Backgrounder:

Carbon Dioxide Removal and the 1.5°C climate target

Refer to WWF's position paper on Carbon Dioxide Removal, with carbon sequestration in natural systems

1. Summary

- The Paris Agreement sets an ambitious challenge to limit global temperature rise to 1.5°C. In the latest IPCC report, scientists will examine a range of different scenarios for how this might be possible.

- In almost all of these scenarios, the world will need to deliberately remove carbon dioxide from the atmosphere. There are a variety of different ways to try and do this, including growing more forests, sucking carbon dioxide directly out of the air, and combining bioenergy with carbon capture and storage, but most have drawbacks in terms of cost, feasibility, sustainability or pressure on land use.

- In scenarios where the world reduces emissions slowly, more carbon dioxide will need to be removed from the atmosphere, and limiting warming to 1.5°C risks being impossible. Only scenarios of very rapid transformational change to reduce emissions keep open the possibility of meeting such temperature targets without any use of carbon dioxide removal.

2. Background

The Paris agreement called on the Intergovernmental Panel on Climate Change (IPCC) to produce a new report examining the feasibility of the 1.5°C target, due to be released in October 2018. In order to create this report, a number of recent scientific papers have modelled pathways showing how the world could limit temperature rise to 1.5°C by the end of the century.

Most of these pathways rely on measures to suck carbon dioxide out of the atmosphere - an approach known as Carbon Dioxide Removal (CDR). They would see temperatures rise 1.5°C or more over pre-industrial levels at some point during the century, but then fall again by 2100. These kind of temperature pathways haven't been widely considered before in the climate policy space, and allowing temperatures to rise higher would bring greater risks and uncertainties. A few outlier scenarios avoid the need for CDR by reducing emissions very rapidly over the next 20 years.

3. Ways to take carbon out of the atmosphere

The idea of actively removing carbon dioxide from the atmosphere is relatively new, meaning that researchers are still exploring possibilities for how it could work. The IPCC suggested in 2014 that carbon dioxide could be captured and stored when crops or trees are burnt in a power station. Some scientists have suggested that this process, called 'Bioenergy with Carbon Capture and Storage' (BECCS), could be a relatively cheap way of removing carbon from the atmosphere. But the technology is still in its testing stages and using BECCS on a large scale could have serious consequences for land and freshwater use, biodiversity, and the functioning of natural systems (see box).

Protecting ecosystems and preventing further destruction of forests are important ways to reduce carbon emissions, and both would make it easier to meet the 1.5 target. Because trees and plants absorb CO_2, large scale forest planting and the restoration of damaged ecosystems like wetlands are also potentially significant methods of CDR in themselves, and also bring many benefits including improved water filtration, flood protection, soil health and biodiversity habitat. Because of these benefits, such 'natural climate solutions' are likely to be high on the priority list for policymakers, but it is worth noting that afforestation has many of the same challenges as BECCS in relation to land use and land rights.

Two to three times as much carbon is already stored in the soil as in the atmosphere, and changes in land management can help store more carbon in the soil, including planting cover crops, changes to crop rotations and altered livestock patterns. Adding charcoal to the soil can also increase the amount of carbon the soil is able to store. Soil conservation and 'biochar' could together store more than 5 gigatonnes of carbon dioxide ($GtCO_2$) a year - about an eighth of 2016's total manmade carbon emissions.[1]

Land-based carbon drawdown may have potential, but it will also have limits, as carbon sinks or soil become saturated with carbon. Various other methods of CDR have been suggested, with all at an early stage of development. These include direct air capture (DAC), where devices directly take carbon dioxide out of the air. DAC is potentially very energy intensive, although researchers are working on ways of making it more energy-efficient and cheaper. Another option is 'enhanced weathering' - pulverising rocks to increase the rate at which they absorb carbon dioxide dissolved in rainwater. Enhanced weathering could potentially remove up to about 3 $GtCO_2$ a year, but would require large-scale mining of rocks.

Most 1.5°C scenarios rely on a combination of forest planting and BECCS to describe how carbon dioxide could be removed from the atmosphere. Other approaches like direct air capture are not yet included in the models scientists use. Although they have considerable potential, methods focused on protecting the natural world - like restoring damaged forests, improving management of plantations, or planting trees in agricultural areas - are not included in many 1.5°C scenarios (see box).

4. Different ways to get to 1.5°C

Predicting how much CDR we might need to get to 1.5°C is difficult, because it's hard to predict how society, technology, politics and population demographics might develop over this century. The world could see a shift towards more or less equality, higher or lower levels of energy demand, and varying levels of economic development in different regions of the world. These all have an impact on how much carbon we will emit, and how much we might have to remove from the atmosphere.

This uncertainty, combined with uncertainty in predicting how the planet will respond to our carbon emissions, means there is no consensus on how much more carbon we can emit, and how much we will need to take out of the atmosphere. The lowest estimates of our remaining 'carbon budget' suggest that we've already burnt enough carbon to push the world over a 1.5°C limit, while the highest suggests that we've got around 20 years of current emissions left.

In most 1.5°C scenarios, temperatures rise more than 1.5°C above pre-industrial levels - perhaps as high as 1.8°C - before returning to 1.5°C or lower by 2100 thanks to the use of CDR. Across different scenarios, the total amount of carbon dioxide that needs to be removed from the atmosphere over the course of the century varies from 401 to 1596 $GtCO_2$[2] - equivalent to about 10-40 years of 2016 carbon emissions.

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[1] The Global Carbon Project estimates total global human-caused carbon emissions in 2016 from energy, industrial processes and land use change at 40.8 ± 2.7 $GtCO_2$. http://www.globalcarbonproject.org/carbonbudget/17/files/GCP_CarbonBudget_2017.pdf p.40.

[2] Calculation undertaken by Carbon Brief, based on data from Rogelj (2018). The figure is based on adding projected negative land use emissions to negative emissions from BECCS over the course of the century. https://www.carbonbrief.org/analysis-how-natural-climate-solutions-can-reduce-the-need-for-beccs

This is cutting-edge science, but some work has already been published that lets us sketch out illustrative scenarios showing how emissions and temperatures might change over the coming century:

4.1 Some ambition: going green scenarios:

Rapid emissions reductions, more sustainability and use of CDR

In one set of possible futures the world shifts gradually towards a more sustainable path, management of common resources slowly improve, the natural world is protected, and educational and health investments lead to better family planning.

In this set of scenarios[3], global carbon dioxide emissions peak before 2030 and decline rapidly over the next two decades. The energy sector is transformed, with solar, wind, hydro and geothermal energy accounting for 60-80% of electricity supply by 2050. The world reaches net zero greenhouse gas emissions by 2055–2075. Energy efficiency measures mean that from 2020 to 2050 the amount of energy used to produce a unit of economic growth falls by 2-4% every year (compared to a fall of 2% a year from 2011 to 2016).

Despite these efforts, large-scale CDR is still needed to limit temperature rise to 1.5°C by 2100. This includes a significant increase in global forest area, of up to 39% above 2010 levels by 2100.[4] On top of this, BECCS is needed to remove 150 to 700 GtCO2[5] over the course of the century, equivalent to about 4-17 years of carbon emissions at 2016 levels. By 2100, BECCS is taking about 15GtCO2[6] out of the atmosphere each year.

Based on previous calculations,[7] this might require 475-875 million hectares of land for growing dedicated energy crops, or about 1.5 to 2.5 times the entire land area of India. The upper end[8] of this estimate would increase land use cover by 19%, forest loss by 10% and biodiversity loss by 7%. But if off-cuts from forest harvesting, food waste or algae were burnt as well as biocrops, this figure could reduce significantly (see box).

4.2 Less ambition: slower change scenarios:

Less sustainability, less emissions reductions and more CDR

In other scenarios, the world follows a less sustainable social, political and economic path. In scenarios where the world is more unequal and unstable, and with only limited efforts to shift away from fossil fuels, the risk of not achieving the 1.5°C target at all increases. Even in a 'middle of the road' scenario, where social, economic and technological trends follow the same patterns as observed over recent years, not all modellers were able to find a way to limit temperature rise to 1.5°C. Those that did suggested global forest cover would need to increase 2-32%[9], and BECCS would need to remove 400-975 GtCO2 over the course of the century, more than in the 'Going Green' scenarios and equivalent to about 10-22 years of carbon emissions at 2016 levels.

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[3] See Scenarios towards limiting global mean temperature increase below 1.5 °C, Nature (2018) for discussion of scenario sets.

[4] Scenarios towards limiting global mean temperature increase below 1.5 °C, Nature (2018), Figure 2e.

[5] Scenarios towards limiting global mean temperature increase below 1.5 °C, Nature (2018)

[6] Supplementary information, Figure 20. This is the figure for the 'marker scenario' for this set of scenarios

[7] Smith (2016) calculates that sequestering 12.1GtCO2 a year via BECCS in 2100 would use up 380-700 Mha of land.

[8] Figures refer to BECCS land area of 870 million hectares.

[9] Scenarios towards limiting global mean temperature increase below 1.5 °C, Nature (2018), Figure 2e.

In a world where energy demand continues to rise, fossil fuels are still used extensively, and global forest cover increases by 6-10% by the end of the century, CDR becomes a crutch, and would need to remove 950-1200 GtCO2 over the course of the century and 23 GtCO2 a year by 2100. Using previous calculations this could need 713-1313 Mha of land for biocrop production by 2100, or 2-4 times the land area of India, if delivered via BECCS using energy crops. Other studies have suggested even more land could be needed.

5. More ambition: Transformative change scenarios:

Radical emissions reductions, big social change and no CDR

Very few scenarios suggest it is possible to meet the 1.5°C target without using any CDR at all. In order for it to be possible, we would need to see the most favourable outcome on factors like the size of the remaining carbon budget and the path of development the world follows in the next few decades.[10]

Two papers published in 2018 illustrate ways in which it could be be done. Neither is prescriptive, but both perhaps give some idea of the scale of the challenge of meeting ambitious climate targets without using any carbon dioxide removal at all.

The first foresees more rapid emissions reductions by focusing on more radical levels of lifestyle and social change and modelling what might happen if various technological breakthroughs take place.

According to the authors, in order to avoid the use of CDR altogether, all of the following things will have to happen:

- **Low carbon energy:** low-carbon energy, including bioenergy, solar, wind and nuclear power, increases from 15% of primary energy supply now to about 80% by 2050.
- **Renewable electrification:** where all the different sectors in the energy system (power, transport and heat) are rapidly electrified, barriers to integrating renewables to the system are overcome, and all new cars are electric by 2030.
- **High efficiency**: in this scenario only the most efficient materials and methods are used in the energy sector, transport, and cement and steel production by 2025.
- **Agricultural intensification:** crop yields improve rapidly and 80% of the world's livestock farming uses the most efficient methods by 2100.
- **Low non-CO2 gases** - greenhouse gases other than carbon dioxide, like methane and nitrous oxide, fall rapidly. By the middle of the century, 80% of meat and eggs consumed come not from farmed animals but cultured protein, including lab-grown meat.
- **Population:** improved access to education accelerates the trend towards reduced fertility, so the global population rises from 7 billion people today to 8.4 billion in 2050 and then falls to 6.9 billion in 2100. The United Nations currently projects there will be 11.2 billion people in 2100.
- **Lifestyle change:** people around the world adopt more environmentally friendly behaviours. By 2050, everyone in the world eats a low-meat diet and food waste has almost entirely disappeared, fewer people fly or use cars, and household appliances are reduced to two per household.

If any of these aren't met, the authors say, bioenergy still needs to provide between 250 and 400 EJ of

[10] One study for example suggested that that it might just be possible to limit temperature rise to 1.5°C without using CDR if the carbon budget is greater than 650 GtCO2. This is at the far upper end of estimates for the budget. http://rsta.royalsocietypublishing.org/content/roypta/376/2119/20160457.full.pdf, https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c

energy a year[11] - about the same[12] amount of energy as BECCS produces in 1.5°C scenarios with CDR. So unless everything on this list is achieved, the study suggests this scenarios may not reduce the amount of land and resources needed to produce bioenergy.

The second study explores a different scenario, examining what happens if social change and technological advances rapidly reduce global energy demand over the next few decades. In this scenario, the use of digital services expands in the global south, while lifestyles changes in the global north like the rise of vehicle-sharing have a significant impact. Energy supply also changes radically. By the middle of the century, nearly 60% of global final energy is delivered by electricity and hydrogen, and coal and bioenergy have been virtually phased out as energy sources. At the same time, the world develops along sustainable lines. Global food supply increases by a third. Hunger in the developing world is eradicated as a result of agricultural intensification and a switch to healthier diets, and global forest cover increases to 4300 million hectares - similar to the level of expansion projected in other 1.5°C scenarios. As a result of all these changes, the world achieves the 1.5°C target at the end of the century without use of CDR, apart from afforestation.

Again, these are not meant to be prescriptive future pathways - but they illustrate why some scientists believe the ability to remove carbon dioxide from the atmosphere will be so important in addressing climate change.

[11] Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies (2018), Nature, Figure 3c.

[12] Scenarios towards limiting global mean temperature increase below 1.5 °C (2018), Nature, Figure 2b.

BECCS, land use and natural climate solutions

Bioenergy with Carbon Capture and Storage (BECCS) involves growing plants or trees, burning them and capturing the carbon dioxide. The technology is used extensively in many 1.5°C scenarios, but it is controversial. It is not clear whether use of bioenergy on this scale would be sustainable or even possible.

*Growing energy crops for BECCS could potentially take up a great deal of land. Limiting temperature rise to 2°C would require 500 million hectares of land, or 1.5 times the land area of India, according to one calculation. 1.5 scenarios could require even more land than this (**see figure**)*

If off-cuts from forest harvesting, wood extracted from natural forests, food waste, or algae were used as well as energy crops, the area of land needed for BECCS could be far smaller. In 2014 the IPCC suggested that if these resources are taken into account, it is technically possible to produce 100 exajoules (EJ) of energy annually from bioenergy, and possibly 300EJ. For contrast, the first set of 1.5°C scenarios described in this brief produce 160EJ from BECCS annually in 2100.[13]

But the IPCC also notes that bioenergy "carries considerable risks" for water use, and competition with food crops. Destroying natural ecosystems to create land for BECCS could reduce the amount of carbon saved by using BECCS. Replacing tropical forest with crops for BECCS could cause more harm than good. Given all these pressures, some researchers argue that no energy can sustainably be produced from bioenergy crops at all,[14] *and others that it puts serious limitations on the extent to which BECCS could be used.*

Recent research suggests that 'natural climate solutions' - methods focused on restoring or enhancing ecosystems - may have a lot of potential as a method of CDR. These methods include restoring forests in areas where they have previously existed, managing forests better, and adding biochar to soil. These methods could cost-effectively remove 225GtCO2 over the course of the century, reducing the need for BECCS by about 30%. One model suggests that if emissions are also reduced rapidly, it could reduce the need for BECCS by 56%.

Data comparison graphics:

1. Data comparing different 1.5C scenarios from Rogelj 2018

Scenario outline	Temp rise above pre-industrial levels in 2100 (C)	Peak temp rise over the course of the century (C)	Fossil fuel and industry emissions 2030 (GtCO2)	Global CO2 emissions 2030 (GtCO2)	Emissions from land use 2100 (GtCO2)[15]	Forest land cover 2100 (Mha)	BECCS by 2100 (GtCO2/yr)[16]
SSP1	1.33-1.400	1.56-1.71	10.639-24.755	10.560-23.404	-3.614 to -1.641	4198-5138	3.24-16.66
SSP2	1.29-1.40	1.57-1.79	18.614-32.294	20.138-36.02	-4.162 to -0.321	4076-4824	11.13-28.99
SSP4	1.31	1.54	12.821	12.74	1.447		19.47
SSP5	1.37-1.39	1.73-1.81	31.325-36.130	35.675-37.770	-3.844 to -1.201	4178-5034	21.90-22.5

[13] Scenarios towards limiting global mean temperature increase below 1.5 °C (2018), Nature, Figure 2b.

[14] Heck (2018) concludes that if strong sustainability constraints are put in place, biogeochemical flows, freshwater use and limitations on the use of land "almost no biomass plantations can be implemented".

[15] Negative values for land use indicates negative emissions.

[16] Positive values for BECCS indicates negative emissions.

Temperature rise above pre-industrial levels in 2010 (C)	Fossil fuel and industry emissions 2010 (GtCO2)	Global CO2 emissions 2010 (GtCO2)	Emissions from land use 2010 (GtCO2)	Forest land cover 2010 (Mha)
0.99	31.16 to 33.15	35.49 to 40.31	3.13 to 7.17	3885.84 to 4172.42

Based on data sent by Rogelj 2018

2. Comparing different estimates for the land area covered by BECCS in 2100 in 1.5C scenarios

Author and date	Temp target	World pathway	BECCS by 2100 (GtCO2)	Source	Mha BECCS 2100	Total land cover (Mha)
Smith 2016	2		12.1		380–700	
Popp et al 2018	2	SSP1			142	
Popp et al 2018	2	SSP4			1517	
Van Vuuren 2018 (base scenario)	1.5	Base scenario			600	
Rogelj 2018 - SSP1	1.5	SSP1	15	Figure 20, suppl info	471-868	
Rogelj 2018 - SSP2	1.5	SSP2	12	Figure 20, suppl info	377-694	
Total world agricultural area 2018						4862
Land area of India 2018						329

Based on a number of different papers, sources on tab 3 here.

This paper was prepared by GSCC to support understanding of issues arising from the IPCC's Special Report on 1.5°C warming.

WWF

Why we are here
To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.
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