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Feasibility of limiting warming to 1.5 and 2°C

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This briefing note outlines the scientific conditions under which warming can be limited to well below 2°C over the 21st century, and return to below 1.5°C by 2100. It provides a scientific overview of the science on some critical mitigation technologies, like bioenergy, carbon capture and storage, and their combination – BECCS. The considerations in this briefing are based on the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5), the 2014 UNEP Emissions Gap Report, the Report of the UNFCCC Structured Expert Dialogue (SED), as well as the recent scientific literature.

Summary

Information on the feasibility of holding warming well below a 2°C increase above pre-industrial, and reducing global warming levels below 1.5°C by 2100 is relevant for elements in the ADP¹ agreement – under negotiation and to be adopted in Paris in December 2015. Emission reductions and targets related to 1.5 and 2°C can only be achieved through a global transformation in all economic sectors. This transformation has been assessed to be technologically feasible and can be implemented without compromising sustainable development or food security. This analysis reviews the state-of-the-art of the science to provide the evidence base of the feasibility of 1.5 and 2°C consistent emission requirements, with a view of strengthening emission reduction goals within the ADP Agreement. It furthermore discusses issues related to the sustainable use of bioenergy and carbon capture and storage, and their combination, BECCS, pointing to the issues that remain to be resolved to maintain the feasibility of holding warming below 2°C and returning to below 1.5°C by 2100.

IPCC assessment and SED report

The scientific findings presented by the IPCC in its latest (Fifth) assessment report show that low-emission scenarios are both **physically and economically feasible** and that warming *can* be held *well* below 2°C above pre-industrial levels² during the 21st century, and return to below 1.5°C by 2100,³ after temporarily exceeding 1.5°C in the 2050s

- The lowest scenario assessed by Working Group I (scenario RCP2.6) leads to a central estimate of warming of about 1.6°C of warming by 2100⁴ (likely below 2°C).
- IPCC Working Group III identified many, both technologically and economically feasible scenarios in line with holding warming well below 2°C, as well as scenarios with lower emissions, in particular with regards to CO₂, which lead to even lower warming
- The Report of the Structured Expert Dialogue⁵ (SED) of the UNFCCC also highlighted that pathways limiting warming to below 1.5°C by 2100 exist, and that, generally, “pathways limiting warming to below 1.5 °C by the end of the century are similar to those limiting warming to 2 °C, but call for more immediate mitigation action and an additional scaling-up of the challenging features of the 2 °C scenarios...”

¹ Ad-hoc Working Group on the Durban Platform

² The 2°C pathways analyzed here are consistent with a long-term goal of holding warming below 2°C with at least 66% probability (‘likely’ in IPCC uncertainty guidelines).

³ The 1.5°C scenarios underlying the emission numbers here have a more than 50% chance of returning to below 1.5°C by 2100 and simultaneously have a probability of about 85% to hold warming below 2°C during the 21st century.

⁴ The average climate-model estimate is 1°C above the 1986-2005 average in the period 2081-2100, while the estimated warming by 1986-2005 is 0.61°C above the 1850-1900 average.

⁵ <http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf>

Differences between 1.5°C and 2°C pathways

Limiting warming to below 1.5°C by 2100 generally requires similar transformations in the energy system as holding warming to below 2°C during the 21st century, but the decarbonisation of the energy system needs to be faster and more pronounced.

Scenarios that keep temperature increase to less than 2°C with a ‘likely’ (a more than 66%) chance already rely on deep emission reductions (40-70% below 2010 levels by mid-century), particularly in the energy-supply sector (reductions of 90% or more below 2010 levels between 2040 and 2070⁶). This transition of the energy system is generally characterised by (1) rapid and sustained increases of energy efficiency; (2) extensive use of CO₂ capture and storage (CCS);⁷ (3) more rapid decarbonisation of electricity generation than in the industry, buildings, and transport sectors. The costs for these scenarios have been assessed by the IPCC to amount to a fraction of the projected consumption growth (about 0.04-0.14% reduction per year, compared to a projected consumption increase over the 21st century of 1.6-3% per year).

The more recent scientific literature⁸ identifies in more detail the additional requirements to limit warming to below 1.5°C by 2100. *In addition* to what is already needed for keeping warming ‘likely’ below 2°C, 1.5°C scenarios are characterised by:

- Aggregated long-term mitigation costs that are about 1.5 to 2.1 times higher for 1.5°C than for 2°C scenarios, with a larger effect on near-term costs than on long-term costs;
- The range of emissions in 2030 that still keeps the option open to limit warming to below 1.5°C by 2100 is significantly lower than for 2°C. Diverting investments towards low-carbon technologies in the coming decade is therefore critical;
- Additional mitigation efforts in the industry, buildings and transport sectors lead to significantly lower emissions from these sectors by mid-century;
- Energy efficiency plays a critical role in low stabilisation scenarios in general. Climate-policy-induced demand reductions are greater in 1.5°C than in 2°C scenarios.

In the short term, emission scenarios consistent with 1.5°C and 2°C have been shown to overlap until the 2020s. The deeper and more rapid emission reductions from the 2030s onwards in 1.5°C scenarios would not only achieve to hold warming below 1.5°C by 2100, but also hedge against technological uncertainties or ensure a high chance (around 85%) of limiting warming below 2°C. This is significantly better than a minimum 66% chance of a ‘likely’ 2°C pathway.

⁶ IPCC AR5 WGIII Figure 7.9

⁷ However, the IPCC also reports scenarios that achieve limiting warming to below 2°C with a much more limited contribution of CCS, or even in the absence thereof. These scenarios then require more stringent early action and that energy demand is limited even stronger through energy efficiency measures.

⁸ Rogelj et al (2015) “Energy system transformations for limiting end-of-century warming to below 1.5 °C”, Nature Climate Change, doi:10.1038/nclimate2572

The IPCC AR5 assessed that “delays in mitigation through 2030 or beyond could substantially increase mitigation costs in the decades that follow and the second-half of the century”, an assessment echoed by the SED report. Delay of reductions to 2030 in ‘likely’ 2°C pathway increases costs by roughly 40% over 2030-2100. However, while there are some pathways that hold warming to below 2°C with an ‘as likely as not’ chance (around 50%) when delaying action to 2030⁹, at present the only pathways that do this with a ‘likely chance’, or return warming to below 1.5°C by 2100, start ambitious global mitigation action no later than 2020. This indicates the urgency of stringent global emission reductions for limiting warming to below 1.5°C by 2100.

Besides higher costs, higher near-term emission levels also imply important trade-offs for mitigation technology requirements. For example, higher emissions in 2020 imply a higher reliance of 2°C scenarios on technologies that can lead to so-called *net negative emissions*, for instance BECCS, the combination of bioenergy with carbon capture and storage (CCS). Rapid emission reductions in the near term leave open the possibility to limit warming to below 2°C with small contributions or even without CCS. In contrast, no options have been identified for limiting warming to below 1.5°C by 2100 without CCS. The deployment of these technologies is often questioned. However, sustainable levels of bioenergy, CCS, and BECCS have been identified, and the 1.5 and 2°C limits are feasible within these boundaries.

Finally, stringent greenhouse gas emission reductions will provide many co-benefits, including public health benefits due to reduced air pollution and energy independence. These co-benefits are not included in the overall costs estimates of mitigation scenarios. However, the IPCC indicates that co-benefits of stringent mitigation scenarios can balance out a large share of the total mitigation costs. For example, while not all co-benefits can be monetised, air-quality co-benefits are estimated to make up for about one third of estimated mitigation costs in 2°C scenarios.¹⁰ In 2030, co-benefits of embarking onto a 2°C-consistent pathway can be estimated at \$330-983 Billion. The more stringent the emission reductions until 2030, the larger the monetised co-benefit.

Negative emissions

Like most 2°C scenarios starting from close to projected emissions for 2020, 1.5°C scenarios depend on the availability of technologies leading to negative CO₂ emissions, with virtually no flexibility to “opt out” of such technologies

- Negative CO₂ emissions mean that at a given point human activities remove more CO₂ from the atmosphere than they emit.
- In the energy-system models used for developing emissions scenarios, negative emissions are primarily assumed to occur by combining bioenergy with carbon capture and storage (BECCS).
- Well-informed choices of bioenergy crops and dedicated policies can avoid much of the risk of competing land uses.¹¹ In the absence of integrative policies, BECCS may require large amounts of land and might therefore compete with other land uses. Indeed, so-called first-generation biofuels¹² require large amounts of land that compete with food production. This is much less

⁹ The only pathways in IPCC AR5 that even after a delay of action to 2030 hold warming below 2°C with a ‘likely’ chance, require sustained large additional emissions of sulphur, leading to cooling to compensate the too-strong warming by CO₂ and other greenhouse gases. This can be seen as a geoengineering activity.

¹⁰ The net present value of air-quality of co-benefits are estimated to be in the range of 0.8-1% of total final consumption between 2010 and 2100, which compares to total estimated mitigation costs (in terms of consumption losses) in the 2.3-3.2% range.

¹¹ As the SED report writes: “To reduce the associated risks, BECCS should be accompanied by an integrative institutional framework that takes into account the competition for land, notably a carbon-pricing mechanism that covers all sectors, including land use”

¹² These biofuels refer to fuel extracted from arable crops such as corn grown for ethanol production.

the case for second- and third-generation biofuels.¹³ The latter two options have also been shown to be more sustainable and put less pressure on ecological diversity, especially if a carbon-pricing mechanism covers all sectors including land use¹¹.

- Any remaining risks of bioenergy in terms of trade-offs with other land uses must be put in the context of the great risks higher levels of warming than 1.5 or 2°C pose to ecosystems, food and water security. IPCC AR5, for example, suggests the negative effects on food prices of large-scale deployment of BECCS by 2050 would be much lower than from (avoidable) impacts of climate change.
- 1.5°C scenarios do not require higher amounts of negative emissions than 2°C scenarios in the longer term, but the same amount somewhat sooner: rapid scale-up of the technologies involved is required about 5-10 years earlier.
- Both 1.5°C and 2°C scenarios are not constrained by the practical geological storage potential for CO₂. The total amount of carbon capture and storage (CCS) required in 1.5°C scenarios by 2100 is about a quarter of the estimated practical geological storage potential.
- Currently BECCS demonstration plants are becoming operational at a scale approaching commercial, with one plant having captured and stored up to 1 million tonnes of CO₂ from bioenergy from 2011 to 2014. Monitoring is set to continue through 2017.
- Further early trial deployments are needed because, notwithstanding the expected technological feasibility, the large-scale deployment of negative emissions technology is not yet established. There is an urgent need for further research into all aspects of this technology and its deployment, including:
 - The policies and measures required to introduce this into energy markets, including addressing legislative, legal, risk and safety concerns
 - The synergies and potential conflicts with fossil carbon capture and storage technologies
 - Increasing understanding about the potential and possible trade-offs of second- and third-generation bioenergy in combination with CCS
- There is no incentive for such development without climate leadership providing unmistakable ambitious reduction targets by 2025 and 2030. Currently most CCS research is focused on enhanced oil recovery. The lack of action thus far has led to insufficient carbon-price signals. Those signals must urgently and unambiguously be strengthened. A carbon-price rise would spur the required investments, which have already emerged on a modest scale. This would provide the test results crucial for getting clarity about these options as soon as possible to inform policy.
- In conclusion, science suggests that the share of BECCS in low-carbon scenarios can be met by the sustainable technical potential of bioenergy and CCS without compromising sustainable development. Large-scale deployment of these technologies hinges on the adoption of a 1.5°C limit to create the incentives to boost these technologies.

Land use and bioenergy

As bioenergy is a low-carbon energy source which is already part of the energy mix today, virtually any mitigation scenario in line with 1.5°C or 2°C uses significant amounts of this energy source.

Recently published commentaries and opinion pieces claim that these scenarios are not feasible, claiming that 500 million hectares of land is needed to provide bioenergy for BECCS in 2°C scenarios. This assertion represents a highly biased view, based on a selective presentation of evidence.

¹³ Second-generation biofuels are extracted from woody biomass, or agricultural and forestry waste. Third-generation biofuels most often refer to bioenergy production from algae, a method still in its development stages.

- Firstly, the requirement of bioenergy does not solely concern 2°C or 1.5°C scenarios but *any* energy-economic scenario, since (modern) bioenergy demand continues to grow rapidly over the next century, irrespective of temperature limit. This means that issues raised in relation to a growing share of bioenergy in the global energy mix are not issues unique to 1.5°C or 2°C scenarios, and cannot be used as a disqualifier of 1.5°C and 2°C scenarios.
- Secondly, the claim that bioenergy generation would require 500 million hectares assumes that only first-generation biofuels extracted from arable crops were available. This claim exaggerates the negative implications for food prices and food security. In fact, bioenergy relies increasingly on second-generation biofuels, which are extracted from woody biomass, or agricultural and forestry waste. This is more sustainable and puts less pressure on ecological diversity. According to the IPCC around 100 EJ/yr can be extracted from agricultural and forestry residues, dung and organic waste alone, sufficient for half of the needs in 1.5 and 2°C scenarios by mid-century and beyond, so that the land requirement is much less than asserted.
- Finally, this assertion conveniently ignores the detrimental effects that higher levels of warming will have on agricultural yields, in particular in developing countries. The IPCC AR5 notes that large-scale bioenergy deployment has a significantly lower effect on aggregate food price by 2050 (around +5 %) than the effect of climate change on crop yields (around +25%). This means that the key priority for food security is to decrease the impacts of climate change.

Overall challenge

Holding warming below the 1.5 or 2°C limit is an important technical and political challenge. There is no ‘silver bullet’ for solving the climate problem. Instead, many solutions and technologies together comprise the many ‘wedges’ to achieve the required emission reductions. Each of these solutions is represented by carefully scrutinised narratives considering potential, feasibility and costs in the large collection of 1.5 and 2°C scenarios in the scientific literature. The overall challenge to hold warming below 1.5 or 2°C has been shown to be within the range of what is physically, technologically and economically feasible, without compromising sustainable development. However, limiting warming to below 1.5°C by 2100 does not allow for any further delay in mitigation action. Global emissions must decline rapidly and steadily after 2020.

Background

Early and ambitious emission reductions, followed by sustained mitigation effort and negative CO₂ emissions in the second half of the 21st century, would bring back carbon-dioxide concentrations to levels close to 350 ppmv CO₂ shortly after 2100. Feasibility concerns for staying below 1.5°C are related to political and economic inertia (see Figure 1); such concerns cannot plausibly be rooted in inescapable geophysical laws.

If, hypothetically, all global emissions suddenly stopped in 2015, warming would temporarily jump to about 1.2°C above pre-industrial levels¹⁴ and gradually decline to about 1°C by 2100. An immediate stop to all global emissions is obviously infeasible but in the long term temperatures will only stabilise if global CO₂ emissions are reduced to near zero.¹⁵ This is a direct consequence of the “carbon budget” concept assessed in the IPCC AR5. It indicates that peak warming is approximately linearly proportional to all cumulative carbon emissions over time. Delaying emission reductions results in higher cumulative emissions and higher warming. If CO₂ emissions were brought down to zero after an initial delay in reductions but without “catching up” with the same initial carbon budget by steeper reductions afterwards, the higher cumulative emissions lead to both concentrations and warming stabilising at a higher level¹⁶. Net negative CO₂ emissions reduce the overall cumulative CO₂ emissions.

Moderate costs

A wide range of technologically and economically feasible scenarios that limit warming to below 2°C or return warming to below 1.5°C by 2100 has been published in the scientific literature¹⁷ also providing cost estimates for achieving them.

Emission reductions required to keep below 1.5°C and 2°C can be achieved at moderate cost. The reductions can be attained at lowest cost, if action to reduce emissions intensifies immediately: the longer the delay, the more difficult and expensive. At some point it will become infeasible to still keep warming below a given temperature limit.

IPCC assessed the average global macro-economic costs over the century and reports that they are modest compared to expected economic growth. For example, under a cost-effective approach macro-economic costs for holding warming below 2°C with a ‘likely’ chance equal an average annual reduction of consumption growth of about 0.04-0.14% per year. This can be compared to a baseline increase of consumption over the 21st century projected at 1.6-3% per year.¹⁸ This would reduce economic growth from 2.30% to 2.24% per year, leading to only a two-year delay in reaching the same level of global wealth over the period from 2010 to 2100. Over the 21st century limiting warming below 1.5°C by 2100 is about 50% more, so about 0.1 % of GDP p.a. This would reduce economic growth from 2.30% to 2.20% per year, resulting in only a four-year delay in reaching the same level of global wealth over the period from 2010 to 2100.

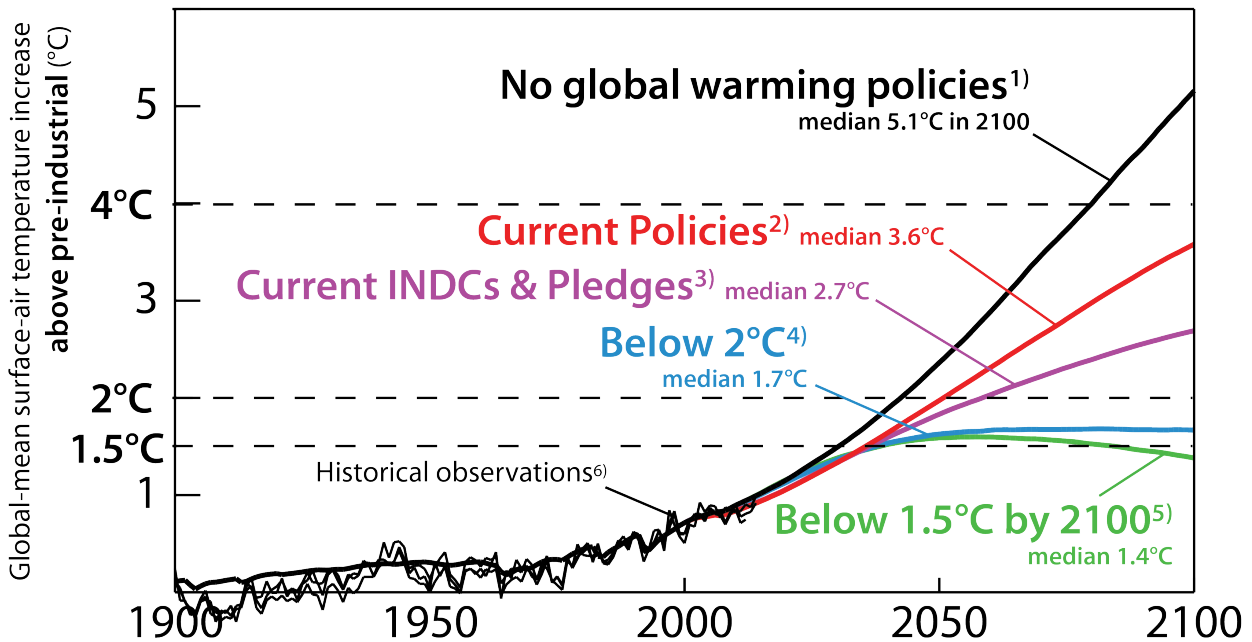
¹⁴ The temporary jump in warming would be caused by to the sudden removal of the overall ‘cooling’ effect of air pollutants that partly mask greenhouse-gas warming prior to the sudden elimination of all global emissions

¹⁵ Matthews and Caldeira (2008) “Stabilizing climate requires near-zero emissions”, *Geophys. Res. Lett.* 35, (4) doi:10.1029/2007gl032388.

¹⁶ Knutti and Rogelj (2015) “The legacy of our CO₂ emissions: a clash of scientific facts, politics and ethics”, *Climatic Change*, doi:10.1007/s10584-015-1340-3.

¹⁷ For example, scenarios assessed by IPCC AR5 Working Group III; UNEP The Emissions Gap Report – A UNEP Synthesis Report (2014); Rogelj et al. (2013) *Nature Climate Change*; Rogelj et al. (2013) *Nature*; Luderer et al. (2013) *Environmental Research Letters*; IEA World Energy Outlook 2011.

¹⁸ See IPCC AR5 Working Group III Contribution, Summary for Policymakers.



- 1) Highest scenario assessed by IPCC AR5 WGI (RCP8.5). If carbon-cycle/climate models are driven by emissions, rather than prescribed concentrations, central warming estimates in IPCC AR5 project 4.5°C warming averaged over 2081-2100 for RCP8.5, close to the model used in this paper at 4.6°C
- 2) Current policies presently in place around the world (<http://climateactiontracker.org/global.html>)
- 3) Unconditional pledges or promises that governments have made, including in submitted INDCs as of 1 October 2015 (<http://climateactiontracker.org/global.html>)
- 4) Lowest scenario assessed by IPCC AR5 WGI (RCP2.6)
- 5) Low-emission pathway leading to warming below 1.5°C by 2100 with >50% chance (Rogelj et al 2015)
- 6) Historical observations from three datasets (IPCC AR5 WGI SPM)

Figure 1 Global warming projections for different scenarios. Red line: business-as-usual scenario in absence of new climate policy. Purple: effect of current INDCs as of October 1, 2015, in lead up to climate summit in Paris and including post-2030 reduction targets for any countries that announced these. Blue: an illustrative low emissions scenario technologically and economically feasible at modest overall costs – the lowest scenario assessed by Working Group I in its contribution to the IPCC Fifth Assessment Report (AR5). Green: a scenario that is typical for scenarios that reach 1.5°C by 2100 with at least 50% chance (Rogelj et al 2015) as also assessed in AR5. Black: the highest scenario assessed by Working Group I without any climate policy. See footnotes for data sources.

International cooperation is required to effectively mitigate greenhouse gas emissions. Effective mitigation will not be achieved if individual agents advance their own interests independently. Regional costs, however, most strongly depend on the assumed burden-sharing (equity) regime.

Not included in the above-mentioned cost estimates are co-benefits of climate change mitigation, like energy independence, the reduction of air pollution, its resulting beneficial effect on public health, and so on. The monetised value of co-benefits ranges significantly across different studies. For example, the co-benefits of globally avoided mortality through the reduction of air pollutants by climate change mitigation has been estimated¹⁹ to be in the range of \$50-380/tCO₂. According to the IPCC AR5, overall air-quality co-benefits range from \$2 to \$420/tCO₂.

The analysis underlying the IPCC numbers²⁰ reported an average monetised value of air-quality co-benefits of \$49/tCO₂. For 2030, co-benefits of embarking onto a 2°C-consistent pathway²¹ can be

¹⁹ West, J.J., S.J. Smith, R.A. Silva, V. Naik, Y.Z. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L. W. (2013). "Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health". *Nature Climate Change* 3, 885–889 (2013). doi:10.1038/nclimate2009.

²⁰ Nemet, G.F., T. Hollowa, P. Meie (2010). "Implications of incorporating air-quality co-benefits into climate change policymaking". *Environmental Research Letters* Volume 5 Number 1 G F Nemet et al 2010 Environ. Res. Lett. 5 014007 doi:10.1088/1748-9326/5/1/014007.

estimated at \$865 billion. The more stringent the emission reductions until 2030, the larger the monetised co-benefits. These estimates are in the same order of magnitude as estimated in other literature sources assessed by IPCC for reduced pollution control and energy security expenditures²² of \$100–600 billion annually by 2030 and also similar to the estimates of how much air-pollution control would actually cost²³. The associated value of air-pollution co-benefits of greenhouse gas mitigation is \$44-179 per capita per year in 2030, increasing to up to \$450 per capita in 2100.

Finally, the net present value of co-benefits of air-quality are estimated to be²⁴ 0.8-1% of total final consumption between 2010 and 2100. As a comparison, estimated mitigation costs (in terms of consumption losses) range from 2.3 to 3.2%, suggesting that the co-benefits associated with air-quality improvements alone may offset about a third of mitigation costs.

Apart from improvements in air quality, further co-benefits of low-emission pathways mentioned in AR5 include higher energy security, and productivity and employment gains. Energy security is positively influenced by climate policy, because energy sources need to become increasingly diverse and the share of domestic resources would typically increase under such climate policies, lowering the need for energy imports from volatile international fossil-fuel markets and possibly unstable production regions. Gains in productivity can be realised since modern, energy efficient buildings usually also provide better working and living conditions. These improved living conditions and monetary and time savings associated with the availability of modern energy types also have a positive influence on economic activity, since many small businesses (workshops, shops, services, groceries) can only flourish when relatively cheap and reliable energy supply is available. It is this kind of activity that can act as a jump-start for further economic development by opening up new possibilities for employment and income generation.

Transformation of various sectors

Scenarios that keep temperature increase under 2°C with a likely chance rely on large emission reductions (more than 90% by mid-century) in the energy sector. This implies a rapid transition in the energy system. This transition is generally characterised by:

- Rapid and sustained increases in energy efficiency
- Extensive use of CO₂ capture and storage (CCS). The IPCC also reports on scenarios that achieve limiting warming to below 2°C with a much more limited contribution of CCS. To allow for that, these scenarios require that energy demand is limited even more strongly through energy-efficiency measures.
- Decarbonisation happening more rapidly in electricity generation than in the industry, buildings, and transport sectors. The low-carbon electricity generation required for this decarbonisation (towards a 60% share by mid-century²⁵) is defined broadly, and includes renewable energy, nuclear power, fossil-fuel power plants with CCS and biomass fuelled plants with CCS (BECCS)

²¹ Rough estimate obtained by applying historical monetised air quality co-benefits per ton of CO₂ to the median value of emission reduction across models for IPCC AR5 category 1 scenarios with stringent action from 2020 onwards (430-480 ppm CO₂e), with no constraints on technologies.

²² Mccollum, D.L., V. Krey, K. Riahi, P. Kolp, A. Grubler, M. Makowski, N. Nakicenovic (2013). "Climate policies can help resolve energy security and air pollution challenges". *Climatic Change* July 2013, Volume 119, Issue 2, pp 479-494

²³ \$400-800 Billion in 2030, in Rao, S., S. Pachauri, F. Dentener, P. Kinney, Z. Klimont, K. Riahi, W. Schoepp (2013). "Better air for better health: Forging synergies in policies for energy access, climate change and air pollution". *Global Environmental Change* Volume 23, Issue 5, October 2013, Pages 1122–1130.

²⁴ Median values across scenarios with immediate and delayed (2020 and 2030) action.

²⁵ Rogelj et al (2015) "Energy system transformations for limiting end-of-century warming to below 1.5 °C", *Nature Climate Change*, doi:10.1038/nclimate2572

Sectorial assessments in IPCC AR5²⁶ point out that, apart from the electricity sector, deep emission reductions in other sectors are also possible already by mid-century. Such deep emission reductions are generally less necessary in 2°C scenarios with availability of BECCS, but provide strong potential to accelerate emission reductions in the next decades and thereby embark on pathways towards holding warming below 1.5°C by 2100.

1.5°C pathway characteristics

In the short term, scenarios consistent with 1.5°C and 2°C have been shown to overlap until the 2020s. Afterwards stronger emission reductions are required for 1.5°C. The IPCC AR5 noted that “only a limited number of studies has explored scenarios that are more likely than not to bring temperature change back to below 1.5°C by 2100 relative to pre-industrial levels.”²⁷ Since the publication of AR5, new scientific literature provides further detail of such 1.5°C scenarios.

In particular, a recent publication²⁵ maps out the key differences between scenarios that return warming to below 1.5°C by 2100 (and at the same time have a high chance of around 85% to stay below 2°C), from scenarios that have a ‘likely’ (at least 66%) chance to stay below 2°C during the 21st century. Figure 2 shows that the carbon intensity of global energy supply improves rapidly in both 1.5°C and 2°C scenarios and confirms that the transformation leads to deeper decarbonisation levels for 1.5°C scenarios from the 2030s onwards.

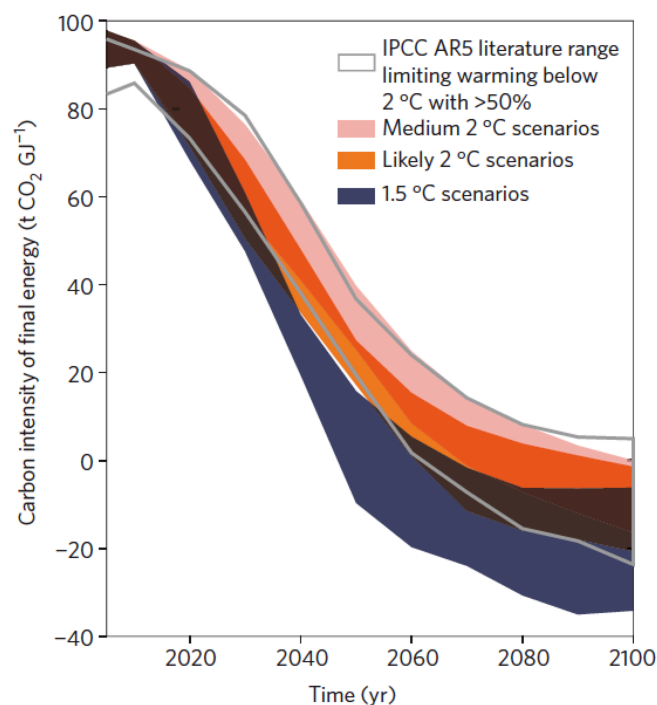


Figure 2 Evolution of carbon intensity of final energy form 2010 until 2100. Results are provided for selected sets of scenarios in line with a specific temperature limit (blue, orange and pink) including the range of scenarios available in the IPCC AR5 scenario database (grey features). Ranges show the 15th to 85th percentile range. 1.5°C scenarios return warming to below 1.5°C by 2100 with at least 50% probability; likely 2°C keep hold warming to below 2°C during the entire 21st century with at least 66% probability (but exclude the more stringent 1.5°C scenarios); Medium 2°C scenarios hold warming to below 2°C with 50-66% during the 21st century. Source: Rogelj et al (2015)

²⁶ For example, see IPCC AR5 Working Group III chapter 6 and 9

²⁷ IPCC AR5 Working Group III Summary for Policy Makers.

The new study²⁵ on 1.5 and 2°C scenarios further summarises the key characteristics of the scenarios in terms of required greenhouse-gas emission reductions and the transformation of priority sectors. These key characteristics are reproduced in the table below (Table 1). Compared to 2°C scenarios, not all sectors provide additional potential for returning warming to below 1.5°C, for example because the reduction potential for non-CO₂ emissions is already virtually fully mobilised in 2°C pathways. Of particular importance for 1.5°C scenarios are an acceleration of energy-efficiency measures, earlier reductions in the power sector, and large reductions in the industry, building and transport sectors by mid-century.

Table 1 Key characteristics of 1.5 °C scenarios and comparison with 2 °C scenarios. Source: Rogelj et al (2015)

Key 1.5°C characteristic	Detailed qualification
CO ₂ reductions beyond global net zero emissions.	1.5°C-consistent scenarios reach global net carbon neutrality by mid-century, 10–20 yr earlier than in scenarios consistent with only 2°C, and show net negative emissions in the 2050–2100 period, which is not a requirement for 2°C-consistent scenarios.
Additional GHG reductions mainly from CO ₂ .	The mitigation potential of non-CO ₂ GHGs is often already exhausted by mitigation action for keeping warming to below 2°C. Therefore, additional reductions in 1.5°C scenarios are mainly from CO ₂ .
Rapid and profound near-term decarbonization of energy supply.	1.5°C scenarios require a decarbonization of energy supply that is more rapid and profound than in 2°C-consistent scenarios. Early CO ₂ reductions in 1.5°C-consistent scenarios are achieved through early reductions in the power sector (Supplementary Fig. S6).
Greater mitigation efforts on the demand side.	By mid-century, mitigation efforts in the industry, buildings and transport sectors lead to significantly lower emissions from these sectors.
Energy efficiency improvements are a crucial enabling factor for 1.5°C.	Energy efficiency plays a critical role in low stabilization scenarios in general. Most 1.5°C scenarios assume energy use per unit of GDP to decrease at a faster pace than historically observed, for example, owing to dedicated energy efficiency policies. In addition, there are substantial climate-policy-induced demand reductions, which are greater in 1.5°C than in 2°C scenarios owing to the more stringent emissions constraints.
Higher mitigation costs.	Aggregated long-term mitigation costs are higher, for example up to two times when comparing corresponding 1.5°C and 2°C scenario pairs. The effect on near-term costs is greater.
Comprehensive emission reductions need to be implemented in the coming decade.	The window of emissions in 2030 that still keeps the option open to limit warming to below 1.5°C by 2100 is much lower and substantially smaller than the corresponding window for 2°C-consistent scenarios. Diverting investments towards low-carbon technologies in the coming decade is therefore critical.

Recommended numbers for ADP Agreement²⁸

Based on an assessment of information available in the IPCC Fifth Assessment Report (AR5), the 2014 UNEP Emissions Gap Report and the scientific literature, a set of recommended emission benchmarks can be formulated which are in line with keeping warming to below 1.5 °C or 2°C, respectively.

Limit warming below 2 °C during the 21st century with a more than 66% chance:

- Global greenhouse gas emissions by 2050 are 40-70%²⁹ (35-55%) below 2010 (1990) levels
- Global greenhouse gas emissions reach zero by 2080-2100
- Global energy and industry CO₂ emissions³⁰ by 2050 are 35-80% (10-70%) below 2010 (1990) levels
- Global energy and industry CO₂ emissions reach zero around 2060-2075

Return warming below 1.5 °C by 2100 with a more than 50% chance³¹:

- Global greenhouse gas emissions by 2050 are 70-95%⁵ (65-90%) below 2010 (1990) levels
- Global greenhouse gas emissions reach zero by 2060-2080
- Global energy and industry CO₂ emissions by 2050 are 95-120% (95-125%) below 2010 (1990) levels
- Global energy and industry CO₂ emissions reach zero around 2050 (range 2045-2055)

²⁸ See “Timetables for zero emissions and 2015 emissions reductions: State of the Science for the ADP agreement”, <http://climateanalytics.org/publications/2015/timetables-for-zero-emissions-and-2015-emissions-reductions>

²⁹ These numbers are drawn directly from the IPCC AR5 Working Group III Summary for Policymakers. The other numbers in this section draw from all scenarios assessed by the IPCC Fifth Assessment Report and the 2014 UNEP Emissions Gap Report and follow the methodologies of the 2014 UNEP Emissions Gap Report, to enable a direct comparison of these other numbers with the information provided in the 2014 UNEP Emissions Gap Report for 2 °C.

³⁰ Referred to by the IPCC as “CO₂ from fossil fuel and industrial sources” (see IPCC AR5 WGIII chapter 6 section 3.1.3).

³¹ The 1.5°C scenarios underlying the emission numbers here have a more than 50% chance of returning to below 1.5°C by 2100 and simultaneously have a probability of about 85% to hold warming below 2°C during the 21st century.

Closing window of opportunity

1.5°C and 2°C pathways start to diverge in the 2020s. Therefore, the range of (global) emissions consistent with 1.5°C pathways by 2030 is a bit lower than the range consistent with 2°C pathways. By 2030, an average level of total global greenhouse-gas emissions consistent with 1.5°C is around 39 GtCO₂e/yr, versus around 42 GtCO₂e/yr for 2°C pathways.³² This is assuming global greenhouse-gas emissions by 2020 are at levels consistent with Cancun pledges, i.e. the ‘emissions gap’ for 2020 is not closed. Given that there is a broad range of global emission levels consistent with 1.5 and 2°C pathways, and that there is still substantial overlap between these ranges by the 2030s, suggested global emission benchmarks for 2025 and 2030 consistent with both the below 2°C limit and the 1.5°C limit are approximately 43 GtCO₂e/yr for 2025 and 39 GtCO₂e/yr for 2030.

As already mentioned, delays in emission reductions over the coming decades will increase overall costs and will limit the flexibility for future policy preferences for shifting between relative shares of technological options. Not only the costs to achieve comparable low levels of warming rise though. At some point it will simply be no longer feasible to achieve a high, or even more modest probabilities to hold warming below 2°C. Figure 3 shows that as technological options for emission reductions get exhausted, delay of action in the near term cannot be compensated for anymore, even with much larger investments in mitigation later on. Moreover, Figure 4, reproduced from the IPCC AR5 Working Group III Report, shows that if near-term emissions until 2030 continue at the ambition levels of the Cancun pledges, global emission rates have to be almost doubled compared to scenarios that significantly reduce emissions before 2030.

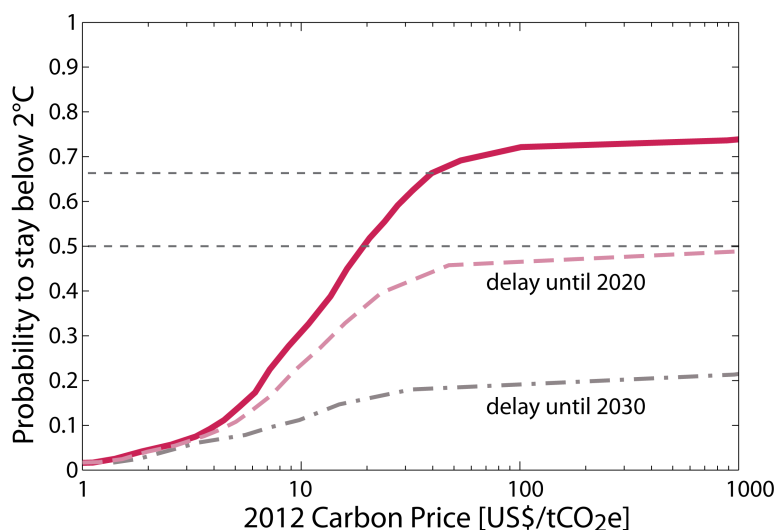


Figure 3. The probability to hold warming below 2°C initially rises with increasing global mitigation investments, or costs (expressed here as carbon price), but reaches a plateau at high costs, for which probability does not rise further, once technological options start to be exhausted. A large global delay of action until 2020, or even 2030, means (1) comparable investments no longer achieve the high probabilities that we still feasible when assuming immediate action; and (2) the overall probability to hold warming below 2°C is lower at maximum investment levels, because available options for further emission reductions get exhausted cannot fully compensate the early lack of action. Source: Rogelj et al (2013)

³² See <http://climateanalytics.org/publications/2015/benchmark-emission-levels-for-2025-and-2030-consistent-with-the-below-2c-limit-and-the-1-5c-limit>

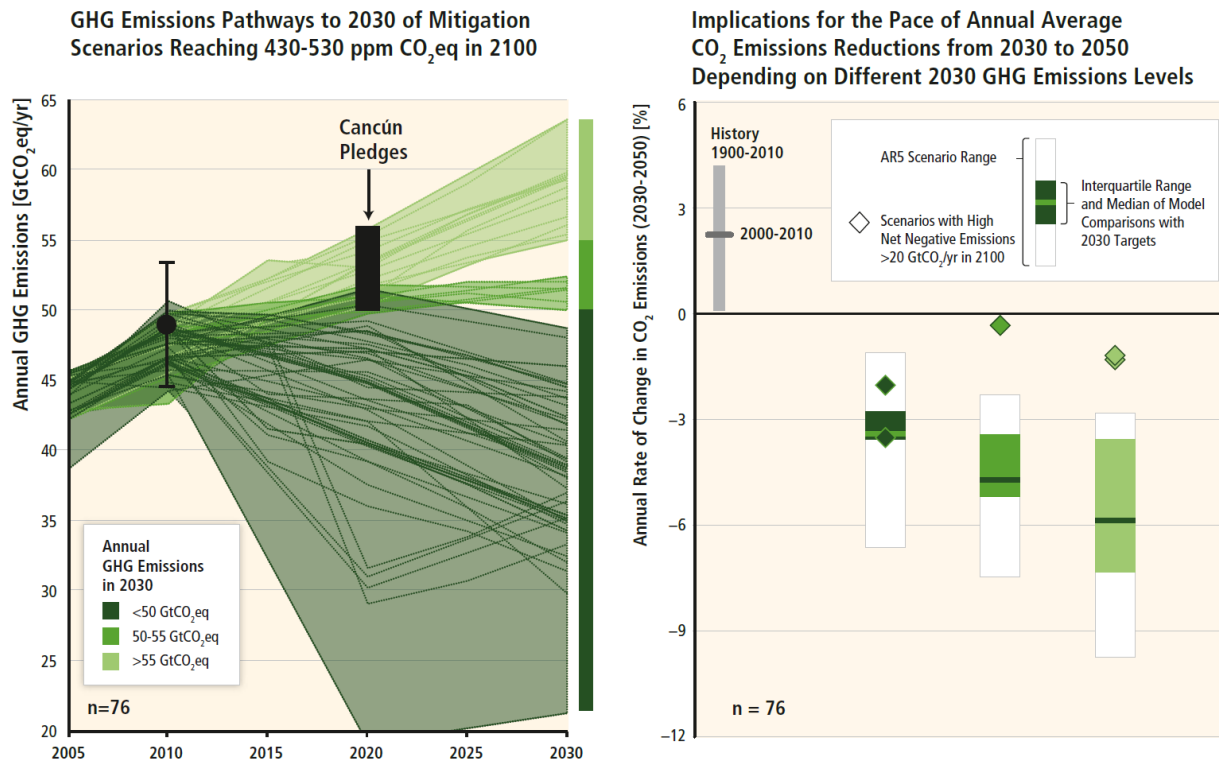


Figure 4. Implications of near-term emissions for required emission reduction rates from 2030 to 2050. Higher emissions in 2030 can lead to almost a doubling in the required emission reduction rates afterwards. Source: IPCC AR5 WGIII Technical Summary, Figure TS. (2014)

Biomass Energy in 1.5°C and 2°C pathways

A key renewable energy carrier in advanced energy systems, and thus also in 1.5°C and 2°C scenarios, is modern biomass, providing bioenergy. While so-called first-generation bioenergy refers to fuel extracted from arable crops, such as corn grown for ethanol production, second-generation bioenergy refers to energy carriers extracted from woody biomass, or agricultural and forestry waste. The implications for other human land-uses are discussed further down in this paper. The most straightforward use of modern biomass as a fuel is in a conventional power plant to produce electricity. But by producing liquid fuels or even hydrogen and capturing at least part of the CO₂ that would otherwise be emitted during this conversion, bioenergy could help to partially decarbonise the transport sector, for which alternative decarbonisation options remain limited. Many integrated assessment model (IAM) scenarios that limit warming to below 1.5°C and 2°C explicitly make sure that biomass energy use is kept within sustainable limits.³³

Role of Carbon Capture and Storage (CCS)

The main purpose of Carbon Capture and Storage (CCS) is to capture carbon dioxide from a combustion process, compress and transport it to a suitable site, and store it on a permanent basis or long (geological) time scales. This technological process prevents the release of carbon dioxide into the

³³ Creutzig et al. (2014) estimate the sustainable technical biomass energy potential to 100-300 EJ/yr with medium agreement.

atmosphere, in the ideal case permanently eliminating carbon-dioxide’s potential contribution to global warming.

Carbon Capture and Storage is not without significant risks and detriments and the necessity of it to limit warming below 2°C, and bring warming back below 1.5°C, can be seen by many as a matter of regret. If climate change action had started significantly sooner, with significant emission reductions already by the first decade of the 21st century, as proposed during the negotiation of the UNFCCC in the early 1990s, deployment of this technology may not have been necessary.

Deployment of CCS reduces the overall cost of achieving low-emission targets. Excluding CCS as a technological option is estimated to more than double the global cost for staying below the 2°C limit and it is clear that this effect would be even more marked for a more ambitious temperature limit.³⁴ Also, CCS availability is a necessary precondition for the removal of CO₂ from the atmosphere using the combination of bioenergy and CCS (see next section on BECCS).

The practical potential of CO₂ storage capacity in deep geological formations is estimated³⁵ at 3900 GtCO₂. When carrying out a like-with-like comparison, the total CO₂ storage capacity used in 1.5°C and 2°C scenarios does not differ much (both are about 800 GtCO₂ by 2100, Table 2). While 2°C scenarios use less BECCS (Table 2), they rely on larger amounts of CCS from fossil-fuel burning because of a slower phase-out of fossil fuels over the next decades.

Table 2 Cumulative CO₂ storage capacity in 1.5 °C and 2 °C scenarios. Numbers are based on a like-with-like comparison of 1.5 and 2°C scenarios (this means that except for the temperature limit, all other assumptions remain equal, e.g. on energy demand or portfolio of technological options). Values are rounded to the nearest 5 GtCO₂. Based on: Rogelj et al. (2015)

	Until 2050 GtCO ₂	Until 2100 GtCO ₂
Total cumulative CO₂ storage capacity		
<i>Returning warming to below 1.5°C by 2100 with 50% chance</i>	135 (100-235)	790 (420-1070)
<i>Holding warming to below 2°C during the 21st century with 66% chance</i>	105 (75-170)	790 (555-990)
Cumulative storage capacity for CO₂ from biomass energy		
<i>Returning warming to below 1.5°C by 2100 with 50% chance</i>	45 (5-165)	520 (155-955)
<i>Holding warming to below 2°C during the 21st century with 66% chance</i>	22 (5-75)	440 (155-780)

All technologies needed for large-scale deployment of CCS are already in use to extract, transport and refine hydrocarbons. Special care has to be taken to ensure the long-term safety of CCS sites to ensure the necessary permanency of storage. Industrial CCS facilities are already reported to store industrial CO₂ underground,³⁶ although the amount of stored CO₂ currently ranges in the million tonnes per year (MtCO₂), not billion tonnes (GtCO₂) as required for CCS for climate change mitigation. This is not surprising without a strong carbon-price signal or other ambitious climate-policy intervention there is no incentive for capturing and storing CO₂ underground.

³⁴ IPCC AR5 WGIII Summary for Policymakers

³⁵ Dooley (2013), Estimating the Supply and Demand for Deep Geologic CO₂ Storage Capacity over the Course of the 21st Century: A Meta-analysis of the Literature, Energy Procedia

³⁶ For example, the Illinois Basin – Decatur Project: <http://www.globalccsinstitute.com/project/illinois-industrial-carbon-capture-and-storage-project>

Bioenergy with carbon capture (BECCS)

BECCS combines energy production from bioenergy with capture and geological storage of the carbon produced (CCS) while combusting the biomass. When biomass is accumulated by vegetation, carbon dioxide is removed from the atmosphere by the plants. If this carbon dioxide is then not released back to the atmosphere when burning this biomass and producing electricity, the net effect is that a certain amount of carbon dioxide has been removed from the atmosphere and permanently stored underground. BECCS is a technology that has been emerging in the past 10 years.

The IPCC Fifth Assessment³⁷ found that “combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions, which plays an important role in many low-stabilization scenarios, while it entails challenges and risks.” The IPCC AR5 also highlights both the important technological potential and the uncertainties related to BECCS deployment. Until 2050, the economic potential is estimated³⁸ to be between 2–10 GtCO₂ per year. Uncertainties and risks of BECCS stem from its constituting technological components: bioenergy and CCS. Both bioenergy and CCS are being used in energy and industrial systems today.

BECCS offers a multitude of technological options.³⁹ In all of these options, the proximity of a storage site is important to make CCS economical. 1.5°C and 2°C scenarios generally extensively deploy BECCS.

2°C scenarios use roughly 150 EJ/yr by 2050 and 250 EJ/yr of modern biomass in primary energy supply (median estimates), with a share of BECCS in bioenergy use around 50% by 2050 and 60-80% by 2100.⁴⁰ However, even without strict long-term climate mitigation incentives (Figure 3 – current INDC trajectory in red), the use of bioenergy is competitive enough to lead to bioenergy deployment by 2050 comparable to levels reached in 2°C scenarios (Figure 3 – blue) about 30 years earlier. Critically, this means that issues raised in relation to a growing share of bioenergy in the global energy mix are therefore not a problem unique to 1.5°C or 2°C scenarios, and cannot be used as a disqualifier of 1.5 and 2°C scenarios, but instead must be addressed under any scenario, whether it includes a strict long-term temperature limit or not.

The 1.5°C scenarios analysed in a recent study⁴¹ show that 1.5°C scenarios do not add much to the maximum deployment of BECCS seen in 2°C scenarios, but do require an acceleration of its large-scale deployment by some 10-20 years (Table 2). BECCS is an option in 2°C scenarios that allows for a delay in emission reductions (at higher overall mitigation costs). In 1.5°C scenarios considerable deployment of BECCS is currently seen as a requirement, not an option.

A CCS advocacy organisation noted that 16 BECCS projects were in exploration stage in 2011,⁴² and currently even more CCS projects are available and planned.⁴³ However, of 22 CCS projects reported to be in operation, or in construction phase, as of November 2015, only 6 are examining dedicated geological storage, whereas all others are focused on enhanced oil recovery. This application of CCS will prolong the reliance on - and viability of - fossil fuels. Without a strong carbon price signal via ambitious reductions commitments from COP21 in Paris, it is unlikely that research and development of BECCS will

³⁷ IPCC AR5 WGIII Chapter 7

³⁸ IPCC AR5 WGIII Chapter 11

³⁹ Klein et al (2014), “The value of bioenergy in low stabilization scenarios: an assessment using REMIND-MAGPIE”, Climatic Change

⁴⁰ 450 ppm category in Figure 6.20 of IPCC AR5 WGIII

⁴¹ Rogelj et al (2015) “Energy system transformations for limiting end-of-century warming to below 1.5 °C”, Nature Climate Change, doi:10.1038/nclimate2572

⁴² Karlsson & Byström (2011), “Global Status of BECCS Projects 2010”, Global CCS Institute

⁴³ <http://www.globalccsinstitute.com/sites/www.globalccsinstitute.com/files/content/page/122877/files/Copy%20of%20Status%20of%20CCS%20Project%20Database%20-%20CURRENT.xls>

take off because, without such price signals, capturing and storing CO₂ will always come at a higher cost compared to the option of releasing it free into the atmosphere.

IPCC AR5 mentions that two small-scale examples of commercial precursors to BECCS are capturing CO₂ emissions from ethanol production facilities for enhanced oil recovery in close-proximity facilities⁴⁴. Another BECCS demonstration project⁴⁵ captured and stored about 1 MtCO₂ over 2011-2014 from bioenergy in dedicated geological storage, with post-injection monitoring to continue until 2017. This amount is roughly equal to the annual emissions of a small island state like the Maldives, half the annual emissions of Grenada, or double the amount of annual emissions of the Solomon Islands.

The large-scale feasibility of negative emissions technology is not yet established. There is therefore a need for further research into all aspects of this technology and its deployment, including:

- The policies and measures required to introduce this into energy markets, including addressing legislative, legal, risk and safety concerns⁴⁶
- The synergies and potential conflicts with fossil carbon capture and storage technologies
- Increasing understanding about the potential and possible trade-offs of second-generation BECCS

The maximum amount of available storage capacity to permanently store CO₂ on geological timescales is uncertain. However, recent research indicates that capacities are sufficient, even for the most stringent climate mitigation scenarios²⁵ in line with limiting warming to below 1.5°C by 2100.

IPCC AR5 is not entirely clear with regard to crops used for BECCS production in low-carbon scenarios, although this is crucial with regards to estimates of the area needed to provide a specific amount of CO₂ removal by means of BECCS. BECCS requires land for the cultivation of bioenergy crops. The ‘competition’ with other land uses needs to be limited by incentivising certain biofuels above others (e.g. so-called second-generation biofuels, like agriculture and forest residue, or waste, above arable crops) and simultaneous incentives for e.g. forest protection. This aspect is further assessed in the next section.

⁴⁴ IPCC AR5 WGIII Chapter 7

⁴⁵ <http://sequestration.org/mgscprojects/deepsalinestorage.html>

⁴⁶ For example: Fuss et al (2014) “Betting on negative emissions” Nature 4, 850-853; Dowd, A.-M., Rodriguez, M., Jeanneret, T. (2015) “Social Science Insights for the BioCCS Industry”, Energies 8, 4024-4042; doi:10.3390/en8054024

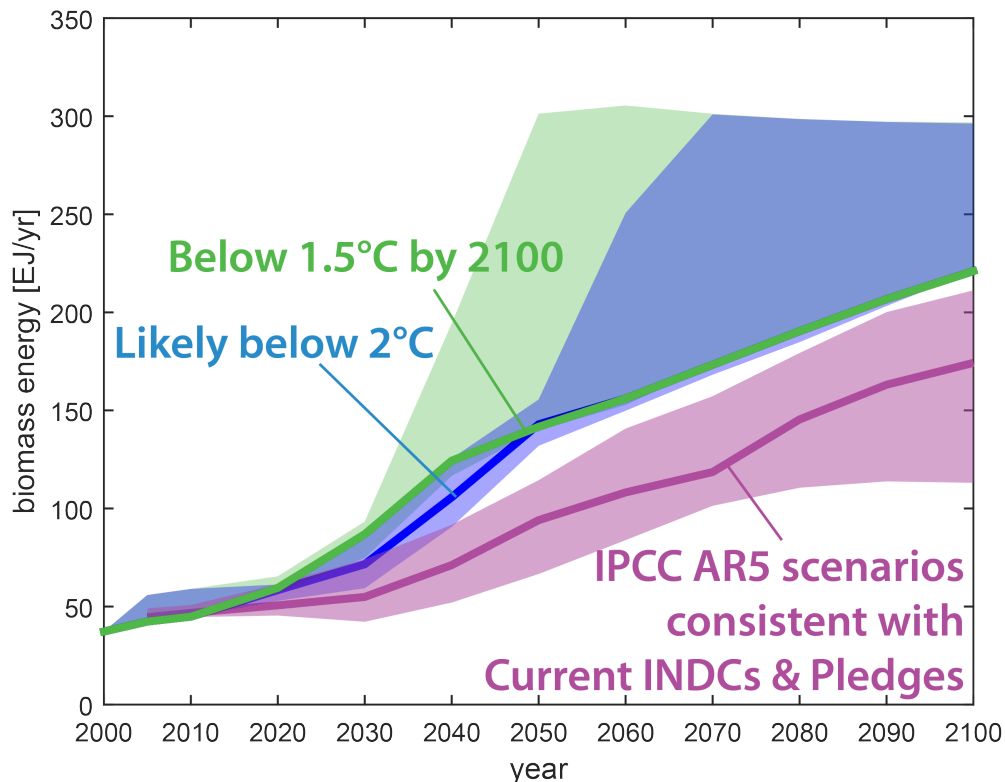


Figure 3. Use of Biomass Energy (total BE both with and without CCS) in 1.5°C scenarios (green), 2°C scenarios (blue) and in AR5 Category 5 emissions scenarios (red). The latter category consists of scenarios that reach concentration and warming levels by 2100 comparable to the levels implied by the current INDCs projections in Figure 1. The shaded range shows the 25-75th percentile range. All scenarios keep global biomass energy use to within the sustainable 100-300 EJ/yr range. Source: scenarios analysed in Rogelj et al (2015) and IPCC AR5 scenario database.

Land use impacts and BECCS

Recent research points toward a total sustainable technical potential of bioenergy up to 300 EJ/yr,⁴⁷ sufficient for the required deployment of bioenergy in the vast majority of 1.5 and 2°C scenarios of up to 150 EJ/yr by 2050 and 250 EJ/yr by 2100.

It is therefore not correct to argue that land area required for BECCS is a prohibitive limitation. For instance, the assumption that 500 Mha land is required for the provision of bioenergy in 2°C scenarios, which would represent about a third of today's global arable land, or 1.5 times the area of India⁴⁸ is incorrect. This assertion represents a highly biased view, based on selective representation of evidence.

Firstly, as mentioned above, the use of bioenergy has been assessed to be competitive enough to lead to large- deployment by 2100 even *without* any climate mitigation incentives, at a level of deployment comparable to levels reached in 2°C scenarios by 2050. Hence, demand for bioenergy must be addressed under any scenario, whether it includes a strict long-term temperature goal or not. Critically, this means that issues raised in relation to a growing share of bioenergy in the global energy mix are therefore not a

⁴⁷ Creutzig et al. (2014) estimate the sustainable technical biomass energy potential to 100-300 EJ/yr with medium agreement.

⁴⁸ Comment by Geden in Nature, 7 May 2015, stating further this would represent about a third of today's global arable land, or 1.5 times the area of India

problem unique to 1.5°C or 2°C scenarios, and cannot be used as a disqualifier of 1.5°C and 2°C scenarios.

Secondly, the actual source paper⁴⁹ that underlies this claim reports an area of around 500 Mha for both BECCS and afforestation *together*. Further, the bioenergy part of such estimates of land requirements refers to only first-generation biofuels extracted from arable crops.⁵⁰ These have much higher risks of competition with other land uses like food and fodder production than second-generation biofuels, which rely on agricultural and forest residues, and possibly have lower yields than third-generation biofuels, which extract energy from algae, for example. According to the IPCC's 2012 *Special Report on Renewable Energy Sources and Climate Change Mitigation* (SSREN) around 100 EJ/yr can be extracted from agricultural and forestry residues, dung and organic waste alone, sufficient for half of the needs in 1.5 and 2°C scenarios by mid-century and beyond.

Overall, land-use conflicts would only arise on a large scale, if BECCS were to depend on arable crops and/or if incentives were created that lead to problems in other sectors (e.g. agriculture or biodiversity, or illegal land grabs by large companies⁵¹). However, if dependence on arable crops is minimised and if BECCS as a mitigation measure is integrated into sustainable development planning and policies, BECCS does not have to lead to any more land-use conflicts than the projected use of bioenergy in baseline scenarios. Given the rapid competitive development of modern bioenergy in scenarios of future energy use even without ambitious climate policies, a set of integrative policies accompanying the expansion of biofuels is thus essential under any scenario, whether it includes a strict long-term temperature limit or not.

Finally, low-emission scenarios that are made feasible by BECCS result in avoided climate damages, for example, to agriculture and ecosystems. Both would lead to reduced pressure on natural systems and agriculture compared to a baseline scenario. In addition, the co-benefits described above could well boost the productivity of poorer parts of a country's rural population. IPCC AR5 writes:⁵² *"A model comparison study with five global economic models shows that the aggregate food price effect of large-scale lignocellulosic bioenergy deployment (i.e., 100 EJ globally by the year 2050) is significantly lower (+5 % on average across models) than the potential price effects induced by climate impacts on crop yields (+25 % on average across models (Lotze-Campen et al., 2013). Possibly hence, ambitious climate change mitigation need not drive up global food prices much, if the extra land required for bioenergy production is accessible or if the feedstock, e. g., from forests, does not directly compete for agricultural land."*

In some scenario cases, IAMs rely on BECCS as a remedy for overshooting the 2°C limit. Given the uncertainties that accompany the possible large-scale deployment of BECCS in the second half of this century, this has been described as "betting on negative emissions."⁵³ The uncertainties in the deployment of BECCS highlight the importance of enhancing our understanding of the potential, trade-offs and synergies of this key mitigation technology. They also highlight that stringent early action is

⁴⁹ Tavoni and Socolow (2013) "Modeling meets science and technology: an introduction to a special issue on negative emissions", *Climatic Change* 118, 1–14.

⁵⁰ Azar et al (2010) "The feasibility of low CO2 concentration targets and the role of bioenergy with carbon capture and storage (BECCS)", *Climatic Change*

⁵¹ This danger from first-generation biofuels was also highlight in a recent report: ActionAid (2015) "Mandating Hunger: The Impacts of Global Biofuels Mandates and Targets"

⁵² IPCC AR5 WGIII Chapter 11

⁵³ Fuss et al. (2014), Betting on negative emissions, *Nature Climate Change*, doi:10.1038/nclimate2392

required to hedge against the possibility that BECCS will not succeed to the extent currently assumed in scenarios limiting warming to below 1.5 or 2°C in the long term.⁵⁴

Besides bioenergy, the IPCC also lists other land-related mitigation options.⁵⁵ An important example is forestry, which comprises reducing deforestation, afforestation/reforestation, forest management, and forest restoration.⁵⁶ All forestry-related carbon mitigation options can be implemented at short timescales, as technologies are readily available, although the IPCC AR5 indicates that they might not always be easy to implement. The forestry mitigation potential in 2030 is estimated at between 1-1.5 GtCO₂/yr for carbon prices up to USD 20, and at over 3 GtCO₂/yr for carbon prices up to USD 100. As any land-based mitigation option where carbon is not removed for geological storage, also forestry raises issues of non-permanence/reversibility and saturation.⁵⁷ Non-permanence and reversibility refer to the release of previously sequestered carbon, for example through forest fires, which negates part of the accumulated benefits. Saturation refers to the point when vegetation and soils are unable to absorb additional carbon. Dedicated management practices can limit these issues for forestry but entirely eliminating these risks is challenging.

⁵⁴ Rogelj et al. (2013), 2020 emissions levels required to limit warming to below 2°C, Nature Climate Change, doi:10.1038/nclimate1758

⁵⁵ IPCC AR5 WGIII Chapter 11

⁵⁶ Forest restoration is the activity by which secondary forest is protected, or degraded forests are given the possibility to restore their carbon stocks.

⁵⁷ See IPCC AR5 WGIII Chapter 11, section 11.3.2