Chapter 4

Bridging the gap - sectoral greenhouse gas emission reduction potentials in 2030

Lead authors: Kornelis Blok (Ecofys), Angélica Afanador (Ecofys), Detlef van Vuuren (PBL Netherlands Environmental Assessment Agency)

Contributing authors: Tom Berg (Ecofys), Christian Breyer (Lappeenranta University of Technology), Oreane Edelenbosch (PBL Netherlands Environmental Assessment Agency), Ann Gardiner (SQ Consult), Danny Harvey (University of Toronto), Atul Kumar (TERI University), Roberto Schaeffer (Universidade Federal do Rio de Janeiro), Pete Smith (University of Aberdeen), Lynn Price (Lawrence Berkeley National Laboratory), Irina van der Hoorn (Ecofys), Paul Waide (Waide Strategic Efficiency), Hans Joosten (Greifswald University)

4.1 Introduction

This chapter explores two central questions: Can the emissions gap in 2030 be bridged, and what are the most promising options to do so? As presented in Chapter 3, the estimated emissions gap in 2030 is 11 to 13.5 $GtCO_2e$ for the below 2°C target (>66 percent 'likely' chance), and 16 to 19 $GtCO_2e$ for the 1.5°C target (50-66 percent 'medium' chance). Chapter 3 furthermore assessed the difference in 2030 between emissions under the current policy scenario and the emission levels consistent with a likely chance of staying below 2°C and a medium chance of staying below 1.5°C of about 17 and 22.5 $GtCO_2e$ respectively (table 3.1). To be sufficient to bridge the gap, emission reduction potentials in 2030 need to be of a comparable magnitude.

The chapter provides a detailed review of greenhouse gas emission reduction potentials in 2030 for key economic sectors (section 4.2). Sectoral emission reduction potentials, also called bottom-up potentials, provide detailed estimates of the level of emission reductions that is feasible within a certain sector or for a specific emissions category up to a certain marginal cost level. When added up, and adjusting for any overlaps, these estimates give an indication of the total potential for reducing global greenhouse gas emissions in 2030. The total potential can then be compared to the gap, to determine whether it can be bridged (section 4.3). In addition, the estimates provide policy makers with a clear and granular view of where important emission reduction options exist, that is, how the gap can be bridged. The sectoral estimates are then compared to emission reduction options provided by integrated assessment models (section 4.4).

Previous Emissions Gap Reports have provided both sectoral emission reduction potential estimates and estimates based on integrated assessment models (see UNEP, 2014; 2013; 2012; 2011). However, most of the previous assessments provide estimates of emission reduction potentials for 2020, and the most recent assessments of sectoral emission reduction potentials date from more than six years ago. These include UNEP (2011) for 2020, IPCC (2007) for 2020 and 2030, and McKinsey (2010) for 2030. Assessments that are more recent include IPCC (2014) and IEA (2017), but these do not include a sector-by-sector assessment of the full emission reduction potential in 2030.

4.2 Assessment of emission reduction potentials by sector in 2030

Drawing on a detailed review of recent studies, this section presents estimates of the global emission reduction potentials that are technically and economically feasible in 2030. The focus is on six main sectors: agriculture, buildings, energy, forestry, industry, and transport (sections 4.2.1 to 4.2.6). However, some promising options for emission reductions are difficult to allocate under one sector. These are considered in section 4.2.7. For all sectors, the main categories of emission reductions for 2030 are identified.

The focus of the analysis is on the socio-economic potential. This means that the potentials presented here refer to the total of emission reductions that can be achieved using all technologies available in a given future year, which are economically attractive from a social cost perspective (IPCC, 2001). This potential is defined as all reductions that can be achieved at a marginal cost of no more than US$100/$tCO_2e$, at current prices, which is the cost level often assumed to be necessary by 2030 for achieving ambitious reduction pathways (IPCC, 2014; IEA, 2016). There are important uncertainties related to assumptions regarding technology deployment and implementation rates, including, for example, how rapidly solar photovoltaic energy production can be scaled up, and the rate at which buildings can be retrofitted. The underlying analysis introduces some degree of 'realism' in the assessment and its respective assumptions. In general, it is assumed that the potentials can be achieved, if countries around the globe are willing to set policies that enable the implementation of the available solutions.

The potentials are assessed against a current policy scenario, which provides a reference level in 2030 against which the greenhouse gas emission reductions could be achieved. The current policy scenario emissions projected for 2030 amount to 61.1 $GtCO_2e$. If emissions from peat degradation and peat fires are excluded, projected emissions are 59.2 $GtCO_2e$ which corresponds well with the 58.9 $GtCO_2e$ current-policy projection listed in Chapter 3, where peat-related emissions are excluded in 3 out of the 4 underlying scenarios. Details on the current policy scenario are included in Appendix B, available online. The following gases are included in the analysis: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfurhexafluoride (SF_6). Black carbon is not included in the assessment (for impacts on global warming of short-lived climate pollutants, including black carbon, see Chapter 6). The potentials are adjusted to be in line with the current policy scenario used for this chapter. Emission factors are based on the average global emission intensities for 2030 from the World Energy Outlook 2016 (IEA, 2016). For the electricity sector the average emission intensity of fossil-fuel based power plants is used. Finally, interactions between mitigation measures (for example, efficient appliances versus power sector decarbonisation) are taken into account and handled on a case-by-case basis.

4.2.1 Emission reduction options and potential in the agriculture sector

Studies of emission reduction potentials for the agriculture sector vary widely. Since IPCC AR5, studies that report mitigation potentials in the agriculture sector with carbon prices up to US$100/$tCO_2$ provide annual reductions of between 0.26 to 4.6 $GtCO_2e$ (Smith *et al.*, 2014)[1]. These estimates exclude demand-side options. However, demand side mitigation options are included in the assessment below. While net carbon emissions from soils are negligible in current policy trajectories, Smith *et al.* (2007) argue that around 90 percent of the mitigation potential can be attributed to carbon sequestration in soils, like cropland, grazing land and the restoration of degraded land. In addition, non-CO_2 greenhouse gases from enteric fermentation and rice cultivation can be avoided. Finally, a large share of peat-related emissions can be avoided.

Regarding cropland management, Smith *et al.* (2008) cite a mitigation potential of 0.74 $GtCO_2e$ in 2030, with 90 percent of the potential coming from CO_2, while long-term biophysical potentials of 2.6 $GtCO_2e$/year are reported (Smith, 2016). The non-CO_2 component is more or less in line with the 0.04 $GtCO_2e$ from USEPA (2013), presenting a range of options to reduce the emissions originating from crop farming. The estimate is established through a combination of no-tillage and residue management, agronomy and nutrient management, which are all three applied on one-third of global croplands. Recently, there has been discussion on no-tillage measures, for example in Dimassi *et al.* (2014), who argue that an increase in the soil-carbon stock may be the result of a redistribution of carbon between soil layers. However, this would not affect the potential from Smith *et al.* (2008), since the area to which no-tillage measures are applied can be substituted with measures that have a more or less similar potential from the other cropland management categories, like agronomy and nutrient management (Smith *et al.*, 2008). We therefore maintain the estimate potential of 0.74 $GtCO_2e$ in 2030 for cropland management.

Grazing lands are typically managed less intensively than croplands, leaving significant potential for enhanced removals and emission reduction. Grazing land measures suggested by Smith *et al.* (2008) include: adjusting grazing intensity and allowing for more biomass growth, increasing land productivity by reducing nutrient deficiencies, using more precise nutrient additions resulting in savings in fertilizer, fire management (reducing frequency and fire intensity in fire-prone areas), and species introduction, for example of grass species with higher productivity from associated nitrogen inputs (Smith *et al.*, 2008). Together, these measures have the potential to sequester an additional 0.75 $GtCO_2$ in 2030, if measures under US$100/$tCO_2$ are adopted.

Degraded wetlands, drained for agricultural use, contribute disproportionally to global greenhouse gas emissions from the land-use sectors, with approximately 25 percent of all land-use emissions originating from degraded peatlands (Bonn *et al.*, 2014). When peatlands are drained, organic matter in soils starts oxidizing and releases significant volumes of carbon dioxide emissions, until drainage is reversed or all peat is lost (Bonn *et al.*, 2014). Currently, global greenhouse gas emissions from peatland degradation and peat fires are in the order of 2.2 $GtCO_2e$/year and are expected to decrease to 1.9 $GtCO_2e$/year in 2030. Smith *et al.* (2008) provides 2030 mitigation potentials for the restoration of cultivated organic (peaty) soils of 1.3 $GtCO_2e$, but excludes mitigation from fires. In practice, peat fires can only be prevented when an economic value is attributed to the peatlands, or when they are rewetted effectively (Joosten *et al.*, 2012). Taking the substantial cost of peat fires into account and considering measures of up to US$100/$tCO_2$, it is assumed that emissions from peat fires can be reduced to zero for the majority of the peat sites in the world (World Bank, 2016; Wichtmann *et al.*, 2016). Remaining emissions from peat fires in the current policy scenario are 0.3 $GtCO_2$. Emission reductions from peatland degradation and peat fires combined would therefore amount to 1.6 $GtCO_2$ in 2030.

Based on a simulation of alternative rice management scenarios using varying management techniques, USEPA (2013) estimates an emissions reduction potential of

1 Lower range figure only concerns non-CO_2 GHGs and thus excludes soil Carbon sequestration where the largest share of the potential lies.

0.18 $GtCO_2e$ in 2030, a reduction of nearly 25 percent compared to emissions under the current policy scenario. The scenarios include measures such as adjusting the flooding regime, applying no-tillage, and using various fertilizer alternatives.

Recently, biochar has gained attention as a potential carbon removal option in agricultural lands, mainly cropland. Biochar is produced by heating biomass under anaerobic conditions, and can under the right conditions enhance soil fertility and improve soil's water retention properties while enhancing the soil organic carbon content. Woolf *et al.* estimate that after 15 years, a reduction of about 0.2 $GtCO_2e$ can be realized (Woolf, *et al.*, 2010).

Although current-policy emissions from enteric fermentation and manure management make up a significant part of total emissions in agriculture, the mitigation potential from livestock management is limited. Based on country-level livestock populations from USEPA (2012), and livestock production and market price projections from Nelson *et al.* (2010), a global mitigation potential at costs below US$100/$tCO_2$ in 2030 of 0.23 $GtCO_2e$ is estimated (8 percent of current policy scenario emissions). The mitigation options with the highest cost-effective potentials are waste and manure digesters, anti-methanogens (vaccines that suppress methane production in the rumen), intensive grazing, and improved feed conversion and propionate precursors (animal feed addition that converts more of the produced hydrogen into propionate instead of methane).

Based on a combination of intensive restoration projects on agricultural lands (15 million hectares) and farmer-managed natural regeneration projects[2] (135 million hectares), the Global Commission on the Economy and Climate estimates that an emission reduction of 1.1 $GtCO_2e$/year can be achieved by 2030 (GCEM, 2015). These estimates are scaled up from case-study results in China and Niger respectively, and an uncertainty range of 0.5 to 1.7 $GtCO_2e$ is applied.

Turning to demand-side mitigation options, efforts can be made to lower the carbon footprint of the average diet. Stehfest *et al.* (2013) model the impact of shifting food patterns to a diet recommended by the World Health Organization, which sets recommendations on the consumption of animal products and fat, and compare this impact using two different economic models: the International Food Policy Research Institute's (IFPRI) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and the so-called LEITAP model from the Global Trade Analysis Project (GTAP). Both models were coupled to the integrated assessment model IMAGE. As a result of less agricultural demand from less land- and resource-intensive diets, total greenhouse gas emissions decrease by 0.37 to 1.37 $GtCO_2e$/year in 2030 (Stehfest *et al.*, 2013).

2 A land restoration method using living tree stumps or roots in crop fields, grazing pastures, woodlands or forests that have proven to have co-benefits in combating poverty and hunger (Haglund *et al.*, 2011).

Stehfest *et al.* (2013) also studied the effect of reducing food waste, utilising the same methods as described in the previous paragraph. Within the agricultural supply chain, significant losses can be identified when factors such as harvesting inefficiency, bad harvesting conditions, deterioration during storage, and consumer behaviour are considered. Estimates of total losses vary considerably, between 30 to 50 percent (Nelleman *et al.*, 2009; Lundqvist, 2009), and the effect of waste reduction is modelled at a 15 percent reduction in the amount of food needed to meet similar nutrition levels, which requires a 45 – 75 percent reduction in the amount of wasted food. Modelled impacts on greenhouse gas emissions are somewhat higher than shifting dietary patterns, with IMPACT reporting 2030 potentials of 0.79 $GtCO_2e$/year and LEITAP of 2 $GtCO_2e$/year.

Combining the potentials of all the measures discussed leads to an emission reduction potential of 3 $GtCO_2e$/year in 2030 (uncertainty range 2.3 – 3.7 $GtCO_2e$), if uncertain measures like biochar, peat-related emission reductions, and demand-side measures are excluded. These three measures add up to an additional potential of 3.7 $GtCO_2e$ (uncertainty range 2.6 – 4.8 $GtCO_2e$) in 2030, after correction for overlap with other measures.

4.2.2 Emission reduction options and potential in the buildings sector

Under the current policy scenario, buildings account for annual energy-related greenhouse gas emissions of 12.6 $GtCO_2$ in 2030. Of these emissions, 29 percent are direct, mainly from space heating and hot water production, and 71 percent are indirect, mainly from electric appliances and lighting. Improvements in energy efficiency is an important emission reduction option for all energy uses. In addition, renewable energy can play a role.

In many countries, policy measures and legislation are already addressing the energy efficiency potential of new buildings. Concepts like net-zero buildings, insulation, smart glazing, and building automation are of increasing interest. While developing new buildings with energy-efficient technologies is an important step in reducing emissions from the sector, retrofitting of existing buildings is also essential.

Based on the method used by the Climate Action Tracker it is estimated that for new buildings between 0.68 and 0.85 $GtCO_2$/year could be avoided in 2030 (Climate Action Tracker, 2016). This would require that all new buildings in OECD countries are near-zero energy from 2020 onwards, and from 2020 to 2025 onwards also in non-OECD countries. It is assumed that near-zero energy buildings have 90 percent lower emissions than the current standard. This figure is consistent with Blok *et al.* (2015) who based on an analysis of several studies estimated a potential from ambitious energy efficiency standards for new buildings of 0.7 to 1.3 $GtCO_2$/year in 2030. This is also consistent with C40 (2014), which reports a reduction potential of 0.9 $GtCO_2$/year in 2030 for heating efficiency in new buildings.

For the thermal retrofit of existing buildings, the estimated emission reduction potential is 0.52 to 0.93 $GtCO_2$/year in 2030 using the same method as in the Climate Action Tracker (2016). The lower range requires annual renovation rates of 3 percent in OECD and non-OECD countries from 2020 onwards, with 75 percent direct emissions reduction per retrofit (GBPN, 2013). The higher range requires annual renovation rates from 2020 onwards of 5 percent in OECD countries and of 3 percent in non-OECD countries, with 90 percent direct emissions reduction per retrofit (GBPN, 2013). This emission reduction potential is consistent with C40 (2014), which forecasts a reduction potential of 0.8 $GtCO_2$/year for existing buildings in 2030.

According to IRENA (2016) and Wagner (2017) heat from renewable sources can grow by 5.4 EJ for solid, liquid and gaseous biofuels and by 2.9 EJ for solar energy compared to the current policy scenario. This equals an emission reduction potential of 0.39 $GtCO_2$/year in 2030 from biomass and 0.21 $GtCO_2$/year for solar heat.

For electric appliances (excluding lighting) in households and the service sector, an assessment of the emission reduction potential is calculated based on Molenbroek *et al.* (2015), leading to an estimate of 3.3 $GtCO_2$/year in 2030. This is in line with the estimation of adopting the world's best end-use equipment technology by CLASP (2011). For energy efficient lighting, a report by UN Environment (UNEP, 2014) estimates energy savings of 4.4 EJ, equivalent to 0.92 $GtCO_2$/year in 2030. Molenbroek *et al.* (2015) reports emission reductions from lighting of 0.67 $GtCO_2$/year in 2030. We will use this figure, which is slightly lower than the older estimate in CLASP (2011).

The total emission reduction potential for direct emissions from buildings is 1.9 $GtCO_2$/year (uncertainty range 1.6 – 2.1 $GtCO_2$) in 2030 after correction for overlap between energy efficiency and renewable energy measures. The reduction potential for indirect emissions is included in the energy sector potential.

4.2.3 Emission reduction options and potential in the energy sector

In the current policy scenario, energy sector emissions amount to 21.3 $GtCO_2$ in 2030, of which 16.3 $GtCO_2$ comes from power generation (IEA, 2016, USEPA, 2012). Main options for reducing emissions in the energy sector are wind and solar energy. In addition, hydro, nuclear, carbon capture and storage and bioenergy combined with carbon capture and storage can contribute. Emission reductions from the oil and gas sector and coal mining are also discussed.

The installed global wind capacity was 487 GW by the end of 2016 (REN21, 2017). Wind energy capacity can grow to between 2,110 and 3,064 GW in 2030 (GWEC, 2016; Teske *et al.*, 2015), compared to 940 GW in the current policy scenario. This represents an emission reduction of between 2.6 and 4.1 $GtCO_2$ in 2030. Reaching these potentials would require an annual growth of installed capacity of 11 to 15 percent per year. For comparison, the growth in the past decade amounted to 21 percent per year.

Solar power capacity can reach 3,725 GW in 2030 (Teske *et al.*, 2015), compared to 708 GW in the current policy scenario, which represents an emissions reduction of 3.0 $GtCO_2$/year in 2030. The installed global solar capacity by the end of 2016 amounted to 303 GW (REN21, 2016). Reaching these potentials would require an annual growth of installed capacity of 14 to 20 percent per year (Teske *et al.*, 2015). For comparison, the growth in the past decade amounted to 48 percent per year. Creutzig *et al.* (2017) find that many models have consistently underestimated deployment of solar photovoltaics. However, some newer studies provide higher potentials. A recent analysis by Breyer *et al.* (2017) estimate a potential of 7,100 – 9,100 GW. This potential would require a growth of the installed solar photovoltaics capacity of 26 to 29 percent per year and would lead to avoided emissions of 5.5 to 7.2 $GtCO_2$/year[3]. For a more electrified energy system, Breyer *et al.* report a potential of 12,000 GW. An Ecofys study done for Sitra, showed that, by scaling up the solar photovoltaics energy strategy of Germany to the whole world, the potential global increase in solar photovoltaics could be in the range of 3,885 to 8,722 GW in 2030. This is equivalent to a potential emission reduction of 2.49 to 6.17 $GtCO_2e$/year in 2030 (SITRA, 2015; Afanador *et al.*, 2015)[4]. Based on the large variation of numbers presented here, and leaving out the highest ones, we come to a potential of 3 to 6 $GtCO_2$/year avoided through solar photovoltaics.

Other electricity production options also have potential to reduce emissions in the energy sector in 2030. Compared to emission levels under the current policy scenario, biomass has a potential of 0.85 $GtCO_2$/year and geothermal has a potential of 0.73 $GtCO_2$/year (Teske *et al.*, 2015). For hydro power and nuclear energy, the IEA (2016) in its 450 scenario indicates a potential increase of 147 GW and 154 GW compared to the current policy scenario. The emission reduction potentials are estimated at 1.89 and 0.87 $GtCO_2$/year in 2030, respectively.

The total emission reduction potential for carbon capture and storage (CCS) is estimated by IEA (2017) at 2.03 $GtCO_2$/year in 2030, which is slightly lower than the estimation of Mac Dowell and Fajardy (2017) of 2.5 $GtCO_2$, based on an earlier IEA study. This includes a reduction of 0.8 $GtCO_2$/year in 2030 for CO_2 for enhanced oil recovery and 0.1 $GtCO_2$/year in 2030 for carbon capture and utilisation in 2030. This reduction potential can be allocated either to the energy sector or to the industry sector. Based on the allocation in IEA (2016), 67 percent is allocated to the industry sector and 33 percent to the energy sector. The amount of carbon dioxide avoided is smaller than the amount of carbon dioxide captured,

3 Given the high penetration of solar photovoltaics, we use average emission factors here instead of marginal emission factors.

4 According to the study, the level of uncertainty of the estimation is about 20 percent, due to data limitations at the country level. The study scales up the solar photovoltaics case of Germany in each individual country and then aggregates them to a global potential. In cases where country data was not available, the authors used regional data.

because it consumes energy to operate CCS. This ratio is 70 to 90 percent (Herzog *et al.*, 2005). Therefore, a 20 percent discount is applied to correct for the stored CO_2 that is reported. In the industrial sector, a correction of 10 percent is applied since the CO_2 in these sectors is often emitted at higher purity. The above leads to a reduction potential of 0.53 $GtCO_2$/year in 2030 for the energy sector and 1.22 $GtCO_2$/year in 2030 for the industry sector[5].

Bioenergy with CCS has a reduction potential of 0.31 $GtCO_2$/year in 2030 (IEA, 2017). There is uncertainty about whether bioenergy with CCS exceeds the costs of US$100/$tCO_2$. Several studies provide cost estimations ranging from above to under the US$100/$tCO_2$. Arasto *et al.* (2014) estimate costs at US$100-200/$tCO_2$, while McGlashan *et al.* (2012) estimate the average costs for bioenergy with CCS to be US$80-90/$tCO_2$, and Johnsen *et al.* (2014) estimates that bioenergy with CCS applied on biofuels production in 2030 will cost €25 – 175/tCO_2. Since there are studies with estimations under and above US$100/$tCO_2$, the potential for bioenergy with CCS is allocated to the energy sector category as an additional option.

This chapter does not include the shift from coal to gas, since natural gas declines in the World Energy Outlook 450 scenario compared to the current policy scenario (IEA, 2016). However, within certain regions the shift from coal to gas can play a role in the reduction of emissions from the energy sector. In the World Energy Outlook 450 scenario, only a small increase is visible in India (0.3 EJ) and South Africa (0.04 EJ) (IEA, 2016). Given the small size, this is not included in the potentials.

The total emission reduction potential in the power sector is large. It makes up nearly 80 percent of the power sector emissions in the current policy scenario, without considering overlaps. Adding electricity savings from the buildings and industry sector implies that power sector emissions in 2030 could be reduced by more than 100 percent compared with the current policy scenario, which is obviously not possible unless bioenergy with CCS is applied on a large scale. However, there will be increasing interaction between the different emission reduction options long before the 100 percent is reached, making the total potential smaller than the sum of the individual options. In the assessment, it is assumed that total emissions in the power sector are reduced by a maximum of 57 to 65 percent, which are the largest percentages found in the literature (Deng *et al.*, 2012; Teske *et al.*, 2015)[6]. This will lead to total emission reductions of 9.3 to 10.6 $GtCO_2$/year in 2030, which indicates the ‘basic’ potential. However, given the large potentials for the individual categories, power sector decarbonization may develop faster (see, for example, Breyer *et al.*, 2017). Implementing large shares of intermittent renewable sources would require the use of flexibility options such as demand response, flexibility of supply, network optimization and expansion, and storage to match supply and demand. For an overview of flexibility options, see Papaefthymiou *et al.* (2014).

Outside the power sector, methane emissions from the distribution of gas and the production and transmission of oil and gas can be reduced by 1.78 $GtCO_2$/year in 2030 (Klimont and Höglund-Isaksson, 2017). This is 75 percent of the current policy scenario emissions from the oil and gas industry. These reductions can mainly be achieved by implementing measures for the recovery and utilization of vented gas and the reduction of leakages.

Methane emissions from coal mining can be reduced by 0.41 $GtCO_2e$/year in 2030, which is a reduction of 56 percent compared to the current policy scenario (Klimont and Höglund-Isaksson, 2017). Measures implemented in this scenario include pre-mining degasification measures and the installation of ventilation air oxidizers.

Combining the potentials of all the electricity-related measures discussed, also in buildings and industry, leads to a potential of 10.0 $GtCO_2e$ (uncertainty range 9.3 – 10.6 $GtCO_2e$/year) in 2030. Bioenergy with CCS could provide an additional potential of 0.3 $GtCO_2e$ in 2030 (uncertainty range 0.2 – 0.4 $GtCO_2e$). Emission reductions from the oil and gas sector and coal mining are 2.2 $GtCO_2e$/year (uncertainty range 1.7 – 2.6 $GtCO_2e$).

4.2.4 Emission reduction options and potential in the forestry sector

Since IPCC AR5, studies of mitigation potentials in the forestry sector with carbon prices up to US$100/$tCO_2$ report values between 0.2—13.8 $GtCO_2e$/year, largely depending on the types of models used (Smith *et al.*, 2014). There are two main options for reducing emissions in this sector: halting deforestation, and restoration of degraded forest land.

Emission reduction potentials from halting deforestation come with great uncertainty. These uncertainties relate, for example, to the degree to which decreased deforestation leads to lowered degradation and associated carbon emissions, but also depend on the baseline used (GCEM, 2015). We assume a global potential in 2030 of 3 $GtCO_2e$ (based on Clarke *et al.*, 2014). This central estimate assumes that the current policy scenario emissions remain stable from current levels.

Global commitments on restoration of degraded forests, such as commitments to the Bonn Challenge and the New York Declaration on Forests, aim to bring a total of 350 million hectares of degraded and deforested land under restoration (Messinger and DeWitt, 2015). Reaching this target by 2030 would yield emission reductions in the order of 1.6-3.4 $GtCO_2$/year, with a central estimate of 2.3 $GtCO_2$/year in 2030 (Verdone *et al.*, 2015).

5 Compared with Chapter 7, this chapter considers different groupings of emission reduction options, timeframes and cost levels. For this reason, estimates are not directly comparable across chapters.

6 For comparison, the recent Energy Technology Perspective reports (IEA, 2016; IEA, 2017), give reductions of 35 percent and 48 percent compared to the current policy scenario.

Combining the potentials of the measures discussed leads to a total contribution from the forestry sector of 5.3 $GtCO_2e$/year (with an uncertainty range of 4.1 – 6.5 $GtCO_2e$).

4.2.5 Emission reduction options and potential in the industry sector

Industry sector greenhouse gas emissions are 19.3 $GtCO_2e$ in 2030 under the current policy scenario. The two main sources of industrial greenhouse gas emissions are direct and indirect (via electricity consumption) use of fossil fuels. There are also smaller sources of greenhouse gas emissions, including 'non-energy' use of fossil fuels (for example, fossil fuels as feedstock for chemical processes) and emissions from industrial processes (for example, carbonization in the cement process and several sources of non-CO_2 greenhouse gases). By applying a broad set of mitigation options (Fischedick, 2014), the industry sector can achieve substantial emission reductions by 2030, mainly from energy efficiency, non-CO_2 measures and CCS, with a smaller contribution from renewable heat.

For energy efficiency, the emission reduction potential for 2030 is estimated at 4.1 $GtCO_2$/year compared to the current policy scenario. This estimate is based on data from ClimateWorks Foundation and the World Bank (Akbar *et al.*, 2014), scaled up from six major regions to the entire world and correcting for measures other than energy efficiency. The emission reduction implies a nearly 30 percent reduction compared to the current policy scenario. This is compatible with the estimate by Worrell and Carreon (2017) (see also Saygin *et al.* (2011), who estimated a static potential of 27 ± 9 percent). It should be noted that the potentials vary by sector and by region. For example, it is estimated at 9 -30 percent for iron and steel, 4-7 percent for primary aluminium, for cement the estimate is 20-25 percent, for petrochemicals 23-7 percent, and for ammonia production 11-25 percent (Worrell and Carreon, 2017). Based on the share in current policy emissions, a 2.2 $GtCO_2$/year emission reduction is allocated to direct emissions and a 1.9 $GtCO_2$/year is allocated to indirect emissions.

Renewable energy use in the form of solid, liquid and gaseous biofuels, solar thermal energy and geothermal can generate 9.7 EJ (IRENA 2016), which is an additional 7.8 EJ compared to the current policy scenario. This will reduce emissions by 0.5 $GtCO_2$/year in 2030.

Carbon capture and storage in the manufacturing industry is associated with an emission reduction potential of 1.22 $GtCO_2$/year in 2030 (see the discussion of the option in the section on the energy sector).

For non-CO_2 greenhouse gases, the largest reduction is from HFCs, which can be reduced by 1.5 $GtCO_2e$/year in 2030 (Purohit and Höglund-Isaksson, 2017)[7]. USEPA (2013) estimates an additional reduction potential for non-CO_2 greenhouse gas emissions of 0.2 $GtCO_2e$/year in 2030, where 0.12 $GtCO_2e$ comes from nitric and adipic acid production and the rest from perfluorocarbons from primary aluminium production and sulphur hexafluoride from electric power systems and magnesium production.

Based on the above, the emission reduction potential for industry for direct emissions is 5.4 $GtCO_2e$/year in 2030 (uncertainty range 4.2 – 6.6 $GtCO_2e$). No correction for overlap is needed, as many industrial plants are so large that energy efficiency measures can be combined with CCS or renewable energy. The reduction potential of indirect emissions is already accounted for in the potential for the energy supply sector.

4.2.6 Emission reduction options and potential in the transport sector

In the current policy scenario, total emissions for transport are 9.7 $GtCO_2$ in 2030, of which 9.42 $GtCO_2$ are direct emissions and 0.28 $GtCO_2$ indirect emissions for electricity use. The emission reduction potential differs per mode of transport, but is most significant for light-duty vehicles and heavy-duty vehicles, with other contributions coming from shipping, aviation and biofuels.

In the automobile sector, fuel efficiency measures could potentially reduce emissions by 0.88 $GtCO_2$/year (heavy duty vehicles) and by 2.0 $GtCO_2$/year (light duty vehicles) by 2030 (ICCT, 2012). These numbers include modal shifts. A shift to more electric vehicles is also included. ICCT (2012) assumes that electric-drive vehicles will form a small, but not insignificant, share (up to 9 percent) of new-vehicle sales by 2030. This is in line with the estimations of IRENA (2016) (10 percent) and Bloomberg New Energy Finance (2017) (7 percent). Note that substantial emission reductions due to fuel economy standards for passenger cars are already included in the current policy scenario.

Aviation can reduce emissions with up to 0.32 (ICCT 2012) or up to 0.42 (ICAO 2013) $GtCO_2$/year in 2030 by using alternative fuels, improved infrastructure use and technical improvements.

Several studies indicate an emission reduction for shipping (Alvik *et al.*, 2010; Faber *et al.*, 2011; Eide *et al.*, 2011; Hoffmann *et al.*, 2012) ranging from 0.39 to 0.99 $GtCO_2$. The studies contain several measures focused on fuel efficiency. The most recent study, from Bouman *et al.* (2017), reports an emission reduction potential of 0.70 $GtCO_2$/year in 2030. The numbers for aviation and shipping are in the same order as those in the study from New Climate Economy (GCEM, 2015), which shows a reduction potential between 0.60 and 0.90 $GtCO_2$ per year.

Biofuels is another measure that is relevant for the transport sector. ICCT (2012) provides no potential for biofuels in 2030 due to the high uncertainty. IRENA (2016) does provide an estimate for biofuels to cover 10 percent of the sector's total fuel use in 2030. Taking into account that greenhouse gas

7 Note that these estimates do not consider the emission reduction impacts associated with implementing the Kigali Amendment to the Montreal Protocol. Taking these impacts into account would lower the estimate (see Chapters 3 and 6).

emissions from biofuels are 70 percent to 90 percent lower than those of conventional fuels (BLE, 2016; Ecofys, 2017 forthcoming) an emission reduction potential of 0.63 to 0.81 $GtCO_2e$/year in 2030 can be calculated.

Based on the above, the total emission reduction potential for the transport sector is 4.7 $GtCO_2$/year in 2030 (with an uncertainty of 4.1 – 5.3 $GtCO_2$). No overlap correction is needed, as biofuels can be used as drop-in fuels.

4.2.7 Other promising emission reduction options and potential

Some options for emission reduction are difficult to allocate to one of the sectors assessed in the previous sections. This may be because it is still unknown in which sector it can best be implemented, or because the option can be applied to multiple sectors. Some promising mitigation measures are described below.

Methane constitutes some 90 percent of greenhouse gas emissions from the waste sector. Landfill gas recovery and utilization is one option for reducing methane emissions. USEPA (2013) estimates that landfill gas recovery can reduce emissions by 0.4 $GtCO_2e$/year in 2030, which represents 42 percent of the emissions in the current policy scenario.

Enhanced weathering measures aim to draw carbon from the atmosphere via, among others, the natural chemical weathering process of silicates (other processes elaborated in Chapter 7). Preliminary global estimates using waste material only, for example from cement and iron and steel manufacturing, arrive at 0.73—1.22 $GtCO_2$/year in 2030, excluding stockpiled waste (Renforth *et al.*, 2012).

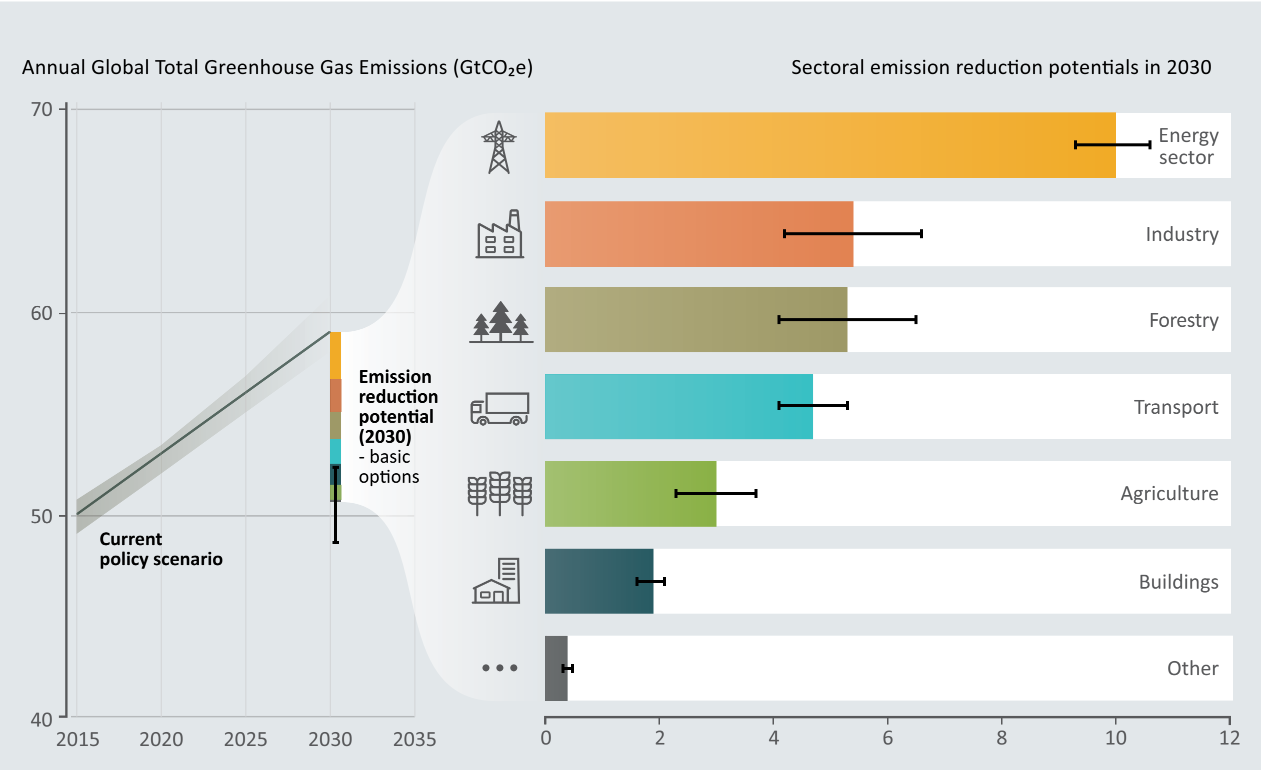
There are other measures that are not included in this chapter. In April 2017 the book, Drawdown, was published containing the 100 most substantive solutions to reverse global warming (Hawken, 2017). Comparing the top 20 of Drawdown with this analysis, two high-ranked measures are missing in this chapter: educating girls and family planning. It is expected that the quantitative impact of such measures is mostly beyond 2030.

4.3 Can the gap be bridged: total emission reduction potential in 2030

An overview of the estimated total emission reduction potentials in 2030 assessed in the previous sections is provided in table 4.1. The table shows that estimates based on proven technologies and relatively precautionary assumptions regarding potentials in 2030 (the 'basic' potential in table 4.1), leads to a total emission reduction potential in 2030 of 33 $GtCO_2e$/year (uncertainty 30 – 36 $GtCO_2e$). The basic emission reduction potential in 2030 is also shown in figure 4.1. If, in addition, areas where estimates of potentials are relatively new, and the feasibility of realizing these in 2030 is more uncertain, are considered (the 'additional' potential in table 4.1), the potential is 38 $GtCO_2e$/year (uncertainty range 35 – 41 $GtCO_2e$).

Importantly, even if only the basic emission reduction potential for 2030 is considered, the estimated total potential listed here is sufficient to bridge the emissions gap in 2030 for 2°C (>66 percent chance) and 1.5°C (50 to 66 percent chance). It exceeds the estimated difference in 2030 between emissions under the current policy scenario and the emission levels consistent with a likely chance of staying below 2°C and a medium chance of staying below 1.5°C of

Figure 4.1: Total emission reduction basic potentials compared to the current policy scenario in 2030.



about 17 and 22.5 $GtCO_2e$ respectively, as indicated in the introduction to this chapter.

An important question is what the efforts and costs of realizing these emission reductions are. Although it is beyond the scope of the current chapter to answer this question in full, a number of observations can be made. It is remarkable that a large part of the potential consists of just six categories, that is, solar and wind energy, efficient appliances, efficient passenger cars, afforestation and stopping deforestation. These six categories sum up a potential of 18.5 $GtCO_2e$ in 2030 (range: 15-22 $GtCO_2e$), making up more than half of the basic potential. Equally important, all these measures can be realized at modest cost, and are predominantly achievable through proven policies:

- *Solar photovoltaics and wind energy.* Many countries around the world have targets for renewable energy and have policies in place to stimulate its adoption. The most dominant policy instruments are feed-in tariffs or feed-in premiums, which have been implemented in 75 countries and 29 states or provinces in the world, providing long-term power purchase agreements with a specified price or premium price per kWh for a renewable energy technology (REN21, 2017). An instrument with increasing popularity is competitive bidding or auctioning, especially for large scale developments, where the renewable energy market is mature and governments have already achieved a degree of success with renewable installation through feed-in-tariffs (REN21, 2017). Costs of electricity from solar and wind electricity have already declined to levels comparable with fossil-fuel based electricity (Lazard, 2016), and auctions have accelerated this trend (IRENA, 2017). Continuation of feed-in policies and/or a shift to auctions are a straightforward and cheap approach to rapid decarbonization of the power sector.
- *Energy efficient appliances and cars.* A combination of labelling and minimum energy performance standards are the dominant policies to stimulate the uptake of efficient appliances. Over 60 countries have adopted or pledged to adopt policies to shift to more energy-efficient lighting (UNEP, 2014). Under the United for Efficiency (U4E) public-private-partnership, UN Environment is supporting developing countries and emerging economies to move their markets to energy-efficient appliances and equipment (UNEP, 2017). In terms of performance standards for cars, several countries have opted to implement fuel economy standards in miles per gallon or CO_2 emission standards in gCO_2 per km; these standards exist in Brazil, the EU, India, Japan, Mexico and the USA (ICCT, 2017). Typically, energy efficiency standards are implemented in such a way that life-cycle costs are minimized, hence leading to net negative costs for the consumer. Similar policies are in place in many countries for new building construction (UNEP, 2016). Further continuation of these policies, scaling them up to more countries while raising ambitions is a way forward to limit the growth of energy use and hence reducing emissions.
- *Stopping deforestation and restoration of degraded forests.* There are several examples of policies successfully stopping deforestation, the most large-scale being the Brazilian 'Action Plan for Prevention and Control of Deforestation in the Amazon', consisting of (1) territorial and land-use planning, (2) environmental control and monitoring, and (3) fostering sustainable production activities. The programme led to a reduction of the rate of deforestation by more than 80 percent. Costs are found to be US$13/$tCO_2e$ on average (Afanador *et al.*, 2015; Sitra, 2015). For reforestation of degraded forests, the scale of operations is not of that size, but promising examples are available for China (Chen *et al.*, 2016), Costa Rica (Afanador et. al 2015), and the Republic of Korea (Kim and Zsuffa, 1994). Costs are comparable with the costs of stopping deforestation.

These are examples of a few of the options that can be implemented at relatively low cost and based on significant existing experience. Together they represent more than half of the basic potential identified. Previous Emissions Gap Reports provide many more examples of scaling up of existing policies and programmes, as do other studies, including the study Green to Scale (Sitra, 2015).

Although the available studies prevent an explicit, economic assessment of all emission reduction options, there is a relatively high degree of confidence that all options included in table 4.1 have costs below US$100/$tCO_2e$ avoided. In many cases, this is explicit in the source documents. For some, however, it is not clear whether the costs will be below US$100/$tCO_2e$. For example, some electricity sources may show costs above US$100/$tCO_2e$, as there are large variations in costs (Lazard, 2016). However, given that there are abundant options in the electricity sector, leaving out these options will not affect the total potential.

Table 4.1: Overview of emission reduction potentials.

Sector	Category	Emission reduction potential in 2030 ($GtCO_2e$)	Category	Sectoral aggregate potential ($GtCO_2e$)
Agriculture	Cropland management	0.74	Basic	3 (2.3 - 3.7)
	Rice management	0.18		
	Livestock management	0.23		
	Grazing land management	0.75		
	Restoration of degraded agricultural land	0.5 - 1.7		
	Peatland degradation and peat fires	1.6	Additional	3.7 (2.6 - 4.8)
	Biochar	0.2		
	Shifting dietary patterns	0.37 - 1.37		
	Decreasing food loss and waste	0.97 - 2		
Buildings	New buildings	0.68 - 0.85	Basic	1.9 (1.6 - 2.1)
	Existing buildings	0.52 - 0.93		
	Renewable heat - bio	0.39		
	Renewable heat - solar	0.21		
	Lighting	0.67	Basic (indirect emissions)	See energy sector potential
	Appliances	3.3		
Energy sector	Solar energy	3 - 6	Basic	10 .0 (9.3 – 10.6)
	Wind energy	2.6 - 4.1		
	Hydropower	1.89		
	Nuclear energy	0.87		
	Bioenergy	0.85		
	Geothermal	0.73		
	CCS	0.53		
	Bioenergy with CCS	0.31	Additional	0.3 (0.2 - 0.4)
	Methane from coal	0.41	Basic	2.2 (1.7 - 2.6)
	Methane from oil and gas	1.78		
Forestry	Restoration of degraded forest	1.6 - 3.4	Basic	5.3 (4.1 - 6.5)
	Reducing deforestation	3		
Industry	Energy efficiency - indirect	1.9	Basic (indirect emissions)	See energy sector potential
	Energy efficiency - direct	2.2	Basic	5.4 (4.2 - 6.6)
	Renewable heat	0.5		
	Non-CO_2 green house gases	1.5		
	CCS	1.22		
Transport	Heavy Duty Vehicles potential (efficiency, mode shift)	0.88	Basic	4.7 (4.1 - 5.3)
	Light Duty Vehicles potential (efficiency, mode shift, electric vehicles)	2.0		
	Shipping efficiency	0.7		
	Aviation efficiency	0.32 - 0.42		
	Biofuels	0.63 - 0.81		
Other	Landfill gas recovery	0.4	Basic	0.4 (0.3 - 0.5)
	Enhanced weathering measures	0.73 - 1.22	Additional	1 (0.7 - 1.2)
Total basic emission reduction potential				**33 (30 - 36)**
Total emissions reduction potential including additional measures				**38 (35 - 41)**

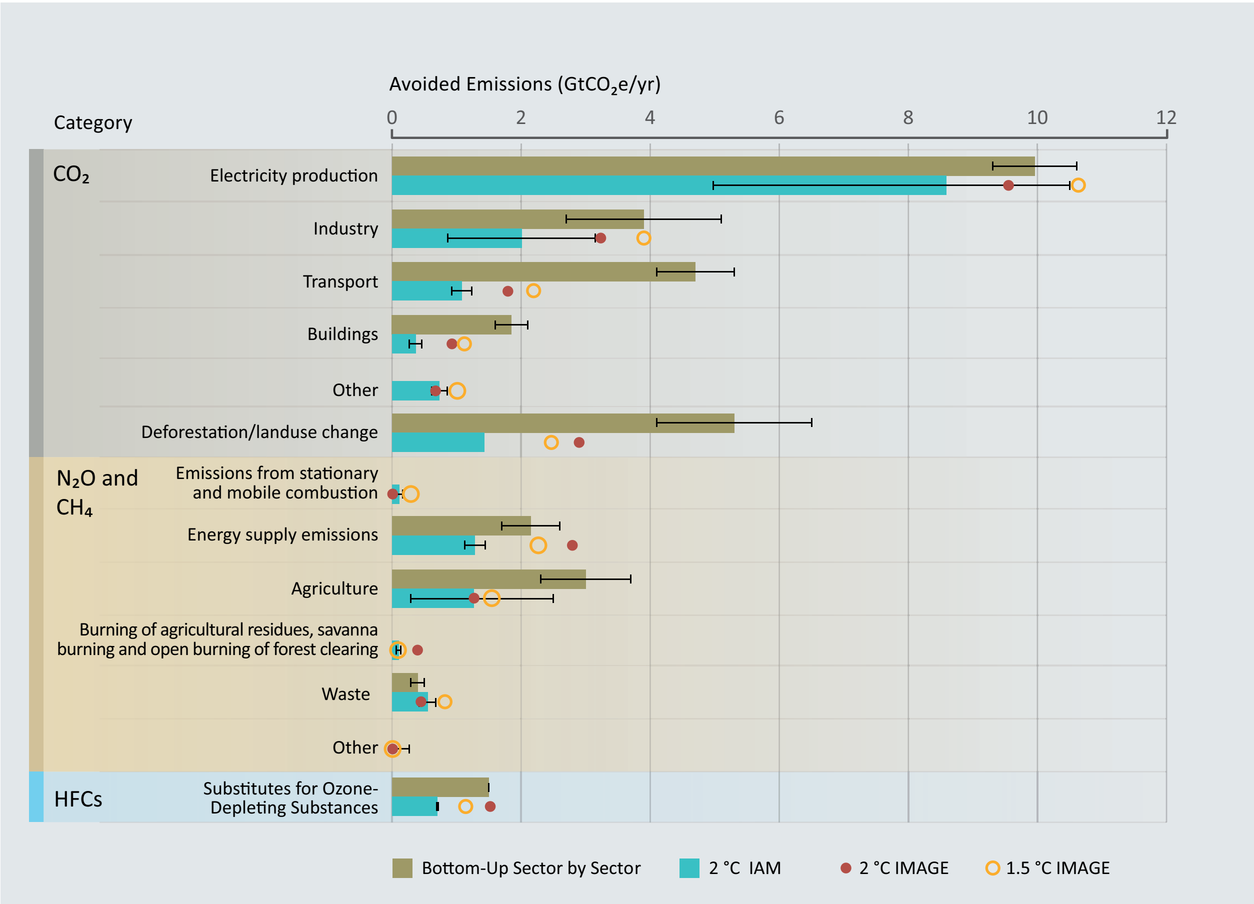
Note: Although for many emission reduction categories a single point estimate is given, there are always uncertainties, assumed to be ±25%. For the categories peatland degradation and peat fires, biochar and energy efficiency, the potential in 2030 is more uncertain. Therefore, a higher uncertainty range of 50% is applied to these categories. In the final column, the categories are aggregated to the sectoral level. The numbers in the third column are not corrected for overlap between measures. The numbers in the final column are corrected for overlap, and this is also reflected in the total potential. Therefore, the total is smaller than the sum of the individual potentials in the third column. The aggregate potentials for indirect emission reductions in buildings and industry are reflected in the electricity sector potential.

4.4 Comparison with results from Integrated Assessment Models

In this section, the results of the bottom-up sector-by-sector assessment is compared with the sectoral emissions as reported by a range of state-of-the-art integrated assessment models. This is relevant because integrated assessment models provide information on how a given climate target can be achieved in a "least-cost" way through a full cost-comparison across all sectors, and by taking account of the interactions between the different reduction options and the interactions with the wider economy. Since the scenarios by definition stay within the 2°C or 1.5°C target, they bridge the emissions gap in 2030 and the difference between emissions levels associated with the current policy scenario and the emissions in line with the 2°C and 1.5°C target. Hence, the package of mitigation measures identified in the scenarios can be viewed as successful examples of how to close the gap. Moreover, the scenarios of the integrated assessment models also provide the foundation for the gap analysis in other chapters of the Emissions Gap Report. Details regarding the baseline scenarios for the integrated assessment models used are provided in Appendix B, available online.

Figure 4.2 compares the emission reduction potentials of the sector-by-sector technology-based analysis with the mitigation activities in the integrated assessment model set for the 2°C scenario, noting that the integrated assessment models assume a slightly higher total 2030 emission level as described in Appendix B, available online. The average total mitigation in 2030 in the integrated assessment model scenarios is 23 $GtCO_2e$, with a full range of 5 - 42 $GtCO_2e$. The wide range across the integrated assessment models is caused by different reduction strategies over time and different baseline assumptions. Overall, the integrated assessment model range of reductions are lower than the total emission reduction potential found in the sector-by-sector analysis, which supports the technical feasibility of the integrated assessment model scenarios. The sectoral breakdown shows that in the electricity sector, emission reductions are

Figure 4.2: Comparison of mitigation in the integrated assessment models under a 2°C pathway with the emission reduction potentials found in the sector-by-sector analysis.



Note: The integrated assessment model results show the results of 6 models, in terms of the mean and the range (15-85th range, thus each time exlcuding the two most extreme models). The red dots indicate the reduction in the integrated assessment model IMAGE for both 2 °C and 1.5 °C (in some cases the IMAGE numbers are outside the indicated range of IAM model results.)

comparable, although the integrated assessment models show a very wide range for this sector. This is also true for the underlying contribution of increased use of renewable and nuclear power, fossil fuel and CCS, fuel switch and bioenergy and CCS. Typically, however, integrated assessment models show a relatively high contribution of bio-energy and fossil fuel CCS technology, certainly also for the long-term. This highlights the importance of research and development with respect to negative emission options, even though their role might still be limited in the short-term. Chapter 7 further discusses this. For the various end-use sectors, the integrated assessment models show considerably lower emission reductions than the sector-by-sector estimates. In the literature, this is explained by 1) the relatively large implementation barriers complicating emission reductions in these sectors, and 2) the possible predominant focus of integrated assessment models on energy supply. While the sectoral, bottom up assessment finds energy efficiency improvements much more important than fuel switching in the end-use sections, integrated assessment models results show both measures to be equally important. The emission reduction potential of biological carbon removal by means of reforestation and increasing carbon in agricultural soil is also less in integrated assessment models than in the sector-by-sector assessment. It should be noted, however, that in general integrated assessment models do not consider the option of increasing carbon in agricultural soils. Finally, for non-CO_2 greenhouse gases, a similar picture emerges: the emission reduction in the integrated assessment model 2°C scenarios is smaller than the total potential of the sector-by-sector analysis.

It is not possible to compare the sector-by-sector analysis with the integrated assessment models for 1.5°C, because most of these integrated assessment model scenarios are yet to be published (see Chapter 3). However, focusing on the results of one integrated assessment model, the IMAGE model, figure 4.2 shows the IMAGE results for both 2°C and 1.5°C. The figure shows that moving to the more ambitious target requires scaling up emission reductions in several sectors, including the electricity sector and most end-use sectors.

In conclusion, the emission reductions of the integrated assessment model 2°C scenarios as well as the IMAGE 1.5°C are typically within the overall sector specific potential of the bottom up assessment. The electricity sector is an exception – but here it should be noted that the current policy emissions in the bottom up assessment were lower than for the integrated assessment models. The analysis also suggests that predominantly further emission reductions in the integrated assessment model scenarios could be achieved via energy efficiency and biological carbon removal options.

4.5 Conclusions

The assessment presented confirms that the total emission reduction potential is more than sufficient to bridge the emissions gap in 2030, with measures that are technically and economically feasible, and at a marginal cost of no more than US$100/t$CO_2$e. The total potential exceeds the difference between the current policy trajectory in 2030 and the emission levels consistent with a 2°C (>66 percent chance) and a 1.5°C (50 to 66 percent chance) temperature target.

All sectors present substantial emission reduction potentials that add up to a total of 33 GtCO_2e/year in 2030 (range: 30 – 36). This does not include emission reduction potentials of fairly new measures (such as direct capture of atmospheric CO_2, decreasing food loss and waste, and biochar) because it is uncertain whether these emission reductions potentials could be realized by 2030.

Notably, six specific categories of measures have the potential to reduce emissions between 15 to 22 GtCO_2e/year in 2030, which is more than half of the total emission reduction potential. This is comparable to the estimated difference in 2030 between the current policy trajectory and the emissions consistent with the 2°C and 1.5°C target. These six categories include solar and wind energy, efficient appliances, efficient passenger cars, afforestation and stopping deforestation. All these measures can be realized at modest costs, and countries around the world have already established policies to implement many of them. By scaling up these measures that are relatively cheap and easy to implement, the world could collectively get on track to bridge the emissions gap by 2030.

To realize the full emission reduction potential, countries need to implement ambitious policies immediately, to enable and accelerate the implementation of the full socio-economic potential of available measures and technologies. Most of the studies used for the bottom-up assessment of sectoral emission reduction potentials assume that implementation of measures start immediately, underscoring the urgency of pre-2020 mitigation action (see also Chapter 2).