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Bridging the gap: Sectoral greenhouse gas mitigation potentials in 2035

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Acknowledgements
Authors: Evelien Smit (Common Futures), Tash Garrood (Common Futures), Kornelis Blok (Independent), Stephanie Roe (WWF), Chris Bataille (Columbia University)
Supported and Reviewed by: Anne Olhoff (UNEP-CCC), John Christensen (UNEP-CCC), Kees van der Leun (Common Futures), Alice Favero (RTI), Robert Beach (RTI), and Kemen Austin (Wildlife Conservation Society), Ruta Bubniene (Secretariat of the United Nations Framework Convention on Climate Change [UNFCCC]), John Christensen (UNEP Copenhagen Climate Centre [UNEP-CCC]), María Paz Cigarán (Libélula), Navroz K. Dubash (Princeton University), Simon Evans (Carbon Brief) (steering committee observer), Niklas Höhne (NewClimate Institute), Fuad Humbatov (Ministry of Ecology and Natural Resources, Azerbaijan), Jian Liu (UNEP), Simon Maxwell (independent), Shonali Pachauri (International Institute for Applied Systems Analysis [IIASA]), Katia Simeonova (independent researcher), Youba Sokona (Intergovernmental Panel on Climate Change [IPCC]), and Oksana Tarasova (World Meteorological Organization [WMO])
Graphic design & Layout: Monna Hammershøy Blegvad

Executive Summary

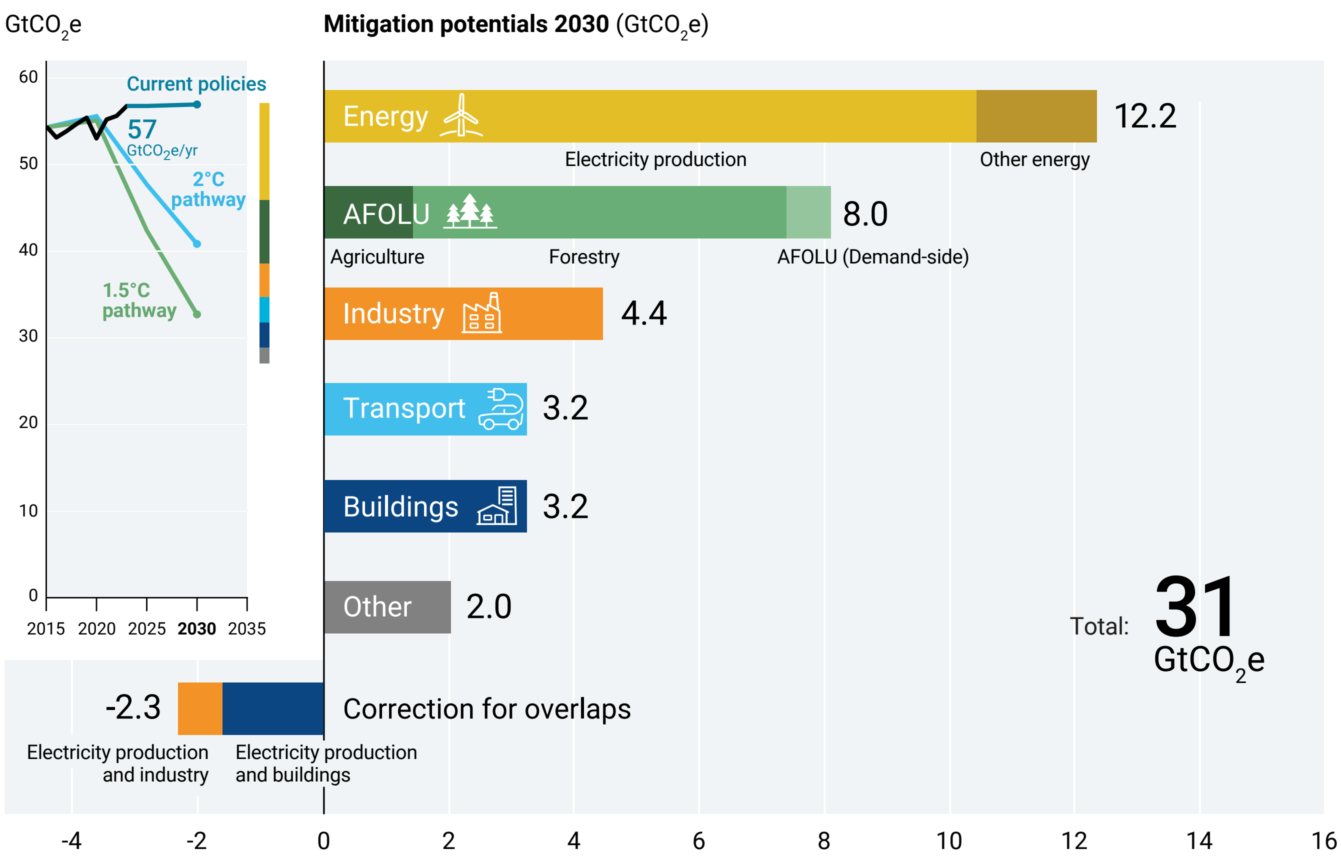
This report was developed in support of the 2024 Emissions Gap Report (EGR) of UNEP. It provides the analysis and findings that are used as background for the development of Chapter 6 of the EGR 2024: "Bridging the gap: Sectoral transformations, benchmarks, potentials, and needed investments".

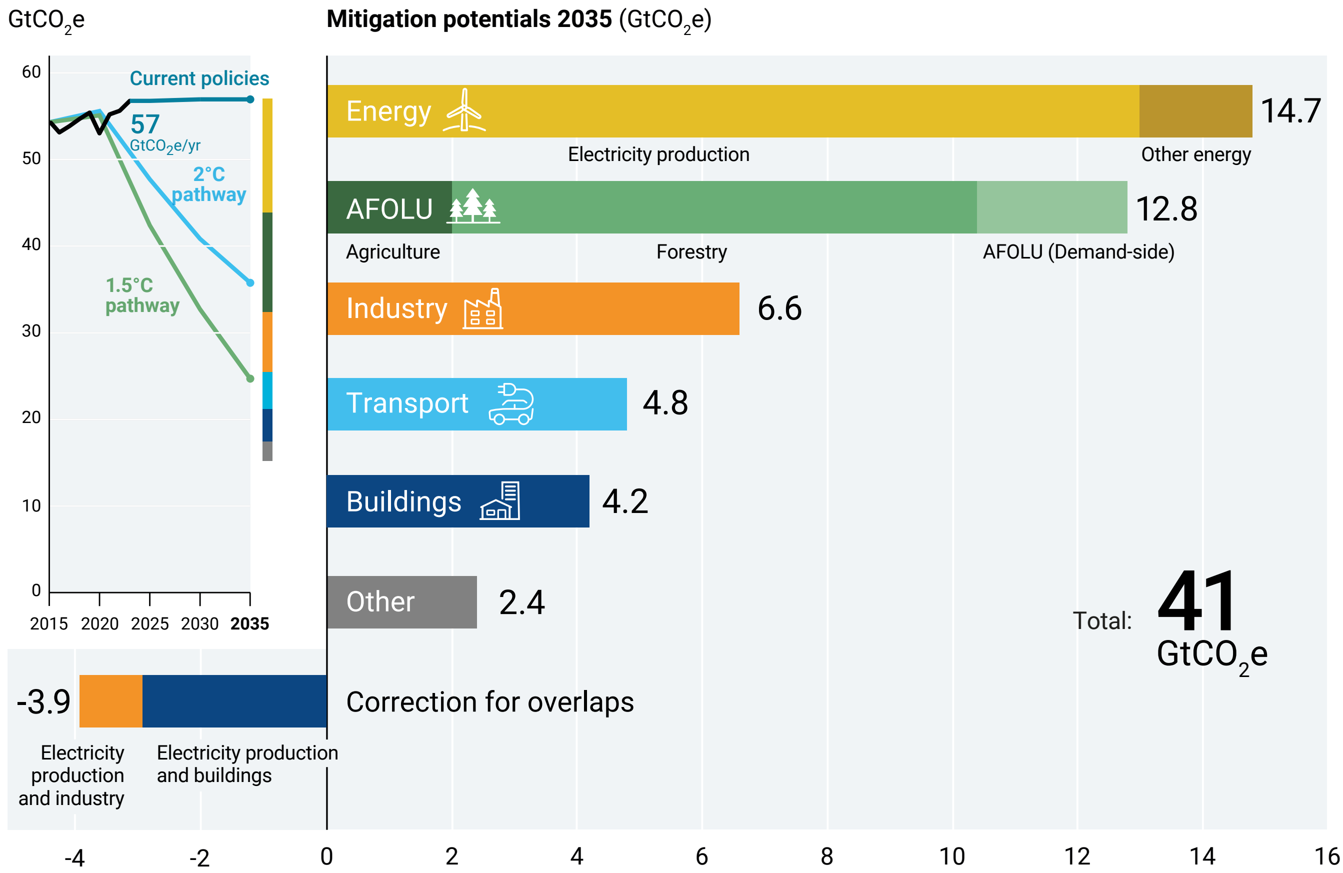
The report addresses two critical questions: can the emissions gap identified for 2030 and 2035 be bridged, and what are the most promising mitigation options to do so? To answer these questions, a comprehensive sectoral analysis has been conducted, focusing on energy, industry, agriculture and forestry, buildings, transport, and waste management. For each sector, the report assesses the expected emissions in 2030 and 2035 under current policies and identifies the additional techno-economic mitigation potentials available by these years.

The mitigation potentials assessed reflect the reductions achievable using technologies available by 2035 at a cost of up to 200 USD/tCO_{2e}.

Key findings indicate that by 2030, the identified mitigation potential is 31 GtCO_{2e}, with an uncertainty range from 25-35 GtCO_{2e}. For 2035, the mitigation potential is estimated to be 41 GtCO_{2e}, with and uncertainty range from 36-46 GtCO_{2e}. The mitigation potential well exceeds the emissions gap for both years identified in the 2024 Emissions Gap Report (UNEP, 2024), being 24 GtCO_{2e} (uncertainty 20-26 GtCO_{2e}) in 2030 and 32 GtCO_{2e} (uncertainty 20-37 GtCO_{2e}). But it evidently faces several real-life challenges in terms of actually realizing the potential. The sectoral emission reduction potentials for 2030 and 2035 at the global level identified in this study are presented in Figure 1.

Figure 1. Sectoral emission reduction potentials at the global level compared to the total emissions gap in 2030 and 2035. Uncertainty ranges for these data are provided in the report.





The findings emphasize the role of energy sector decarbonisation, with solar and wind energy providing the highest mitigation potential, followed by measures in agriculture and forestry. The transport sector also offers substantial opportunities for mitigation through a shift to electric vehicles, sustainable fuel adoption, and behavioural changes such as increased use of public transport and cycling. Industry and buildings sectors contribute through energy efficiency improvements, material efficiency, cementitious material substitution, and increased electrification.

Achieving these potentials would require rapid and decisive policy action, particularly in addressing barriers such as technology development, governance, and finance. The report concludes that, with rapid and decisive policy implementation, the emissions gap for 2035 can be bridged, contributing significantly to global climate goals. But this would require a dedicated global effort of an unprecedented magnitude.

Table of Contents

1. Introduction

The objective of this report is to address two main questions: can the emissions gap in 2030 and 2035 – as identified in Chapter 4 of the Emissions Gap Report (UNEP, 2024) - be bridged, and if so, what are the most promising options to do so? To answer these questions, a comprehensive analysis was conducted across several sectors: Energy, Industry, Agriculture & Forestry, Buildings, Transport and Other (namely, waste management and mitigation options that span multiple sectors). For each sector expected emissions in 2030 and 2035 according to current policies were assessed, as well as additional mitigation potentials of various measures available and achievable by that year.

Mitigation potentials are the quantity of greenhouse gas emission reductions or removals that can be delivered by a given mitigation option in a specific period relative to specified emission baselines (IPCC, 2022b, Glossary), and it can be estimated as the reductions possible given current technology (technical potential), with selected cost constraints (economic potential), and with reflections on other political and sustainability constraints. This assessment provides economic potentials for mitigation options available up to 200 $/tCO_{2e}$[1], considering internal monetary costs and savings (e.g. costs of equipment and benefits due to saved energy), but excluding external costs and benefits, like the costs due to climate change impacts.

The report provides policymakers with a granular overview of where policies can be best applied to achieve maximum climate mitigation impact. It builds on earlier efforts (Blok et al., 2017; UNEP, 2017, Chapter 4; IPCC, 2022b, Section 12.2) that estimated mitigation potentials for the year 2030. In this report, the analysis estimates focus on 2035 and where available 2040. The year of 2035 was chosen as a primary target year because, while a great deal of data already exists for what is achievable by 2030, there is still limited research looking at 2035.

This I also a reflection of the room for action by 2030 will be gradually closing, while much can be implemented over the next decade. The report is also aiming to inform the new NDCs to be submitted in 2025, which will include targets for 2035.

The mitigation potential assessment in this report relies on many underlying literature sources, often with a focus on specific sectors, options or technologies. Each source has its own approach and methodology, including the use of different baselines. Estimates reflect global warming potentials with a 100-year time horizon (GWP100) for methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6)[2] using the IPCC AR6 values (IPCC, 2022b). Where necessary and possible, the assessment corrected for differences in methodologies and baselines to improve comparability. The current policy baseline reflects climate policy in place, where mitigation will already occur to a certain degree in 2030 and 2035. The mitigation potentials reported in this report show what is achievable beyond that level. The mitigation potentials of the individual options discussed in this report cannot be simply added together as they may interact, overlap, or compete with each other. Mitigation potentials in this report are expressed in $GtCO_{2e}$ and are intended to be valid for the specific year.

The report was developed in the context of the UNEP Emissions Gap Report (EGR) 2024. The results of this work are used in the development of Chapter 6 of the EGR 2024: "Bridging the gap: Sectoral transformations, benchmarks, potentials, and needed investments".

The report first summarizes the overall findings in Chapter 2. Chapter 3 presents the methodology behind the analysis. This is followed by a description of the baseline policy scenario in Chapter 4, which presents the projected emission trajectory towards 2030 and 2035 based on current policy. Chapter 5 presents the detailed sectoral analysis.

1 In a previous assessment (UNEP, 2017) a cut-off level of 100$/$tCO_{2e}$ was chosen, but (IPCC, 2022b, Table 12.3) showed that there is some interesting, though limited potential in the range between 100 and 200 $/$tCO_{2e}$. The cost analysis takes a social cost perspective, e.g. using a social discount rate. External costs and benefits are not taken into account. Cost levels are taken from the underlying studies as reported.

2 NF_3 is not included in this analysis, but total emissions and associated emission reduction potentials are expected to be small in absolute terms.

2. Main findings: Can the emissions gap be bridged with the available mitigation potential?

By the year 2035, we identify a total mitigation potential of 41 $GtCO_{2e}$ (uncertainty 36 – 46 $GtCO_{2e}$) across a range of measures (Figure 2), showing the emissions gap of 32 $GtCO_{2e}$ in 2035, as identified in Chapter 4 of UNEP's 2024 Emission Gap Report (UNEP, 2024), can be more than sufficiently bridged. The largest and most readily available potentials are found in increased deployment of solar PV and wind energy, and reduced CH_4 emissions from oil & gas in the energy sector, reduced deforestation, increased afforestation/reforestation, improved forest management in the land sector, a shift towards sustainable healthy diets, material efficiency, and fuel switching, electrification and efficiency in the energy demand sectors (Figure 2). Various measures, including in forests and other ecosystems, agriculture, energy, industry and waste, also provide benefits beyond mitigation, including cost savings, improving air, water and soil quality, and enhancing biodiversity and human wellbeing.

Mitigation potentials increase over time in most sectors, largely due to the longer period to implement measures. Although there are only 6 years left before 2030, we estimate that – with some exceptions[3] – most of the potential is still achievable by 2030, but it would require unprecedented rapid and strong policy implementation.

Effectively implementing mitigation measures and closing the emissions gap will require addressing barriers that hinder progress as well as enabling factors that support progress, including regulations, governance, finance, technology development, infrastructure, and private sector action. In the sectoral sections below, we provide an overview on the progress of implementation of the options and what is needed to accelerate their deployment.

The mitigation estimates in this report are different from previous assessments (see Table 1). Notable changes in mitigation potential are observed across various sectors, largely due to the higher carbon price threshold in this report (<$200/$tCO_{2e}$), changes in the progress of adoption of mitigation activities, and higher existing mitigation in the baseline scenarios.

The most significant difference is in the AFOLU (land) sector, with lower estimates for agriculture and forestry. This discrepancy is mostly because the IPCC estimates reflect average mitigation values for 2030-2050, and this report relies on a more limited set of updated data with higher levels of mitigation in the baseline and more conservative assumptions in agriculture mitigation.

One of the conclusions in the 6th assessment report of the IPCC (2022b) was that about half of the mitigation potential by 2030 can be achieved at low costs (<$20/$tCO_{2e}$). Beyond estimating potentials available with costs up to $200/$tCO_{2e}$,[4] a deeper analysis of mitigation costs is beyond the scope of this assessment. However, it is considered likely that the IPCC finding is also valid for the potentials identified in this assessment. There will be modest developments towards either lower or higher costs of mitigation. For solar and wind energy, further cost declines can be expected. This may be partly offset by the additional costs of integrating high shares of variable energy sources into power systems (Brown et al., 2018; IEA, 2024d). Electrification, for example in transport, can also lead to lower costs. In the industry sector we see a higher emission reduction potential; industrial facilities typically take 5-10 years to plan, permit, finance and build, so larger near zero emitting potentials become possible in the early to mid-2030s. However, this higher emission reduction potential comes with a modest shift to higher-cost categories.

3 Examples of these are options that have long project implementation times (like nuclear power plants) and options that rely on replacement of the capital stock (e.g. new buildings that are not constructed in an energy-efficient way will be difficult to retrofit).

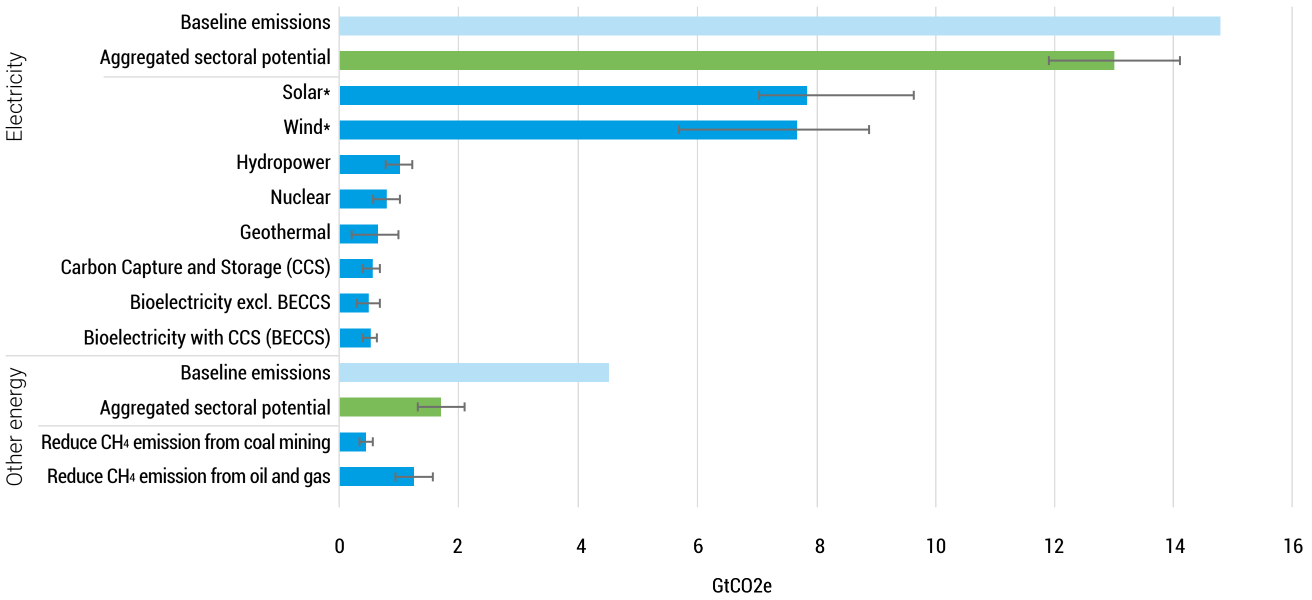
4 In this assessment, we added the cost category of 100-200 US$ per tonne CO_{2e}, but the share of mitigation potential in this category is limited, about 10% (based on IPCC, 2022b, Table 12.3).

Figure 2. Summary of annual mitigation potential by abatement measure by 2035 up to 200 $/tCO$_{2e}$.

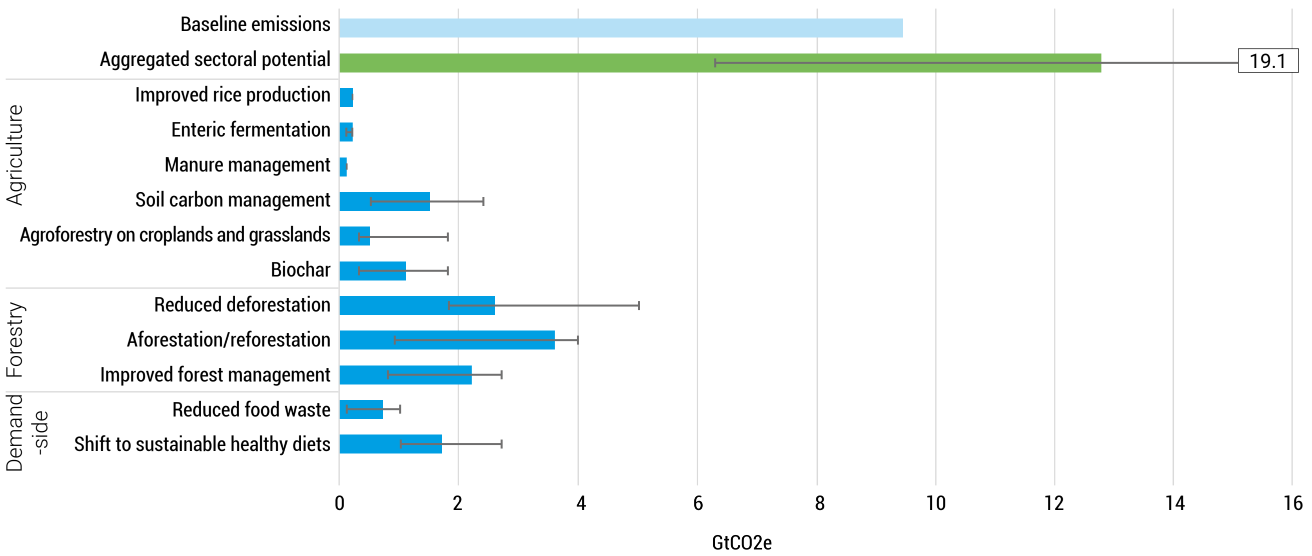
Each abatement measure relies on different methodologies and assumptions, including baselines, therefore these values cannot be summed directly to calculate the total reduction potential as some may overlap. Also note that the overall emission reduction potentials can be compared with the findings in SPM.7 in the IPCC AR6 report (2022b), but that an extended analysis of mitigation costs is beyond the scope of this assessment.

**The potentials of mitigation options marked with an asterisk (*) may be higher than reported here. For solar PV and wind in the electricity sector, studies report higher potentials in the case of extensive electrification of the energy system. For appliances in the building sector, a recent study by IEA suggest double this mitigation potential but precise baseline emissions are not available. For EVs, the mitigation potential is based on IEA's (2024c) recent Global EV Outlook, which uses lower baseline emissions compared to Chapter 4 of the 2024 Emissions Gap Report (UNEP, 2024).*

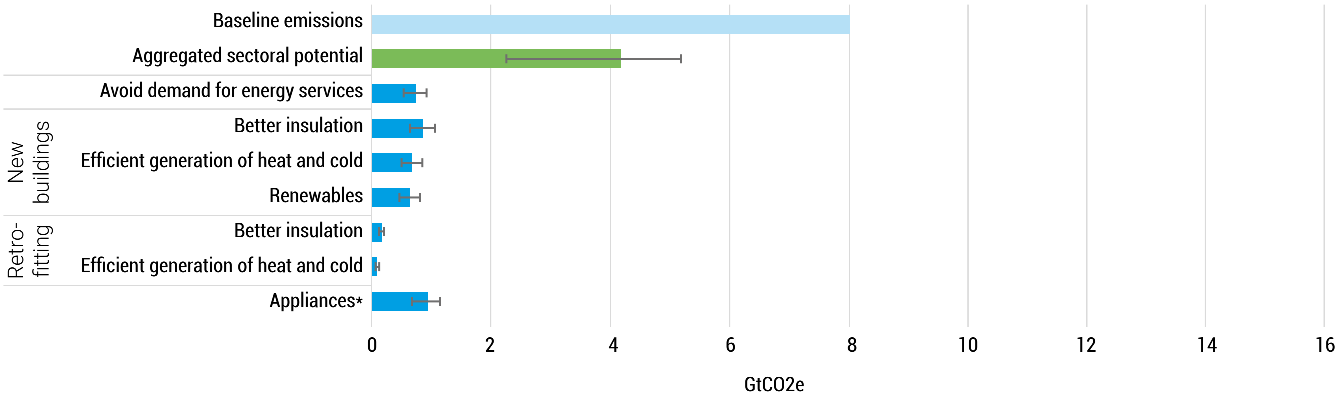
2035 emission reduction potentials of all mitigation measures explored in the ENERGY SECTOR, indicating error margins



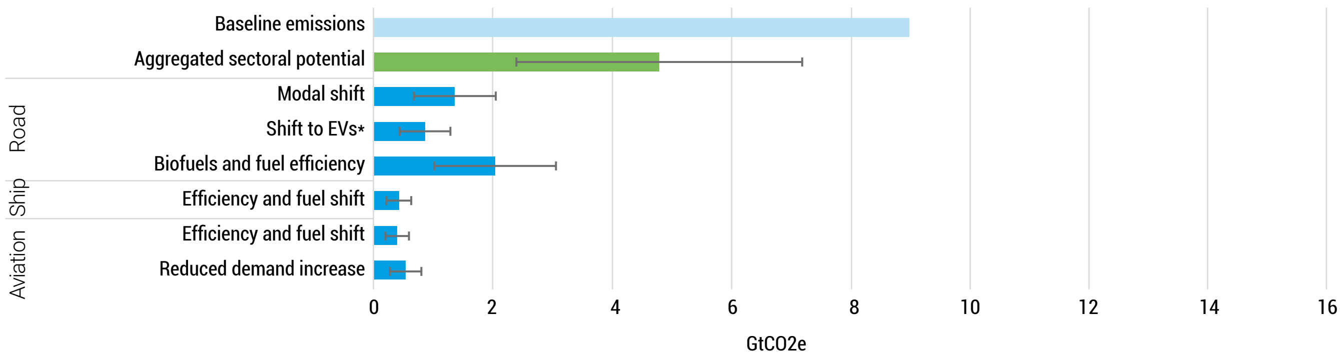
2035 emission reduction potentials of all mitigation measures explored in the AFOLU SECTOR, indicating error margins



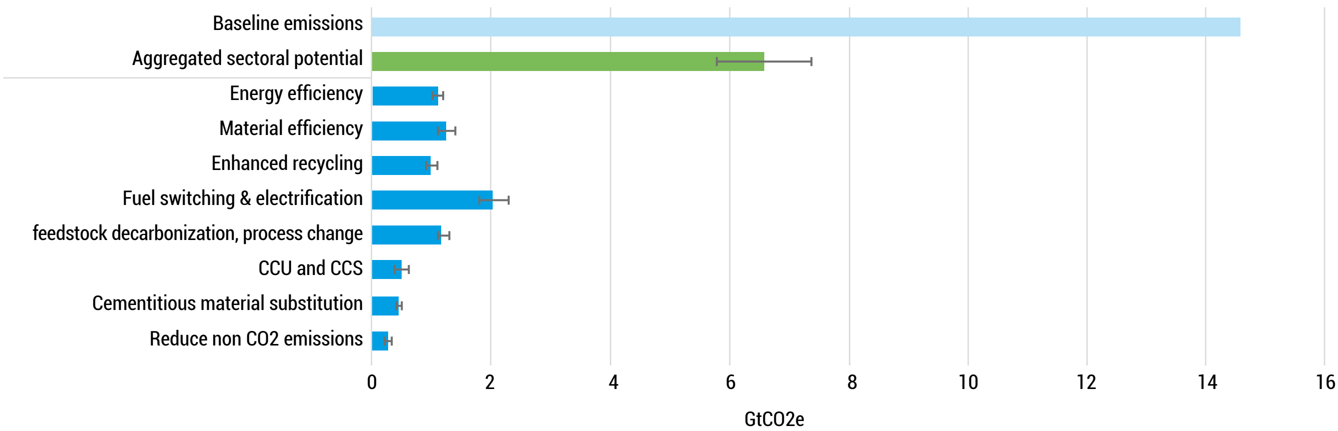
2035 emission reduction potentials of all mitigation measures explored in the BUILDING SECTOR, indicating error margins



2035 emission reduction potentials of all mitigation measures explored in the TRANSPORT SECTOR, indicating error margins



2035 emission reduction potentials of all mitigation measures explored in the INDUSTRY SECTOR, indicating error margins



2035 emission reduction potentials of all mitigation measures explored NOT RELATED TO A SPECIFIC SECTOR, indicating error margins

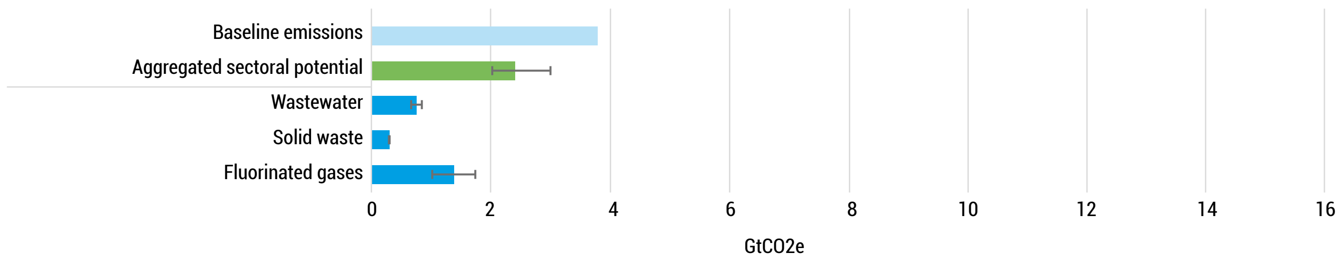


Table 1. Mitigation potentials in 2030 and 2035 in this report, compared to UNEP 2017 and IPCC AR6(2022b).

Mitigation potential ($GtCO_{2e}$)	UNEP 2017	IPCC AR6	EGR 2024	
	2030	2030	2030	2035
Cost cut-off ($/$tCO_{2e}$)	*100*	*100*	*200*	*200*
Electricity production	10.3	11.0	10.3	13.0 *(11.9 - 14.1)*
Methane from fossil fuels	2.2	1.6	1.9	1.7 *(1.3 - 2.1)*
Agriculture	6.7	4.1	1.4	2.0 *(1.3 - 2.1)*
Forestry	5.3	7.3	5.9	8.4 *(3.5 – 11.7)*
AFOLU demand side	*Included in agriculture*	2.2	0.7	2.4 *(1.1 – 3.7)*
Buildings *Direct + indirect*	5.9	3.2	3.2	4.2 *(3.1 - 5.2)*
Transport	4.7	3.8	3.2	4.8 *(2.4 - 7.2)*
Industry	5.4	5.4	4.4	6.6 *(5.8 – 7.4)*
Fluorinated gases	-	1.2	1.2	1.4 *(1.0 - 1.8)*
Waste and wastewater	0.4	0.7	0.8	1.0 *(0.9 - 1.2)*
DACCS & enhanced weathering	1.0	-	*small*	*small*
Correction for overlap between sectors	*Included in sector estimates*	-1.0	-2.3	-3.9
Electricity sector and Buildings		-1.0	-1.6	-2.9
Electricity sector and Industry		-	-0.7	-1.0
Total (corrected for overlap)	38 *(35 – 41)*	38 *(32 – 44)*	31 *(25 - 35)*	41 *(36 - 46)*
Emissions gap for achieving 1.5 °C (UNEP, 2024, Chapter 4)			24 *(20 - 26)*	32 *(20 - 37)*

All values are in $GtCO_{2e}$. The total aggregates are corrected for overlap between sectors. see section 3.3 The potentials can be compared to the emissions gap identified in Chapter 4 of the 2024 Emissions Gap Report (see bottom of table). All data have a current policy emission level as a reference. In parenthesis, uncertainty ranges are given. For the sectoral mitigation potentials, we only added such uncertainties for 2035, but similar uncertainty ranges apply for the other years. Please note that there is a small difference in the sum of the aggregated sectoral potentials (including the correction for overlap) and the total mitigation potential due to rounding.

3. Methodology

The sectoral emissions reduction potential is estimated similarly to the previous iteration of this report (Blok et al., 2017), in order to allow comparisons and therefore a discussion on progress to be made. That approach is as follows:

1. Select an indicative baseline emission for each sector in 2030 and 2035, reflecting the latest climate policy settings, where mitigation will already occur to a certain degree.
2. Identify abatement measures per sector which can be implemented by 2030 and 2035 with a maximum cost of 200 USD/tCO_{2e}.[5]
3. Determine the emissions abatement potential of each measure, which is the emission reduction potential additional to the emissions abatements already achieved for the measures in the baseline scenario.
4. Aggregate individual measures to sectoral mitigation potentials, including corrections for interaction and overlaps of measures.
5. Aggregate sectoral mitigation potentials, including corrections for overlap and interaction and determining the uncertainty range in the overall mitigation potentials.

This assessment relies on a large number of underlying literature sources, mostly with a focus on a specific sector, or even on specific options or technologies. Each source has its own approach and methodology. The analysis tries as much as possible to identify the studies that explore the limits of what is achievable for the target years of this analysis. If necessary and possible, differences in methodologies were corrected for to improve comparability.

3.1 Selecting the baseline

For an assessment of mitigation potentials, a baseline for development of emissions is needed as a reference point. In this study, we use a current policy baseline. This assessment is based on a wide range of underlying studies that may have a variety of baselines. We have made the baseline as much as possible compatible with the median 'current policy' baseline as described in Chapter 4 of the 2024 Emissions Gap Report (UNEP, 2024). An overview of the indicative baselines used is given in Table 2.

For energy-related CO_2 emissions in the baseline, the IEA's 'stated policies' scenario (STEPS) is used as a primary source. This scenario is designed to 'provide a sense of the prevailing direction of the energy system progression, based on a detailed review of the current policy landscape' (IEA, 2023b). The advantage of using IEA projections is that they provide the most sectoral and technological detail. However, the STEPS scenario is quite optimistic about the development of wind and solar electricity production, leading to about 4 Gt lower CO_2 emissions from the power sector than in the current policy baseline developed in Chapter 4 of the 2024 Emissions Gap Report (UNEP, 2024). Therefore, we adapted our baseline to be compatible with the Chapter 4 baseline. The correction was based on data for electricity production from solar and wind, according to the scenarios that are the basis for the current policy baseline in Chapter 4, using the same weighting as in Chapter 4 to determine the median current policy baseline.

For non-CO_2 emissions, the baseline projections are mostly based on EPA (2019), which provides projections for a wide range of non-CO_2 greenhouse gas (GHG) emissions for the years 2030 and 2050. The baseline emissions for 2035 are estimated using linear interpolation, and corrected to match the most recent estimations on Global Warming Potentials (GWPs).

More details on the approach are provided in Chapter 4 'Baseline: Stated Policy Projections in 2035'.

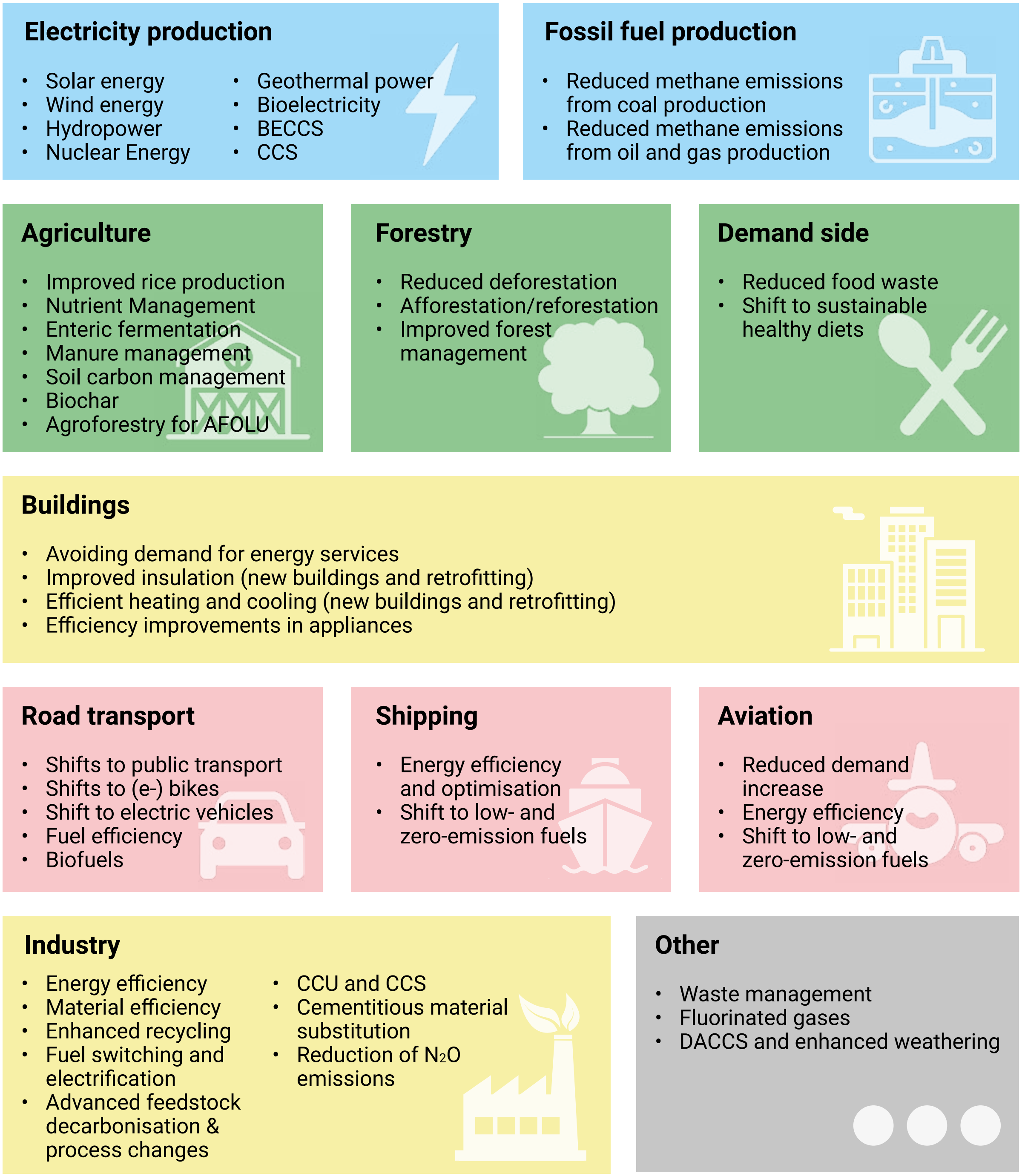
5 The previous report included measures to 100 USD/tCO_{2e}. A higher cost is selected in this iteration because although most abatement options are below 100 USD/tCO_{2e} anyway, CCUS abatement measures in particular often sit in the 100 – 200 USD range.

3.2 Identifying abatement measures and estimating the sectoral emissions reductions potentials

The most recent extensive global sectoral emissions reductions potentials was conducted by the WGIII for the Sixth Assessment Report of the IPCC in 2022 (IPCC, 2022b). This report, and the many sources behind it, form a starting point for estimating our emissions reductions potentials, since there have not been significant developments in many of the measures. Where newer literature exists, in particular for the most promising measures, these have been incorporated into the analysis.

Measures are limited to those below 200 USD/tCO_{2e} to ensure feasibility from both a technical and cost perspective. The following measures were considered in the analysis:

Figure 3. Overview of mitigation measures included in the analysis.



For each measure, we assess the most recent literature from institutions such as IRENA, IEA, EPA, OECD, global industry associations for relevant sectors (such as the Global Solar Council for solar energy), and recent academic literature. We then estimate the emissions reductions potentials of each measure for the year 2035, accounting for differences between our baseline and the source. Where available, data for 2030 and 2040 is also discussed. In cases where 2035 data was not available, an interpolated value is used. The type of interpolation used depends on the historic and expected developments of that measure.

3.3 Estimating the total emissions reduction potential

The emission reduction impacts of the individual options discussed in this chapter cannot be simply counted together, as they may interact or compete with each other. In Chapter 2, an aggregated overview is presented that is corrected for these overlaps.

Overlaps within sectors are evaluated on a case-by-case basis to avoid double counting and to reflect the complexity of sectoral overlaps. The methods used to correct for these overlaps are explained in further detail in the sector-specific sections of Chapter 5 of this report.

Overlaps between sectors occur especially between the electricity sector and the energy demand sectors. We apply the following corrections:

- The impact of the reduction of indirect emissions in the buildings sector has less impact, if the electricity sector decarbonizes. For 2030 we only count 25% of the indirect emission reductions (in line with IPCC, 2022b), and for 2035 we exclude it from the aggregation.
- The emission reduction in industry (combustion of manufactured gases for electricity production, and specifically mainly coke oven and blast furnace top gases) overlaps with the emission reductions in the electricity sector. We estimate this overlap effect to be 1.0 $GtCO_2$ in 2035 and proportional to the total industrial mitigation potential in other years.

There is also overlap between emission reduction in the energy supply sector (methane from coal mining and oil and natural gas operations) and end-use sectors. However, if fossil energy use is reduced, the methane emissions will anyway be mitigated, so no overlap correction is needed. Finally, we avoid potential overlaps in carbon sequestration in agricultural lands by only including soil carbon management in the combined AFOLU estimate and leaving out biochar and agroforestry.

Each sectoral potential has its own uncertainty range. As it is unlikely that for all the sectors, the actual potentials are at the extreme end of the range, we use the standard error propagation rules to determine the range in the overall mitigation potential:

$\Delta P_{tot}=\sqrt{(\Delta P_1^2+\Delta P_1^2+...)}$

in which:

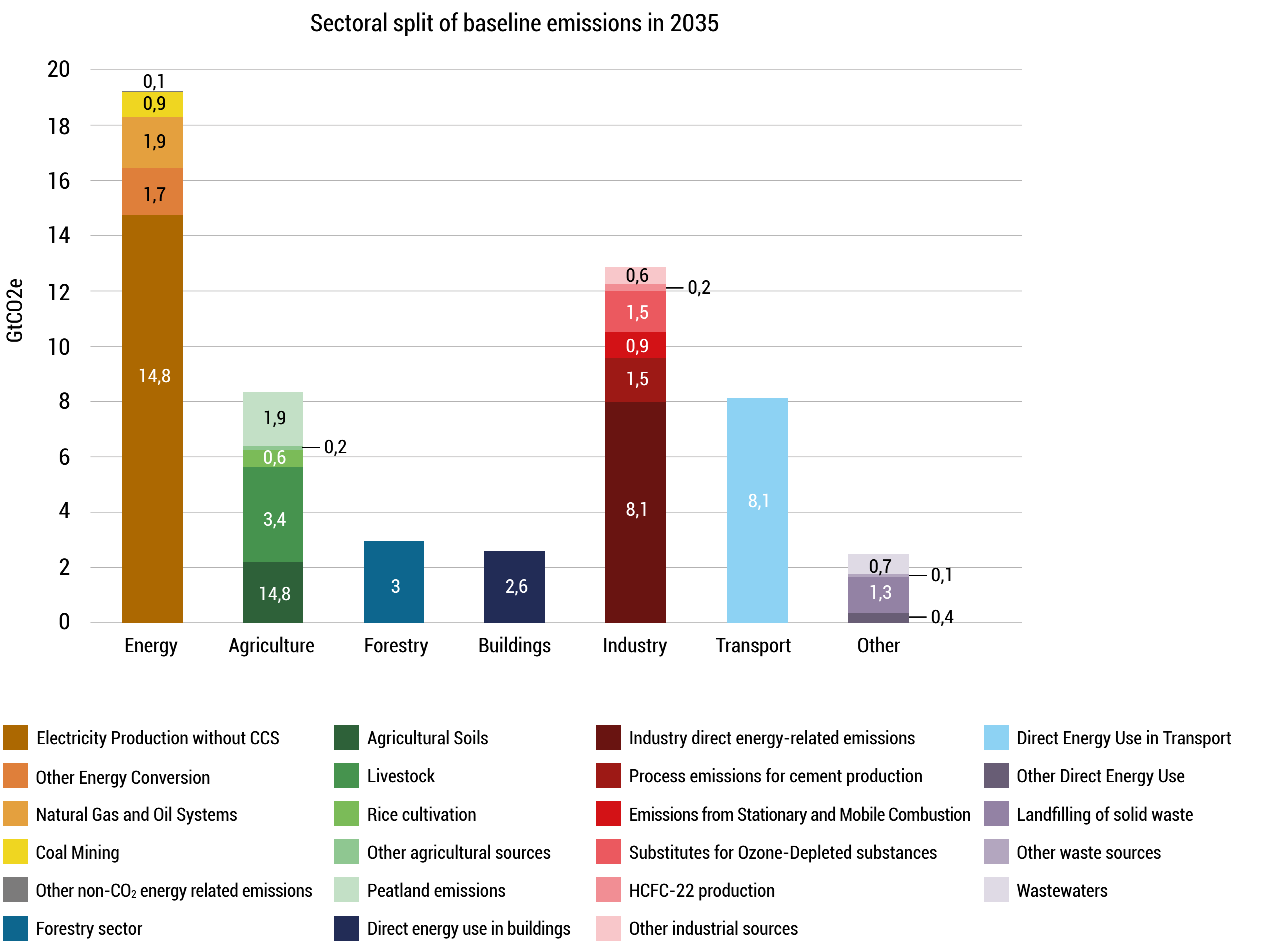
ΔP_{tot} = uncertainty in the overall mitigation potential

$\Delta P_1, \Delta P_2, ...$ = uncertainties in the sectoral mitigation potentials

4. Baseline: Current Policy Projection in 2035

This chapter describes the baseline as a reference level in 2035 against which the GHG emission reductions are assessed. An overview of the baseline emissions from each sector are provided in Figure 4 and Table 2, as well as the baseline emissions used in the previous iteration of this report (Blok et al., 2017). This baseline comprises 57 $GtCO_{2e}$ emissions in the year 2035.

Figure 4. Projected sectoral emissions for 2035 in the indicative current policy baseline scenario used to determine the emission reduction potential.



4.1. Energy-related CO_2 emissions

Total energy-related CO_2 emissions now are projected to be lower than estimated before. This is especially the case for the electricity production sector. Reduced estimates are also seen for the buildings and transport sector.

Table 2. Overview of indicative baseline emissions ($GtCO_{2e}$) by sector used in this study.

Table 2. Overview of indicative baseline emissions ($GtCO_{2e}$) by sector used in this study.

Emissions by sector ($GtCO_{2e}$)		Blok et al. 2017	EGR 2024	
	GHG	2030	2030	2035
Energy Sector		21.3	18.7	19.4
Electricity production *(in parenthesis most recent IEA projections)*	CO_2	16.3	14.1 *(12.3)*	14.8 *(10.7)*
Other Energy Conversion	CO_2	1.9	1.8	1.7
Natural Gas and Oil Systems	CH_4	2.4	1.8	1.9
Coal Mining	CH_4	0.7	0.9	0.9
Other non-CO_2 energy related emissions	All non-CO_2	-	0.1	0.1
Agriculture Sector		6.9	6.3	6.5
Agricultural Soils	N_2O	2.5	2.2	2.3
Livestock	CH_4, N_2O	2.8	3.3	3.4
Rice Cultivation	CH_4, N_2O	0.5	0.6	0.6
Other Agricultural Sources (incl. Savannahs burning, forest clearing, residues)	CH_4, N_2O	1.2	0.2	0.2
Peatland emissions	CO_{2e}	1.9	1.9	1.9
Forestry Sector		3.5	3.3	3.0
Deforestation	CO_2	3.4	N/A	N/A
Afforestation and forest management	CO_2	0.9	N/A	N/A
Other land use change	CO_2	0.9	N/A	N/A
Buildings Sector		3.7	2.8	2.6
*Electricity Use-Related**	*CO_2*	*8.9*	*6.3*	*5.4*
Direct Energy Use	CO_2	3.7	2.8	2.6
Industry Sector		12.7	12.5	12.9
*Electricity Use-Related**	*CO_2*	*6.6*	*5.0*	*4.1*
Industry direct energy-related emissions	CO_2	7.3	8.0	8.1
Process emissions for cement production	CO_2	2.3	1.5	1.5
Emissions from Stationary and Mobile Combustion	CH_4, N_2O	0.8	0.9	0.9
Sustitutes for Ozone-Depleted substances	HFCs	1.6	1.5	1.5
HCFC-22 production	HFC-23	0.2	0.2	0.2
Other industrial sources	All non-CO_2	0.5	0.5	0.6
Transport Sector		9.4	8.3	8.1
*Electricity Use-Related**	*CO_2*	*0.3*	*0.6*	*0.7*
Direct Energy Use	CO_2	9.4	8.3	8.1
Other		2.2	2.4	2.5
*Electricity Use-Related**	*CO_2*	*0.6*	*0.5*	*0.5*
Other Direct Energy Use	CO_2	0.5	0.4	0.4
Landfilling of solid waste	CH_4	1.0	1.2	1.3
Other waste sources	CH_4, N_2O	0.0	0.1	0.1
Wastewater	CH_4, N_2O	0.7	0.7	0.7
Total	CO_{2e}	61.6	56.1	56.8

*According to most recent IEA projections (2023b).

4.2 Agriculture and forestry

For agriculture, the baseline emissions in this report are derived using the DAYCENT model reported in EPA 2019. The baseline emissions in 2030 and 2035 are lower than Blok et al. 2017 based on evolving policy and cost dynamics. For forestry, the baseline emissions in this report are from the Global Timber Model (GTM) adapted from Austin et al., 2020, and are similar to the 2017 report.

4.3 Industry

For the iron & steel,[6] cement & concrete,[7] the chemicals sector,[8] and aluminium sectors emissions are based on known intensities and output for 2022, except 2019 for other industry. For broader industry baseline emissions in 2021 are based on subtracting known emissions from the sectors above from adjusted 2019 estimates in Figure 11.4 and Table 11.1 of Chapter 11 of IPCC AR6 (IPCC, 2022a). To make total industrial sector emissions from 2019 to 2021 match historical emissions they are grown at -3.1% in 2020 and +6.1% in 2021.[9] All sectors were checked against IEA's ETP 2020 (IEA, 2020a) and NetZero scenario (IEA, 2021a) and their 2023 NZ and World Energy Outlook updates (IEA, 2023a, 2023b), as this is the recent time detailed intensities, outputs, and net-zero pathways were published in a coherent fashion for these sectors. Long term individual growth rates for these sectors (1.4% for iron and steel; 0.8% for cement & concrete; 3.5% for chemicals; 5.4% for aluminium; 0% pulp and paper; other industry 2%) are summarized in (Bataille, 2020) as required by the Paris Agreement. To reduce industrial emissions with sufficient speed to meet the Paris goals, this article argues for the rapid formation of regional and sectoral transition plans, implemented through comprehensive policy packages. These policy packages, which will differ by country, sector and level of development, must reflect regional capacities, politics, resources, and other key circumstances, and be informed and accepted by the stakeholders who must implement the transition. These packages will likely include a mix of the following mutually reinforcing strategies: reducing and substituting the demand for GHG intense materials (i.e. material efficiency and updated in (IPCC, 2022a).

As noted in the main text, a key difference from IEA baseline estimates is that all fossil fuels key to product processes (e.g. coal for coking and heat in steel) are counted as part of the sector, because they form part of the mitigation potential for the sector.

The following provides a comparison of this report's baseline and that of the IEA WEO-2023: 40% of energy efficiency is allocated to natural technology stock turnover and current policy, and 10% of all other reductions to current policy. This provides a similar percentage increase between both estimates.

Note that in the industry section, the analysis starts from a higher baseline, including oxidation of all intermediary fuels, especially in the steel sector. In Table 2, these emissions are accounted for in the electricity sector and the 'other energy sector'. This may lead to some double-counting, for which we will correct when aggregating the potentials.

4.4 Non-CO_2 greenhouse gas emissions

This category groups baseline emissions from the following sources: waste, coal mining and oil and gas systems, emissions from stationary and mobile combustion, substitutes for ozone-depleting substances, and other industrial sources.

The total emissions originating from the waste sector are estimated to be 1.9 $GtCO_{2e}$ and 2.1 $GtCO_{2e}$ in 2030 and 2035. This predominantly includes methane emissions from landfilling of solid waste, but also some N_2O emissions from wastewaters and other waste sources.

Energy-related methane emissions are estimated to be 2.7 $GtCO_{2e}$ in 2030 and 2.8 $GtCO_{2e}$ in 2035. These emissions are specifically related to coal mining and oil and natural gas systems.

Emissions originating from fluorinated gases (HFCs) are included in projections on non-CO_2 GHG emissions by EPA (2019) as well. Based on their estimates for 2030 and 2050, emissions from substitutes for ozone-depleting substances are estimated to be 1.5 $GtCO_{2e}$ and emissions from HCFC-22 production are estimated to be 0.2 $GtCO_{2e}$ in 2035. Other industrial emissions, including N_2O from the production of adipic acid and nitric acid are estimated to be 0.6 $GtCO_{2e}$. Methane and nitrous oxide emissions from the combustion of fossil fuels and biomass in both stationary and mobile sources, e.g. airplanes and automobiles, are estimated to be 0.9 $GtCO_{2e}$ in 2035.

Baseline emissions from the calcination process in the cement industry are taken from IEA (2023b) STEPS, and estimated at 1.5 $GtCO_{2e}$ in 2035.

6 https://www.statista.com/statistics/1446819/steel-emissions-intensity-by-production-route/ & https://worldsteel.org/media/press-releases/2023/december-2022-crude-steel-production-and-2022-global-totals/

7 https://www.iea.org/energy-system/industry/cement

8 (IEA, 2020)

9 https://www.statista.com/statistics/1033936/industrial-production-growth-worldwide/ & https://www.statista.com/statistics/273951/growth-of-the-global-gross-domestic-product-gdp/

5. Assessment of sectoral emission reduction potentials by 2030 and 2035

This chapter provides an in-depth assessment of the potential for sectoral emission reductions by 2035, based on a detailed review of a number of recent studies and published research. The analysis spans a range of sectors, including Energy, Agriculture & Forestry, Buildings, Transport and Industry, covering a variety of mitigation measures within each. Some promising options that do not fit neatly within a single sector - such as those related to waste management - are discussed separately in the final section of this chapter.

5.1 Energy

In 2023 the energy sector emitted 20.8 $GtCO_{2e}$ (UNEP 2024, Chapter 2). Emissions in the energy sector include emissions from electricity production and emissions from fossil fuel production.

The **electricity sector** emitted 15.1 $GtCO_{2e}$ in 2023 (UNEP 2024, Chapter 2). In the current policy baseline, emissions are projected to slightly decrease to 14.1 $GtCO_{2e}$ in 2030 and 14.8 $GtCO_{2e}$ in 2035 (UNEP 2024, Chapter 4). There has been a rapid development of electricity production from solar and wind in recent years and already in the baseline there is substantial further growth. Beyond the baseline, the emission reduction potential for the electricity sector is estimated to be 10.3 $GtCO_{2e}$ for 2030 and 13.0 $GtCO_{2e}$ for 2035, which is 74% and 88% respectively of the electricity baseline emissions. The primary contributions to these potentials are from increased electricity generation with solar PV and wind energy (Table 3).

The effective deployment of solar and wind energy technologies is often constrained by the limitations of existing grid infrastructure, a challenge which is already being felt in much of Europe, the US and China. The current grid systems require significant upgrades to accommodate the variability and distributed nature of renewable energy sources. To fully realize the potential of renewable electricity, substantial investments in modernising and expanding grid infrastructure are essential (IEA, 2023c). In addition, for a smooth integration of solar and wind energy, the use of demand response (e.g. controlled charging of vehicles) and storage systems are essential. Another barrier for the deployment of solar and wind energy is formed by high upfront costs. These can be countered by the use of feed-in tariffs or renewable energy auctions. Also, some regions are very much dependent on employment in coal mining – requiring alternative employment options, e.g. in renewable energy manufacturing. Lastly, achieving the identified potential for renewable energy deployment would require a significant scale-up of production capacity, and may face challenges in the need for rare earth minerals. However, the industry is continuously innovating to the reliance on these scarce materials.

In 2023, emissions related to **fossil fuel production** amounted to approximately 4.0 $GtCO_{2e}$ (UNEP 2024, Chapter 2). Methane emissions related to fossil fuel production are expected to decrease gradually under the current policy baseline, by about 20% in 2035 compared to the present level (IEA, 2023b). The emission reduction potential at costs less than 200 US$/$tCO_{2e}$ is estimated to be 1.24 $GtCO_{2e}$ for oil and natural gas operations, and 0.43 $GtCO_{2e}$ for coal mining, most at low costs (Table 3).

This section will first describe the mitigation potential in the electricity sector, diving into each individual measure. This is followed by a brief discussion of the mitigation potential in fossil fuel production.

Table 3. Emission reduction potentials in the energy sector (electricity generation and fossil fuel production) by abatement measure. Please note that individual contributions cannot be summed due to overlaps. The aggregated potentials take these overlaps into account.

Measure	Mitigation potentials ($GtCO_{2e}$)		
	2030 (uncertainty range)	2035 (uncertainty range)	
Baseline emissions ($GtCO_{2e}$)	18.7	19.4	*UNEP (2024), Chapter 4*
Energy sector (aggregated)	12.2	14.7 *(13.2 – 16.1)*	
Electricity sector (aggregated)	10.3 *(7.4 – 11.8)*	13.0 *(11.9 – 14.1)*	
Solar Energy*	4.2	7.9 *(7.0 – 9.6)*	*IEA (2023a), DNV (2023), IRENA (2023), Nijsse (2023), Bogdanov (2019)*
Wind Energy*	4.2	7.7 *(5.7 – 8.9)*	*IEA (2023a), DNV (2023), IRENA (2023), Teske (2019)*
Hydropower	0.5	1.0 *(0.8 – 1.2)*	*IEA (2023a), DNV (2023), IRENA (2023)*
Nuclear Energy	5.9	0.8 *(0.6 – 1.0)*	*IEA (2023a), DNV (2023), IRENA (2023), NEA (2022)*
Bioenergy excl. BECCS	0.3	0.5 *(0.3 – 0.7)*	*IEA (2023a), IRENA (2023)*
Bioelectricity with CCS (BECCS)	0.1	0.5 *(0.4– 0.6)*	*IEA (2023a)*
Carbon Capture and Storage (CCS) excl. BECCS	0.2	0.5 *(0.3 – 0.6)*	*IEA (2023a)*
Geothermal	0.5	0.6 *(0.2 – 1.0)*	*IEA (2023a), IRENA (2023), Teske (2019)*
Fossil fuel production (aggregated)	1.9 *(1.4 – 2.4)*	1.7 *(1.3 – 2.1)*	
Reduce CH_4 emissions from coal mining	0.5	0.4 *(0.3 – 0.5)*	*IEA (2024b)*
Reduce CH_4 emissions from oil and gas	1.4	1.2 *(0.9 – 1.6)*	*IEA (2024b)*

**Several studies suggest high solar PV and wind potentials could be achieved for 2035 (17 - 22 TW for solar PV; 10-13 TW for wind) and 2040 with extensive electrification of the energy system and significant expansion of the electricity grid (Breyer 2021, Bogdanov 2021, Jacobsen 2019). These higher potentials were excluded in determining the mitigation potential.*

5.1.1. Electricity production

To estimate the reduction potential in the electricity sector, a wide range of the low-emission electricity production technologies were analysed: solar PV, wind energy, hydropower, nuclear energy, geothermal power, bioelectricity, and BECCS and CCS in electricity production. The mitigation potential for each measure was estimated using the corresponding assumed potential annual generation (TWh) for each technology additional to the annual generation included in the baseline. This potential additional annual electricity generation was then multiplied by the average emissions factor for fossil-fuel based electricity generation for the corresponding year, using the following formula:

$$\text{Mitigation Potential}=(E_{\text{technology potential}} - E_{\text{technology baseline}}) * EF$$

Where:
E = Total annual generation of technology (TWh),
EF = Emission Factor ($GtCO_{2e}$/TWh)

Emission factors are based on the average emission intensity of fossil power generators in the IEA STEPS 2023 scenario (IEA, 2023b):

2030: 790 $kgCO_{2e}$/MWh
2035: 780 $kgCO_{2e}$/MWh
2040: 762 $kgCO_{2e}$/MWh

The calculated individual reduction potentials for each technology cannot be summed directly, due to potential overlaps. The aggregated emission reduction potential for the electricity sector was determined as follows. For the year 2030, the emission reduction fractions (compared to the baseline) as used in IPCC (2022b) are taken. For 2035 and 2040, we use as a minimum the emission reduction potential as given in the IEA (2023a) Net-Zero Energy scenario. A higher implementation may be possible, given the total available potentials for individual sources (illustrated by NREL, 2022; CAT, 2023). For 2035, we assume as a maximum 95% emission reduction, given that there will be remaining issues, e.g. grid interconnection, and lack of low-carbon back-up power that prevent reaching 100% by then. For the year 2040, we assume that as a maximum fully decarbonized electricity generation is possible, even for countries that are still in an early stage of power system decarbonisation (see, e.g. Langer et al. 2024). The emission reduction fractions are given in Table 4.

For the year 2030, we assume the total reduction fractions assumed by IPCC (2022b). For the years beyond, we use as a lower bound the trajectory set out in the IEA (2023a) Net-Zero Energy scenario and on the other hand a trajectory towards full decarbonization in 2040.

Table 4. Calculation of the emission reduction potential for the electricity sector.

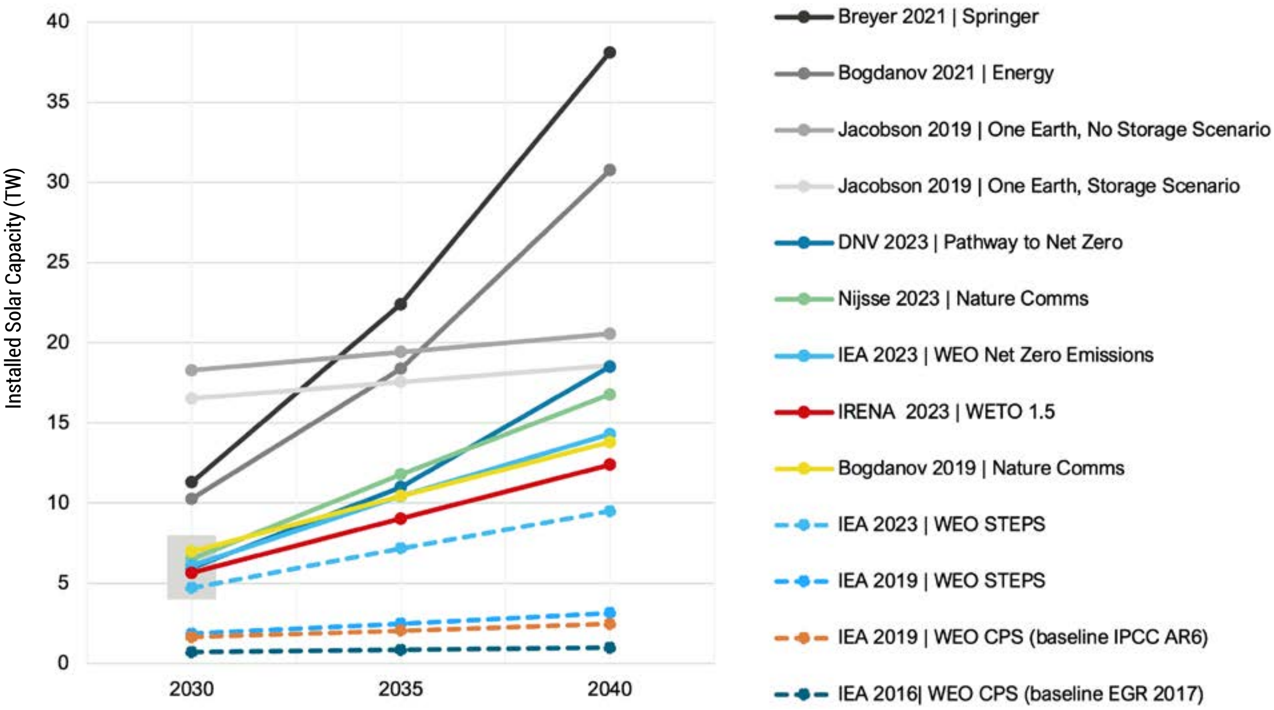
Year	2020			2035			2040		
Baseline emissions ($GtCO_{2e}$)	14.0			14.8			15.1		
Emission reduction potential	Best	Min.	Max.	Best	Min.	Max.	Best	Min.	Max.
Emission reduction fraction	74%	53%	84%	88%	81%	95%	99%	97%	100%
Potential ($GtCO_2$)	10.3	7.4	11.8	13.0	11.9	14.1	15.0	14.8	15.2

Solar PV

For solar PV, the emission reduction potential is estimated to be 4.2 $GtCO_{2e}$ in 2030 and 7.9 $GtCO_{2e}$ in 2035. Estimations of the mitigation potential of solar PV have drastically risen since the previous iteration of this report in 2017. The rapid progress of solar is illustrated in Figure 5, which shows that in the previous iteration of this report (UNEP 2017), the maximum potential for solar was estimated at 4-8 terawatts (TW) of installed capacity by 2030. Now, solar capacity is expected to reach nearly 5 TW in 2030 even under baseline conditions without any further ambition. The development in baseline potentials is shown by the dotted lines in Figure 5 below.

Literature reports a wide range of potential installed capacities by 2030 and 2035, as visualised in Figure 5. A number of studies suggest very high solar potentials could be achieved, if there is extensive electrification of the energy system and a significant expansion of the electricity grid (Bogdanov, 2021; Jacobson, 2019). These study potentials are coloured grey in Figure 5 below. Global solar capacity reached 1.6 TW in 2023. Reaching the ~10 TW to 19 TW in 2030 would require a build-out capacity of over 1TW – 3 TW per year. SolarPower Europe's (2024) Global Market Outlook suggest annual installations will not exceed 1 TW per year until 2028 at the earliest. The potentials suggested by these studies are therefore not included in determining the emission reduction potential from solar PV.
The emission reduction potential from increased deployment solar PV is calculated using the average installed capacity of the studies marked with colours in Figure 5 below (Bogdanov, 2019; DNV, 2023; Nijsse, 2023; IEA, 2023b; IRENA, 2023).

Figure 5. Range of installed solar capacities as per reports for the baselines used in the UNEP 2017, IPCC AR6, and this report (dotted lines), and potentials according to various sources.

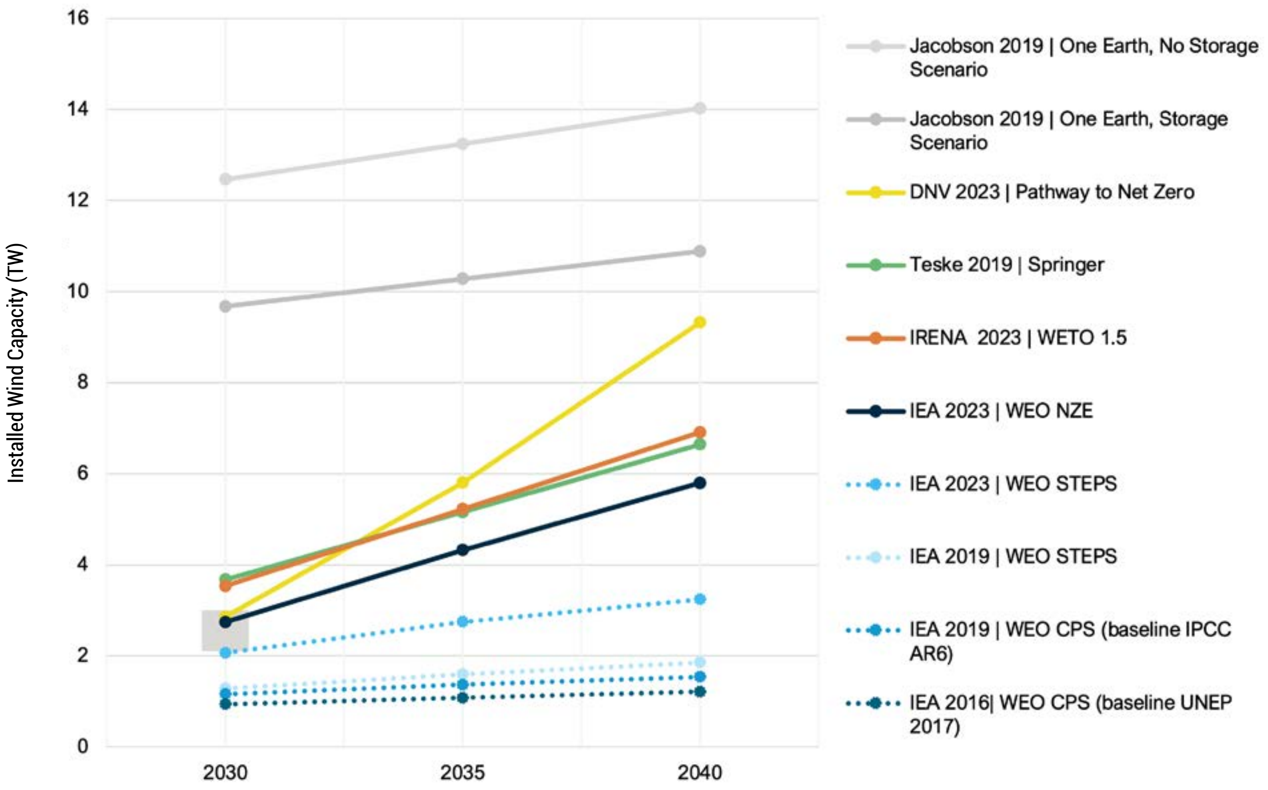


Note that the grey shaded box refers to the maximum potential range for 2030 estimated in UNEP EGR 2017. This range is now aligned with the current IEA STEPS projections, showing the remarkable progress made in solar installed capacity.

Wind energy

The emission reduction potential from wind energy has also seen significant revisions since earlier reports. In 2017, Blok et al. (2017) estimated a potential installed capacity range for wind energy between 2.1 and 3.0 terawatts (TW) by 2030. Current stated policy projections, such as those from the IEA STEPS (Stated Policies Scenario), align with the lower end of this range, with a baseline estimate of 2.1 TW by 2030. By 2035, the potential for wind energy deployment is projected to reach around 5.1 TW, corresponding to a reduction of 7.7 Gt-CO_{2e} emissions. The range of potential estimates for 2035 varies from 4.3 to 5.8 TW (IEA, 2023b; DNV, 2023; IRENA, 2023; Teske, 2019). Jacobson (2019) suggest higher wind potentials could be achieved in 2035 (10-13 TW) and 2040 (11-14 TW) with extensive electrification of the energy system and significant expansion of the electricity grid. These higher potentials were excluded here as outlayers when determining the best-estimate mitigation potential.

Figure 6. Range of installed wind capacities as per reports for the baselines used in the UNEP 2017, IPCC AR6, and this report (dotted lines), and potentials according to various sources.

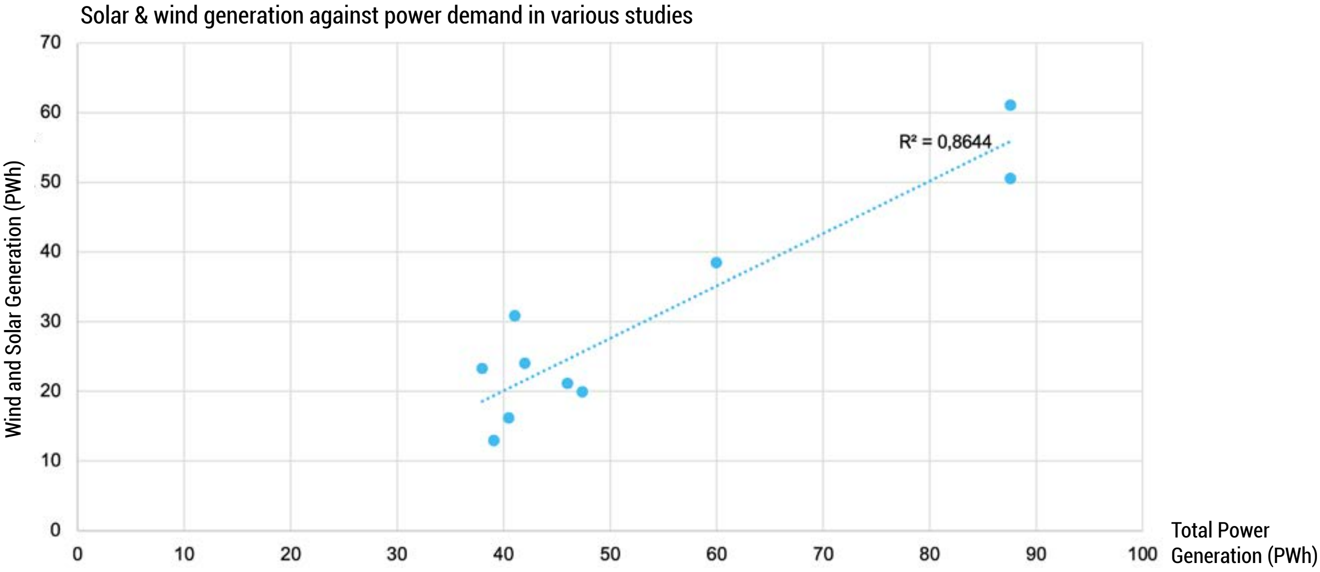


Note that the grey shaded box refers to the maximum potential range for 2030 estimated in UNEP EGR 2017. This range is now aligned with the current IEA STEPS projections, showing the remarkable progress made in wind installed capacity.

Wind and solar energy together are the main drivers of the emission reduction potential in the electricity sector, making up the majority of projected electricity generation across various studies. However, there is often a trade-off between the deployment potentials of wind and solar energy: studies that emphasize higher solar potentials, such as Nijsse and Bogdanov (2019), tend to project lower wind capacities, while those focusing on wind, like Jacobson (2019), project lower solar capacities.

The relationship between the deployment of wind and solar energy and the assumed rates of electrification in the energy system in various studies is visualised in Figure 7 below. Realizing the full potential capacity from wind energy and solar PV relies heavily on achieving high levels of electrification and balancing the integration of wind and solar resources within the energy system.

Figure 7. Relationship between the deployment of wind and solar energy and the assumed rates of electrification in different studies.



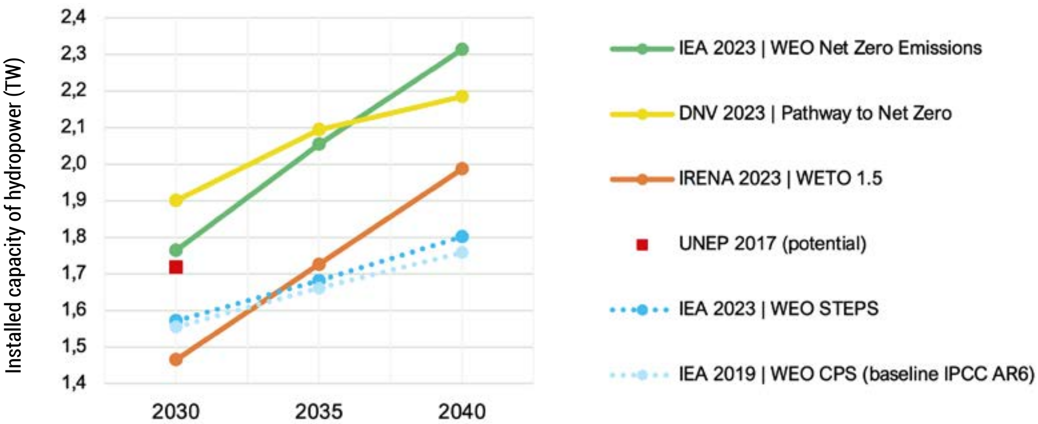
Hydropower

The emission reduction potential from hydropower deployment remains relatively stable compared to earlier assessments, with projected baseline installed capacities reaching 1.6 TW by 2030 and 1.7 TW by 2035, up from 1.2 TW today. Current literature on hydropower potential is rather limited but estimates such as the IEA's NZE (2023b) suggest that installed capacity could increase to 1.8 TW by 2030 and 2.1 TW by 2035. Similar projections are provided by DNV's (2023) Pathway to Net Zero (1.9 TW by 2030 and 2.1 TW by 2035) and IRENA (1.5 TW by 2030 and 2.1 TW by 2035). These scenarios correspond to a reduction potential of approximately 1.0-1.1 $GtCO_{2e}$ by 2035.

The International Hydropower Association (IHA, 2024) estimates a global potential of 3.8 TW for hydropower, although no timeline is provided. This likely represents a long-term technical potential, requiring substantial efforts and investments in the development of large-scale projects. Such large-scale hydropower projects often involve considerable challenges, including impacts on ecosystems, water resources, and local communities. However, to illustrate, if this potential were to be achieved by 2035 it could result in emission reductions of around 5.3 $GtCO_{2e}$.

Finally, it should be noted that these estimates do not account for pumped hydropower, which is considered a storage technology similar to batteries and is likely crucial for system integration to achieve the full potential of renewable energy.

Figure 8. Range of installed capacities of hydropower in various studies and scenarios.

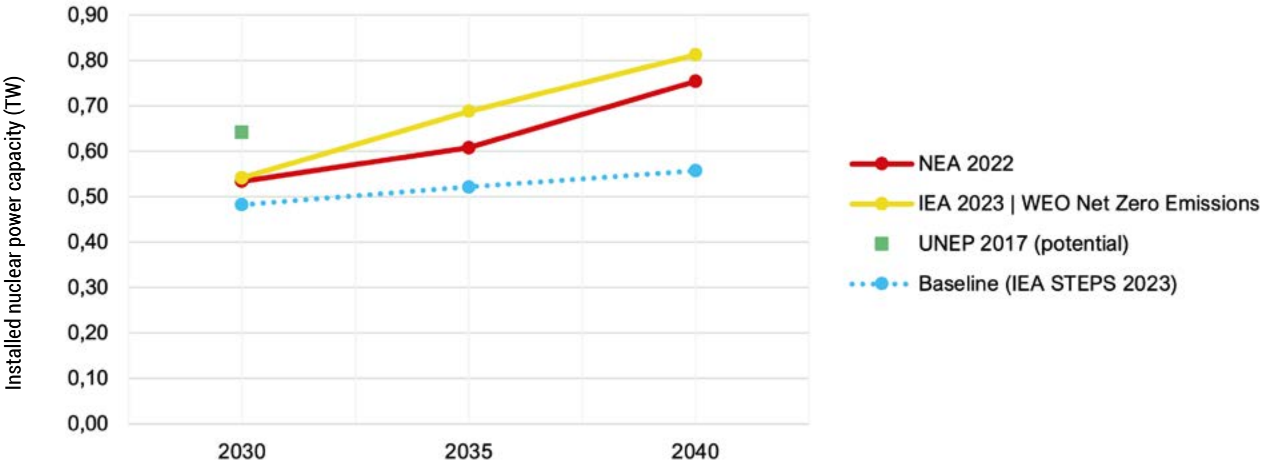


The dotted lines indicate the installed capacities in current and stated policies scenarios, whereas the filled lines indicate the potential installed capacities in more ambitious scenarios.

Nuclear Energy

The emission reduction potential from nuclear energy varies significantly across different studies. The IEA NZE scenario projects nuclear capacity to reach between 0.6 and 0.7 terawatts (TW) by 2035, corresponding to a potential reduction of 0.6 to 1.0 $GtCO_{2e}$ (IEA, 2023b). The Nuclear Energy Association's (2022) report on the role of nuclear energy in meeting climate targets presents slightly lower projections than the IEA's 1.5°C Scenario. Note that DNV's (2023) Pathway to Net Zero (PNZ) presents a higher scenario but that is likely in terms of primary energy. The estimates from the IEA and NEA are used to estimate range for the emission reduction potential of nuclear energy.

Figure 9. Range of installed nuclear energy capacities in various studies and scenarios.



The dotted lines indicate the installed capacities in current and stated policies scenarios, whereas the filled lines indicate the potential installed capacities in more ambitious scenarios.

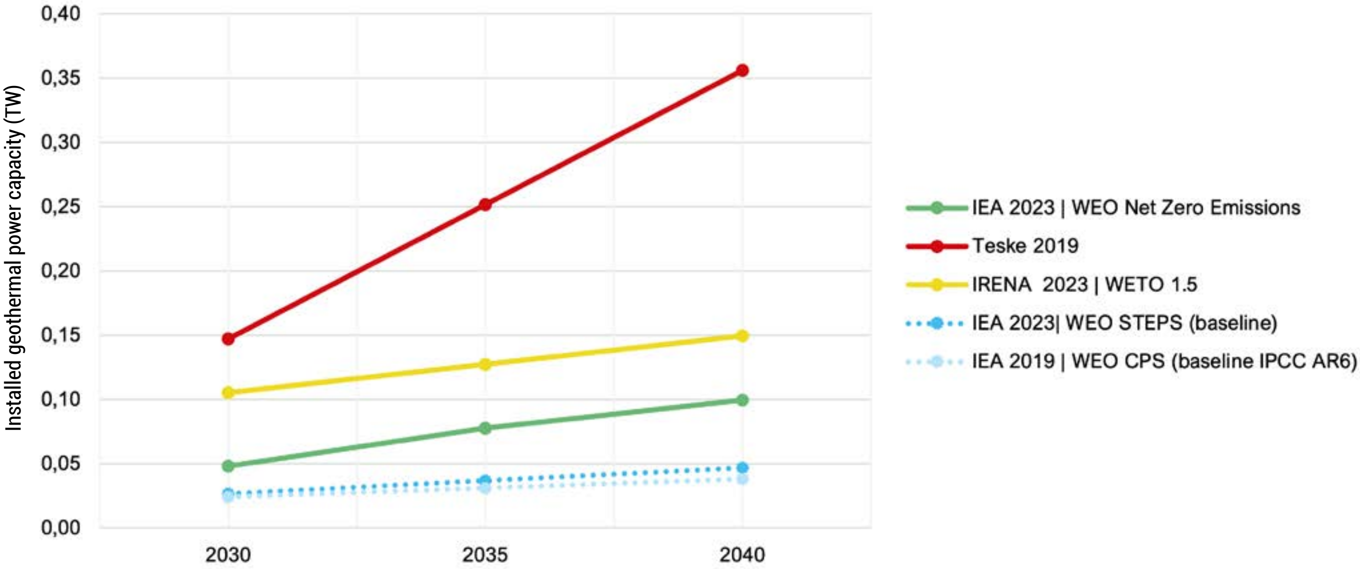
Geothermal power

The emission reduction potential from geothermal electricity varies widely across different studies, reflecting both conservative and more optimistic projections. The IEA Steps scenario provides a baseline, projecting an installed geothermal capacity of 27 GW by 2030 and 37 GW by 2035. In contrast, the IEA Net Zero Emissions (NZE) scenario estimates a doubling of capacity during the same period, reaching 48 GW by 2030 and 78 GW by 2035. This would result in emissions reductions compared to the IEA STEPS baseline of approximately 0.1 by 2030 and 0.2 $GtCO_{2e}$ by 2035 (IEA, 2023a).

More ambitious projections are found in studies like IRENA's (2023) World Energy Transitions Outlook 1.5°C scenario and Teske's 2019 report, which foresee significantly higher geothermal capacities. IRENA estimates 105 GW by 2030 and 127 GW by 2035, while Teske's projections range from 147 GW to 252 GW over the same period. These higher capacities could lead to a much larger emission reduction potential—ranging from 0.5 to 0.8 $GtCO_{2e}$ by 2030, and 0.7 to 1.0 $GtCO_{2e}$ by 2035.

To provide a balanced estimate, the average of these three sources is used to determine the emission reduction potential. By 2030, geothermal energy could lead to a reduction of approximately 0.45 $GtCO_{2e}$ (uncertainty 0.1 to 0.8 $GtCO_{2e}$). By 2035, this potential increases to around 0.63 $GtCO_{2e}$ (uncertainty 0.2 to 1.0 $GtCO_{2e}$). These estimates highlight the significant role geothermal power could play in mitigating emissions, particularly if more ambitious capacity targets are met.

Figure 10. Range of installed geothermal power capacities in various studies and scenarios



The dotted lines indicate the installed capacities in current and stated policies scenarios, whereas the filled lines indicate the potential installed capacities in more ambitious scenarios.

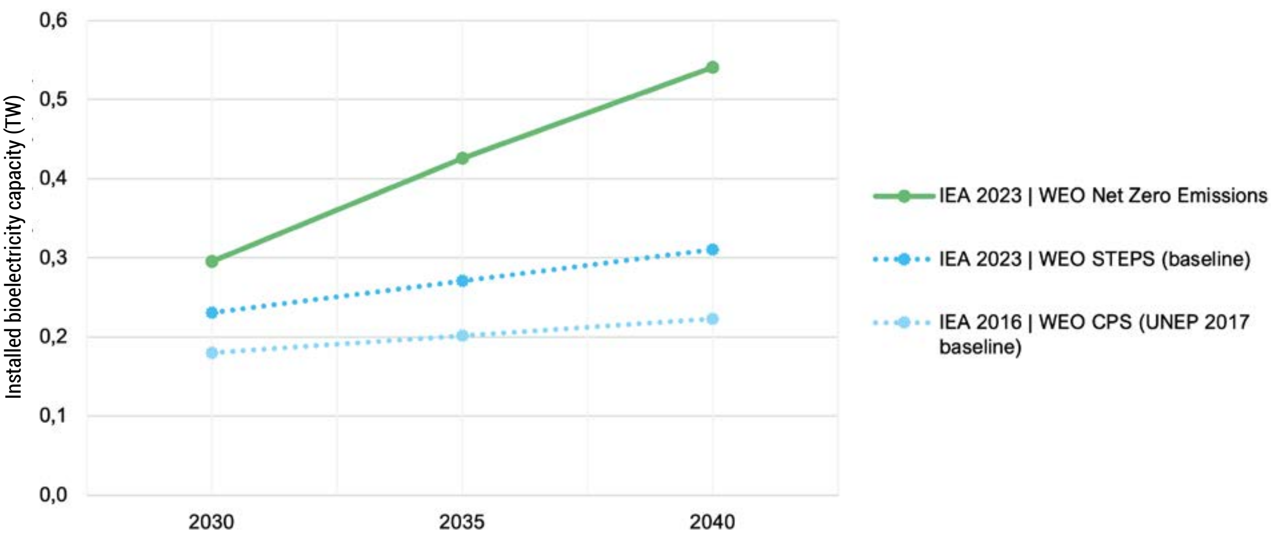
It is relevant to note the geographical limitations of geothermal power generation. Unlike geothermal heat, which can be harnessed in a wider range of locations, geothermal electricity generation requires much higher temperatures. These high-temperature resources are typically found in specific regions, primarily along the "Ring of Fire" around the Pacific Ocean.

This includes areas along the East Coast of Asia and Australia, as well as the West Coast of the Americas. As a result, the global potential for geothermal electricity generation is concentrated in these regions, which may limit its widespread deployment compared to other renewable energy sources.

Bioelectricity and BECCS

The contribution of Bioelectricity and Bioenergy with Carbon Capture and Storage (BECCS) to the mitigation potential is relatively small. Bioelectricity, with an installed capacity of 0.27 TW under the IEA STEPS scenario and 0.43 TW under the IEA NZE scenario, offers an emission reduction potential of around 0.3 $GtCO_{2e}$.

Figure 11. Range of installed bioelectricity capacities in various IEA scenarios.



The dotted lines highlight the installed capacities in current and stated plicies scenarios, whereas the filled line indicates the potential installed capacities in IEA (2023a) NZE scenario.'

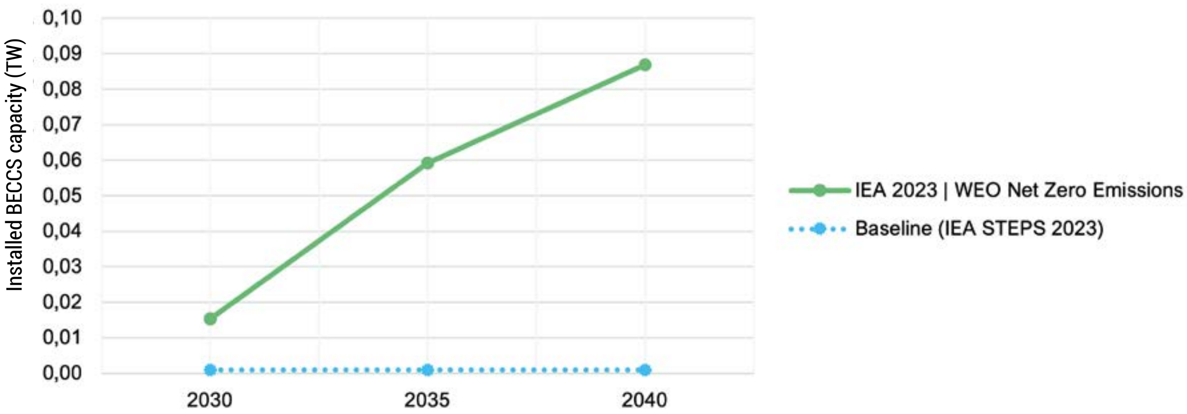
For BECCS, IEA (2023a) shows a substantial increase in deployment potential between baseline and 1.5°C scenarios. Under baseline conditions, BECCS is projected at 1 GW, whereas in the 1.5°C scenario, it could reach 58 GW. This represents a mitigation potential of approximately 0.5 $GtCO_{2e}$, assuming an emissions factor of 0.001 $GtCO_2$ per TWh for the biofuel source.

The feasibility of (BE)CCS is constrained by high costs in the case of high deployment of renewable electricity sources, as highlighted by a recent report of Common Futures (2024). This report concluded that dispatchable power with (BE)CCS could exceed 600 €/tCO_2 due to low full-load hours (FLH). This cost barrier presents a challenge for scaling BECCS as a cost-effective mitigation strategy within current carbon price limits.

Carbon Capture and Storage (CCS) in the electricity sector

The potential for emission reductions from electricity produced with Carbon Capture and Storage (CCS) technologies shows a significant difference between the IEA STEPS and IEA Net Zero.

Figure 12. Installed capacities of BECCS in the IEA (2023b) STEPS and NZE scenarios



Emissions (NZE) scenarios, particularly for coal and natural gas. The electricity produced (TWh_e) from fossil fuels with CCS in the scenario's are shown in Table 5 below.

Table 5. Electricity production from fossil fuels with CCS (TWh_{el}) in the IEA Stated Policies scenario and Net Zero Energy scenario.

TWh_{el}	2030	2035	2040
Coal			
IEA STEPS	4	14	22
IEA NZE	156	445	566
Natural gas			
IEA STEPS	3	16	37
IEA NZE	64	266	301

The total emission reduction potential for electricity produced with CCS is estimated at 0.17 $GtCO_{2e}$ in 2030, 0.53 $GtCO_{2e}$ in 2035, and 0.64 $GtCO_{2e}$ in 2040. These values are calculated by analyzing the difference in energy produced with CCS (in TWh) between the IEA STEPS and IEA NZE scenarios, considering the emission factor (EF) of the energy carrier and a capture rate (CR) of 90%. The mitigation potential is determined using the formula:

$$\textit{Mitigation Potential}=(E_{technology\ potential}-E_{technology\ baseline})\ {}^{*}EF\ {}^{*}CR$$

Where
E = Total annual generation of fossil fuels with CCS (TWh),
EF = Emission Factor ($GtCO_2$/TWh)
CR = Capture Rate of the CCS. Assumed to be 0.9

5.1.2 Methane emissions from fossil fuel production

In 2023, methane emissions related to fossil fuel production amounted to about 4 $GtCO_{2e}$. Methane emissions related to fossil fuel production are expected to decrease gradually, by about 20% in 2035, compared to the present level (IEA, 2023b). The decrease in emissions is less than what is targeted by the Global Methane Partnership, where the associated pledge is for an emission reduction of all methane of 30% by 2030 compared to 2022 (IEA, 2024b).

Recent data on the additional emission reduction potentials and associated costs are provided by IEA (IEA, 2024a), see Table 6. Much of the potential is at low costs.

Table 6. Current emission reduction potentials for fossil fuel production (IEA, 2024a)

	Emission reduction potentials oil and natural gas operations (Mt CH_4)	Emission reduction potentials coal mining (Mt CH_4)
Technical potential	59.6	20.7
Costs below 200 $/tCO2e	59.4	20.7
Costs below 20 $/tCO2e	58.7	20.1
Costs below 0 $/tCO2e	39.9	5.8

Table 7. Emission reduction potentials for methane from fossil fuel production estimated for 2030 and beyond.

Year	Emission reduction potentials oil and natural gas operations (Gt $CO_{2}e$)	Emission reduction potentials coal mining (Gt $CO_{2}e$)
For comparison IPCC estimate for 2030 (IPCC, 2022b)	1.15	0.50
2030	1.42	0.49
2035	1.24	0.43
2040	1.11	0.39

For the period after 2023 the relative emission reductions may decrease due to the fact that part of the potential is already adopted by then. However, some new potential may develop due to technological development. As a proxy, we will assume that the relative potentials will remain the same. Therefore, we scale the emission reductions in line with the development of emissions in the baseline. The resulting potentials are listed in Table 7. The emission reduction potential at costs less than 200 US$/$tCO_{2e}$ is estimated to be 1.24 $GtCO_{2e}$ for oil and natural gas operations, and 0.43 $GtCO_{2e}$ for coal mining, most at low costs. This is comparable to the emission reduction potentials reported in (IPCC 2022b).

5.2. Agriculture and Forestry

In 2023, net emissions from agriculture, forestry and other land use (AFOLU, or land sector) totalled 10.7 $GtCO_{2e}$ – about a fifth of global GHG emissions – with approximately 60% (6.5 $GtCO_{2e}$) from agriculture, and the other 40% (4.2 Gt CO_{2e}) from land use, and land-use change (LULUCF) (UNEP, 2024, Chapter 2) At the same time, the land sector produced anthropogenic carbon removals of approximately 2 $GtCO_{2e}$ in 2023, primarily through afforestation and reforestation (Smith et al., 2024). Both natural and anthropogenic terrestrial sinks have removed an average of 12 $GtCO_{2e}$ each year over the last decade, equivalent to about a third of anthropogenic carbon emissions (Friedlingstein et al., 2023). Under current policies, emissions from agriculture and LULUCF are projected to decrease to 6.3 $GtCO_{2e}$ and 3.3 $GtCO_{2e}$ in 2030, and 6.5 $GtCO_{2e}$ and 3 $GtCO_{2e}$ in 2035 respectively (EPA, 2019; UNEP, 2024, Chapter 4). As discussed in Chapter 2 of the 2024 Emissions Gap Report (UNEP, 2024), these estimates and CO_2 emissions from LULUCF in particular, have a high level of uncertainty.

The land sector economic mitigation potential (up to USD200/tCO_{2e}) is estimated at approximately 8 $GtCO_{2e}$ and 12.8 $GtCO_{2e}$ in 2030 and 2035 respectively. If the full potential is achieved, the land sector could become a sizeable carbon sink. Most of the land sector potential comes from LULUCF measures which provide 65%, and the remaining are provided by agriculture measures (16%), and demand-side measures (19%) (Table 8). The AFOLU sector offers significant near-term mitigation, with most actions readily deployable within the next five years at relatively low cost (Nabuurs et al., 2022). More than half of the potential from forestry is available under USD50/tCO_{2e}.

LULUCF measures in this report include reduced deforestation, afforestation/reforestation (A/R), and improved forest management. Coastal wetlands, peatlands, grasslands and other non-forest ecosystems were excluded due to a lack of updated economic data. Current policies already produce a large reduction of deforestation emissions in the baseline, therefore reduced deforestation (2.55 $GtCO_{2e}$) makes up a lower amount of the total mitigation potential compared to carbon dioxide removals (CDR) from afforestation/reforestation (A/R) and improved forest management (3.6 and 2.2 $GtCO_{2e}$ respectively). However, reducing deforestation and ecosystem conversion provide the highest mitigation density (mitigation per unit area) of any AFOLU measure, at an average of about 300 tCO_{2e}/ha for forests, and 1200-1500 tCO_{2e}/ha for mangroves and peatlands (Roe et al., 2021). The mitigation density and carbon sequestration efficiencies of A/R vary widely by activity and region, with native regeneration and reforestation in the tropics having the highest gains (Roe et al., 2021; Cook-Patton et al., 2020). Regionally, potential for reduced deforestation and A/R is highest in tropical forest countries of Latin America, Southeast Asia and Africa, while improved forest management is more geographically dispersed. Protecting forests and other ecosystems from conversion, particularly of old growth or primary ecosystems, also have significant potential for delivering co-benefits, as they can continue to sequester carbon and provide vital ecosystem services including the regulation and filtration of water and air, and protection of biodiversity (Nabuurs et al., 2022).

Agriculture measures in this report include reducing methane (CH_4) and nitrous oxide (N_2O) emissions from rice cultivation, nutrient management, enteric fermentation, manure management as well as enhancing carbon removals from soil carbon management and biochar. Broader categories like climate-smart agriculture or regenerative agriculture are excluded due to a lack of updated economic data for 2035. However, most agriculture measures in this report are practices deployed in climate-smart and regenerative agriculture. The highest agriculture potentials come from carbon removals (2.6 $GtCO_{2e}$) and reduced emissions from rice production and enteric fermentation (0.2 $GtCO_{2e}$ each). Regionally, mitigation potentials of non-CO_2 emissions and carbon removals in agriculture are highest in Asia Pacific followed by developed countries. Most measures can provide a wide array of potential co-benefits including enhancing soil quality, water efficiency and yields and reducing pollution (Nabuurs et al., 2022). Although agriculture measures have lower mitigation density than measures in forests and other ecosystems, multiple agriculture measures can often be applied on the same parcel of land (Roe et al., 2021).

Demand-side measures, including shifting to healthy sustainable diets and reduced food waste also provide significant potential, at 2.4 $GtCO_{2e}$ in 2035 at <$200/$tCO_{2e}$ when only considering diverted food production and excluding land-use impacts. This potential increases 3-fold when also accounting for emission reductions from land-use impacts like deforestation. Similar to the agriculture potentials, the highest demand-side potentials are primarily in Asia Pacific followed by developed countries. By enhancing efficiencies and reducing agricultural land needs, demand-side measures complement and enable supply-side measures such as reduced deforestation, restoration, as well as reducing N_2O and CH_4 emissions from agricultural production (Nabuurs et al., 2022). We do not cover demand for biomass, for example for hard wood products, buildings or bioenergy, however it is important to note that some potentials in other sectors could impact emissions on land.

Key barriers to implementing land-based mitigation include lack of available finance for farmers and landholders, differences in cultural values, illegality, governance, and technical capacity (Nabuurs et al., 2022). Realizing land sector potentials will require additional and effective policy support and finance, including for technology transfer, improved governance, tenure rights and community forestry, biodiversity conservation, corporate supply chain management, redirecting harmful subsidies, and payment for ecosystem services (Nabuurs et al., 2022).

Table 8. Mitigation potentials of AFOLU measures in 2030 and 2035 available up to USD$200/tCO2e.

Measure	Mitigation potentials ($GtCO_{2e}$)		Source
	2030	2035	
Baseline emissions ($GtCO_{2e}$)	9.6	9.5	*EPA (2019)*
AFOLU aggregated *(Agriculture, Forests, Demand-side)*	8.02 *(4.1 – 16.7)*	12.76 *(6.3 – 19.1)*	
Agriculture (aggregated)	1.42 *(1.1 – 3.9)*	2.01 *(1.7 – 4.7)*	
Improved rice production	0.2 *(0.15 – 0.22)*	0.2 *(0.15 – 0.22)*	*Adapted from Beach et al., 2015; EPA, 2019*
Nutrient management	0.04 *(0.03 – 0.05)*	0.04 *(0.03 – 0.05)*	*Adapted from Beach et al., 2015; EPA, 2019*
Enteric fermentation	0.17 *(0.13 – 0.18)*	0.17 *(0.08 – 0.18)*	*Adapted from Beach et al., 2015; EPA, 2019*
Manure management	0.11 *(0.07 – 0.12)*	0.1 *(0.07 – 0.12)*	*Adapted from Beach et al., 2015; EPA, 2019*
Soil carbon management	0.9 *(0.4 – 1.6)*	1.5 *(0.5 – 2.4)*	*Adapted from IPCC AR6 WG3, Ch 7*
Agroforestry on croplands and grasslands	0.54 *(0.4 – 1.8)*	0.54 *(0.3 – 1.8)*	*Naturebase*
Biochar	0.8 *(0.3 – 1.8)*	1.1 *(0.3 – 1.8)*	*Adapted from IPCC AR6 WG3, Ch 7*
Forests (aggregated)	5.9 *(2.7 – 8.9)*	8.35 *(3.5– 11.7)*	
Reduced deforestation	1.8 *(1.6 – 4.0)*	2.55 *(1.8 – 5.0)*	*Adapted from Austin et al., 2020*
Afforestation/ Reforestation	2.6 *(0.5 – 3.0)*	3.6 *(0.9 – 4.0)*	*Adapted from Austin et al., 2020*
Improved forest management	1.5 *(0.6 – 1.9)*	2.2 *(0.8 – 2.7)*	*Adapted from Austin et al., 2020*
Demand-side (aggregated)	0.7 *(0.4 – 3.9)*	2.4 *(1.1 – 3.7)*	
Reduced food waste	0.2 *(0.1 – 0.6)*	0.7 *(0.1 – 1.0)*	*Adapted from IPCC AR6 WG3, Ch 7*
Shift to sustainable healthy diets	0.5 *(0.3 – 3.0)*	1.7 *(1.0 – 2.7)*	*Adapted from IPCC AR6 WG3, Ch 7*

Values represent the median, and values in parentheses represent the full range of potential. Individual measures cannot be summed due to overlaps. The aggregated potentials take these overlaps into account.

5.3 Buildings

In 2023, the net annual emissions from the built environment totalled 3.6 $GtCO_{2e}$ (UNEP, 2024, Chapter 2), of which approximately 67% originated from the residential sector (IEA, 2023b). In the IEA Stated Policies Scenario (STEPS), the annual emissions from this sector are projected to decrease to 2.8 $GtCO_{2e}$ by 2030 and 2.6 $GtCO_{2e}$ by 2035. The progress of mitigation in the building sector so far is modest. For example, in IEA countries, 1% of existing buildings are retrofitted per year, whereas 2.5% per year is needed to reach ambitious climate targets (IEA, 2022). Most progress is made in the area of energy efficiency standards, without which electricity consumption in the US and the EU would have been 15% higher (IEA, 2021a). For the major appliances, energy efficiency standards now have a global coverage of two-thirds of countries or more (IEA, 2022).

As no new global estimates of mitigation potential in the build environment have become available in the last years, we base our work on IPCC's Sixth Assessment Report, interpolating linearly between the years of 2030 and 2040. This results in a total direct mitigation potential of 1.1 $GtCO_{2e}$ in 2030 and 1.2 $GtCO_{2e}$ in 2035 for the buildings sector. For appliances, information from IEA on 2030 (IEA, 2024e) suggests that the potential could be up to double what is reported here, but due to unclear baselines we should be cautious using this number. An overview of the potentials by abatement measure is presented in Table 9.

Table 9. Summary of direct and indirect mitigation potential of measures in the building sector. Direct measures refer to non-electricity energy use in the building sector, while indirect measures refer to electricity use, and are therefore attributable to the energy sector.

	Direct			Indirect			Totals		
	2030	2035	2040	2030	2035	2040	2030	2035	2040
Avoid demand for energy services	0.2	0.3	0.3	0.3	0.5	0.6	0.6	0.8	1.0
New buildings - Better insulation	0.2	0.3	0.3	0.4	0.6	0.7	0.6	0.9	1.1
New buildings - Efficient generations of heat and cold	0.2	0.3	0.3	0.4	0.4	0.6	0.6	0.7	0.8
New buildings - Renewables	0.0	0.0	0.0	0.4	0.6	0.8	0.4	0.6	0.8
Retrofitting - Better insulation	0.1	0.1	0.2	0.0	0.0	0.0	0.2	0.2	0.2
Retrofitting - Efficient generation of heat and cold	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Appliances*	0.2	0.2	0.3	0.5	0.7	0.9	0.7	0.9	1.1
Total (GtCO2e)	**1.1**	**1.2**	**1.4**	**2.2**	**2.9**	**3.7**	**3.2**	**4.2**	**5.2**

**Information from IEA (2024e) suggests mitigation potential for appliances could be double of what is reported here, but due to unclear baselines these estimates were excluded.*

Up to 0.6 $GtCO_{2e}$ and 0.7 $GtCO_{2e}$ of the emission reduction potential in respectively 2030 and 2035 is projected in the developed countries, primarily through avoided demand and efficiency improvements for new builds. In the developing countries, 0.5 $GtCO_{2e}$ by 2030 and 0.6 $GtCO_{2e}$ by 2035 of the emission reduction potential is projected, mainly driven by heating, ventilation, and air conditioning (HVAC) systems, demand-side management measures for new buildings and improved efficiency of appliances.

The major policy for speeding up mitigation in the building sector is energy efficiency standards for appliances and new buildings. These have been shown to be successful and broader application of ambitious standards is the key policy in this sector. The main challenge is with the existing building stock, for which a range of policy instruments can be applied. Energy performance standard may also be instrumental here to speed up the low-carbon transition (Kamenders et al., 2022).

5.4. Transport

In 2023, the net annual emissions from transport totalled 8.4 $GtCO_{2e}$, of which approximately 74% originated from road transport, 14% from aviation and 11% from shipping and 14% from other transport sectors (UNEP, 2024, Chapter 2). In the baseline developed in Chapter 4 of the UNEP 2024 Emission Gap Report (UNEP, 2024), the annual emissions from this sector are projected to grow to 8.8 $GtCO_{2e}$ by 2030 and 9.0 $GtCO_{2e}$ by 2035 and 2040. Underlying these projected developments, there is an increase in emissions from aviation and heavy-duty road transport, and a decrease in emissions from passenger cars.

The emission reduction potential for the transport sector is estimated to be 3.2 $GtCO_{2e}$ for 2030 and 4.8 $GtCO_{2e}$ for 2035. The primary contributor to emission reductions is road transport, with an estimated reduction potential of 2.5 and 3.6 $GtCO_2$ in 2030 and 2035 respectively. Other contributions come from shipping and aviation.

The emission reduction potentials for road transport and shipping are mainly determined based on insights from the IEA (2023a) Net-Zero Emissions scenario, cross-checked with a wide range of other studies and scenarios. In addition, ITDP & UC Davis (2021) was used to determine the emission reduction potential of a modal shift in road transport to public transport and (e-)bikes.
To determine the emission reduction potentials in aviation, ICAO (2022) was used to estimate the reduction potential of a fuel shift, improved aircraft technology and improved operations. The emission reduction potential from reduced increase in aviation demand was based on insights from Bergero et al. (2023).

An overview of the unaggregated emission reduction potentials per reduction measure is presented in Figure 13 below, the aggregated potentials can be found in Table 10. Materialising the identified options for mitigation of transport emissions faces a variety of challenges, including technological dependencies, regulatory changes, social-cultural factors, and significant investments (Geels et al. 2017). For example, promoting car-free mobility and reduced aviation requires changes in individual behaviour and societal acceptance, which are often slow to materialise (IPCC, 2022b). An increase in electric vehicles and high-speed railways requires urban planning changes and significant infrastructure investments. Developing sustainable fuels for aviation and shipping demands international coordination and R&D investment (Borén 2019; Sclar et al. 2019; Marinaro et al. 2020). Addressing these barriers requires a comprehensive and coordinated effort from policymakers, industry stakeholders, and communities.

Figure 13. Overview of unaggregated emission reduction potential for mitigation measures in transport

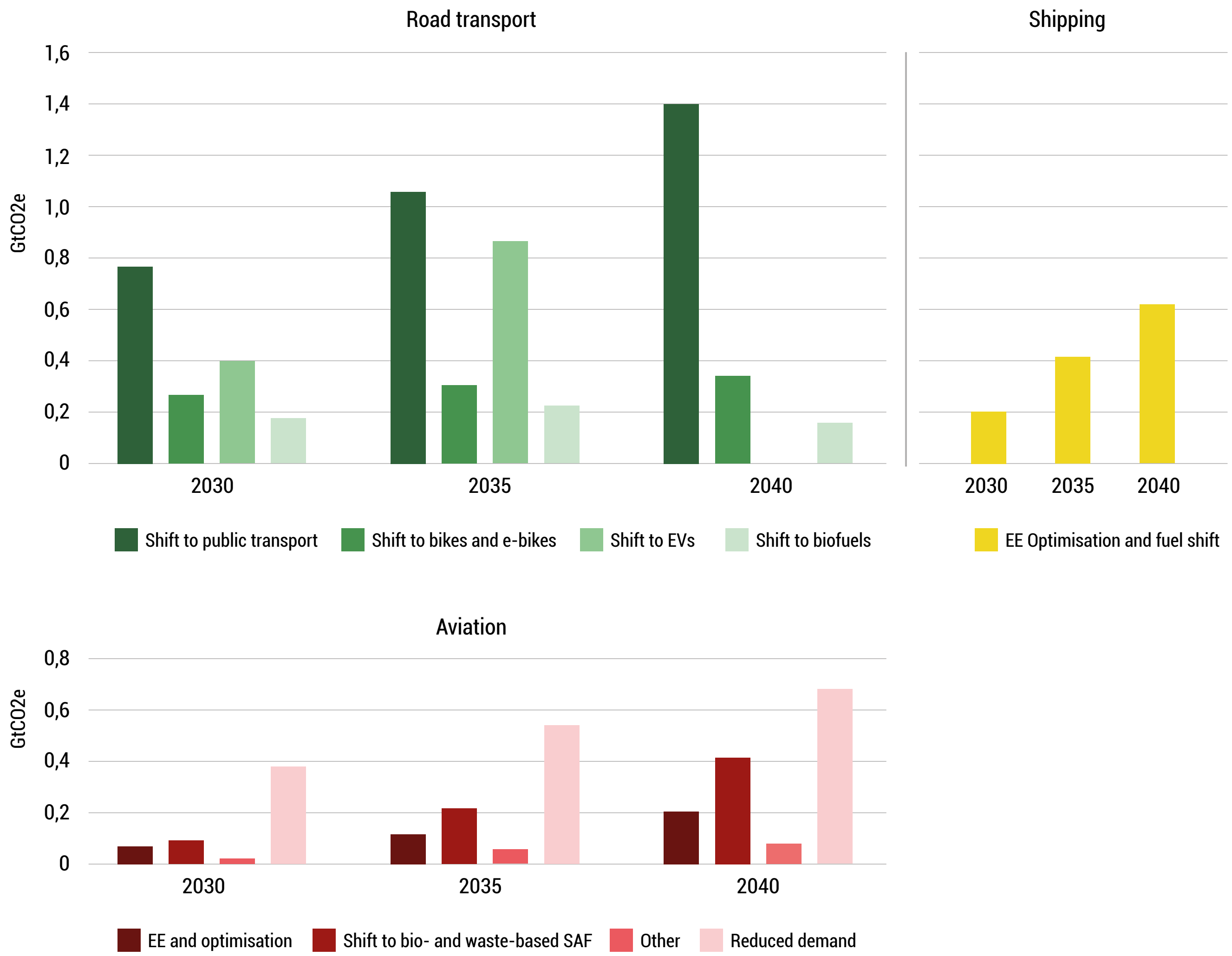


Table 10. Mitigation potentials in the transport sector by abatement measure.
Please note that individual contributions cannot be summed due to overlaps.The aggregated potentials take these overlaps into account.

Measure	Mitigation potentials ($GtCO_{2e}$)			Source
	2030 *(uncertainty range)*	2035 *(uncertainty range)*	2040 *(uncertainty range)*	
Baseline emissions ($GtCO_{2e}$)	8.8	9.0	9.0	*UNEP (2024) Chapter 4*
Transport (aggregated)	3.2 *(1.6 – 4.8)*	4.8 *(2.4 – 7.2)*	6.1 *(3.0 – 9.1)*	
Road transport (aggregated)	2.5 *(1.2 – 3.7)*	3.6 *(1.8– 5.4)*	4.4 *(2.2 – 6.6)*	
Shifts to public transport	0.8 *(0.4 – 1.2)*	1.1 *(0.5 – 1.6)*	1.4 *(0.7 – 2.1)*	*ITDP & UC Davis (2021), ITDP & UC Davis (2015)*
Shifts to bikes and e-bikes	0.3 *(0.1 – 0.4)*	0.3 *(0.2 – 0.5)*	0.4 *(0.2 – 0.5)*	*ITDP & UC Davis (2021), ITDP & UC Davis (2015)*
Shift to electric LDV	0.3 *(0.2 – 0.5)*	0.6 *(0.3– 1.0)*	3.7 *(1.9 – 5.6)*	*IEA (2024c) Global EV Outlook*
Shift to electric HDV	0.1 *(0.0 – 0.1)*	0.2 *(0.1 – 0.3)*		*IEA (2024c) Global EV Outlook*
Fuel efficiency LDV	0.5 *(0.3 – 0.8)*	0.7 *(0.4 – 1.1)*		*Based on IEA (2023a) NZE*
Fuel efficiency HDV	0.6 *(0.3 – 0.9)*	1.1 *(0.5 – 1.6)*		*Based on IEA (2023a) NZE*
Biofuels	0.2 *(0.1 – 0.3)*	0.2 *(0.1 – 0.3)*	0.2 *(0.1 – 0.2)*	*IEA (2023a) NZE*
Shipping (aggregated)	0.2 *(0.1 – 0.3)*	0.4 *(0.2 – 0.6)*	0.6 *(0.3 – 0.9)*	
Energy efficiency and optimisation, and a shift to low- and zero-emission fuels	0.2 *(0.1 – 0.3)*	0.4 *(0.2 – 0.6)*	0.6 *(0.3 – 0.9)*	*IEA (2023a) NZE*
Aviation (aggregated)	0.5 *(0.3 – 0.8)*	0.8 *(0.4 – 1.2)*	1.1 *(0.5 – 1.6)*	
Reduced demand increase	0.4 *(0.2 – 0.6)*	0.5 *(0.3 – 0.8)*	0.7 *(0.3 – 1.0)*	*Bergero et al. (2023)*
Energy efficiency and optimisation	0.1 *(0.0 – 0.1)*	0.1 *(0.1 – 0.2)*	0.2 *(0.1 – 0.3)*	*Based on ICAO (2022)*
Shift to low- and zero-emission fuels	0.1 *(0.0 – 0.1)*	0.2 *(0.1 – 0.3)*	0.4 *(0.2 – 0.6)*	*Based on ICAO (2022)*
Other	0.0 *(0.0 – 0.0)*	0.1 *(0.0 – 0.1)*	0.1 *(0.0 – 0.1)*	*Based on ICAO (2022)*

**The transport baseline emissions estimated in UNEP (2024) Chapter 4 are higher than the estimates of the IEA STEPS scenario on which the mitigation potentials were largely based (+0.5 GtCO2e in 2030 and +0.9 GtCO2e in 2035). This means that the mitigation potential can be higher.*

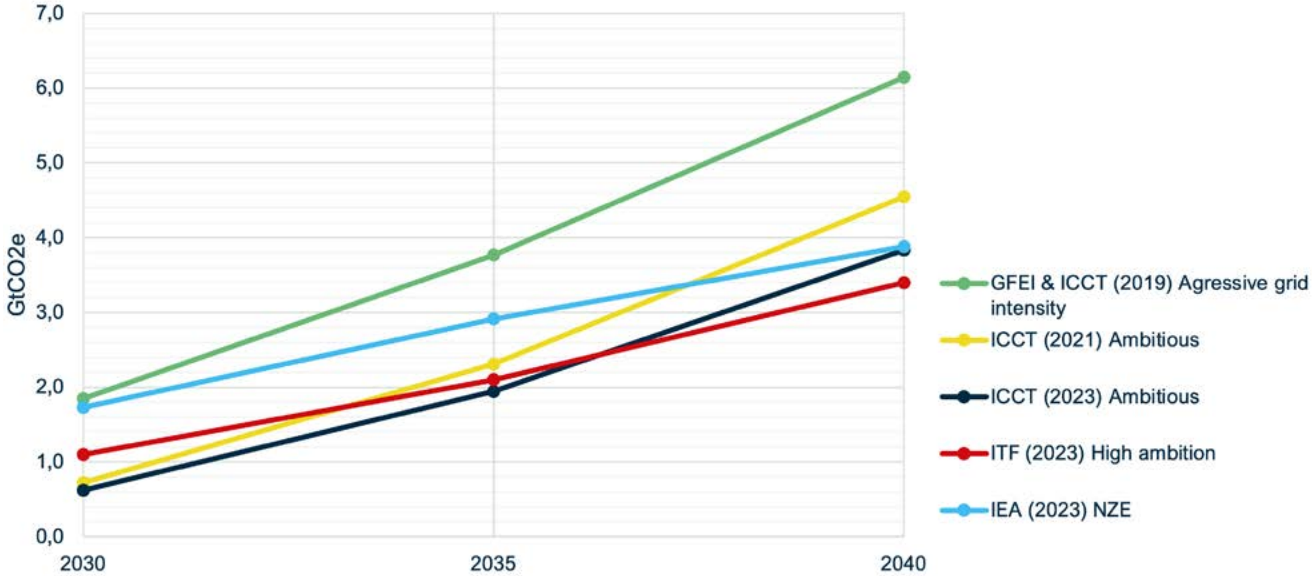
5.4.1 Road transport

IEA (2023b) estimates an emission reduction potential in road transport to be 1.7 $GtCO_2$ in 2030 and 2.9 $GtCO_2$ in 2035. This is in the range of the emission reduction potentials found in other studies (see Figure 14), which report an emission reduction potential of 0.6-1.9 $GtCO_2$ in 2030 and 1.9-3.8 $GtCO_2$ in 2035 (GFEI & ICCT, 2019; ICCT, 2021; ICCT, 2023; OECD, 2023).

IEA (2023) emission reduction potential is expected to mainly cover emission reductions from the transition to electric vehicles, biofuel deployment and improved fuel efficiency.

The contribution to emission reduction from a ***shift to EVs*** was estimated 0.4 $GtCO_2$ in 2030 and 0.9 $GtCO_2$, according to the IEA (2024c) Global EV Outlook. This is a reduced potential compared to IPCC AR6, where the estimated contribution to emission reductions from deployment of EVs was 0.8 $GtCO_2$ in 2030.

Figure 14. Emission reduction potential in road transport - study comparison



This a result of the fact that the strong developments in EV sales and deployments in recent years are included in the baseline already. In the IEA Global EV Outlook (2020b) the avoided GHG emissions from EV deployment in the stated policies scenario (STEPS) was estimated to be 0.2 $GtCO_{2e}$ in 2030, whereas the STEPS scenario in most recent update of the Global EV Outlook (2024c) projects the avoided GHG emissions from electric vehicle deployment in 2030 to be 0.8 $GtCO_{2e}$. This represents a difference of 0.6 $GtCO_{2e}$ in emission reductions that has already been incorporated into the baseline, explaining the reduced potential in newer estimates.

The contribution from the ***deployment of biofuels*** was estimated 0.18 $GtCO_2$ in 2030 and 0.23 $GtCO_2$ in 2035 based on the share of biofuels in road transport reported by IEA (2023b), comparing the STEPS scenario to the NZE scenario, and assuming an average reduction potential of 0.07 $GtCO_2$/EJ compared to conventional fuels.

The remaining emission reduction potential in road transport identified by IEA (2023b) is expected to be a result of increased ***fuel efficiency***, amounting to 1.1 $GtCO_2$ in 2030, and 1.8 $GtCO_2$ in 2035.

In addition to deployment of electric vehicles and biofuels, and improved fuel efficiency, road transport emissions can also be reduced by a ***modal shift*** to public transport and (e-) bikes. This potential was estimated 1.0 $GtCO_2$ in 2030 and 1.4 $GtCO_2$ in 2035 based on ITDP & UC Davis (2021).

Aggregated mitigation potential in road transport

The emission reduction potentials in the road transport sector were derived from multiple sources, primarily IDTP & UC Davis (2021) for modal shift potentials and the IEA (2023b) for other reduction measures such as fuel efficiency improvements and the adoption of electric vehicles. Since the shift to electric vehicles and increased fuel efficiency (taken from IEA, 2023b) can reduce the overall impact of a modal shift to bicycles and public transport, interactions between these measures were carefully considered during the aggregation process.

To aggregate the emission reduction potentials, the baseline emissions of 5.9 $GtCO_{2e}$ for 2030 and 5.6 $GtCO_{2e}$ for 2035 under current policy scenarios were used as the starting point. The emission reduction potential from modal shifts (1.0 $GtCO_{2e}$ in 2030 and 1.4 $GtCO_{2e}$ in 2035) corresponds to reductions of 17% and 24% of baseline emissions in those years, respectively. To account for the interaction between measures, these percentages were applied to the baseline emissions after subtracting the reduction potentials of 1.7 $GtCO_{2e}$ (for 2030) and 2.9 $GtCO_{2e}$ (for 2035) attributed to other measures reported by IEA (2023b). This adjustment provides the net or "aggregated" reduction potential from the modal shift, ensuring that overlaps with other measures are minimized.

The combined reduction potential from IEA (2023b) and the adjusted modal shift potentials results in an overall emission reduction potential for the road transport sector of 2.5 $GtCO_{2e}$ in 2030 and 3.6 $GtCO_{2e}$ in 2035.

5.4.2. Shipping

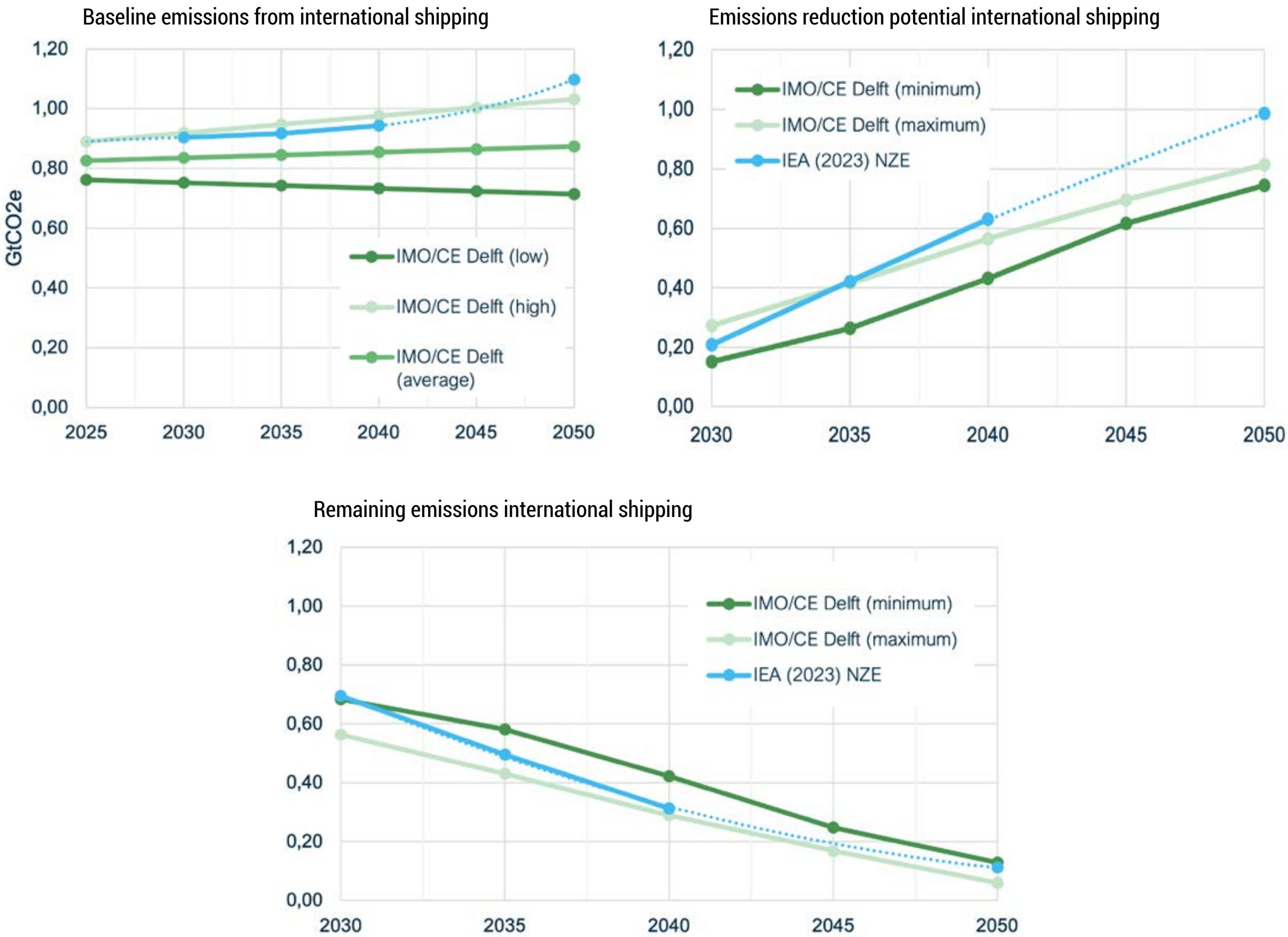
Based on IEA (2023b) the emission reduction potential from shipping is estimated to be 0.2 $GtCO_2$ in 2030 and 0.4 $GtCO_2$ in 2035. This includes a shift to zero- or low-emission fuels like biofuels, hydrogen, methanol and ammonia, operational emission reduction measures like lower speeds, and technical emission reduction measures like wind-assisted propulsion.

IEA (2023b) sees an important role for zero- or low-emission fuels like biofuels, hydrogen and hydrogen-based fuels in reducing emissions in the shipping sector, with their fuel share increasing from 0% in 2022, to 19% in 2030 and 85% in 2050.

Alongside improvements in energy efficiency, biofuels and ammonia are expected to be the dominant emission reduction option towards 2035, representing 13% and 15% of the final energy consumption respectively. Thereafter, ammonia becomes the dominant lever, with a share of 44% in the 2050 final energy mix.

When comparing the total emission reduction potential from shipping in IEA (2023b) NZE scenario to reduction targets in the recent update of IMO (2023) Strategy on Reduction of GHG Emissions from Ships and the technical potential study by CE Delft (2023) underlying this, the emission reduction potential is at the higher end (Figure 15). The same is true for the baseline emissions.

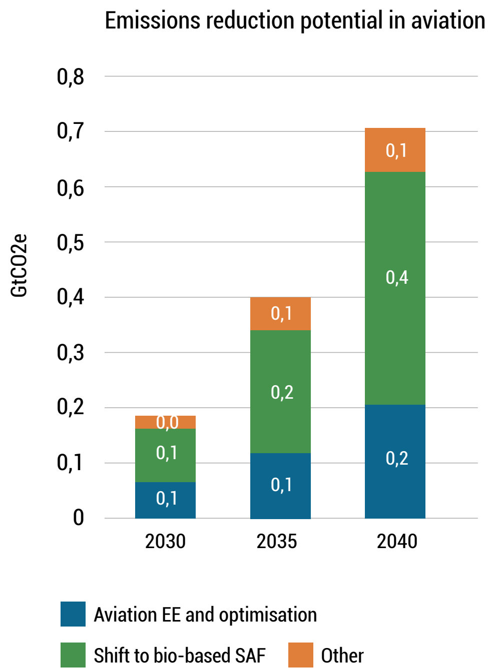
Figure 15. Comparison of estimates on baseline emission, emission reduction potentials and remaining emissions from shipping in the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, the CE Delft underlying this and IEA (2023).



5.4.3. Aviation

The emission reduction potential from aviation in 2030 and 2035 are estimated to be 0.5 $GtCO_{2e}$ and 0.8 $GtCO_{2e}$ respectively. This includes a shift to renewables-based aviation fuels (SAF), operational emission reduction measures improved air traffic management and infrastructure, and emission reduction from improved aircraft technology, based on ICAO (2022), and a behavioural shift limiting the increase in demand for aviation, based on Bergero et al. (2023). The aviation sector is still expected to see strong growth beyond 2035, mainly in emerging markets and developing economies. However, growth in emissions can be limited with the emission reduction options introduced above.

Figure 16. Emission reduction potential for 2030, 2035, and 2040 in aviation split by mitigation measure.



In the IEA (2023b) NZE scenario, aviation oil demand is projected to peak in the mid-2020s due to advancements in traffic optimisation, energy efficiency, behavioural changes, and a strongly increased development of bio-based SAF. Post-2030, oil demand is expected to decline sharply as synthetic SAF becomes more prevalent and the deployment of hydrogen-powered aircrafts starting in the second-half of the 2030s.

The ICAO (2022) IS3 scenario sees similar developments contributing to reducing aviation emissions in 2035. Biomass-based and gaseous waste-based fuels are expected to play the largest role (~50%), followed by technological advancements (~15%) and operational optimisation (~15%).

The ambitious demand shift scenario from Bergero et al. (2023) was used to determine the emission reduction potential from a reduced increase in aviation demand. This scenario projects an average annual growth rate of 1%. This contrasts significantly with the business-as-usual (BAU) scenario of 4% annual growth and the industry projections of 2.8% annual growth. As a result, the demand for aviation can be 32% and 41% lower compared to the BAU scenario in 2030 and 2035 respectively. Comparing this to the IEA (2023b) STEPS baseline emission for aviation, the emission reduction potential from reduced increase in aviation demand is estimated to be 0.4 $GtCO_2$ in 2030 and 0.5 $GtCO_2$ in 2035. It is important to note that the ambitious scenario represents a substantial deviation from the historical correlation between aviation demand and anticipated population and economic growth.

The aggregated potential for emission reduction potentials in aviation was calculated in the same way as was done for road transport.

5.5. Industry

In 2023, the net annual emissions from industry totalled 10.7-11.7 $GtCO_{2e}$, depending on whether coke oven and blast furnace top gases are counted in industry or heat and power. In the global emissions of 57.0 $GtCO_{2e}$ presented in Chapter 2 of the UNEP Emissions Gap Report 2024, which uses the latter method, industrial energy use represents 11% and industrial process emissions are 8% (UNEP 2024, Chapter 2).

Industry provides both the physical structure of our societies as buildings materials (i.e. concrete, steel, glass, plastics and wood) as well as a number of important feedstock chemicals, e.g., ammonia for fertilizers and methanol and olefins for plastics. Total industrial emissions, ~26% of direct global CO_2 emissions and ~34% including purchased heat and electricity emissions, are a function of demand for industrial commodities and the GHG intensity of making them. The main strategies for reducing CO_2 and other GHG emissions from production of industrial commodities (Figure 17) are: reduced consumption through material efficiency and substitution with lower GHG intensity options; energy efficiency; material circularity (mainly through recycling); cementitious material substitution in the cement sector; fuel switching and electrification (e.g., heat pumps) that is viable but uncompetitive due to regional relative fossil fuel and electricity costs; advanced process changes including feedstock decarbonization & electrification; and finally "carbon management" through carbon dioxide capture from fuel combustion or the atmosphere, utilization, and permanent geological storage. Material and energy efficiency, enhanced recycling (especially of metals), and cementitious material substitution are all relatively low-cost actions with high impact that do not lock in emissions over the long term, while reducing the need for high-cost production decarbonisation options. All the above options, by reducing and replacing fossil fuel use, have strong local air quality improvement impacts.

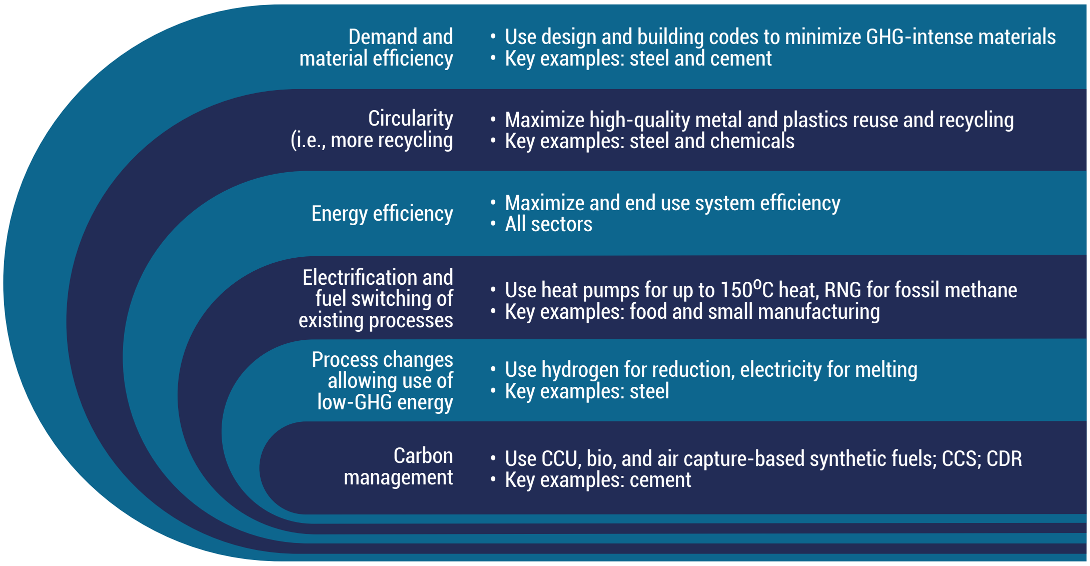
Table 11. Emission reduction potentials in industry by abatement option. See the remainder of this chapter and Table 12 for values for all calculations.

Measure	Mitigation potentials ($GtCO_{2e}$)		
	2030 *(uncertainty range)*	2035 *(uncertainty range)*	2040 *(uncertainty range)*
Baseline emissions ($GtCO_{2e}$)*	14.2 *(13.4 – 15.1)*	14.7 *(13.1 – 16.4)*	15.2 *(12.9 – 17.8)*
Industry (aggregated)	5.2 *(4.9 – 5.6)*	7.7 *(6.9 - 8.8)*	*10.2* *(7.6 – 12.7)*
Industry (aggregated), corrected for autonomous implementation**	4.4 *(4.2 – 4.8)*	6.6 *(5.8 - 7.4)*	8.7 *(6.5 – 10.8)*
Energy efficiency**	1.0 *(1.0 - 1.1)*	1.1 *(1.0 - 1.2)*	1.1 *(1.0 - 1.3)*
Material efficiency	0.7 *(0.7 - 0.8)*	1.2 *(1.1 - 1.4)*	1.8 *(1.5 - 2.1)*
Enhanced recycling	0.6 *(0.5 - 0.6)*	1.0 *(0.9 - 1.1)*	1.3 *(1.2 - 1.6)*
Fuel switching and electrification (viable but uncompetitive without climate policies)	1.6 *(1.5 - 1.7)*	2.1 *(1.8 - 2.3)*	2.6 *(2.2 - 3.1)*
Advanced feedstock decarbonization & process changes	0.7 *(0.7 - 0.8)*	1.2 *(1.1 - 1.3)*	1.7 *(1.4 - 2.0)*
CCU and CCS	0.1 *(0.1 - 0.1)*	0.5 *(0.4 - 0.6)*	0.8 *(0.7 - 0.9)*
Cementitious material substitution (e.g., 1/3 ground limestone & 2/3 calcined clays, replacing <=50% clinker)	0.3 *(0.3 - 0.3)*	0.4 *(0.4 - 0.5)*	0.6 *(0.5 - 0.7)*
Reduction of N_2O emissions	0.2 *(0.2 - 0.2)*	0.3 *(0.3 - 0.3)*	0.3 *(0.3 - 0.4)*

** Baseline emissions include all onsite CO2 emissions inherent to the process, e.g., coking and excess BFBOF top gases possibly used to generate heat or electricity.*
*** Energy efficiency and some of the other options are partially market driven along with stock turnover, EE programs and regulation. Therefore, the aggregate was corrected for this autonomous implementation, assumed to be 15% of the total potential.*

The estimates of emissions reduction potential provided are based on known sectoral GHG intensities and forecasted output for iron and steel, cement and concrete, chemicals, non-ferrous metals, and pulp and paper, which are then adjusted by sector using the above mitigation strategies sequentially and additively to avoid double counting – please see the supplementary material for details and references). For "Other industry" emissions, which cover all other CO_2 emissions outside the specified sectors above, estimates from IPCC AR6 CH.11 are extrapolated from 2019 and then adjusted downward using the same strategies.

Figure 17. The main strategies for decarbonizing industry. Source: Bataille (2022)



Source: Author configuration based on IPPC, Climate Change 2022: mitigation of Climate Change, April 4, 2022, ch. 11, fig. 11.9 http://www.ippc.ch/report/ar6/wg3/

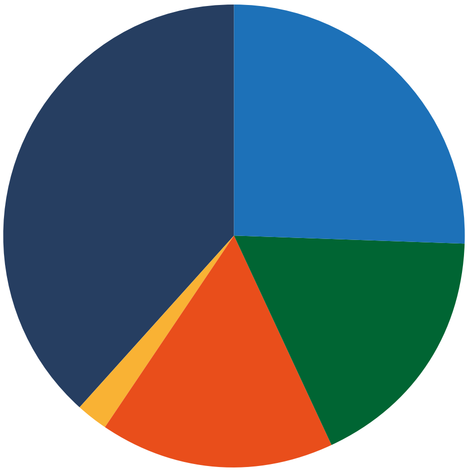
End use activity demand growth from 2022 to 2035 is estimated to add about 2.0 $GtCO_2$ of emissions assuming the technology mix remains unchanged, from 10.3 $GtCO_2$ in 2019 through 12.0 $GtCO_2$ in 2022, 14.2 $GtCO_2$ in 2030, and 13.5 $GtCO_2$ in 2035. These values are higher than IEA estimates of 9.0 Gt in 2022 and 9.6 $GtCO_2$ by 2035 partly because all fossil fuel oxidation (i.e. chemical combination of carbon with oxygen that eventually ends up as CO_2 released to atmosphere) central to production is included, e.g., coke oven gases in steel and other metallurgy. This is necessary to account for emissions reduction potential to switch away from coke-based metal reduction. Energy efficiency improvements, typically estimated at about 1% per year for heavy industry based on natural stock turnover and operational improvements, are also estimated to offset all industrial emissions by 1.1 $GtCO_2$, reducing baseline emissions estimates to ~13.6 $GtCO_2$ in 2035. After considering these two dynamics, about 7.4 $GtCO_2$ of emissions reduction potential remains in 2035.

In 2035, of the overall 7.4 $GtCO_2$, 5.7 $GtCO_2$ can be assigned to material efficiency, enhanced recycling, cementitious material substitution, and electrification and fuel switching that is viable but uncompetitive due to regional relative fossil fuel and electricity costs, e.g., heat pumps and coal to gas. For other options, such as CCS (0.5 $GtCO_2$) and process transformations allowing energy input switching to electricity and hydrogen (1.2 $GtCO_2$), more potential becomes available moving from 2030 to 2035. This is because more time is available to initiate, design, permit, finance and construct new industrial facilities, which typically take 5-10 years depending on the region.

Finally, nitrous oxide emissions from nitric acid and adipic acid production can be reduced to a large extent (EPA, 2019). Emission reduction for fluorinated gases will be dealt with later in the section 'Other'.

It is important to note knowledge of decarbonization options is evolving quickly in the industry sector since the Paris Agreement, e.g., prior to 2016 most mitigation potential was focussed on energy efficiency, some minor electrification and the assumption that broad post-combustion CCS would someday prove viable.

Figure 18. Emission reduction potentials 2035 split by industrial sector.



It should also be noted that other than in a few jurisdictions, such as under the EU ETS and a few sub-national jurisdictions, almost nowhere in the world is policy strong enough to drive transformational demand and supply side deep mitigation in the industrial sector. To activate the potential for material efficiency and circularity/recycling, building codes, public procurement and regulation must all be employed, with education for architects, structural engineers and designers of all kinds. To activate viable electrification, fuel switching, and concentrated CO_2 flow and CCS options, rising carbon pricing or performance regulations are required. To bring new electrification, hydrogen, process change and post combustion CCS to market strong innovation and commercialization support is required, followed by public and private lead markets paying a premium – carbon pricing and regulations alone will not be enough.

The following tables details all the key numeric 2022 intensity and output, material efficiency, recycling, energy efficiency, fuel switching and CCUS assumptions need to sequentially prepare the mitigation estimates by sector.

Table 12. Overview of key assumed vlaues for each industrial sector.

Iron and steel	Value	Source
2022 CO_{2e} intensity per tonne	1.91	Worldsteel.
2022 output in tonnes	1879	Worldsteel. Grown at 1.4% per year, see Bataille 2020 for detailed sourcing
%/yr material efficiency improvement	0.68	Based on 29% over 50 years, IEA ETP 2020 (IEA, 2020a)
%/yr recycling improvement	1.25	Bataille et al., 2021, 2024)
%/yr energy efficiency improvement	1.00	Chapter 11, IPCC AR6 (2022a)
%/yr fuel switching	1.00	Based on extrapolation of coal to NG switching in (Bataille et al., 2024)
Production decarbonization and CCS/CCU	See text	This is based on the literature review in Bataille et al 2024 on the capacity to switch BFBOFs for DRI with CCS and 100% hydrogen DRI. In AR6 all $50-100/t CO2e. Now cost allocated half to 50-100 and half to 100-200 based on DRI with CCS vs 100% hydrogen DRI. Recent modelling shows DRI+CC dominates the first round of investments, roughly 100 Mt. With the right policy these could be convertible. (Bataille et al., 2024)
Cement and concrete	**Value**	**Source**
2022 kg CO_{2e} intensity per kg cement	0.639	900kg CO_2 (~300 heat, ~600 process) per tonne clinker at 71% clinker share per kg cement
2022 clinker output in Mt	4100	https://www.iea.org/energy-system/industry/cement Grown at 0.8% per year, see Bataille 2020 for sourcing
%/yr material efficiency improvement	0.60	Based on 26% over 50 years, IEA ETP 2020
%/yr clinker ratio (LC3 cements)	1.40	Based on LC3 cements used to reach a 50:50 clinker ratio https://lc3.ch/
%/yr energy efficiency improvement	1.00	Chapter 11, IPCC AR6 (2022a)
%/yr fuel switching	1.00	Based on extrapolation of coal to NG & waste switching Chapter 11, IPCC AR6 (2022a)
Production decarbonization and CCS/CCU		Process change or 90% CCUS retrofit/rebuild (33% by 2040, 66% by 2050.)
Chemicals	**Value**	**Source**
2022 kg CO2e intensity per tonne chemicals	2.06	Energy Technology Perspectives (IEA, 2020a)
2019 output ammonia, methanol and HVCs	680	Energy Technology Perspectives (IEA, 2020a) HVCs and methanol grown at 4% per year, ammonia at 1% per year. See Bataille 2020 for detailed sourcing
%/yr material efficiency improvement	0.60	Based on 25% over 50 years, IEA ETP (2020a)
%/yr enhanced recycling	0.9	<5% today, increased to 20% of markets share by 2050
%/yr energy efficiency improvement	1.00	Chapter 11, IPCC AR6 (2022a)
%/yr fuel switching	1.00	Based on extrapolation of coal to NG, direct electrification & heat pumps, and district heat sharing /cascading Chapter 11, IPCC AR6 (2022a)
Production decarbonization and CCS/CCU		CCUS, clean H2, biocarbon, electric crackers (33% by 2040, 66% by 2050.)
Notes:		Future assessments should separate ammonia, methanol, olefins (aka high value chemicals) and other, as their growth rates and intensities are dissimilar.

Aluminum	Value	Source
2022 kg CO_{2e} intensity per kg aluminum	2.6	kg GHGs per kg aluminum not including Scope 2 electricity. 0.8 PFC, 1.5 cathode, (IEA, 2020a, pp. 2-)
2022 output aluminum Mt	68.5	Energy Technology Perspectives (IEA, 2020a) Grown at 5.4% per year, see Bataille 2020 for detailed sourcing
%/yr material efficiency improvement	1.0	Based on 25% over 30 years, IEA ETP (2020a)
%/yr enhanced recycling	1.2	25% today, increased by 25% of markets share by 2050
%/yr energy efficiency improvement	1.0	Chapter 11, IPCC AR6 (2022a)
%/yr fuel switching	0	
Production decarbonization and CCS/CCU		zero GHG electricity and inert electrodes; 33% remainder by 2040, 66% by 2050.
Pulp and Paper	**Value**	**Source**
2022 CO_{2e} intensity	NA	
2022 output	NA	
Bioenergy and clean electrification		141 Mt per year by 2035
Production decarbonization and CCS/CCU/CDR		282 Mt or more by 2050
Other Industry	**Value**	**Source**
2022 kg CO_{2e} intensity	NA	
2022 output	NA	
2022 CO_2 emissions		10320 Mt CO2 grown at -3.1%, 6.1% & 2.5% per year 2019->2020, 2020-> 2021, 2021->2022. Grown at 2.0% per year thereafter.
%/yr material efficiency improvement	0.5	Based on 12.5% over 30 years
%/yr enhanced recycling	NA	
%/yr energy efficiency improvement	1.00	Chapter 11, IPCC AR6 (2022a)
%/yr fuel switching	2.5	Based on coal to NG to direct electrification Chapter 11, IPCC AR6 (2022a)
Production decarbonization and CCS/CCU		Other fuel switching (e.g. bio or synth methane, 25, 50 and 75% of remainder)

5.6. Other emission reduction options

5.6.1. Waste

There is an increasing political interest in methane emission reduction also for the waste sector, partly as a result of the Global Methane Pledge, initiated in 2021. In the current assessment, we use as a starting point data from (IPCC, 2022b) for 2030 and data from EPA (2019) and Höglund-Isaksson et al. (2020) for 2050. Through linear interpolation we estimate potentials for 2035 and 2040. The results are given in Table 13. The high end of the range focusses more on integral waste management strategies reducing the need for landfilling, whereas the low end relies more on landfill gas recovery.

Table 13. Methane emission reduction potentials for the waste sector. All numbers are in $GtCO_{2e}$, using a GWP for biogenic methane of 27.2. For 2035 and 2040 the mid-range is the average of the available estimates.

Emission reduction from ...	2030 Mid-range	2035 Mid-range *(full range)*	2040 Mid-range
... solid waste	0.63	0.75 *(0.65- 0.84)*	0.89
... wastewater	0.20	0.29 *(0.28 - 0.31)*	0.34
Total	**0.83**	**1.04 (0.95 - 1.21)**	**1.23**

For the waste sector, we relied on two sources, IIASA (Höglund-Isaksson et al., 2020) and EPA (2019). The data were extracted from a PowerPoint presentation (Höglund-Isaksson, 2020). To the IIASA data a small correction was applied to take into account the fact that not the entire potential comes at costs less than 200 US$/$tCO_{2e}$, based on the breakdown given in IPCC (2022b). Note that in IPCC (2022b), and also in the Global Methane Assessment (UNEP, 2021) a third source is given which is not taken into account in this analysis (Harmsen et al., 2019). Harmsen does not give a potential for options with negative costs, assuming they are already included in the baseline. The potential is on the low end of the range given here.

5.6.2. Fluorinated gases

A large part of the fluorinated gas emissions will be regulated under the Kigali Amendment to the Montreal Protocol, the implementation of which is in progress. We use emission reduction potentials from EPA (2019) and Purohit and Höglund-Isaksson (2017), brought to the same baseline. The results are given in Table 14.

Table 14. Emission reduction potentials for fluorinated gases (in $GtCO_{2e}$).

	2030	2035	2040
Emission reduction potential	0.80 - 1.42	1.01 - 1.66	1.30 - 2.03

For fluorinated gases, the EPA data were retrieved with help of the Non-CO_2 Greenhouse Gas Data Tool (EPA, 2024). The potential is given in cost bins, but only up to 100 $ per tonne of CO_2 avoided. In addition, a technical potential is given. We assumed that the potential with costs up to 100 $ per tonne of CO_2 is in the middle of these two numbers. The potential provided by IIASA is directly extracted from the paper by Purohit and Höglund-Isaksson (2017). Also in this case, the data by Harmsen et al. (2019) are not taken into account, but in the IPCC (2022b) analysis it turns out that Harmsen is pretty much in between EPA and IIASA.

5.6.3. DACCS and enhanced weathering

New technologies that remove carbon dioxide from the atmosphere, like direct air capture with CCS and enhanced weathering are in an early stage of deployment (Smith et al., 2024) and their costs are high. It is estimated that for DACCS, costs are in the range of 100-300 $/$tCO_2$ removed (IPCC, 2022b). It could well be that deployment of these technologies will see widespread adoption in the period that we consider here, but it is highly uncertain to what extent this will occur and whether costs will already drop below 200 $/$tCO_2$, (Young et al., 2023). Therefore, we do not include these technologies in the assessment.

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