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IPCC Working Group I report on the Physical Science Basis of Climate Change 2021

The IPCC has finalized the first part of the Sixth Assessment Report (AR6), 'Climate Change 2021: The Physical Science Basis', the Working Group I (WGI) contribution to AR6. It was finalized on 6th August 2021 during the 14th Session of Working Group I and 54th Session of the IPCC.

This report from IPCC's WGI is their update on the science of climate change. It includes new evidence from climate science, and re-emphasises why we need to reduce emissions quickly, and why CCS is needed for permanent CO_2 removal (CDR). It is very comprehensive in its 3949 pages, covering the current state of the climate, the future climate, risk and adaptation, and limiting future climate change. It explores why and how CDR is needed to compensate for residual emissions in order to reach net-zero. A sobering conclusion is that even with achieving sustained net-zero emissions, while there would be limits to temperature increases and gradual reversals of atmospheric CO_2 and surface ocean acidification, other climate changes already in the global systems would continue for decades and more. The WGI report draws heavily from the findings of the recent Special Reports: SR1.5, SRCCL, and SROCC.

IEAGHG's main input is to IPCC's WGIII (Mitigation) but it is good to see our work also used in this WGI report (an IEAGHG paper from GHGT-12 in 2014 on the London Protocol).

Some of the key findings and conclusions of the WGI report include:

- Anthropogenic CDR has the potential to remove CO_2 from the atmosphere and durably store it in reservoirs. CDR aims to compensate for residual emissions to reach net zero CO_2 or net zero greenhouse gas (GHG) emissions or, if implemented at a scale where anthropogenic removals exceed anthropogenic emissions, to lower surface temperature. CDR methods can have potentially wide-ranging effects on biogeochemical cycles and climate, which can either weaken or strengthen the potential of these methods to remove CO_2 and reduce warming, and can also influence water availability and quality, food production and biodiversity.
- Anthropogenic CDR leading to global net negative emissions would lower the atmospheric CO_2 concentration and reverse surface ocean acidification. Anthropogenic CO_2 removals and emissions are partially compensated by CO_2 release and uptake respectively, from or to land and ocean carbon pools. CDR would lower atmospheric CO_2 by an amount approximately equal to the increase from an anthropogenic emission of the same magnitude. The atmospheric CO_2 decrease from anthropogenic CDR could be up to 10% less than the atmospheric CO_2 increase from an equal amount of CO_2 emissions, depending on the total amount of CDR.
- Potential negative and positive effects of CDR for biodiversity, water and food production are methods-specific, and are often highly dependent on local context, management, prior land use, and scale. (IPCC WGII and WGIII assess the CDR potential, and ecological and socio-economic effects of CDR methods in their AR6 contributions.)
- Emission pathways that limit global warming to 1.5°C or 2°C typically assume the use of CDR approaches in combination with GHG emissions reductions. CDR approaches could be used to compensate for residual emissions from sectors that are difficult or costly to decarbonize. CDR could also be implemented at a large scale to generate global net negative CO_2 emissions, which could compensate for earlier emissions as a way to meet long-term climate stabilization

goals after a temperature overshoot. (Again, a comprehensive assessment of the ecological and socio-economic dimensions of CDR options is left to the WGII and WGIII reports.)

- CDR methods have a range of side effects that can either weaken or strengthen the carbon sequestration and cooling potential of these methods and affect the achievement of sustainable development goals (SDGs). Biophysical and biogeochemical side-effects of CDR methods are associated with changes in surface albedo, the water cycle, emissions of CH_4 and N_2O, ocean acidification and marine ecosystem productivity. These side-effects and associated Earth system feedbacks can limit the CO_2 sequestration and cooling potential of specific CDR methods. Deployment of CDR, particularly on land, can also affect water quality and quantity, food production and biodiversity. These effects are often highly dependent on local context, management regime, prior land use, and scale. The largest co-benefits are obtained with methods that seek to restore natural ecosystems or improve soil carbon sequestration (SOCS). The climate and biogeochemical effects of terminating CDR are expected to be small for most CDR methods.
- For virtually all scenarios assessed by the IPCC, CDR is necessary to reach both global net zero CO_2 and net zero GHG emissions, to compensate for residual anthropogenic emissions. This is in part because for some sources of CO_2 and non-CO_2 emissions, abatement options to eliminate them have not yet been identified.
- If CDR is further used to go beyond net zero, to a situation with net-negative CO_2 emissions, anthropogenic CO_2-induced warming will decline. A further increase of CDR, until a situation with net zero or even net-negative GHG emissions is reached, would increase the pace at which historical human-induced warming is reversed after its peak. Net-negative anthropogenic GHG emissions may become necessary to stabilize the global surface temperature in the long term, should climate feedbacks further affect natural GHG sinks and sources.
- The climate system response to net negative CO_2 emissions is expected to be delayed by years to centuries. Net negative CO_2 emissions due to CDR will not reverse some climate change, such as sea level rise, at least for several centuries.
- The importance of CDR for reaching net zero or negative CO_2 emissions in mitigation pathways is assessed in the AR6 WGIII report. The risks for and impacts on human and natural systems due to solar radiation management (SRM) are assessed in the AR6 WGII report, and the international governance issues related to SRM and CDR are assessed in the AR6 WGIII report.
- The effect of SRM options on global temperature and precipitation response would be detectable after one or two decades, which is similar to the timescale for the detection of strong mitigation. A sudden and sustained termination of a high level of SRM against a high-GHG background would cause a rapid increase in temperature at a rate that far exceeds that projected for climate change without SRM. However, a gradual phase-out of SRM combined with mitigation and CDR would more likely than not avoid large rates of warming.
- CDR can play a pivotal role in limiting climate warming to 1.5°C or 2°C. However, two review papers were identified that conclude it is implausible that any CDR technique can be implemented at the scale needed by 2050.
- When CDR is applied continuously and at scales as large as currently deemed possible, under RCP8.5 as the background scenario, the widely discussed CDR options such as afforestation, ocean iron fertilization and surface ocean alkalinisation are individually expected to be relatively ineffective, with limited (8%) warming reductions relative to the scenario with no CDR option.

- There is high confidence that sea-level rise will not be reversed by CDR at least for several centuries.
- Land- and ocean-based CDR methods have the potential to sequester CO_2 from the atmosphere, but the benefits of this removal would be partially offset by CO_2 release from land and ocean carbon stores. After some time, which is determined by the magnitude of the removal and the rate and amount of CO_2 emissions prior to the CDR application, land and ocean carbon reservoirs begin to release CO_2 to the atmosphere making CDR less effective.
- Following CDR, the atmospheric CO_2 concentration declines rapidly at first and then rebounds. This rebound is due to CO_2 released by the terrestrial biosphere and the ocean in response to declining atmospheric CO_2 levels. These results corroborate the high confidence placed by WGI AR5 Chapter 6 on the partial compensation of CDR from the atmosphere by CO_2 outgassing from the land and ocean. Due to disagreement between models, the magnitude of this outgassing and in the relative contribution of land and ocean fluxes remains low confidence.
- The removal effectiveness of CDR is only slightly dependent on the rate and magnitude of removal and is smaller at lower background atmospheric CO_2 concentrations.
- Extensive deployment of bioenergy with carbon capture and storage (BECCS) and afforestation/reforestation (A/R) will require larger amounts of freshwater resources than used by the previous vegetation, altering the water cycle at regional scales. Consequences of high water consumption on downstream uses, biodiversity, and regional climate depend on prior land cover, background climate conditions, and scale of deployment. Therefore, a regional approach is required to determine the efficacy and sustainability of CDR projects.

In conclusion, the WGI report underlines the importance of CDR for reaching climate targets, both in terms of 1.5/2°C and net-zero/net-negative pathways but also reminds of the temporal aspects, i.e. the response of the climate system will be delayed. It also highlights regional approaches will be required due to the different benefits and trade-off of each CDR method.

It is also worth mentioning that the tables presenting the sequestration potential of the different CDR options have the caveat that for some potential estimates (e.g. BECCS, A/R, SOCS, biochar) environmental and social factors were considered, whereas for others (e.g. DACCS, enhanced weathering) they were not. The latter are areas where IEAGHG could contribute with future studies, as we are currently carrying out a study with Element Energy on DACCS, which will be published later this year.

The WGI report 'Climate Change 2021: The Physical Science Basis' is available on the IPCC's website:

https://www.ipcc.ch/report/ar6/wg1/

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