2020); IEA (2021d)

Transformation to zero-carbon aviation and shipping: As economic activity recovers from the COVID-19 pandemic, greenhouse gas emissions from aviation and shipping are expected to resume growth. Electrified aircraft including electric or hydrogen-fueled planes will play an important role, but sustainable aviation fuels (SAFs) - including drop-in e-fuels produced with additional renewable electricity - will also play a part and are already in the market. SAFs today are mostly biofuels and have only recently begun to penetrate the market, contributing less than 0.1 per cent of global aviation fuel consumption in 2020 (Air Transport Action Group 2021). The literature suggests that reaching 1.5°C requires SAFs to meet 13-18 per cent of aviation fuel needs in 2030 and 78-100 per cent in 2050, requiring a significant increase in uptake (IEA 2021d; University Maritime Advisory Services 2021;

Boehm *et al.* 2022; Graver *et al.* 2022). Maritime shipping faces similar problems with a dearth of options for decarbonization outside zero-emissions fuels. Vessels have not yet begun to use zero-emissions shipping fuels, but the literature suggests they will need to meet 5-17 per cent of maritime shipping needs in 2030 and 84-93 per cent by 2050 (IEA 2021d; Boehm *et al.* 2022). The European Union's ReFuel EU mandate will require SAFs to meet an increasing portion of aviation fuel use through 2050 and the FuelEU program will implement similar requirements for zero-emission shipping fuels (European Council 2022). More requirements such as these can help create demand for these fuels.

While greenhouse gas emissions have global effects, it is important to consider that the sources are not equally distributed. This is especially true for aviation. In 2018, only about 2-4 per cent of the global population flew internationally (Gössling and Humpe 2020). Furthermore, high-income countries are responsible for the largest share of aviation emissions — the U.S. alone contributes about 23 per cent. The next largest emitter is China, at just over 10 per cent. When considering interventions to address aviation emissions, actors should understand where demand reduction, operational adjustments, and new technologies can make the most difference without disproportionately burdening populations who are already not contributing to aviation emissions.

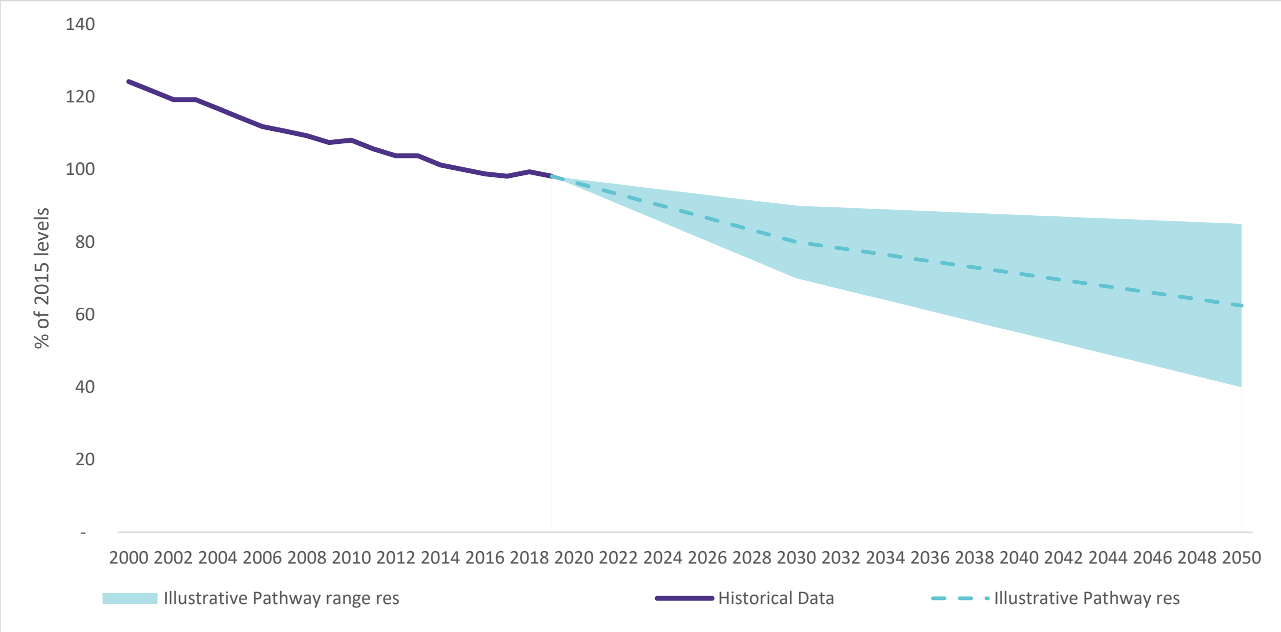
D.4 Buildings

Buildings play a crucial role in people's wellbeing. Heating and cooling (space and water) and appliances (including cooking, lighting, and electronics) consume large amounts of energy and emit GHG emissions. Direct emissions through building operations are relatively small compared to other sectors and estimated at 5 percent of global GHG emissions, but this number increases to 17 per cent when accounting for indirect emissions from electricity and heat consumption (IPCC 2022). While direct emissions have remained relatively stable at 3 Gt CO_2 /year, indirect have almost doubled since 1990 (IEA 2020b). To decrease emissions in the building sector, four major shifts are necessary: (1) excess floor area has to be minimized, (2) energy intensity needs to be reduced, (3) emissions intensity of energy use needs to decline, and (4) embodied emissions from construction need to be reduced (Boehm *et al.* 2022).

(1) Reduce excess floor area: Energy use and emissions from space and water heating and cooling are directly linked to the total amount of floor area that undergoes active thermal control. Furthermore, the greater the extent of new floor area that is constructed, the more materials are required and the higher the embodied emissions. The amount of floor area used per person is vastly different across countries but also within a country. Minimizing the amount of floor area that is well above that needed to meet basic needs can have a large effect on emissions in the sector. Floor area per capita is closely linked to wealth, and it is recognized that floor area per person can increase in developing countries. If more affluent citizens reduce the floor area they inhabit, it could have direct effects in reducing overall emissions in the building sector.

(2) Reduce energy intensity of buildings: The energy intensity of building operations, in other words the energy that is used for heating, cooling and appliances per square meter of floor area, should decrease globally by 10-30 per cent in commercial and 20-30 per cent in residential buildings, relative to 2015 levels by 2030 (Climate Action Tracker 2020). Global average energy intensity in buildings reduced by 19 per cent between 2000 and 2015 but the reduction has slowed down in recent years with only an additional 2 per cent between 2015 and 2019 (Boehm *et al.* 2022). A faster decline in energy intensity is possible through the use of more efficient technologies but also by improving building structures and reducing the need for heating and cooling, for example by making buildings more energy efficient (Climate Action Tracker 2020). Local climates determine needs for thermal regulation and vary substantially across the globe meaning that both the current energy intensity of buildings and the required reductions also vary substantially. Other energy demand activities, namely appliance use and lighting, are more closely related to wealth and minimizing growing energy demand while meeting needs can be met with use of highly efficient appliances.

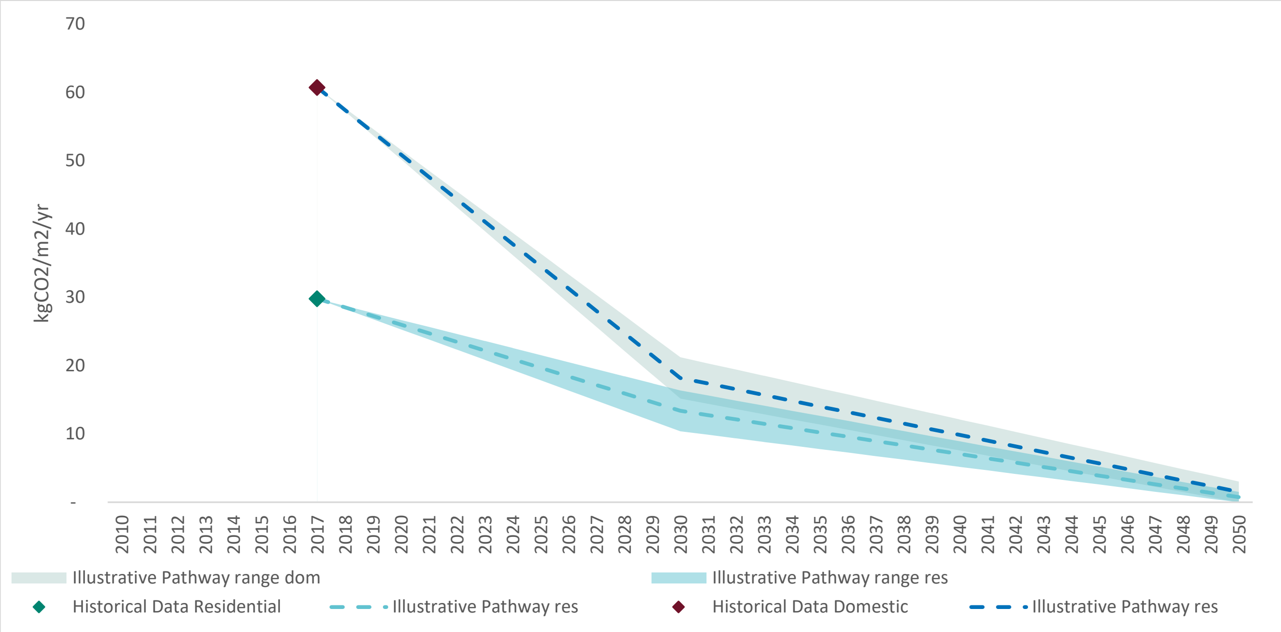
Figure D.5 Energy intensity of building operations



Sources: Historical Data: (Boehm *et al*. 2022); Targets: CAT (2020)

(3) Reduce emissions intensity of energy use in buildings: Emissions intensity, or the amount of CO_2 emitted per floor area, is related to energy intensity but adds the decarbonization factor, meaning that a switch from fossil fuels to electric power (sourced by renewable energy) is needed. In buildings, this entails installing and replacing cooking and heating devices with cleaner technologies, such as heat pumps instead of oil or gas heating or district heating in dense urban areas (Climate Action Tracker 2020). Emissions intensity in buildings should be reduced by 45-65 per cent for residential buildings and 65-75 per cent for commercial buildings compared to 2015 levels by 2030 and 95-100 per cent by 2050 (Climate Action Tracker 2020). Although emissions intensity has decreased steadily the pace needs to be accelerated to meet the targets (Boehm *et al.* 2022).

Figure D.6 Carbon intensity of building operations



Sources: Historical Data: Boehm *et al*. (2022); Targets: CAT (2020)

(4) Reduce emissions from construction: Producing materials, such as steel, cement, and concrete, to construct buildings is a highly energy and emissions intensive process. While measures to reduce the emissions intensity of these materials should be pursued (see section on industry above), further reductions can be achieved by more efficient use of these materials. This can include reconstruction of existing buildings (rather than demolition and new construction), minimizing the volume of materials required, and substituting alternative construction materials (Energy Transitions Commission 2019). Integrated planning and design can be used to minimize energy demand throughout the building construction phase, including transport and on-site energy use. Furnishing the interior of buildings can also be energy intensive with circular economy principles providing opportunities for lifecycle emissions reductions.

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Appendix E

Supplementary material for chapter 6: Transforming Food Systems

E.1 Regenerative Agriculture

The aims most often associated with Regenerative Agriculture are the restoration of soil health, the capture of carbon to mitigate climate change, and the reversal of biodiversity loss (Giller *et al*. 2020; Newton *et al*. 2020). Tentative definitions (Schreefel *et al*. 2020) suggest it is "an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production." However, since the term was first popularized in the 1980's, a clear operational definition of regenerative agriculture has often been lacking (Soloviev and Landua 2016; Merfield 2019).

The practices most often associated with Regenerative Agriculture include an emphasis on zero or low external inputs, the integration of livestock, a lack of synthetic fertilizers or pesticides usage, a reduction or elimination of tillage, and the use of cover crops (McGuire 2018; Burgess *et al*. 2019; Merfield 2019; Giller *et al*. 2020). From a climate change perspective, most attention surrounding Regenerative Agriculture has been on its claims of sequestering carbon in the soil. However, the degree to which soil carbon sequestration is possible depends on the type of soil and its starting condition. For example, a fertile soil under continuous cultivation is often close to its carbon saturation potential (Six *et al*. 2002), with little potential for further sequestration (Stewart *et al*. 2007; Smith 2014; Poulton *et al*. 2018). Low-yielding soils therefore have the greatest potential to increase soil carbon (van der Esch *et al*. 2017), but such increases have been shown to be temporary as accumulation attenuates and a new equilibrium is reached (Baveye *et al*. 2018).

Despite the claims that the practices of Regenerative Agriculture could sequester more carbon than is currently emitted (Moyer *et al*. 2020) and "has the potential to reverse climate change" (Kastner 2016), case studies suggest a more modest potential. For example, a case study from China (Gao *et al*. 2018) found that crop rotation and other management practices led to an amount of soil carbon sequestration that compensated about 10 per cent of agricultural GHG emissions, but this was outweighed by the GHG emissions associated with those practices themselves. In particular, the reliance on livestock and on manure as fertilizer can be seen as counterproductive for GHG mitigation: compared to mineral fertilizer, the use of manure has been shown to increase nitrous oxide emissions by about a third (Zhou *et al*. 2017), which is enough on its own to offset any soil carbon sequestration. Studies also suggest that large-scale conversions to regenerative-agriculture practices such as organic are only feasible in conjunction with major dietary shifts towards less resource-intensive diets that are more plant-based (Erb *et al*. 2016; Muller *et al*. 2017; Hayek and Garrett 2018).

Given Regenerative Agriculture's likely modest contributions to GHG mitigation, academic discussions have called for increased scrutiny of the term to prevent the often-outsized claims by industry and the potential for "green washing" (Goswami *et al*. 2017; Giller *et al*. 2020; Newton *et al*. 2020). At a minimum, they suggest to clearly define the term and intended purpose, outline the mechanisms by which any declared goal will be achieved, and discuss whether the described set of practices can be integrated in a context-specific manner. This is particularly important in the context of several countries and regions having recently started to include regenerative agriculture in their climate policies (e.g., Japan, Canada, Uruguay, Namibia), and started incentivizing its practices (e.g., New Zealand and the state of California in the US).

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