Sectoral Greenhouse Gas Emission Reduction Potentials in 2030

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Foreword: We can, but will we?

By Mari Pantsar, Director of the Finnish Innovation Fund Sitra
Helsinki, 31 October 2017

Two years ago in Paris, world leaders did something many had considered unthinkable. They raised the ambition of climate targets, committing the world to limit global warming to "well below" two degrees – and even striving for just 1.5 degrees.

Since then experts have been trying to understand what meeting these goals would require. There has been relatively little recent research looking at global emission reductions compatible with the Paris Agreement – particularly analysing all sectors one by one.

This study is important in two ways. First, it fills an important knowledge gap by providing an up-to-date, sector-by-sector analysis of full emission reduction potentials globally by 2030.

Second, the study answers a key question: is it possible to bridge the emissions gap between current trajectories and pathways compatible with the Paris Agreement? It is indeed and by a clear margin – even when applying reasonable cost limits and reality checks. Taking into account additional and often more difficult to define solutions, such as moving towards a circular economy, would increase the potential further.

While this report fills an important gap, it also reinforces the message from various other studies. For example, Green to Scale, a project run by the Finnish Innovation Fund Sitra, found that simply scaling up 17 existing climate solutions would cut global emissions by 12 Gt by 2030 – equal to the emissions of China and Japan combined. Just like in this study, the largest potential comes from a handful of categories: solar and wind power, tackling deforestation and promoting reforestation, as well as energy efficiency in buildings and appliances.

What is particularly exciting is that emissions can be significantly reduced with existing, commercially available solutions – even when scaled up only to the extent that some countries have already achieved today. In other words, just catching up by 2030 to what comparable countries have done by now, would take us a long way in bridging the emissions gap.

These and many other studies underline the fact that we can reach the goals set in Paris. The real question is if we will do so.

Now it is up to policy makers, business leaders, local governments, citizens – in short, all of us – to make sure this potential is realised. We not only can, but we will bridge the emissions gap and meet the goals of the Paris Agreement.

Foreword: Let’s do it together

By Marcel J.M. Beukeboom, Climate Envoy of The Netherlands
The Hague, 31 October 2017.

The UN Environment Emissions Gap Report 2017 has again reported there is still a substantial gap between the emission levels expected from countries’ National Determined Contributions and societal initiatives and those needed to meet the temperature goals we agreed upon in Paris.

The good news is that, as this report demonstrates, based on available and affordable technologies there is still ample opportunity in various sectors to strengthen our efforts up to 2030.

This information is very timely for the IPCC in preparing its Special Report on the implications of the 1,5 degree goal and for the 2018 Facilitative Dialogue later next year under the UNFCCC.

We hope that this information will stimulate all countries to look again at their national opportunities to enhance climate action until 2030, taking into account their national capabilities and sustainable development goals, and in collaboration with all societal actors.

In The Netherlands we are working on doing our part. We have elaborated our long term strategy in accordance with the goals agreed in Paris for moving to zero emissions around the middle of the century. We also have already raised the bar for 2030 by aiming at a 49% reduction of our emissions from 1990 levels.

We hope others will follow suite. Let’s do it together!

Summary

The UNEP DTU Partnership contracted Ecofys to estimate the potential volume of greenhouse gas (GHG) emissions that could be reduced in 2030, at a sector level for the whole world. We define the potentials as the total emission reductions that could be realised in 2030 using existing available technology with an abatement cost of no more than USD100/tCO_2e[1]. Ecofys assessed six sectors: agriculture, buildings, energy, forestry & other land use, industry and transport. UNEP DTU used the results of this work for the development of the 2017 edition of the UNEP Emissions Gap Report.

Key findings

Ecofys estimated that the global emission reduction potential in 2030 is between 30 – 36 GtCO_2e. This potential is sufficient to close the total emissions gap in 2030 between the current policy trajectory and the emissions consistent with a 2°C and a 1.5°C temperature target. We illustrate this in Figure 1.

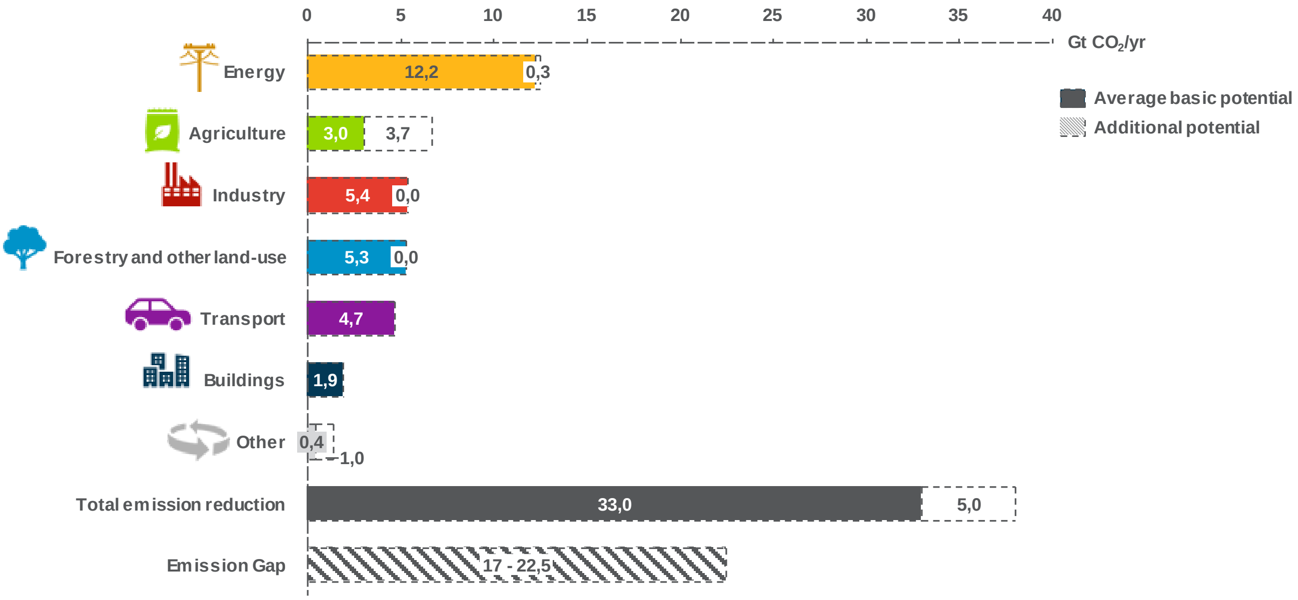

Figure 1. Sectoral emission reduction potentials at the global level compared to the total emissions gap in 2030. The additional potentials refer to potentials that could be achieved by implementing measures that are fairly new, with high uncertainties of whether they can be achieved by 2030.

[1] According to the IPCC (2014) and WEO (2016), the assumption of this abatement cost limit is necessary for achieving ambitious reduction pathways by 2030.

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From the measures that we analysed in each sector, we found that collectively, solar and wind energy, efficient appliances, efficient passenger cars, afforestation and stopping deforestation have the potential to bridge the emissions gap. This is a remarkable finding for two reasons: (i) these measures can be realised at modest or even net-negative costs, and (ii) a large number of countries have already demonstrated that implementing these measures is feasible. Therefore, the question is of scalability. Countries that are lagging behind, should consider starting to replicate the low-carbon solutions that exist among these measures, based on the success of other countries. And countries that have advanced, should consider scaling up the measures to achieve the full potential.

Table 1 summarises the emission reduction potentials by sector. The category labelled "additional" refers to potentials that could be achieved by implementing measures that are fairly new and the uncertainty of realising the potentials by 2030 is high. This fairly new measures are, for example, shifting dietary patters, decreasing food loss and waste and enhancing weathering measures, among others.

Table 1. Sectoral emission reduction potentials. The additional potential refers to fairly new abatement measures that have high uncertainty of realising reductions in 2030.

Sector	Category	Emission reduction potential in 2030 ($GtCO_2e$)
Agriculture	Basic	3.0 (2.3 - 3.7)
	Additional	3.7 (2.6 - 4.7)
Buildings	Basic	1.9 (1.6 - 2.1)
	Basic (indirect emissions)	See energy sector potential
Energy sector	Basic	12.3 (11.0 – 13.2)
	Additional	0.3 (0.2 – 0.4)
Forestry and other land-use	Basic	5.3 (4.1 - 6.5)
Industry	Basic (indirect emissions)	See energy sector potential
	Basic	5.4 (4.2 - 6.6)
Transport	Basic	4.7 (4.1 - 5.3)
Other	Basic	0.4 (0.3 - 0.5)
	Additional	1.0 (0.7 - 1.2)
Total potential		**33 (30 – 36)**
Total excluding additional measures		**38 (35 – 41)**

Table of contents

1 Introduction

The aim of this report is to provide sectoral greenhouse gas emission (GHG) reduction potentials for 2030 at the global level. This year is chosen because it is the target year for most of the Nationally Determined Contributions (NDCs) submitted by countries in the framework of the 2015 Paris Agreement. Sectoral emission reduction potentials provide, at a fairly detailed level, how much emission reduction is feasible within a certain sector or for a specific emission category. The most recent assessments of sectoral emission reduction potentials date from more than six years ago, these include the ones done by UNEP (2011) for 2020, IPCC (2007) and McKinsey (2010) for 2030. More recent assessment were made by IPCC (2014) and IEA (2017), but both did not make a sector-by-sector assessment of the full emission reduction potentials.

Sectoral emission reduction potentials, also indicated as bottom-up potentials, provide policy makers with a clear and granular view of where the important emission reduction options can be found. They are presented in a transparent way and provide a good indication of the areas where climate mitigation action is most effective. In this report, the focus will be on the socio-economic potential. We present the methodology in chapter 2.

In the chapter 3 the current policy projections in 2030 are described. Chapter 4 presents the assessment of emission reduction potentials on a sector-by-sector basis against current policies (the baseline). Chapter 5 provides an overview of the results and in Chapter 6 the findings from the sectoral emission reduction potentials are compared to the outcomes of the emission reductions calculated with integrated assessment models. The final chapter summarizes the main conclusions.

2 Methodology

We estimated the sectoral emission reduction potential using a five-step approach:

1. Select the baseline emissions for each sector in 2030
2. Identify the abatement measures per sector that can be implemented by 2030 with a maximum cost of USD100/tCO_2e
3. Investigate the emission reduction potentials for each measure in 2030 and correct the estimates to adjust to the baseline
4. Estimate the overlap between measures and the uncertainty level of the potential of individual measures, and deduct these from the estimates
5. Aggregate the abatement potentials of measures into sector emission reduction potentials

We applied the five-step approach to every sector individually and subsequently, we aggregated the sector potentials into an estimated global emission reduction potential in 2030. To reflect uncertainties in both the sector potentials and the global potential, we provide the estimates in ranges.

Selecting the baseline (step 1)

For energy-related carbon dioxide emissions (CO_2), we used the Current Policy Scenario (CPS) of the International Energy Agency's World Energy Outlook (IEA, 2016). The CPS assumes no changes in policies from mid-2016, and it provides a level from which the impact of new policies and technologies can be measured against.

For non-CO_2 GHGs, we used baselines from various sources. For example, for the agriculture sector, we used the baseline trajectories estimated by the United States Environmental Protection Agency (USEPA, 2012), which include emissions from agricultural soils, livestock management (enteric fermentation and manure management), rice cultivation and other agricultural sources such as the burning of savannahs, forest clearing and agricultural residues. Non-CO_2 energy sector emissions were taken from personal communications with IIASA (Klimont & Höglund-Isaksson, 2017). Emissions originating from fluorinated gases (HFCs, PFCs and SF_6) were taken from Purohit & Höglund-Isaksson (2017), whereas other industrial non-CO_2 emissions and emissions from stationary and mobile combustion were drawn from USEPA (2012).

For non-energy related CO_2 emissions from the calcination process in cement manufacturing we used data from the IEA (2017). For other non-energy related CO_2 emissions, such as from peatland degradation and peat fires we used the Global Peatland Database, various scientific papers and insights from personal communications with Dr. Hans Joosten, from Greifswald University. For forestry and other land use emissions, we used the baseline projections of the IMAGE-LPJmL model.

Estimating the sectoral emission reduction potentials (steps 2 to 5)

We used the most recent available literature to find estimates of emission reduction potentials in 2030. We constrained the sample of abatement measures to those that could be realised through technologies that are available by 2030 at a cost of maximum USD100/tCO_2e. This ensured that potentials from abatement measures that are feasible from a technological and cost perspective were chosen. The following chart shows the measures we considered in this study.

- Cropland management
- Rice management
- Livestock management
- Grazing land management
- Restoration of degraded agricultural land
- Peatland degradation and peat fires
- Biochar
- Shifting dietary patterns
- Decreasing food loss and waste

- Solar energy
- Wind energy
- Hydropower
- Nuclear energy
- Bioenergy
- Geothermal
- CCS and BECCS
- Methane from coal
- Methane from oil and gas

- New buildings
- Existing buildings
- Renewable heat – bio
- Renewable heat – solar
- Lighting
- Appliances

- Energy efficiency – indirect
- Energy efficiency – direct
- Renewable heat
- Non-CO_2 GHG
- CCS

- HDV potential
- LDV potential
- Shipping efficiency
- Aviation efficiency
- Biofuels

- Restoration of degraded forest
- Reducing deforestation

- Landfill gas recovery
- Enhanced weathering measures

When the estimates from literature were based on baselines that differ from the ones used in this study, we made a correction to adjust to our baseline.

We estimated overlaps between abatement measures and applied a correction factor to subtract double-counting. This was done specifically in four sectors: agriculture, buildings, energy and industry sector.

» Agriculture: overlap between shifting dietary patterns and decreasing food loss and waste
» Buildings: overlap between the construction of new buildings, retrofit of existing buildings, the implementation of energy efficient lighting and energy efficient appliances.

- Energy: overlap between solar, wind, hydropower, nuclear, bioenergy, geothermal and bioenergy with carbon capture and storage (BECCS); and overlap between carbon capture and storage (CCS) and BECCS.
- Industry: overlap between indirect energy efficiency measures and the energy supply sector

After correcting for overlap, we calculated the uncertainty of the size of the emission reduction potentials. In some cases, the estimates we found in the literature were single point potentials, in other cases, the estimates were given in ranges. To ensure consistency and reflect the uncertainty of the size of the potentials, we applied a general ±25% uncertainty factor to individual abatement measures. For measures with higher uncertainty, we applied a ±50% uncertainty factor. We applied the latter to seven abatement measures out of 39 in total: peatland degradation and peat fires, biochar, shifting dietary patterns, decreasing food loss and waste, energy efficiency (direct and indirect), and enhanced weathering measures.

By applying these uncertainty factors, we were able to calculate the aggregated margin of error for each sector. We did this in three steps:

1. Squaring (raising to the power of two) the margin of error of each measure
2. Calculating the total sum of the squared margins of error for each sector
3. Applying the square root to the sectoral margins of error

Finally, to calculate the ranges of emission reduction potentials for each sector, we applied the sectoral margins of error to each sector aggregate.

Estimating the total emission reduction potential

In addition to the ranges of emission reduction potentials for each sector, we calculated the range of the total emission reduction potential. This was done by applying a margin of error to the total emission reduction potentials. The margin of error was calculated in three steps:

1. Squaring (raising to the power of two) the margin of error of each measure
2. Calculating the total sum of the squared margins of error of all measures
3. Applying the square root to the sum calculated in step 2

3 Current policy projections in 2030

This chapter describes the baseline as a reference level in 2030 against which the GHG emission reductions could be achieved. The following gases are included in the analysis: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Black carbon is not included in the analysis. For an overview of the baseline emissions in all sectors, see Table 2.

3.1 Energy-related carbon dioxide emissions

Energy-related CO_2 emissions are produced directly by the combustion of fossil fuels and indirectly through the use of electricity; therefore, emissions under this category cover the buildings, industry, transport and energy supply sector. The Current Policy Scenario (CPS) of the International Energy Agency's (IEA's) World Energy Outlook is taken as the reference for the assessment presented in this report (IEA, 2016). The CPS includes only those policies firmly enacted as of mid-2016. This default setting for the energy system is a benchmark from which the impact of new policies and technologies can be measured. In this scenario, energy-related CO_2 emissions increase from 32.2 gigatonnes (Gt) in 2014 to 38.6 Gt in 2030.

3.2 Agriculture

The agriculture sector is a large emitter of non-CO_2 GHGs. Based on baseline trajectories developed by the U.S. Environmental Protection Agency (USEPA, 2012), agricultural soils emitting N_2O contribute significantly to the total, with about 2.48 $GtCO_2e$. Livestock management is responsible for 2.73 $GtCO_2e$ emissions in 2030, which can be subdivided into emissions originating from enteric fermentation (2.35 $GtCO_2e$) and manure management (0.38 $GtCO_2e$). Other sources of emissions are rice cultivation (0.51 $GtCO_2e$) and other agricultural sources such as the burning of savannah and burning of agricultural residues, which makes up 1.18 $GtCO_2e$ of the total, mostly emitting CH_4 and to a lesser extent N_2O (USEPA, 2012). Furthermore, CO_2 fluxes from agricultural lands are significant, though net emissions are negligible on a global scale at around 40 $MtCO_2$ (USEPA, 2013).

An important aspect to consider is that emissions from peat degradation and peat fires are often not included in climate models. Data from the Global Peatland Database maintained by the Greifswald Mire Centre shows that microbial oxidation of drained peatlands is currently responsible for 1.6 $GtCO_2e$ emissions worldwide (Tanneberger & Appulo, 2016). Regarding peat fires, Miettinen et al. (2017) estimate emissions of 1.2 GtC for the period 1997 to 2015 for the insular South-East Asia region. If this is all converted to CO_2, average annual emissions would be 0.23 $GtCO_2$/year. Peat fires in insular South-East Asia are expected to contribute to about half of the global emissions from peat fires. When taking into account that a substantial amount of the carbon is not oxidised to CO_2 but to more potent GHGs such as

CH_4 (Rossi, et al., 2016), global emissions are likely in the order of 0.6 $GtCO_2e$/year[2]. Combining peat degradation and peat fires results in peat global emissions of 2.2 $GtCO_2e$/year. However, given that awareness on peat degradation and peat fires is growing strongly in the insular SE Asia region, we come to a reduction under current policies of 0.3 $GtCO_2$/year by 2030, leading to total emissions of 1.9 $GtCO_2e$/year (Joosten, Couwenberg, & Von Unger, 2016; Wilson, et al., 2016).

Adding up the emissions originating from the agricultural sectors discussed in this section results in total emissions of 8.8 $GtCO_2e$ in 2030; this includes emissions from peatland degradation and peat fires. Excluding this category yields 6.9 $GtCO_2e$.

3.3 Forestry and other land-use

Few recent baseline projections for the global forestry sector are published. These come with a considerable amount of uncertainty since forests are vulnerable to climate change, even under low-warming scenarios (Settele, et al., 2014), and are also affected by natural disturbances not linked to climate change. Currently, deforestation produces emissions of approximately 3.22 $GtCO_2$. This is calculated by linking IMAGE with the Dynamic Global Vegetation Model LPJmL, starting in 1970 with observed climate, and followed by climate simulations from 2005 onwards (Stehfest, Van Vuuren, Kram, & Bouwman, 2014). Baseline projections by IMAGE-LPJmL expect a slight increase to 3.44 $GtCO_2e$ by 2030. Net deforestation emissions are projected to increase more, due to decreased uptake of CO_2e from afforestation and forest management activities, which will together absorb 0.88 $GtCO_2e$ in 2030 under the baseline (PBL, 2017). Other land-use change emissions that decay back to the atmosphere through microbial decomposition amount to 0.93 $GtCO_2e$ in 2030. Hence, total emissions from the forestry sector are expected to rise from 3.15 $GtCO_2e$ in 2015 to 3.49 $GtCO_2e$ in 2030.

3.4 Other emissions

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

Total emissions originating from the waste sector are estimated to be 1.7 $GtCO_2e$ in 2030 (USEPA, 2012) and are predominantly made of methane emissions. About 10% of the emissions are N_2O.

Energy sector methane emissions are taken from Höglund-Isaksson (2012), who recently updated these to reflect IEA data from 2016 (Klimont & Höglund-Isaksson, 2017). This study focuses specifically on the

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[2] It is important to note that there is a large degree of variability in year-to-year emissions from peat fires. In 1997, 2006 and 2015, emissions from peat fires were estimated to have exceeded those of peat oxidation (Miettinen, Hooijer, Vernimmen, Chin Liew, & Page, 2017).

development of methane emissions up to 2030. Emissions from coal mining and oil and gas systems are the most significant and add up to 3.1 GtCO_2.

Emissions originating from fluorinated gases (HFCs, PFCs and SF_6) were taken from Purohit & Höglund-Isaksson (2017), who estimate that emissions from substitutes for ozone-depleting substances in the current policy scenario are 1.6 GtCO_2e in 2030, and that emissions from HCFC-22 production are 0.2 GtCO_2e in 2030[3]. Other industrial non-CO_2 emissions, such as N_2O from the production of adipic acid and nitric acid, are taken from (USEPA, 2012). Methane and nitrous oxide emissions from stationary and mobile combustion, e.g. from airplanes and automobiles, are estimated to be 0.77 GtCO_2e in 2030 (USEPA, 2012).

Emissions from the calcination process in the cement industry are based on the expected cement production of 4,595 Mt in 2030 (IEA, 2017) and the emission factor for process emissions in cement (Van Ruijven, Vuuren, Boskaljon, Neelis, & D. Sasygin, 2016). The cement process emissions in the baseline are estimated at 2.3 GtCO_2e.

3.5 Current policy projections in 2030

For a detailed sectoral breakdown in the current policy projection, see Table 2. The total emissions projected for 2030 amount to 61.1 GtCO_2e. If we exclude emissions from peat degradation and peat fires we arrive at 59.2 GtCO_2e.

[3] The same study estimates that if the Kigali Amendment is in place, this will reduce emissions from substitutes for ozone-depleting substances to 1.0 Gt CO_2e in 2030.

Table 2: Emissions by sector in the current policy scenario ($GtCO_2e$). The emissions related to electricity production are also allocated to the end-use sectors, so these are listed twice in this table. These allocated emissions are given in grey italics and not counted in the total figure (USEPA, 2012, IEA, 2016; IEA, 2017; Klimont, 2017).

Sector	Category	Gas	2030 emissions ($GtCO_2e$)	Sector aggregates (GtCO2e)
Agriculture	Agricultural soils	N_2O	2.48	8.8
	Enteric fermentation	CH_4	2.35	
	Manure	CH_4, N_2O	0.38	
	Rice cultivation	CH_4, N_2O	0.51	
	Other agricultural sources (incl. burning of savannahs and from forest clearing, agricultural residues)	CH_4, N_2O	1.18	
	Peat degradation and peat fires[4]	CO_2, CH_4	1.9	
Buildings	Direct energy use	CO_2	3.7	3.7
	Electricity use-related	*CO_2*	*8.89*	
Energy	Electricity production	CO_2	16.31	21.3
	Other energy conversion	CO_2	1.85	
	Natural gas and oil systems	CH_4	2.38	
	Coal mining	CH_4	0.73	
Forestry	Deforestation	CO_2	3.44	3.5
	Afforestation and forest management	CO_2	-0.88	
	Other land-use change	CO_2	0.93	
Industry	Industry direct energy-related emissions	CO_2	7.31	12.7
	Electricity use-related emissions	*CO_2*	*6.58*	
	Process emissions for cement production	CO_2	2.3	
	Emissions from stationary and mobile combustion	CH_4, N_2O	0.77	
	Substitutes for Ozone-Depleting Substances	HFCs	1.6	
	HCFC-22 production	HFC-23	0.2	
	Other industrial sources	All non-CO_2	0.5	
Other	*Other electricity use-related*	*CO_2*	*0.56*	1.7
	Landfilling of solid waste	CH_4	0.96	
	Other waste sources	CH_4, N_2O	0.03	
	Wastewater	CH_4, N_2O	0.71	
Transport	Direct energy use	CO_2	9.42	9.4
	Transport electricity use-related	*CO_2*	*0.28*	
Total including peatland emissions		**CO_2e**	**61.1**	
Total excluding peatland emissions		**CO_2e**	**59.2**	

[4] This emission category is often not included in climate models.

4 Assessment of Emission Reduction Potential per Sector in 2030

This chapter presents estimates of the global emission reduction potentials that could be achieved in 2030 based on a detailed review of recent studies. The focus is on six main sectors: agriculture, buildings, energy, forestry, industry, and transport (sections 4.1 - 4.6). However, some promising options for emission reductions are difficult to allocate under one sector. These are considered in section 4.7. For all sectors, the main categories of emission reduction for 2030 are identified.

The focus of the analysis is on the socio-economic potential. This means the potentials presented here refer to the total of emissions reductions that can be achieved using all technology available in a given future year that is 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 USD100/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 development and implementation rates, including how rapidly solar photovoltaic energy production can be scaled up, and the rate at which buildings can be retrofitted. Most of the underlying analysis introduces some degree of 'realism' in the assessment and its respective assumptions. In general, it is assumed in the following 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 reduction potentials are adjusted to be in line with the current policy scenario described in chapter 3, specifically, when their estimations use a baseline that differs significantly from this current policy scenario, Emission factors are based on the average global emission intensities for 2030 from the World Energy Outlook 2016 (IEA, 2016). For the electricity sector we use the average emission intensity of fossil-fuel based power plants. We calculate from World Energy Outlook 2016 (IEA, 2016) the average emission intensity for fossil-fuel based power plants in 2030 as 758 kg CO_2/MWh. 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.

4.1 Emission reduction options and potential in the agriculture sector

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 USD100/tCO_2 provide reductions of between 0.26 to 4.6 GtCO_2e (Smith et al., 2014).[5] This excludes demand-side options. While net carbon emissions from soils

[5] Lower range figure only concerns non-CO_2 GHGs and thus excludes soil C sequestration where the largest share of the potential lies.

are negligible in current policy trajectories, Smith et al. (2007) argue that around 90 per cent 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 GHGs from enteric fermentation and rice cultivation can be avoided. Finally, a large share of peat-related emissions can be avoided. Demand-side mitigation options are also assessed.

Regarding cropland management, Smith et al. (2008) cite a 2030 mitigation potential of 0.74 $GtCO_2e$ in 2030 with the 90 per cent of the potential coming from CO_2, while long-term biophysical potentials of 2.6 $GtCO_2e$/yr. 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. Suggested grazing land measures by Smith et al. (2008) include: adjusting grazing intensity and allowing for more biomass growth, increasing land productivity by reducing nutrient deficiencies, more precise nutrient additions and thus, savings in fertiliser, fire management (reducing frequency and fire intensity in fire-prone areas) and species introduction – e.g. grass species with higher productivity from associated N inputs (Smith et al., 2008). Together, these measures have the potential to sequester an additional 0.75 $GtCO_2$ in 2030, if measures under USD100/tCO_2 are adopted.

Degraded wetlands, drained for agricultural use, disproportionally contribute to global GHG emissions from the land-use sectors, with approximately 25 per cent of all land-use emissions originating from degraded peatlands (Bonn et al., 2014). When peatlands are drained, organic matter in soils starts oxidising and releases significant volumes of carbon emissions until drainage is reversed or all peat is lost (Bonn et al., 2014). Global GHG emissions from peatland degradation and peat fires are currently in the order of 2.2 $GtCO_2e$/year and are expected to decrease to 1.9 $GtCO_2e$/year in 2030 (see chapter 3). 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. Peatland fires can, in practice, only be prevented when an economic value is attributed to them or when they are rewetted effectively (Joosten et al., 2012). Taking into account the substantial cost of peat fires, it is assumed that emissions from peat fires can be reduced to zero on the majority of the peat sites in the world when limiting the potential to measures not exceeding USD 100/tCO_2 (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 0.18 $GtCO_2e$ in 2030, a reduction of nearly 25 per cent compared to current policy emissions. 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, which under the right conditions can enhance soil fertility and improve soil's water retention properties while enhancing the soil organic carbon content. Using a mix of dedicated crops, residues, manure and other agricultural inputs, Woolf et al. (2010) estimate that a maximum of 1.8 $GtCO_2e$ can be mitigated over the course of a century. Pratt & Moran (2010) also arrive at this potential, yet under the economic conditions of a 2030 world with a carbon prices of $35 and $6 for Europe/North America and the rest of the world, respectively. However, biochar production will ultimately be limited by the rate at which biomass can be extracted and pyrolyzed sustainably. Under their 'maximum sustainable technical potential' scenario, Woolf et al. estimate that after 15 years, a reduction of about 0.2 $GtCO_2e$ can be realised (Woolf, et al., 2010). The maximum area of available land for biochar application in the scenario is 1.53 giga hectares (Gha), roughly half the size of India, with an application rate of 50 t C/ha. The maximum scenario assumes a biomass availability of about 2.3 Gt/year, though only a fraction of this is used in 2030. The biomass that is used to produce biochar can consequentially not be used to produce bioenergy; though, biochar shows higher carbon mitigation results on average (Woolf, et al., 2010). Finally, it should be considered that applying biochar to soil requires tillage, and that a potential soil carbon accumulation from no-tillage practices is therefore unlikely. Currently, the Global Environment Facility is funding the Biochar for Sustainable Soils (B4SS) project, which is being implemented by UNEP and aims to demonstrate and promote the adoption of sustainable land management practices involving biochar.

Most soil carbon is derived from recent photosynthesis that takes carbon into root structures and further into below-ground storage. Breeding crops specifically for characteristics that improve below-ground soil carbon storage is thought to have significant mitigation potentials (Kell, 2012; Smith, et al., 2008). Potentials for 2030 are not reported; although, first order estimates cite a global technical potential of 1 $GtCO_2$/year (Paustian, et al., 2016). Economic potentials have not been assessed.

Although current policy emissions from enteric fermentation and manure management make up a significant part of total agriculture emissions, mitigation potential from livestock management so far is limited. Based on country-level livestock populations from USEPA (2012), and livestock production and market price projections from Nelson et al. (2010), the study estimates a global mitigation potential at costs below USD 100/tCO_2 in 2030 of 0.23 $GtCO_2e$ (8 per cent of current policy scenario emissions). The mitigation options with the highest cost-effective potentials are waste and manure digesters, antimethanogens (vaccines that suppress CH_4 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 ha) and farmer-managed natural regeneration projects[6] (135 million ha), 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. We therefore apply an uncertainty range of 0.5—1.7 $GtCO_2e$.

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 effect in two different economic models: IFPRI's IMPACT and GTAP's LEITAP. Both were coupled to the integrated assessment model IMAGE. As a result of less agricultural demand from less land and resource-intensive diets, total GHG emissions decrease by 0.37 to 1.37 $GtCO_2e$/year in 2030, in LEITAP and IMPACT, respectively (Stehfest et al., 2013).

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 considering factors such as harvesting inefficiency, bad harvesting conditions, deterioration during storage or consumer behaviour. Estimates of total losses vary considerably, between 30—50 per cent (Nelleman et al., 2009; Lundqvist, 2009) and the effect of waste reduction is modelled as a 15 per cent reduction in the amount of food needed to meet similar nutrition levels, which requires a 45 – 75 per cent reduction of the wasted amount of food. Modelled impacts on GHG emissions were somewhat higher than shifting dietary patterns, with IMPACT reporting 2030 potentials of 0.79 $GtCO_2e$/year and LEITAP 2 $GtCO_2e$/year.

Combining the potentials of all the measures discussed leads to a potential of 3 $GtCO_2e$/year in 2030 (uncertainty range 2.3 – 3.7 $GtCO_2e$) if we exclude uncertain measures like biochar, peat-related emission reductions and the demand-side measures. The latter measures add up to a 3.7 $GtCO_2e$ potential (uncertainty range 2.6 – 4.8 $GtCO_2e$) in 2030, after correction for overlap with the earlier measures. An overview of the emission reduction potential in the agriculture sector is visible in Figure 2.

[6] 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).

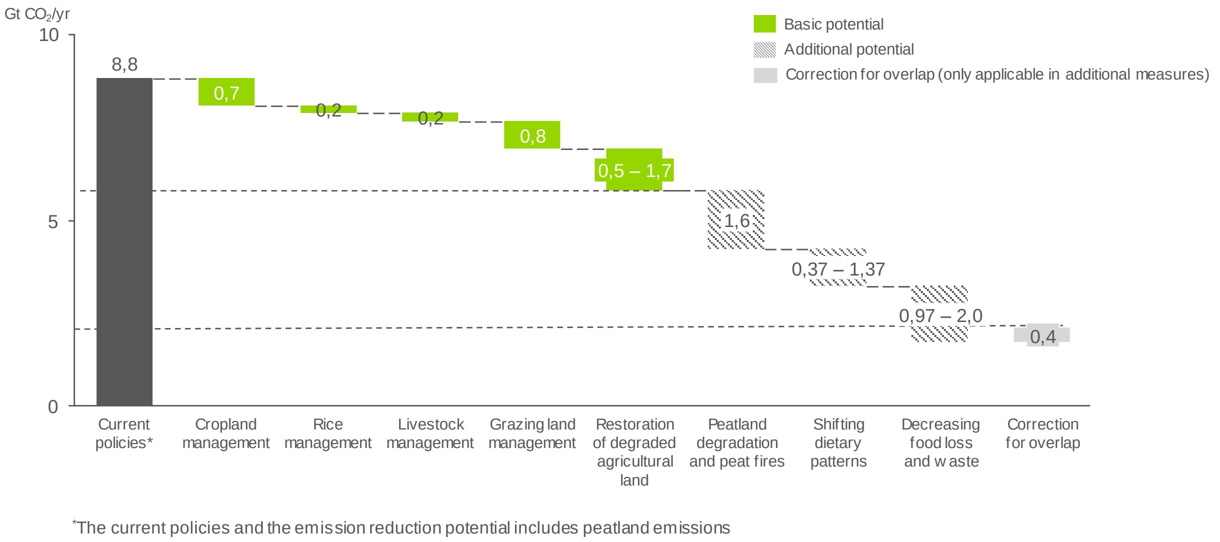


Figure 2. Emission reduction options and potentials in the agriculture sector

4.2 Emission reduction options and potential in the buildings sector

Buildings are responsible for annual energy-related GHG emissions of 12.6 $GtCO_2$ in 2030 under the current policy scenario. Of these emissions, 29 per cent are direct, mainly for space heating and hot water production, and 71 per cent are indirect, mainly for electric appliances and lighting. For all these energy uses, energy efficiency improvement is an important emission reduction option. 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 we estimate that for new buildings, between 0.68—0.85 $GtCO_2$/yr. 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 in non-OECD countries from 2020 – 2025 onwards. It is assumed that near-zero energy buildings have 90 per cent lower emissions than the standard. This figure is consistent with Blok et al. (2015) who estimated, based on an analysis of several studies, a potential of ambitious energy efficiency standards for new buildings of 0.7 – 1.3 $GtCO_2$/yr. in 2030. It is also consistent with C40 (2014), which reports a reduction potential of 0.9 $GtCO_2$/yr. 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 $GtCO_2$,/yr. in 2030 using the same method as in the Climate Action Tracker (2016). The lower range requires annual renovation rates of 3 per cent in OECD and non-OECD countries from 2020 onwards with 75 per cent direct emissions reduction per retrofit (GBPN, 2013). The higher range requires annual renovation rates of 5 per cent in OECD countries and of 3 per cent in non-OECD, in both cases from 2020 onwards with 90 per cent direct emissions reduction per retrofit (GBPN, 2013). The reduction potential is consistent with C40 (2014), which forecasts a reduction potential of 0.8 $GtCO_2$/yr. for existing buildings in 2030.

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

For electric appliances (excluding lighting) in households and the service sector an assessment of the potential is calculated based on Molenbroek et al. (2015), leading to an emission reduction potential of 3.3 $GtCO_2$/yr. 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 UNEP (2014) estimates energy savings of 4.4 EJ, equivalent to 0.92 $GtCO_2$/yr. in 2030. Molenbroek et al. (2015) also reports emission reductions from lighting of 0.67 $GtCO_2$/yr. in 2030. We will use this figure, which is slightly lower than the older estimate in CLASP (2011).

A cross-cutting option is to stimulate more efficient behaviour by providing advanced feedback to households, facilitated by new technology, like smart meters and smart thermostats. There are different estimations on to what extend feedback will induce behaviour, influenced by the used technology (e.g. smart meters, smart thermostats), the level of feedback given (e.g. real-time feedback, periodically feedback) and regional differences. For a higher form of feedback via In Home Displays, several studies give estimation on energy savings: 5-6% (ECN, 2017), 9-12% (Ehrhardt-Martinez, 2012); 11-18% (Lewis, 2014). Kerksen (2013) even mentions a reduction in gas-use of 21-26% for high-quality smart thermostats. Savings of 10% will lead to emission reductions of approximately 0.9 $GtCO_2$. Because of the uncertainty and the overlap with other measures, this option will not be added to the total.

The total reduction potential for direct emissions from buildings is 1.9 $GtCO_2$/yr. (uncertainty range 1.6 – 2.1 $GtCO_2e$) 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. An overview of the emission reduction potential in the building sector is visible in Figure 3.

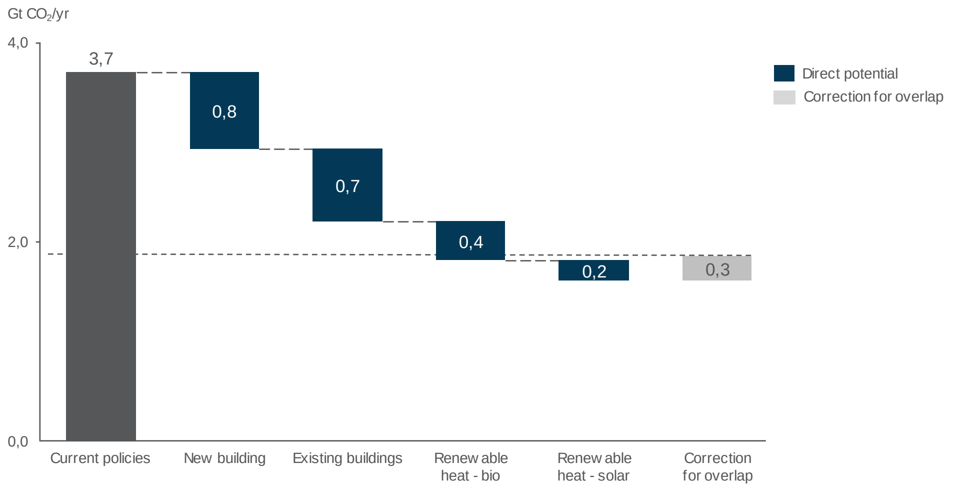


Figure 3. Emission reduction options and potentials in the buildings sector

4.3 Emission reduction options and potential in the energy sector

The energy sector in the current policy scenario is responsible for 21.3 $GtCO_2$ emissions in 2030 of which 16.3 $GtCO_2$ is from power generation (IEA, 2016, USEPA, 2012). IRENA (2016) provides an overview of estimates for all renewable energy production options; the highest potentials reported in the review are from Teske et al. (2015). Main options in the energy sector are wind and solar energy. In addition, there are contributions from hydro, nuclear and bioenergy and CCS. Emission reductions from the oil and gas sector and coal mining are also discussed.

The installed global wind capacity by the end of 2016 was 487 GW (REN21, 2017). Wind energy capacity can grow to between 2,110 and 3,064 GW (GWEC, 2016 and Teske et al., 2015), compared to 940 GW in the reference scenario in 2030. This provides an emission reduction between 2.6 – 4.1 $GtCO_2$; reaching these potentials would require an annual growth of installed capacity of 11-15% per year. For comparison, the growth in the past decade amounted to 21% per year. Note that some recent studies present substantially higher potentials. Breyer et al. (2017) suggest a potential of approximately 5,000 GW by 2030. Jacobson et al. (2017), present a global potential for 2050 with 13,000 GW wind power capacity in 2050, of which about 80% (10,000 GW) is already to be realized in 2030. The context of this study is a largely electrified energy system with a much higher total electricity generation than in the baseline. The results of the latter study are subject to academic debate (Clack, et al., 2017) (Jacobsen, Delucchi, Cameron, & Frew, 2017). Reaching these higher potentials would require annual growth rates of 19 – 25% per year. For comparison, the growth in the past decade amounted to 21 per cent per year.

Solar power capacity can reach 3,725 GW in 2030 (Teske et al., 2015), compared to 708 GW in the reference scenario, which would provide an emission reduction of 3.0 $GtCO_2$/yr. 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 – 20 per cent per year (Teske et al., 2015). For comparison, the growth in the past decade amounted to 48 per cent per year. Creutzig et al. (2017) find that many models have consistently underestimated deployment of solar PV. Some newer studies, however, provide higher potentials. A recent analysis by Breyer et al. (2017) come to a potential of 7,100 – 9,100 GW. This potential would require a growth of the installed solar PV capacity of 26 – 29 per cent per year and lead to avoided emissions of 5.5 – 7.2 $GtCO_2$.[7] 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 PV energy strategy of Germany to the whole world, solar PV, globally, could potentially increase in the range of 3,885 – 8,722 GW in 2030. This is equivalent to a potential emission reduction of 2.49 – 6.17 $GtCO_2e$/yr. in 2030 (Sitra, 2015; Afanador et al., 2015).[8] Based on the large variety of numbers presented here, and leaving out the highest ones, we come to a potential of 3 – 6 $GtCO_2$ avoided through solar PV.

There are also other electricity production options that have potential to reduce emissions in the energy sector in 2030. Biomass has a potential of 0.85 $GtCO_2$/yr. and geothermal 0.73 $GtCO_2$/yr. compared to the baseline (Teske et al., 2015). For hydro power and nuclear energy the IEA (2016) provides an indication for the potential of hydro and nuclear energy in its 450 scenario; with respectively an increase of 147 GW and 154 GW compared to the baseline, the reduction potential is estimated as 0.32 and 0.87 $GtCO_2$/yr. in 2030, respectively.

The total emission reduction potential for carbon capture and storage is estimated by IEA (2017) as 2.03 $GtCO_2$, which is slightly lower than the estimation of Mac Dowell & Fajardy (2017) of 2.5 $GtCO_2$, based on an earlier IEA study. This includes a reduction of 0.8 $GtCO_2$/yr. in 2030 for CO_2 for enhanced oil recovery (EOR) and 0.1 $GtCO_2$/yr. in 2030 for carbon capture and utilisation (CCU).

Bioenergy with carbon capture and storage (BECCS) has a reduction potential of 0.31 $GtCO_2$/yr. in 2030 (IEA, 2017). Arasto et al. (2014) estimate costs 100 – 200 USD/tCO_2, while McGlashan et al. (2012) estimate the average costs for BECCS to be 80 – 90 USD/tCO_2 and Johnsen et al. (2014) estimates that BECCS applied on biofuels production in 2030 will be cost €25 – 175/tCO_2. Since there are studies with estimations under and above 100 USD/tCO_2, the potential for BECCS will be allocated to the energy sector category as an additional option.

This study does not include the shift from coal to gas since natural gas declines in the World Energy Outlook 450 scenario compared to the baseline (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, within the World Energy

[7] Given the high penetration of solar PV, we use average emission factors here instead of marginal emission factors.

[8] According to the study, the level of uncertainty of the estimation is about 20 per cent, due to data limitations at the country level the study scales up the solar PV 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.

Outlook 450 scenario there is only a small increase 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 potential in the power sector is large—all numbers counted together make up about 70 per cent of the current policy scenario emissions in the power sector when summing up all individual potentials, without considering overlap. Adding electricity savings from the buildings and industry sector have the potential to avoid the full current policy emissions in the power sector, bringing the total to over 100 per cent, which is obviously not possible unless BECCS is applied on a large scale. But already long before the 100 per cent is reached, there will be increasing interaction between the different options, making the total potential smaller than the sum of the options. In the overall assessment, we first assumed that total emissions in the power sector are not reduced by more than 57 – 65 per cent, which are the largest fractions found in the literature (Deng et al., 2012; Teske et al., 2015)[9]; this will lead to total emission reductions of 9.3 – 10.6 $GtCO_2$, which indicates the 'basic' potential. However, given the large potentials for the individual categories, power sector decarbonisation may develop even faster (see e.g. Breyer et al., 2017). Implementing large shares of intermittent renewable sources will require the use of flexibility options to match supply and demand, like demand response, flexibility of supply, network optimization and expansion, and storage, and this is even more the case if the 'additional potential' is to be realised. 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 $GtCO_2$/yr. in 2030 (Klimont & Höglund-Isaksson, 2017). This is 75 per cent of the baseline emissions from the oil and gas industry. These reductions can mainly be achieved by implementation of 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 $GtCO_2e$/yr. in 2030, which is a reduction of 56 per cent compared to the current policy scenario (Klimont & Höglund-Isaksson, 2017). Measures implemented in this scenario include pre-mining degasification measures and the installation of ventilation air oxidisers.

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 $GtCO_2e$/yr.) in 2030. BECCS 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 $GtCO_2e$/yr. (uncertainty range 1.7 – 2.6 $GtCO_2e$). An overview of the emission reduction potential in the energy sector is visible in Figure 4.

[9] For comparison the recent Energy Technology Perspective reports (IEA, 2016; IEA, 2017), give reductions of 35 per cent and 48 per cent compared to the current policy scenario.

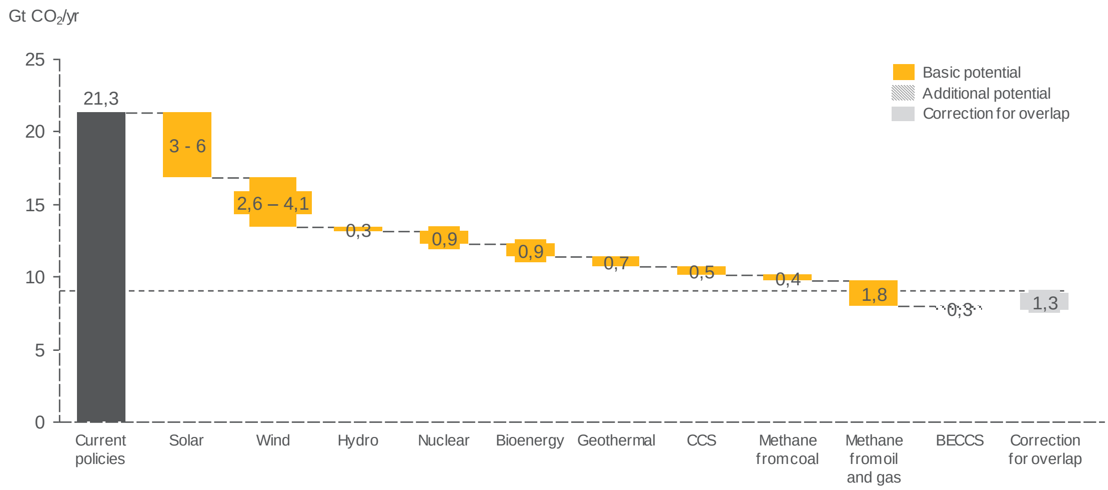


Figure 4. Emission reduction options and potentials in the energy sector

4.4 Emission reduction options and potential in the forestry sector

Since IPCC AR5, studies that report mitigation potentials in the forestry sector with carbon prices up to USD100/tCO_2 report values between 0.2—13.8 GtCO_2e/yr., mainly due to differences in the types of models used (Smith et al., 2014). There are two main options in this category: 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 which baseline is used (GCEM, 2015). We assume a global potential in 2030 of 3 GtCO_2e (based on Clarke et al., 2014). This central estimate is under the assumption that the baseline remains stable from current levels.

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

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 $GtCO_2e$). An overview of the emission reduction potential in the forestry sector is visible in Figure 5.

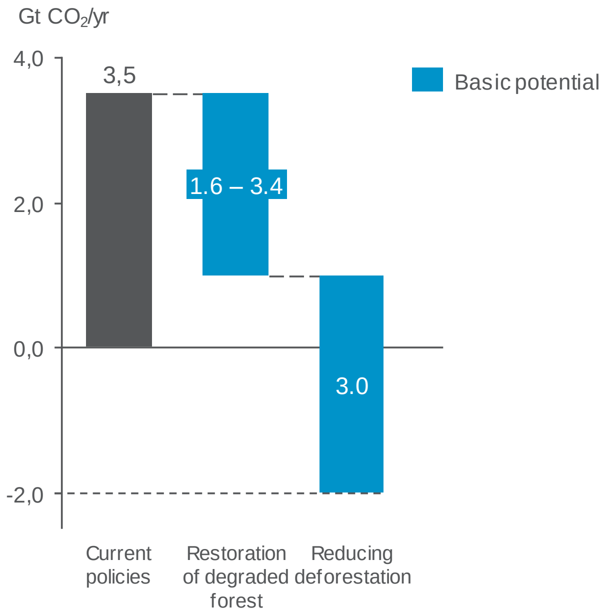


Figure 5. Emission reduction options and potentials in the forestry sector

4.5 Emission reduction options and potential in the industry sector

The industry sector GHG emissions in the current policy scenario are 19.3 $GtCO_2e$ in 2030. The two main sources of industrial GHG emissions are direct use of fossil fuels and the indirect use of fossil fuels via electricity consumption. There are also smaller sources of GHG emissions including ‘non-energy’ use of fossil fuels (e.g. fossil fuels as feedstock for chemical processes) and emissions from industrial processes (for example, carbonisation in the cement process and several sources of non-CO_2 GHGs). The industry sector can achieve substantial emission reduction in 2030 by applying a broad set of mitigation options (Fischedick, 2014), but 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 $GtCO_2$ 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 other measures than energy efficiency. The emission reduction means a reduction of nearly 30 per cent compared to the current policy scenario. This is compatible with the estimate by Worrell & Carreon (2017; see also Saygin et al. (2011) who estimated a static potential of 27 ± 9 per cent). Note that the potentials vary by sector and by region. For example, it is estimated at 9 to 30 per cent for iron and steel, 4 to 7 per cent for primary aluminium, for cement the estimate is 20 to 25 per cent, for petrochemicals 23 to 27 per cent, and for ammonia production 11 to 25 per cent (Worrell & Carreon, 2017). Based on the share in current policy emissions, 2.2 $GtCO_2$/yr. emission reduction is allocated to direct emissions and 1.9 $GtCO_2$/yr. 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 save 0.5 $GtCO_2$/yr. in 2030.

Carbon capture and storage in manufacturing industry has an emission reduction potential of 1.22 $GtCO_2$/yr. 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 HFC's, which can be reduced by 1.5 $GtCO_2e$/yr. in 2030 (Purohit & Höglund-Isaksson, 2017).[10] USEPA (2013) estimates an additional reduction potential for non-CO_2 GHG emissions of 0.2 $GtCO_2e$/yr. in 2030, where 0.12 $GtCO_2e$ comes from nitric and adipic acid production and the rest from PFC's from primary aluminium production and SF_6 from electric power systems and magnesium production.

Measures to reduce material use in industry can also reduce emissions. Concepts related to circular economy, such as recovery and reuse, lifetime extension, sharing and service models, and digital platforms can all reduce emissions. The use of different materials can also contribute, e.g. the cement industry has the possibility to use additives for clinker like fly ash, blast furnace slag, limestone or natural pozzolans. Recovery and reuse can reduce life-cycle emissions of products (Worell & Carreon, 2017). Although, no emission reduction potentials for 2030 have been reported for this family of options, a study by Ecofys and Circle Economy (2016) reports that circular economy measures can reduce emissions in 2030 by 9.7 $GtCO_2$. This numbers overlaps significantly with other measures and is therefore not included in the overall add-up.

Based on the above, the reduction potential for industry for direct emissions is 5.4 $GtCO_2e$/yr. in 2030 (uncertainty range 4.2 – 6.6 $GtCO_2$). 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. An overview of the emission reduction potential in the industry sector is visible in Figure 6.

[10] If the Kigali Amendment is included both the baseline as the reduction potential will reduce by 0.6 Gt CO_2e (Purohit & Höglund-Isaksson, 2017).

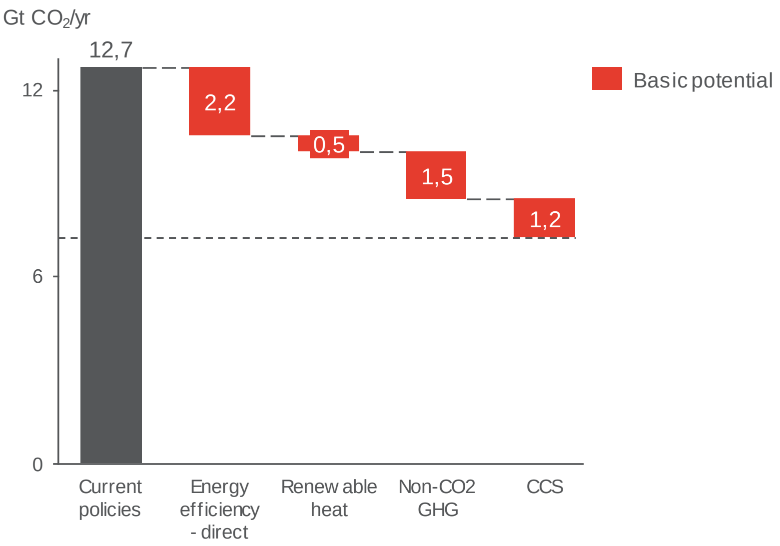


Figure 6. Emission reduction options and potentials in the industry sector

4.6 Emission reduction options and potential in the transport sector

The total emissions for transport in the current policy scenario 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 $GtCO_2$/yr. (high duty vehicles) and by 2.0 $GtCO_2$/yr. (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 per cent) of new-vehicle sales by 2030. This is in line with the estimations of IRENA (2016) (10 per cent) and Bloomberg New Energy Finance (2017) (7 per cent). 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 0.32 – 0.42 $GtCO_2$/yr. in 2030 by using alternative fuels, improved infrastructure use and technical improvements (ICAO, 2013; ICCT 2012).

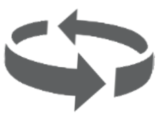
Several studies indicated an emission reduction for shipping (Alvik et al., 2010; Faber et al., 2011; Eide et al., 2011; Hoffmann et al., 2012), ranging from 0.39 to 0.99 $GtCO_2$. The studies contain several measures focused on fuel efficiency. The most recent study, from Bouman et al. (2017), reports an emission reduction potential of 0.70 $GtCO_2$/yr. 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.

Another measure that is relevant for the transport sector is biofuels. ICCT (2012) provides no potential for biofuels due to the high uncertainty of biofuels in 2030. IRENA (2016) does provide an estimate for biofuels to cover 10 per cent of the sector's total fuel use in 2030. Taking into account that greenhouse gas emissions from biofuels are 70—90 per cent lower than those of conventional fuels (BLE, 2016; Ecofys, 2017 *forthcoming*)—an emission reduction potential of 0.63 to 0.81 $GtCO_2e$/yr. in 2030 can be calculated.

Based on the above, the total emission reduction potential for the transport sector is 4.7 $GtCO_2$ 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. An overview of the emission reduction potential in the transport sector is visible in Figure 7.

Figure 7. Emission reduction options and potentials in the transport sector

4.7 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 per cent of GHG emissions from the waste sector. An emission reduction option is landfill gas recovery and utilization. USEPA (2013) estimates that landfill gas recovery can reduce emissions by 0.4 $GtCO_2e$/yr. in 2030 which is 42 per cent 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). Biogeochemical activity in soils naturally accelerates the weathering of rock and thereby leeches out calcium and magnesium, which then reacts with dissolved CO_2 (HCO_3^-, CO_3^{2-}) (Renforth, 2012). To efficiently distribute the ground silicates, which can either originate from the industrial waste or can be mined and ground subsequently, existing infrastructures can be used for the management of farm and forest soils (Hawken, 2017). First global estimates using wastes only, arrive at 0.73—1.22 $GtCO_2$/year, excluding stockpiled waste (Renforth, et al., 2011). This estimate includes the silicate wastes originating from the cement (cement kiln dust), iron and steel (slag) and coal power (fly ash) industries and is not for 2030 and does not account for existing uses for these industrial silicate wastes.

The direct capture of atmospheric CO_2 has multiple uses. It can be deployed to produce feedstock for low-carbon fuels, enhanced oil recovery or synthetic hydrocarbon-based materials. However, in combination with the geological storage of CO_2 substantial volumes of 'negative emissions' could be sequestered. A key barrier is the availability of sufficient low-carbon thermal energy to draw a meaningful amount of CO_2 from ambient air, but due to low land requirements the technical potential is in fact only restrained by geological storage availability and that the costs seem to be larger than USD100/tCO_2. Long-term global removal potentials have been suggested to be larger than 10 $GtCO_2$/year (McLaren, 2012).

There are also 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. An overview of other promising emission reduction potential is visible in Figure 8.

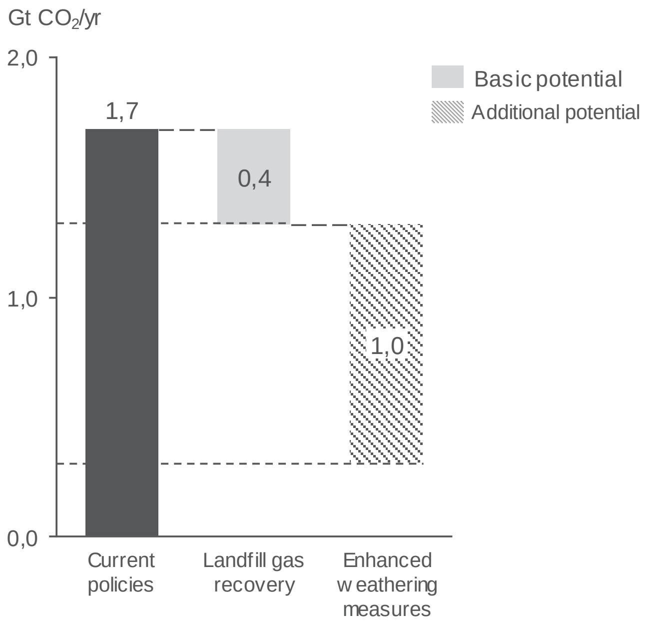


Figure 8 Emission reduction options and potentials in other sectors

5 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 chapters is provided in Table 3. The Table shows that estimates based on proven technologies and relatively precautionary assumptions regarding potentials (the 'basic' potential in Table 3), lead to a total emission reduction potential in 2030 of 33 $GtCO_2e$/yr. (uncertainty 30 – 36 $GtCO_2e$). 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 3), the potential is 38 $GtCO_2e$/yr. (uncertainty range 35 – 41 $GtCO_2e$).

According to 2017 emissions gap report (UNEP, 2017), 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, are respectively 17 and 22.5 $GtCO_2e$. Importantly, even if only the basic emission reduction potential for 2030 is considered, the estimated total potential listed in this report is sufficient to bridge the emissions gap in 2030 for 2°C (>66 percent chance) and 1.5°C (50 to 66 per cent chance).

An important question is what the efforts and costs are of realizing these emission reductions. 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 relatively homogeneous 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 (see **Error! Reference source not found.**). E qually important, all these measures can be realised at modest or in some cases even net-negative costs, and are predominantly achievable through proven policies:

- ***Solar PV and wind energy.*** Many countries around the world have targets for renewable energy and have policies in place to stimulate the 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 auction, especially for large scale developments, where the renewable energy market is mature and governments have already achieved a degree of success with RES 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 decarbonisation of the power sector.

- ***Energy efficient appliances and cars***. To stimulate the uptake of efficient appliances, the combination of labelling and minimum energy performance standards are the dominant policies. 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, 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 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 deforestation rate by over 80 per cent. Costs are found to be on average USD13/tCO_2e (Afanador et al., 2015; Sitra, 2015). For reforestation of degraded forests, the scale of operations is not that size, but promising examples are available for China (Chen et al., 2016), Costa Rica (Afanador et. al 2015; Sitra, 2015), and the Republic of Korea (Kim & Zsuffa, 1994). Costs are comparable with the costs of stopping deforestation.

These are examples of a few of the options that can be implemented relatively cheap and easy, and that together represent more than half of the basic potential identified. Many more examples of upscaling of existing policies and programmes are listed in 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 3 have costs below 100 USD per tCO_2e avoided. In many cases, this is explicit in the source documents. For some, however, it is not clear whether the costs will fall below USD100 /tCO_2e. For example, some electricity sources may show costs above USD100/tCO_2e, in specific cases, 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.

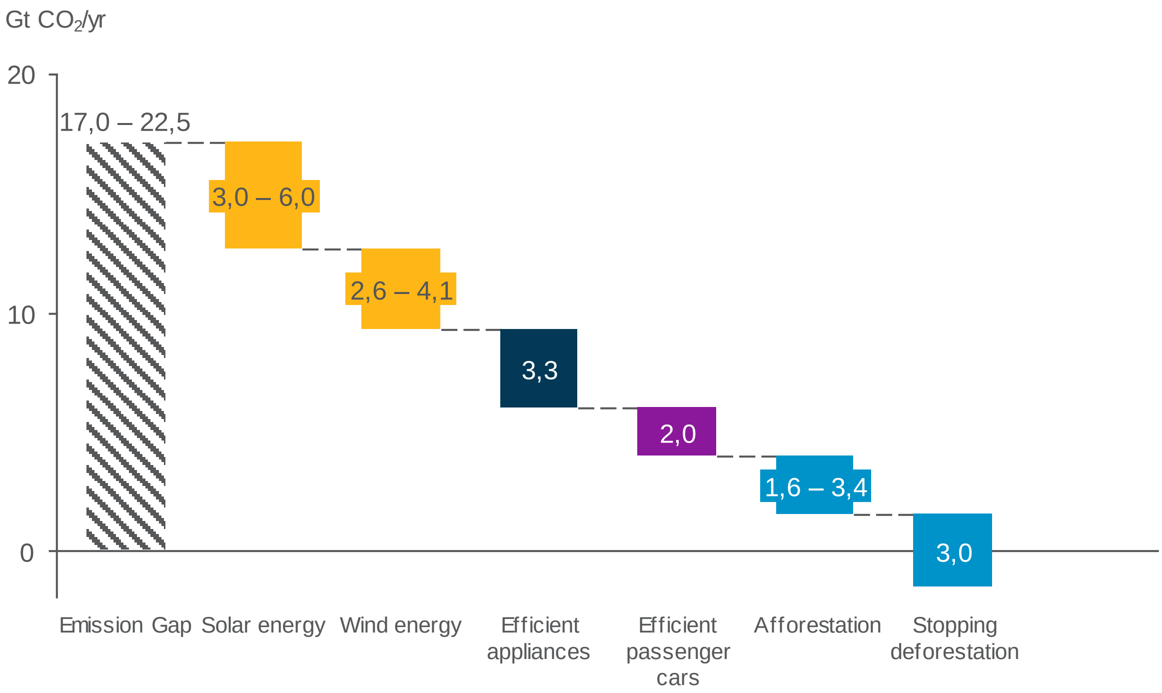


Figure 9. The six most promising emission reduction options and their potentials

Table 3: Overview of emission reduction potentials. 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 for these categories. In the final column, the categories are aggregated to the sectoral level (see discussion in the text). 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 for 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.

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	Solar energy	3 - 6	Basic	10 .0 (9.3 – 10.6)
	Wind energy	2.6 - 4.1		
	Hydropower	0.32		
	Nuclear energy	0.87		
	Bioenergy	0.85		
	Geothermal	0.73		
	CCS	0.53		
	BECCS	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-CO2 GHG	1.5		
	CCS	1.22		
Transport	HDV potential (efficiency, mode shift)	0.88	Basic	4.7 (4.1 - 5.3)
	LDV 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)**

6 Comparison with results from Integrated Assessment Models

In this chapter, 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 (IAMs). This is useful because IAMs 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 and 1.5°C target, they also bridge the gap between current policy emissions in 2030 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 IAM models also underlie the gap analysis in other chapters of the 2017 Emissions Gap report (UNEP, 2017). For the comparison, we use the SSP2 baseline results scenario as developed by six IAMs (Riahi et al., 2017). The SSP2 is the ‘middle-of-the-road’ scenario of the Shared Socioeconomic Pathways, a new scenario framework facilitating the integrated analysis of future climate policy and impacts. Subsequently, we compare the derived mitigation scenarios aiming for a likely (>66%) probability of staying below 2^{o}C, with the bottom-up assessment of mitigation potential. It should be noted that the SSP2 baseline scenarios range from 62 – 69 $GtCO_2e$, which is higher than the baseline emissions used in Table 1, i.e. 59 $GtCO_2e$. The reason is that SSP2 shows emission development in the absence climate policies, whereas the baseline of the sector-by-sector analysis is a current-policies scenario. Estimates of current policies scenarios in IAM models (e.g. Tavoni et al., 2016) show a similar emission range as included in Table 1.

At the sector level, the model-based projections show that baseline emissions can grow rapidly in industry and transport sectors. Direct emissions from the buildings sector, in contrast, are projected to grow only slowly or even stabilize due to an increase in electrification rates (Edelenbosch, forthcoming).

Figure 10 also shows that a similar sectoral pattern emerges in the SSP2 set as in the sector-by-sector analysis implying that it is possible to also compare the mitigation potential. While in the electricity and agriculture sector, the sector-by-sector baseline emissions are significantly below the average of the IAMs, they are in most sectors within or close to the total range reported by the IAMs.

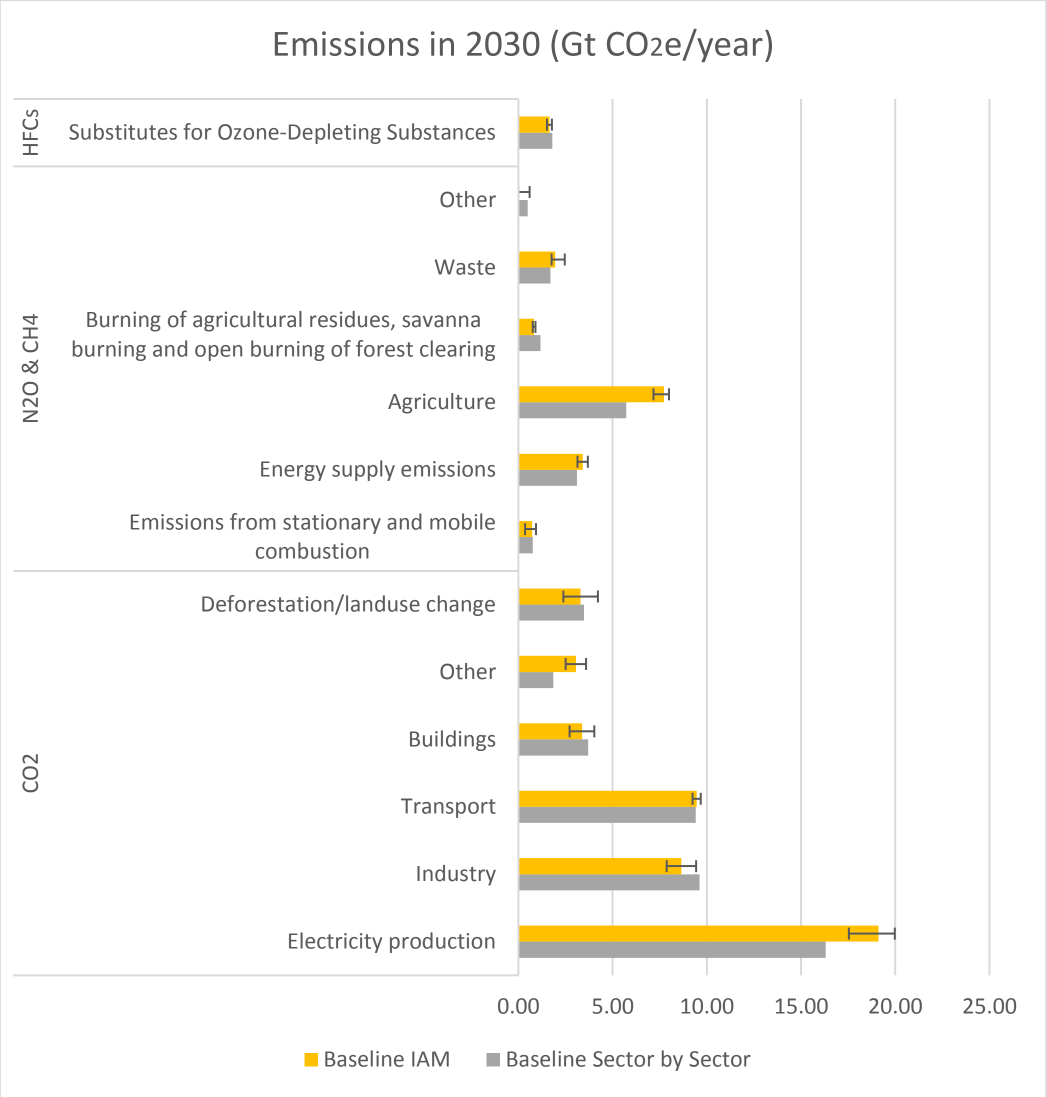


Figure 10. Comparison of the 2030 baseline emissions in the sector-by-sector analysis with the baselines assumed in the 6 integrated assessment models. **The IAM results show the mean and the 15-85% percentile range. For the latter, the average, highest and lowest value are given.**

Figure 11 compares the emission reduction potentials of the sector-by-sector technology based analysis with the mitigation activities in the IAM set for the 2 °C scenario, noting that the IAMs assume a slightly higher total 2030 emission level. The average total mitigation in 2030 in the IAM scenarios is 23 $GtCO_2e$, with a full range of 5 - 42 $GtCO_2e$. The wide range across the IAMs is caused by different reduction strategies over time and different baseline assumptions. Overall, the IAM range reductions from baseline are lower than the total emission reduction potential found in the sector-by-sector analysis, providing evidence that the IAM scenarios are technically feasible. The sectoral breakdown shows that in the electricity sector, emission reductions are comparable, although the IAMs 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, IAMs 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 on the short-term. For the various end-use sectors, the IAM models show considerably less emission reduction 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 IAM 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, IAMs 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 IAMs than in the sector-by-sector assessment. It should be noted, however, that IAMs in general 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 IAM 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 IAM models for 1.5 °C, because most of these IAM scenarios have not been published yet. However, focusing on the results of one IAM, the IMAGE model, Figure 11 shows the IMAGE results for both 2 °C and 1.5 °C. The figure shows that to 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 IAM 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 IAMs. The analysis also suggests that further reductions in the IAM scenarios could mostly be achieved via energy efficiency and biological carbon removal options.

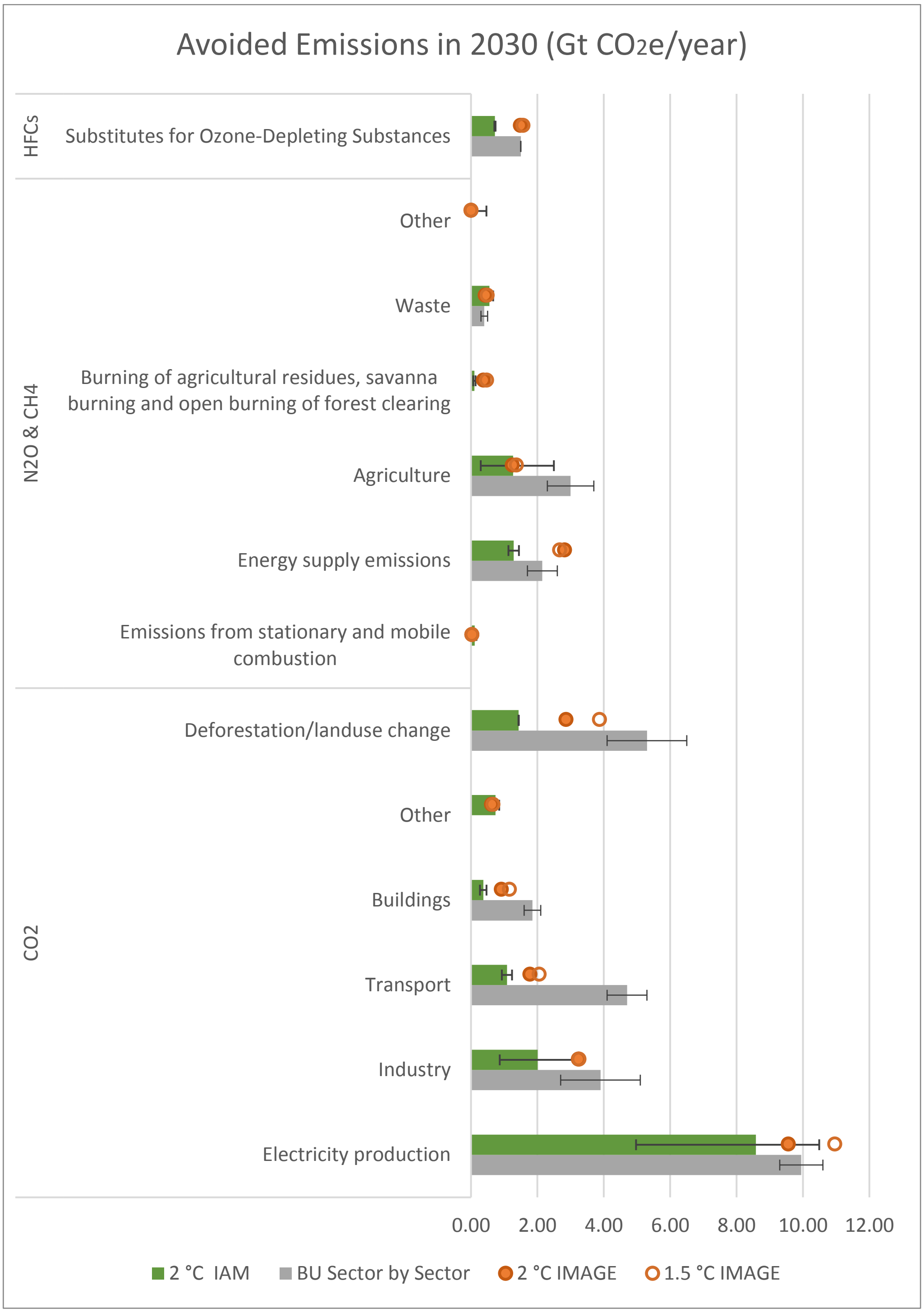


Figure 11. Comparison of mitigation in the IAMs under a 2 °C pathway with the emission reduction potentials found in the sector-by-sector analysis. **The IAM results show the mean and the 15-85 percentile range. The red dots indicate the reduction in the IMAGE model for both 2 °C and 1.5 °C (in some cases the IMAGE numbers are outside the 15-85% percentile of the IAM uncertainty range)**

7 Conclusions

The analysis confirms the potential to close the global emissions gap with measures that are technically and economically feasible to implement by 2030, at a marginal cost of no more than USD100/tCO_2e. The total potential is more than sufficient to bridge the total emissions gap in 2030 between the current policy trajectory and the emissions consistent with a 2 °C (>66 per cent chance) and a 1.5 °C (50 to 66 per cent chance) temperature target.

All sectors present substantial emission reduction potentials, which add up to a total of 33 GtCO_2e/yr. in 2030 (range: 30 – 36). This sum does not include 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 could realise their estimated emission reductions potentials in 2030.

Notably, six specific measures have the potential to reduce emissions between 15 – 22 GtCO_2e/yr. in 2030 (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 realised at modest costs, and in most of the cases, countries around the world have already established policies to implement these measures. By scaling up these relatively "cheap and easy to implement" measures, the world could collectively get on track to bridge the emissions gap. To realise 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.

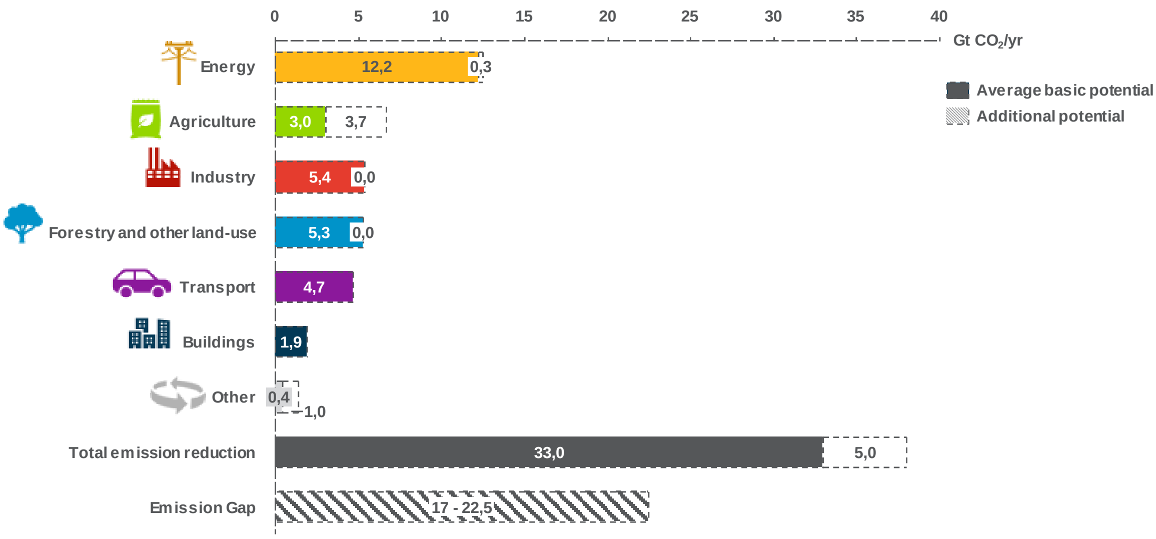


Figure 12. Sectoral emission reduction potentials at the global level compared to the total emissions gap in 2030

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