**Extract from Section 12.2.2 Summary data acquisition on Costs and Potentials**

Firstly, a brief overview of the process of data collection is presented, with a more detailed overview being found in Supplementary Material SM 12.A.2. For the energy sector, the starting point for the determination of the emission reduction potentials was the Emissions Gap Report (UNEP 2017), but new literature was also assessed, and a few studies that provide updated estimates of the mitigation potentials were included. It was found that higher mitigation potentials than in the UNEP report are now reported for solar and wind energy, but at the same time electricity production by solar and wind energy in the reference scenario has increased, compared to earlier versions of the World Energy Outlook. The net effect is a modest increase of the average value of the potential, and a wider uncertainty range. Costs of electricity generating technologies are discussed in Chapter 6, (Section 6.4.7) with a summary of LCOEs from the literature being presented in Section 6.4.7. Mitigation costs of electricity production technology depend on local conditions and on the baseline technology being displaced, and it is difficult to determine the distribution over the cost ranges used in this assessment. However, it is possible to indicate a broad cost range for these technologies. These cost ranges are presented in Table 12.3. For onshore wind and utility scale solar energy, there is strong evidence that despite regional difference in resource potential and cost, a large part of the mitigation potential can be found in the negative cost category or at cost parity with fossil fuel based options. This is also the case for nuclear energy in some regions. Other technologies show mostly positive mitigation potentials, the highest mitigation costs are for CCS, bioelectricity with CCS, for details see Supplementary Material SM 12.A.2.

For the AFOLU sector, assessments of global net emission reduction studies were provided by Chapter 7 (Table 7.3). The number of studies depends on the type of mitigation action, but ranges from 5 to 9. Each of these studies relies on a much larger number of underlying data sources. From these studies, emission reduction ranges and best estimates were derived. The studies presented refer to different years in the period 2020 to 2050, and the mitigation potential presented for AFOLU primarily refers to the average over the period 2020 to 2050. However, because most of the activities involve storage of carbon in stocks that accumulate carbon, or conversely decay over time (e.g., forests, mangroves, peatland soils, agricultural soils, wood products), the 2020 to 2050 average provides a good approximation of the amount of permanent atmospheric CO2 mitigation that could be available at a given price in 2030. The exception is BECCS which is in an early upscaling phase, so the potential estimated by Chapter 7 as an average for the 2020 to 2050 period is not included in Table 12.3. Note that for the energy sector a small potential for BECCS has already been provided.

The emission reduction potentials for the buildings sector were based on the analysis by Chapter 9 authors of a large number of sectoral studies for individual countries or regions. In total, the chapter analysed the results of 67 studies that assess the potential of technological energy efficiency and onsite renewable energy production and use, and the results of 11 studies that assess the potential of sufficiency measures helping avoid demand for energy and materials. The sufficiency measures were included in models by reorganization of human activities, efficient design, planning, and use of building space, higher density of building and settlement inhabitancy, redefining and downsizing goods and equipment, limiting their use to health, living, and working standards, and their sharing. Most of these studies targeted 2050 for the decarbonisation of buildings; the potentials in 2030 reported here rely on the estimates for 2030 provided by these studies or on the interpolated estimates targeting these 2050 figures. Based on these individual country studies, regional aggregate emission reduction percentages were found. The potential estimates were assembled in the order sufficiency, efficiency, renewable options, correcting the amount of the potential at each step for the interaction with preceding measures. Note that the option ‘Enhanced use of wood products’ was analysed by Chapter 7, but is listed under the buildings sector in Table 12.3, as such enhanced use of wood takes place predominantly in the construction sector.

For the transport sector, Chapter 10 provided data on the emission reduction potential for shipping. For the other transportation modes, additional sources were used to achieve a complete overview of emission reduction potentials (for further details, see Supplementary Material 12.A.2). A limited number of estimates for global emission reduction potential is available: the total number of sources is about 10, and some estimates rely on just one source. The data have been coordinated with Chapter 10 authors.

For the industrial sector, global emission reduction potentials per technology class per sector were derived by Chapter 11 authors, using primarily sectoral or technology-oriented literature. The analysis is based on about 75 studies, including sectoral assessments.

For methane emission reduction from oil and gas operations, coal mining, waste treatment and wastewater, an analysis was done, based on three major data sources in this area (US EPA 2019; Harmsen et al. 2019; Höglund-Isaksson et al. 2020), and for oil and gas operations complemented by (IEA 2021a). A similar analysis for reductions of emissions of fluorinated gases was carried out based on analysis by the same institutes (Purohit and Höglund-Isaksson 2017; US EPA 2019; Harmsen et al. 2019). Data for CDR options not discussed previously (such as DACCS and enhanced weathering) were taken from Section 12.3. For more details about data sources and data processing, see Supplementary Material 12.A, Section SM 12.A.2.

## Supplementary Material 12.A: Detailed explanation of the data on costs and potentials in Section 12.2

SM 12.A.1. Introduction

In this Supplementary Material, background information is provided on the way the data on costs and potentials has been synthesised. Section SM 12.A.2 provides information on how the extended Table 12.3 on costs and potentials of mitigation options was constructed using the input of the sectoral chapters and other information. Section SM 12.A.3 provides information on the construction of Figure SPM.9 in the Summary for Policy Makers.

**SM 12.A**.**2. Data on emission scenarios and mitigation potentials (Table 12.3)**

***Energy sector***

For the energy sector, the starting point for determining the mitigation potential was UNEP (2017), which was also published as Blok et al. (2020). This assessment was checked for key updates that substantially influence the ranges as reported in these literature sources.

The reference emissions scenario in the World Energy Outlook 2016 report (IEA 2016) was compared to the preferred reference scenario for this assessment, World Energy Outlook 2019 (IEA 2019). There is limited change in the overall parameters between the World Energy Outlooks of 2019 and 2016. Total electricity production in 2030 was marginally higher (0.6%) and the average fossil fuel emission factor 2.4% lower in WEO2019 as compared to WEO2016. A substantially higher contribution of wind and solar energy was seen in the reference scenario (Current Policies), leading to a reduction of the remaining potential by 0.50 and 0.95 GtCO2 for wind and solar respectively. In contrast, the contribution of nuclear energy in the reference scenario has become smaller. For all other low-carbon sources the differences are small.

Estimating the potential deployment of low-carbon electricity sources by 2030 is difficult. The technical potentials are significant, and for all technologies are higher or much higher than the potentials identified by UNEP (2017). In many cases, the technical potential of electricity generating technologies is even much higher than the anticipated electricity demand projected for 2030, see for example recent assessments for solar energy (Creutzig et al. 2017; Dupont et al. 2020), onshore wind energy (Bosch et al. 2017), offshore wind energy (Bosch et al. 2018) and hydropower (Hoes et al. 2017).

There are few studies that explicitly explore the limits of deployment of technologies by 2030. For solar energy a group of solar energy experts (Haegel et al. 2019) showed the feasibility of achieving 10 TW of installed photovoltaic energy capacity in 2030, which is higher than the highest end of the 8.2 TW estimate in the UNEP (2017) report. Bogdanov et al. (2019) provide a somewhat lower contribution of solar energy in 2030 (installed power 7 TW), but a somewhat higher contribution from wind energy than assumed before, i.e., 3.3 TW. Combined with a substantially higher full-load equivalent hours of wind turbines (3200 h/y versus 2600 h/y), this leads to a higher production and associated avoided emissions compared to UNEP (2017). Combined with the higher reference levels for solar and wind energy, this brings the achievable mitigation potential range for 2030 for solar energy to 2 to 7 GtCO2 (from 3 to 6 GtCO2) and for wind energy to 2.1 to 5.6 GtCO2-eq (from 2.6 to 4.1 GtCO2).

Regarding nuclear energy, (IEA 2019a) explores the role of lifetime extensions of nuclear power plants. The report shows that an extra 80 GW can stay online by 2030, which would be equivalent to about 0.4 GtCO2 of avoided emissions. This is well below the potential estimate in UNEP (2017) and could be part of the realisation of that potential, compensating for the fact that the potential for new-built power plants in the timeframe until 2030 will gradually decrease given the long lead times required to get nuclear power plants online (IEA 2019b). Based on these considerations, the potential for nuclear energy is not updated from the figures presented in UNEP (2017).

For other low-carbon electricity sources, no studies were found that led to a downward or upward revision of the potentials identified in UNEP (2017).

The mitigation cost data per electricity generation technology were provided by Chapter 6. The starting point was electricity production cost data for 2019 and 2030 provided by IEA for four marker regions: Asia (China), Asia (India), Europe, and North America. For these regions, mitigation costs were calculated for two scenarios, the first in which coal-fired power plants are replaced, and the second in which natural-gas fired power plants are replaced, leading to a total of eight cases. Although these cases cannot be used to determine an accurate global distribution of mitigation costs, they are considered sufficiently representative for the *range* of mitigation costs for each technology.

For onshore wind and utility solar energy the mitigation costs end up in the negative cost bins, if we compare full LCOE of these technologies with the full LCOE of conventional power production. However, if solar and wind energy develop rapidly, they will not necessarily replace existing capacity, but rather just avoid the fuel and other operational costs of existing power plants. Taking that into account, the mitigation costs will become higher. In many cases still negative costs occur, but also costs in the ranges of 0 to 50 USD tCO2-eq-1 (for wind) and 0 to 100 USD tCO2-eq-1 (for solar) occur. This full range of cost bins is used, noting that the majority of the potential will be in the negative cost bin. The latter is also confirmed by the analysis of the historic development of electricity production costs in Chapter 6 (Figure SPM.5). Offshore wind currently is more expensive, but also here negative costs are expected by 2030. For nuclear energy, costs can vary widely, largely region-dependent, the cases end up in the cost bins ranging from negative to over 100 USD tCO2eq-1. For bio-energy, carbon capture and storage and bio-energy combined with carbon capture and storage (BECCS), mitigation costs virtually all end up in the range of 50 to 200 USD tCO2eq-1. For hydropower and geothermal energy costs in the range of 0 to 100 USD tCO2eq-1 are assumed. It should be stressed that costs vary widely depending on local and regional conditions (see also Section 6.4.7), but the cost ranges presented here are considered to represent how the various technologies compare in mitigation costs, along with the variability per technology.

***Methane emission reductions (excluding AFOLU)***

Data for CH4 emission reductions from coal, oil and natural gas operations, solid waste and waste water were provided by three organisations: IIASA, Netherlands Environmental Assessment Agency PBL and US-EPA. For oil and gas, data from the IEA were also used. In this analysis, as far as possible global warming potentials (GWPs) as established in the 6th Assessment Report are used: 27 for biogenic methane and 28.9 for fossil methane (Cross-Chapter Box 3 in Chapter 2).

The analysis by IIASA is reported in Höglund-Isaksson et al. (2020). Data were provided by Mrs. Lena Höglund-Isaksson (most recent version on 27 Oct. 2021). The data were reported in EUR tCO2-1 and allocated to USD tCO2-1 cost bins using a USD to EUR ratio of 0.86.

The analysis by the Netherlands Environmental Assessment Agency PBL is reported in (Harmsen et al. 2019a). Data were provided by Mr. Mathijs Harmsen in Excel format (1 Feb. 2021), see also (Harmsen et al. 2019b). Cumulative relative emission reduction potentials were provided. The relative emission reductions were applied to the SSP2-baseline provided with the PBL dataset and subsequently organised in cost bins.

The analysis by the United States Environmental Protection Agency is reported in US EPA (2019). Data were downloaded via the Non-CO2 Greenhouse Gas Data Tool (US EPA 2021), which provides cumulative cost data, and organized in cost bins. The mitigation potentials were corrected for the GWPs used in AR6. However, as EPA originally uses a GWP of 25, there may still be a small mismatch over the cost bins.

Data from the IEA for oil and gas were downloaded from the Methane Tracker Database (IEA 2021). Costs are given in USD BTU-1, these were converted using a conversion factor of 21.5 kg methane per million BTU.

The results are shown in Table SM 12.A.1. There are notable differences between the sources in mitigation potentials. There is however a fair agreement between the data sources as to whether mitigation potentials typically appear in lower or higher cost ranges. In the table, a ‘best estimate’ per cost bin is also presented, based on an average of the estimates. For coal and oil/gas, PBL and IIASA are each allocated half of the weight of the other sources, based on the observation that PBL relies heavily on IIASA for these sources. For the ‘less than zero’ cost bin, data from PBL were not taken into account as these potentials are already included in the baseline. The uncertainty ranges are determined by the lowest and highest value per cost bin. Cumulative uncertainty ranges are based on cumulative values and are in relative terms substantially smaller.

Table SM 12.A.1: Methane mitigation potentials for the year 2030 for coal mining, oil and gas operations, waste and waste water from four different sources. For comparison, the reference emissions are also given. A ‘best estimate’ per source is given in italics. Sources: see text.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sector / data source | Cost ranges (USD tCO2-eq-1) | | | | | | Total mitigation potential (GtCO2-eq) | Reference 2030 emissions (GtCO2-eq) |
| <0 | 0–20 | 20–50 | 50–100 | 100–200 | >200 |
| *Coal* |  |  |  |  |  |  |  |  |
| IIASA | 0.06 | 0.22 | 0.05 | 0.02 | 0.00 | 0.00 | 0.36 | 1.21 |
| EPA | 0.01 | 0.64 | 0.02 | 0.01 | 0.00 | 0.00 | 0.68 | 0.91 |
| PBL |  | 0.15 | 0.02 | 0.03 | 0.00 | 0.00 | 0.20 | 1.28 |
| *Best estimate* | *0.04* | *0.41* | *0.03* | *0.02* | *0.00* | *0.00* | *0.50* |  |
|  |  |  |  |  |  |  |  |  |
| *Oil and gas* |  |  |  |  |  |  |  |  |
| IIASA | 0.56 | 0.19 | 0.20 | 0.05 | 0.00 | 0.00 | 1.01 | 2.88 |
| EPA | 0.12 | 0.23 | 0.03 | 0.01 | 0.29 | 0.00 | 0.67 | 1.78 |
| PBL |  | 0.41 | 0.04 | 0.29 | 0.00 | 0.00 | 0.74 | 3.28 |
| IEA | 0.26 | 1.30 | 0.06 | 0.00 | 0.00 | 0.00 | 1.61 | 2.15 |
| *Best estimate* | *0.31* | *0.61* | *0.07* | *0.06* | *0.10* | *0.00* | *1.15* |  |
|  |  |  |  |  |  |  |  |  |
| *Solid waste* |  |  |  |  |  |  |  |  |
| IIASA | 0.43 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.56 | 1.49 |
| EPA | 0.24 | 0.15 | 0.07 | 0.10 | 0.12 | 0.00 | 0.68 | 1.19 |
| PBL |  | 0.14 | 0.08 | 0.01 | 0.10 | 0.15 | 0.48 | 1.04 |
| *Best estimate* | *0.33* | *0.11* | *0.06* | *0.04* | *0.08* | *0.06* | *0.69\** |  |
|  |  |  |  |  |  |  |  |  |
| *Wastewater* |  |  |  |  |  |  |  |  |
| IIASA | 0.05 | 0.05 | 0.07 | 0.04 | 0.01 | 0.00 | 0.21 | 0.61 |
| EPA | 0.00 | 0.04 | 0.03 | 0.03 | 0.16 | 0.00 | 0.27 | 0.68 |
| PBL |  | 0.01 | 0.01 | 0.02 | 0.03 | 0.07 | 0.14 | 0.84 |
| *Best estimate* | *0.02* | *0.03* | *0.04* | *0.03* | *0.07* | *0.02* | *0.22* |  |

\*) This number is the summation over the cost bins and can be higher than all the values per institute because PBL is not taken into account for the negative-bin.

***Agriculture, forestry and land-use change (AFOLU)***

The data for agriculture, forestry and land-use change were obtained from Chapter 7 (Table 7.3), where potentials below a certain cost level are provided. These values were converted into cost bins in Table 12.3 by calculating the additional potential when going from one cost level to the next. The uncertainty ranges of the cost bin were scaled down proportionally from the cumulative values.

***Buildings***

The data for Buildings were obtained from Chapter 9. A more extended overview than in Table 12.3, with a breakdown for developing and developed countries, can be found in Tables SM9.2 and SM9.3.

***Transport***

For the transport sector, an assessment was made by Chapter 12, partly based on information from Chapter 10.

Data for the technical options for passenger cars were taken from ICCT (2019). The authors explore the potential of rapid further fuel economy technologies (50% reduction in new passenger vehicle per kilometre CO2 emissions in 2030 compared to 2005) and fast adoption of electric vehicles (35% of sales in 2030). This share in new vehicle sales is comparable with what is assumed in Chapter 10 (30%) and estimated in BNEF (2020). For heavy duty trucks the reduction in new per kilometre CO2 emissions is 35% in 2035 compared to 2005, and the share of electric vehicles sales is 19% in 2030. The emission reduction in freight transport is comparable to the potential calculated in IEA (2020b). According to ICCT (2019) the fuel economy measures are cost-effective, i.e. negative costs per tonne of CO2 avoided. Electric light duty vehicles currently still are often more expensive over the lifetime than vehicles with internal combustion engines. Costs of batteries are falling rapidly, and it is expected that price-parity with conventional vehicles is reached in the mid-2020s (BNEF 2020), meaning that life-cycle benefits will already exceed costs prior to that date. This means that mitigation costs will be highly variable until 2030, so not mitigation costs could be assigned to this technology. The same is valid for electric heavy duty vehicles.

Data for the impact of modal shifts in passenger transport are taken from ITDP and UC Davis (2015). They calculate that costs, both for the shift to public transport and the shift to cycling, are lower than for transport by passenger cars.

For aviation, limited estimates are available. Emission reduction potentials (excluding biofuels) in the range of 0.12 to 0.32 GtCO2 are reported (ICAO 2019; ICCT 2020; IEA 2020), but underlying assumptions are not very well documented.

For shipping, in Chapter 10 an emission reduction potential of 39% (range 30 to 56%) compared to business-as-usual is quoted (Section 10.6.4), which translates to 0.7 GtCO2, using an average business-as-usual emissions of approximately 1.8 GtCO2 (Bouman et al. 2017). It is assumed that one-third of the potential is for biofuels, which are excluded here, as this is a separate category in this overview. The review study by Bouman et al. (2017) quotes earlier studies “that it is possible to improve energy efficiency and reduce emissions in a cost effective manner, either with zero costs or with net cost savings”, and so it is assumed that the potential will mostly be in the below-zero cost bin.

IRENA (2016) estimates that 10% of the fuels for the transport sector can be in the form of biofuels in 2030. For the calculation of avoided CO2 emissions, the approach in UNEP (2017) is used. Mitigation costs for transportation biofuels are uncertain. Transportation biofuels are currently mostly more expensive than regular fuels, but they could move closer to parity with regular fuels, especially if next generation biofuels are applied (Junqueira et al. 2017; IEA Bioenergy 2020). Given this uncertainty, it can be expected that costs will end up in the range of 0 to 100 USD tCO2eq-1, although the distribution over the cost bins is uncertain.

***Industry***

The data for industry were obtained from Chapter 11. The reference shows an increase in CO2 emissions from 2017 to 2030 of 28%. For comparison, industrial final energy use increases by 24% in the Current Policies scenario of the World Energy Outlook 2019 (IEA 2019b) (no data on CO2 emissions is available for the World Energy Outlook scenario). This suggests that the Chapter 11 reference emissions are slightly higher than in the World Energy Outlook (assuming no major fuel shifts in the Current Policies scenario).

***Fluorinated gases***

Data for fluorinated gas emission reductions were taken from three sources. Data from IIASA are taken directly from Purohit and Höglund-Isaksson (2017). The analysis by the United States Environmental Protection Agency is reported in US EPA (2019). Data were downloaded via the Non-CO2 Greenhouse Gas Data Tool (US EPA 2021), which provides cumulative cost data, which were subsequently organized in cost bins. The analysis by the Netherlands Environmental Assessment Agency PBL is reported in (Harmsen et al. 2019a), Data were provided by Mr. Mathijs Harmsen in Excel format (1 Feb. 2021), see also (Harmsen et al. 2019b). Cumulative relative emission reductions were provided. The emission reduction potentials for the various gases were summed together and subsequently organised in cost bins.

The results are presented in Table SM 12.A.2. There are notable differences between the sources in mitigation potentials. There is, however, a fair agreement that most of the potential appears in the lower cost ranges. In the table, a ‘best estimate’ per cost bin is also presented, using an average value per cost bin. For the ‘less than zero’ cost bin, data from PBL were not taken into account as these potentials are already included in the baseline. The uncertainty ranges are determined by the lowest and highest value per cost bin. Cumulative uncertainty ranges are based on cumulative values and are, in relative terms, substantially smaller.

Table SM 12.A.2: Methane mitigation potentials for fluorinated gases for 2030 from three different sources. For comparison, the reference emissions are also given. A ‘best estimate’ per source is given in italics. Sources: see text.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Data source | Cost ranges (USD tCO2-eq-1) | | | | | | Total emission reduction potential (GtCO2-eq) |
| <0 | 0–20 | 20–50 | 50–100 | 100–200 | >200 |
| IIASA | 0.50 | 0.90 | 0.10 | 0.00 | 0.00 | 0.00 | 1.50 |
| EPA | 0.01 | 0.55 | 0.01 | 0.07 | 0.05 | 0.00 | 0.70 |
| PBL |  | 0.58 | 0.42 | 0.20 | 0.05 | 0.00 | 1.25 |
| *Best estimate* | *0.26* | *0.68* | *0.18* | *0.09* | *0.03* | *0.00* | *1.24* |

***Carbon dioxide removal options not treated previously in this Supplementary Material***

The information for direct air carbon capture and storage and enhanced weathering is that reported in Section 12.3.

**SM 12.A**.**3. Construction of Figure SPM.9 for the Summary for Policy Makers**

Figure SPM.9 is directly derived from Table 12.3, considering the following:

* The mid-range numbers were used. If no mid-range was provided, the average of the low and high extremes was selected.
* For the demand-side options in AFOLU the so-called feasible potential was used.
* Options for which no potential was estimated were excluded from Figure SPM.9, to avoid the impression that the potential is zero.
* For options stretching over more than one cost range, without an indication of the share of each cost range, a smooth transition between the colours was applied (this was done for the energy sector and the buildings sector, and for the option biofuels in transportation).
* For solar energy and wind energy, the notion that ‘the majority of the potential is in the negative cost bin’ is translated in the picture by putting 60% of the potential in that cost bin. The rest is evenly distributed over the other cost bins. As raised in the previous point, the transition between the cost bins was smoothed to avoid the impression of high precision over the cost bins.
* Uncertainty ranges were indicated with error bars. The error bars represent the uncertainty in the total potential per option. In most cases, the uncertainty range can be derived directly from Table 12.3. For AFOLU, the ranges presented in Table 7.3 for the options with costs less than 100 USD tCO2-eq-1 were used. For the emission reduction of methane (excluding in AFOLU) and fluorinated gases the lowest and highest potential cumulative potential found for the various estimates were used as the lowest and highest bound of the error bars presented.