The fifteenth meeting of the research dialogue, 2023

8 June 2023

Summary report by the Chair of the SBSTA

February 2024

Introduction and overview

1. Outcomes from research and latest scientific findings are an essential component in advancing the implementation of the UNFCCC and the Paris Agreement, which recognises that effective response and management of climate change should be based on the best available science.[1] The research dialogue provides a platform for the research and scientific community to share latest findings, information and lessons in areas relevant to advancing global climate action. The platform is utilised by Parties and non-Party stakeholders to identify research needs, lessons learnt and capacity-building requirements, particularly those of developing countries, to support the implementation of the Convention and the Paris Agreement.

2. The fifteenth research dialogue coincided with the conclusion of the IPCC's Sixth Assessment Cycle, with the publication of the Sixth Synthesis report[2], whose outcomes and results inform negotiations, including the agenda item on research and systematic observation under the SBSTA. Findings from AR6 were extensively reflected across the research dialogue, including references of scenarios, models and pathways, policy recommendations and good practices.

3. The fifteenth meeting of the research dialogue (RD15)[3] was held during the 2023 Bonn Climate Change Conference on June 8th. The dialogue's themes were identified according to the submissions of Parties and non-Party stakeholders in response to the call issued by the SBSTA Chair and in consideration of the mandates and the wider context of ongoing work under the UNFCCC, such as the global stocktake and thematic work streams. Based on submissions from Parties and non-Party stakeholders, RD15 focused on the three themes of: **Transformational adaptation**; **non-carbon dioxide greenhouse gases**; and **negative emissions technologies including carbon dioxide removal.**

4. The meeting was co-chaired by the SBSTA chair Harry Vreuls, Netherlands, Binyam Yacob Gebreyes, Ethiopia and Frank McGovern, Ireland. An information note[4] was made available in advance of the event to provide an overview of the themes, as well as guiding questions to help focus presentations and discussions.

5. This summary report captures and provides an overview of the proceedings of the dialogue, including the plenary presentations and discussions and further provides reflections of the key messages from the dialogue. The SBSTA Chair encourages Parties to consider the information in this summary report for their programming and during negotiations on RSO at upcoming SBSTA sessions.

[1] See Paris Agreement Art 4.1 https://unfccc.int/sites/default/files/english_paris_agreement.pdf
[2] AR6 Synthesis Report: Climate Change 2023 (ipcc.ch)
[3] Research Dialogue 15 | UNFCCC
[4] RD15 InfoNote_23.05.23.pdf (unfccc.int)

Key outcomes and messages

Transformational adaptation

- Transformational adaptation adopts a deep, large scale and whole-societal transformation approach to climate change adaptation and facilitates shifts of development pathways towards sustainability.
- Due to the rapidly closing window to secure a sustainable future for all, caused by climate change, incremental adaptation will be inadequate to achieve societal-wide transitions. These transitions are required in the interdependent sectors of energy, urban settlements, infrastructure, industrial systems and ecosystems.
- The key dimension of transformational adaptation is strategic adaptation that responds to comprehensive risk assessments in a holistic and coherent manner; recognizes transboundary and cascading risks; and integrates equity by addressing structural inequalities, inclusion and unintended consequences.

Non-CO_2 greenhouse gases

- Non-CO_2 gases account for a quarter of global net anthropogenic GHG emissions; and in most current modelled pathways to limit global warming, non- CO_2 emissions are reduced by 20-85 per cent by 2050, whereas CH_4 emissions are reduced by 45 per cent, N_2O is reduced by 20 per cent and F-gases are reduced by 85 per cent.
- Limiting human-induced global warming and aligning with 1.5°C- 2°C pathways requires deep reductions in CO_2 and alongside non-CO_2 GHGs, such as CH_4.
- While non-CO_2 GHGs have a common label, they vary in accordance with sources, chemistry, abatement strategies, mitigation potential and costs of such. The common and major mitigation potential of non-CO_2 gases lies in coal, oil and gas and the agriculture sector.
- Mitigation of CH_4 emissions and other non-CO_2 GHG emissions can lead to significant co-benefits in human health, such as preventing premature deaths and respiratory diseases, and supporting terrestrial ecosystems' sustainability.

Negative emissions technologies including carbon dioxide removal

- Almost all current scenarios and pathways to limit warming to 1.5°C-2°C and closing the emissions gap include CDR options to either reduce emissions in the short-term to reach peak levels or reducing emissions after the peak period.
- According to the state of CDR, two Gt CO_2 is removed through CDR annually mainly through conventional methods such as conventional management of land while only 1 per cent is from novel methods such as bioenergy with carbon capture and storage and biochar.
- Current CDR technologies are limited to pilot and field tests, hence there is uncertainty related to upscaling, sustainability and climate risks, and gaps in understanding implications of at-scale solutions. Strategies exist to reduce the reliance on CDR, such as lifestyle changes and early steep emission reductions.

I. Transformational adaptation

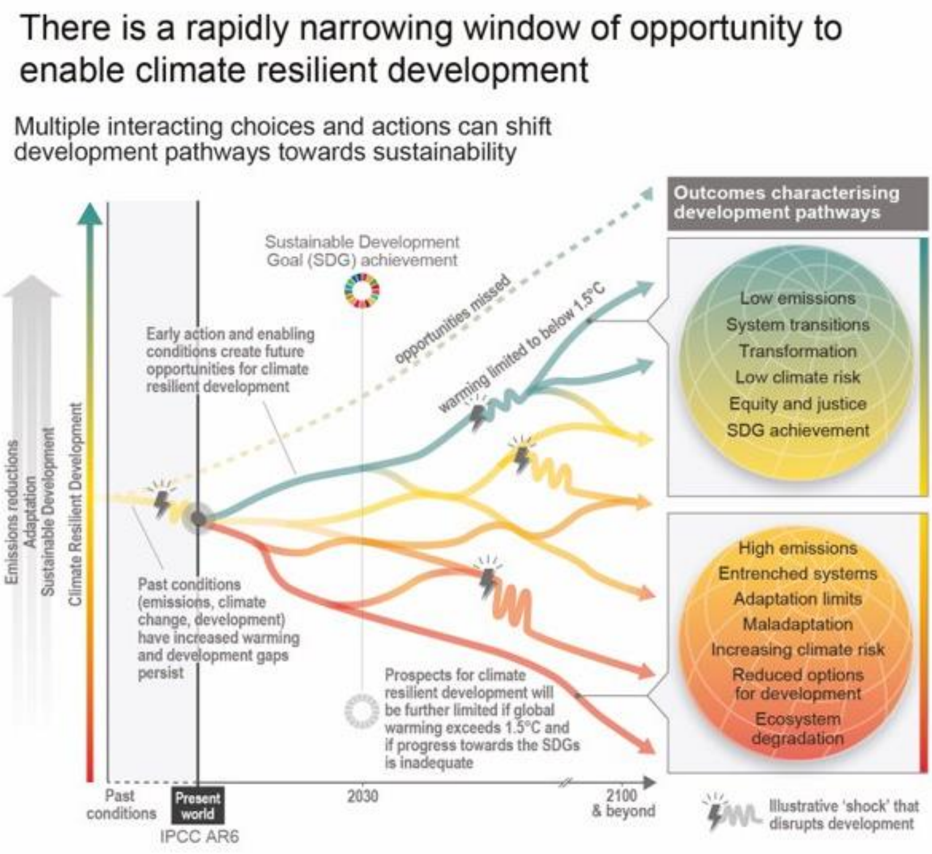
6. Presenters contributing were Katy Harris, Senior Policy Fellow at SEI, Lisa Schipper, Siri Eriksen, Debbie Ley, Henry Neufeldt and Christopher Trisos, IPCC Experts from WGII. Proceedings are summarized in this section. The RD webpage[5] contains the full the recording and presentations.

Transformational adaptation vis-à-vis incremental adaptation

7. Climate-resilient development, as reflected in the IPCC AR6, is a key framing concept in understanding transformational adaptation whose building blocks also encompass adaptation and mitigation efforts to advance the SDGs. Transformational adaptation refers to actions to adapt to the impacts of climate change, resulting in significant shifts in structure or function by going beyond adjusting existing practices. These actions must be adopted at a large scale and lead to new strategies, translate to deep and long-term societal changes and reconfiguration of social, economic and ecological systems, including values and world views. Participation of all is particularly central to advancing transformational adaptation, as opportunities for transforming systems are not equitable.

8. In comparison, incremental adaptation is defined as an activity that is added onto existing development and planning approaches and which maintains the essence and integrity of a system or process at a given scale. In selected cases, incremental adaptation can lead to transformational adaptation but may not independently be sufficient to drive urgent and transformation that is deep enough in the face of higher global warming levels as demonstrated in figure 1.

Figure 1: **Climate resilient development pathways**

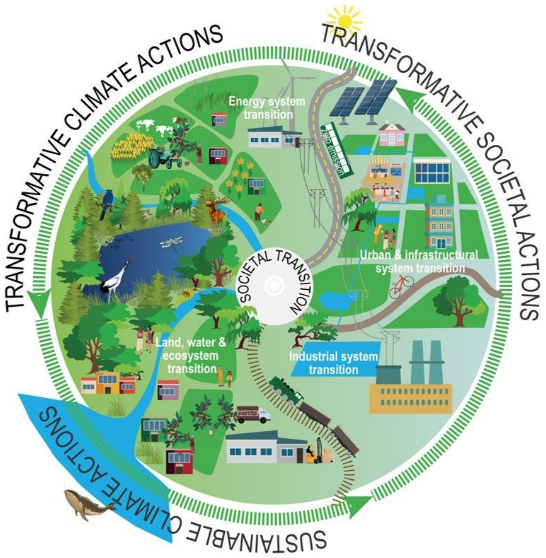


Source: Slide 2 of Lisa Schipper's presentation, IPCC AR6

9. Transformational adaptation requires societal choices that drive systems' transitions in the interdependent sectors of energy, urban, infrastructure and industrial systems, and land and water ecosystems, leading to whole-societal transition, as demonstrated in figure 2.

[5] See Research Dialogue 15 | UNFCCC

Figure 2: **Whole-societal transitions**



Source: Slide 4 of Lisa Schipper's presentation, IPCC AR6, WGII

10. A transformational approach to adaptation is critical, due to increasing global warming and entails changes to how adaptation is facilitated and such elements include: how to design, plan and implement interventions and how institutions take into consideration power relations, locally-led initiatives, trade-offs, risks and unexpected outcomes. Transformational adaptation therefore goes beyond financing and embraces knowledge pluralism, fosters bottom-up coalitions, and recognizes rights and justice considerations.

11. For example, building a seawall for coastal communities to prevent flooding could be considered incremental adaptation while transformational adaptation would require reviewing land-use regulations and a programme on management retreat. In a related instance, early warning systems while helping in planning for vulnerable groups, may only be accessible to and usable by people of a higher socio-economic status and hence not transformational.

Operationalising transformational adaptation: the three dimensions of transformational adaptation

12. The three dimensions of transformational adaptation comprise adaptation that is strategic, adaptation that is cross-scale and adaptation that is socially just.

13. The first dimension responds to climate change risks present in economies, societies, and ecosystems in a comprehensive way. It involves undertaking national risk assessments to understand all key sectors of the economy: such as how climate change affects health plans and strategies, trade relationships, agricultural goals, diplomatic relations and partnerships, investment portfolios, shared ecosystems, jobs and well-being. To achieve effective adaptation, institutional architectures need reforms to prioritize adaptation and coordinate policies, including a consideration of trade-offs and synergies, towards societal resilience. It also involves adaptation plans that are developed across sectors, beyond environment ministries to include ministries responsible for trade, agriculture, finance, social and foreign affairs, with the engagement of stakeholders, particularly risk owners. Further, this dimension considers adaptation actions that include and go beyond small-scale and timebound projects, aimed at managing risks across entire systems and sectors with adequate funding and support.

14. The second dimension of transformational adaptation implies adaptation that responds to complex transboundary and cascading risks that climate change presents, informed by national risk assessments that account for climate change impacts on development plans and strategies beyond a country's borders. To further understand this dimension, examples of such risks include a country's high level of food imports, heavy reliance on remittances from or foreign direct investments in climate-vulnerable regions and disruption of shared ecosystems. In this instance, regional bodies and organizations play a significant role in coordinating adaptation efforts between their members to build resilience to these cross-boundary and systemic risks.

15. The third dimension aims to tackle the root causes of vulnerability and inequality, particularly for marginalised groups. In this dimension, risk assessments therefore evaluate structural dynamics driving inequalities and power imbalances and adaptation projects that involve meaningful participation of the most

vulnerable and evaluates results based on their resilience, rights, and well-being. This dimension advances adaptation that builds “just resilience” and is cognizant of unintended consequences.

16. Examples of latest research and projects that take these dimensions into account include Horizon2020,[6] which considers the risks of cross-border and cascading climate change impacts in Europe, the global partnership Adaptation Without Borders,[7] and research conducted by SEI[8] which demonstrates that transformational adaptation reduces systemic risks and addresses inequalities. Further research is required around models to measure complex cross-border risks, how these are impacting various countries and exploring ownership and accountability mechanisms around the risks.

What are the main constraints and barriers for transformational adaptation, especially for small islands and developing states and the future research needs? To what extent does the lack of knowledge on transformational adaptation impede countries from adopting its approaches?

17. The IPCC recognises that there is considerable adaptation practice, however, most of it has not been documented systematically and therefore not collectively assessed. This also applies to challenges in documentation and knowledge gaps on maladaptation practices. It also highlights that lack of knowledge, information and technology constrain planning and implementation efforts to advance transformational adaptation. However, acknowledging the gaps should not impede the advancement of transformational adaptation. In the short term, it is vital to facilitate changes in attitude, promote locally-led adaptation and frame transformational adaptation as a global responsibility. In relation to research gaps, only 4 per cent of global climate-related research financing was dedicated to Africa and only 1 per cent to African institutions, which remains inadequate to identify risks and solutions.

Where is the intersection between transformational adaptation and mitigation for planners and implementers to note and what are the opportunities for transformational adaptation to have synergies with other objectives such as sustainable development?

18. Climate resilient development pathways illustrates the linkage of development and transformational adaptation, as transformational adaptation is conducted within the development process. Climate resilient development adopts a whole-society approach across scales and sectors; bringing synergy between the various sectors and thematic areas. In this process, facilitating systems transition also helps in identifying synergies and trade-offs, whereas trade-offs need to be minimised. There are opportunities in advancing adaptation in various sectors such as trade and supply chairs and the engagement of the private sector and all relevant stakeholders is key.

How can we evaluate the effectiveness and impact of transformational adaptation and what are the most relevant indicators to assess its progress?

19. While it is difficult to set one standard in assessing transformational adaptation, the outcomes should be linked to developmental results. Similarly, reducing climate risks should consider characteristics of the adaptation process such as participation, gender inclusion and cross-sectoral relations within the adaptation tracking framework. Sources of indicators can be obtained from multi-dimensional feasibility assessments; including those related to social, cultural and institutional dimensions that reflect communities’ expectations and perceptions.

What is the role of transformational adaptation in the context of loss and damage and what are the research needs in this area, particularly for the vulnerable regions such as small island states?

20. The ideal scenario is in continuing to advance climate resilient development pathways that limits warming and climate change impacts to minimize loss and damage and advances social transformation.

As lessons from countries demonstrates that EWS has drastically led to reduction in loss of lives, EWS should be considered as an example of actionable, operationalised large-scale adaptation.

21. The emphasis on strategies that are transformational lies in how the strategies are conducted and delivered, and the participation of relevant stakeholders. In essence, there is no list of incremental strategies versus transformational adaptation strategies. EWS as a transformational adaptation strategy should be coupled with effective response mechanisms.

How does limiting warming to 1.5°C support the achievement of transformational adaptation? How do nature-based adaptation approaches fit within the transformative adaptation concept, and the effectiveness of such approaches in the face of increasing warming?

[6] See https://www.cascades.eu/
[7] See https://adaptationwithoutborders.org/
[8] See https://www.sei.org/

22. It is important to recognise that warming above 1.5°C and especially 2°C, in many ecosystems such as coral reefs, forests wetlands and others such as peat land will reach adaptation limits and can no longer be reliable to facilitate adaptation and mitigation.

What is the existing research on systems transitions and system transformations and its synergy with food security?

23. There are considerable discussions on transformation of agri-food systems in the face of climate change. Recent experiences from global food crises demonstrate that we can anticipate fluctuations and instability in food systems due to climate change impacts in areas where key staples are grown, hence the resilience of production systems and supply chains is crucial.

Which regions have successful examples of transformational adaptation to support implementation in other countries?

24. In listing some experiences in transformational adaptation: Japan has engaged in river basin and flood management, moving from conventional methods to an integrated policy, which includes climate change impact assessment, and in the next steps will engage with private sector. From this experience, gaps remain in providing tailored flood-risk information for stakeholders.

What are information needs and research questions to improve our understanding of cross-border impacts; and how would diverse and transboundary ecosystems fit in the transformative agenda?

25. Lack of knowledge is a major risk to our understanding particularly of transboundary climate risks. Conceptual research is required to develop assessment methods and frameworks to identify, measure and monitor such risks. Empirical research is also required for countries to identify urgent risks for their action to address.

What is the role of international collaboration and multilateral processes in supporting transformational adaptation and ensuring that individual countries lessen the burden of implementation? How can transformational adaptation address fragmented nature of and promote a more integrated approach to adaptation?

26. Regional institutions such as the African Union and the EU in their latest climate change response strategies recognise the cross-border nature of climate risks and call for collaborative transformational action. Planning for adaptation through National Adaptation Plans (NAPs) should consider coordination and cooperation within and across countries and financial incentives for countries to collaborate and address transboundary risks.

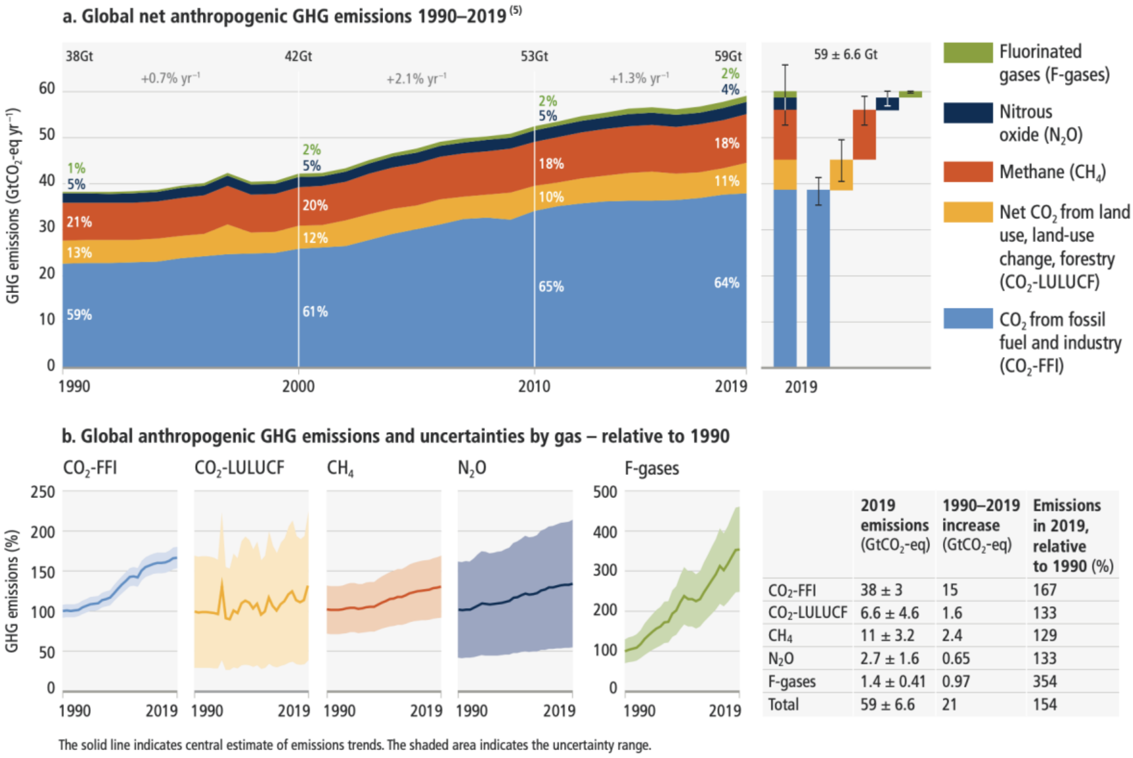
II. Non-CO_2 greenhouse gases

27. Presenters contributing were Joana Portugal-Pereira and Andy Reisinger, IPCC AR 6 WGIII. The proceedings are summarized here and visit the RD webpage[9] for a full recording and presentations.

28. Non-CO_2 gases account for approximately 25 per cent of global net anthropogenic GHG emissions and are key to limiting warming between 1.5°C and 2°C and reaching net zero emissions**.** While the increase in CO_2 emissions is well recognised, historical evolution of GHGs also reflects growing emissions from non-CO_2 gases. Of these gases, CH_4 has witnessed the second largest increase of emissions in absolute terms over time, and F-gases show the highest relative increase, as shown in figure 3, which also illustrates the contribution of CH_4 and other non- CO_2 gases towards global warming.

[9] See Research Dialogue 15 | UNFCCC

Figure 3: **Global net anthropogenic emissions**



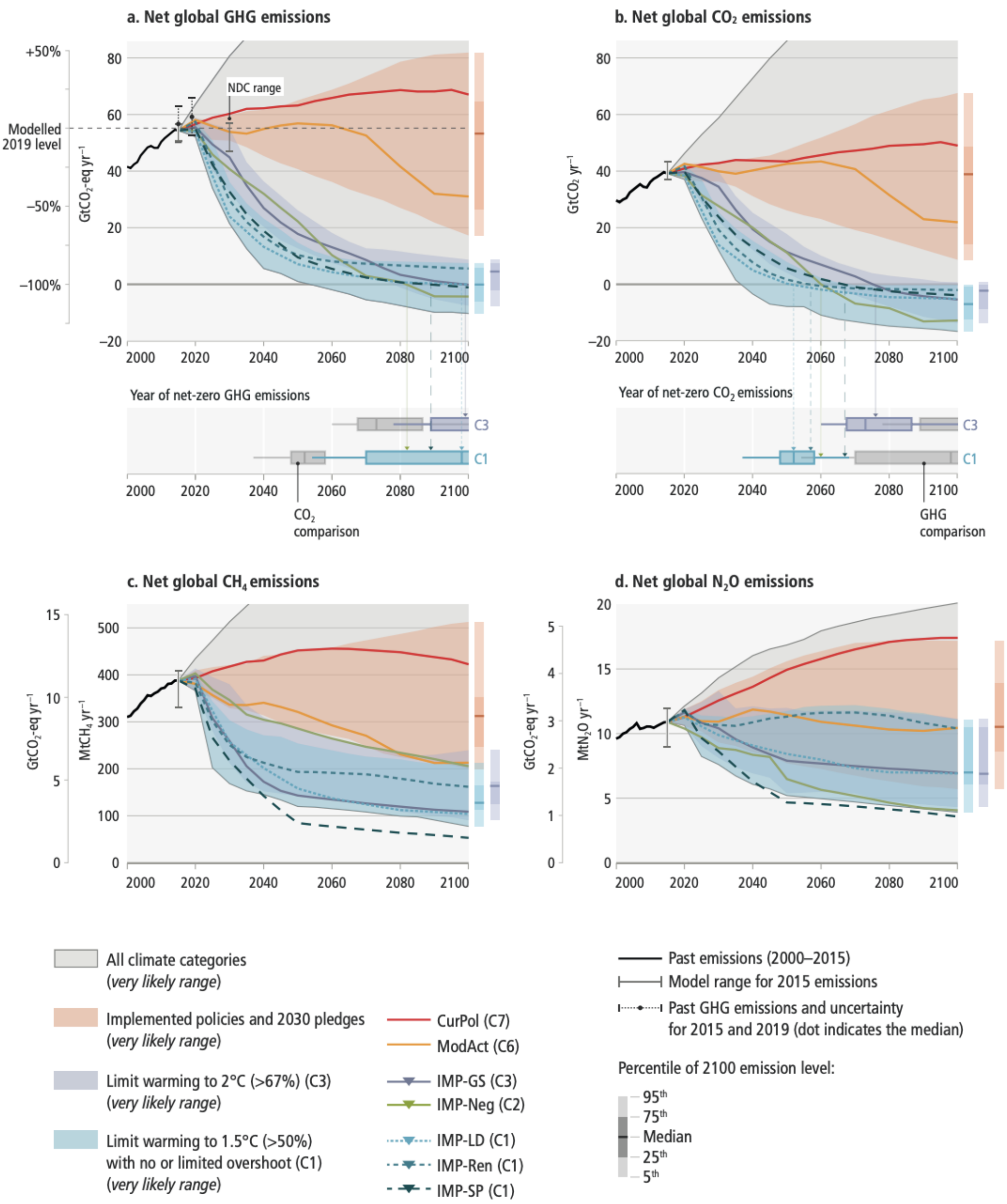
	2019 emissions (GtCO$_2$-eq)	1990–2019 increase (GtCO$_2$-eq)	Emissions in 2019, relative to 1990 (%)
CO$_2$-FFI	38 ± 3	15	167
CO$_2$-LULUCF	6.6 ± 4.6	1.6	133
CH$_4$	11 ± 3.2	2.4	129
N$_2$O	2.7 ± 1.6	0.65	133
F-gases	1.4 ± 0.41	0.97	354
Total	59 ± 6.6	21	154

Source: Joanna Portugal-Pereira presentation slide 2, IPCC WGI and WGIII AR6.

29. Limiting human caused global warming requires at-least net zero CO_2 emissions along with deep reduction of other GHG emissions such as CH_4. To reach net zero GHG emissions and consider limiting warming up to 1.5°C, it primarily requires, at the first stage, a sustained and deep reduction in CO_2, CH_4, and other GHG emissions implying net negative CO_2 emissions. Removals are also key to compensate residual emissions, as CDR is critical to reach net negative emissions. Long-term mitigation and emissions pathways to reach and sustain global net zero emissions proposes net zero CO_2 emissions by mid-century and thereafter, thus 2050 onwards, net zero GHG emissions. As there are presently no removal methods for non-CO_2 gases, achieving this target will require counterbalancing residual emissions with both CO_2 and non-CO_2 GHG gases and respective negative emissions.

30. In the IPCC AR6 WGIII, several mitigation pathways were designed to consider strategies and trajectories towards achieving the Paris Agreement goals by the end of the century. Across all of the modelled pathways, in 2050, CH_4 is reduced up to 45 per cent, N_2O is reduced by 20 per cent and F-gases, facing relatively the highest increase, are reduced by 85 per cent.

Figure 4: **Pathways for net global GHG emissions**



Source: Slide 5 of Joana Portugal Pereira presentation, IPCC AR6 SPM

31. Mitigation of CH_4 and other non-CO_2 GHG emissions provide significant synergies and co-benefits for attaining development goals and improving human well-being. Strategies, such as the reduction of CH_4 from coal, oil and gas and N_2O from agriculture have scored high levels of feasibility and demonstrated synergies between mitigation, adaptation and attaining SDGs. There are additional co-benefits of such strategies beyond climate action as listed in UNEP's Global CH_4 Assessment report: such as in health, particularly in preventing premature death (over 250,000 deaths) and reducing respiratory diseases and addressing crop losses in agriculture. Beyond the strategies listed herein, other mitigation approaches, such as reducing food loss and waste and increasing efficiency in buildings also have explicit benefits and translate to non-CO_2 emissions reduction. According to the current models, human caused CH_4 emissions could be reduced by 45 per cent by 2030 and improve overall human health and ecosystem sustainability.

32. Policies are required to limit non-CO_2 emissions and the IPCC AR6 WGIII report highlights such good examples. For instance, China has engaged in regulations and incentives to reduce CH_4 emissions from coal industries; cooling action plans to reduce hydrofluorocarbons (HFCs) in China and India; tradable quota for HFCs and inclusion of N_2O emissions, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride (NF_3) under emissions trading schemes in the EU; and improving industrial processes based on best available technologies. Some gases are already under regulation in relation to their production, import,

export and destruction, while others, mostly non-CO_2, gases are not and impact collective delivery of the Paris Agreement.

What is the importance and effectiveness of focusing on limiting non-CO2 mitigation to limit global warming to less than 1.5°C, and how does this change over time as we reach the temperature target including research needs? Would the emphasis on CH4 emissions reduction undermine the ambition of CO2 emissions reduction?

33. There is no trade-off between emission reduction on one GHG to the other as the modelled pathways used require stringent, continued and sustained, deep reductions of all GHGs. In essence, regardless of the metrics being used, a steady increase in GHGs will, in turn, contribute to global warming and urgent and deeper emissions reduction will delay peak warming and support the stabilization of global warming.

What is the link between CH4 and improved terrestrial ecosystem sustainability, and how can this be achieved?

34. CH_4 emissions reduction also reduces the potential of the production of ozone, thereby reducing global warming levels that are already affecting many regions. It also has direct correlation with increasing crop productivity or decreasing the chances of affecting the productivity of specific crops and improving sustainability of ecosystems.

Will emissions reduction of CH_4 and other non-CO_2 gases lead to food insecurity and how can developing nations, effectively balance their needs for economic growth and food security with drastically reducing the GHG emissions in line with the modelled pathways?

35. Available popular studies assume that there is a limit to how much CH_4 could be reduced without running into severe challenges for food security, hence CH_4 from agriculture tends to reduce at a lower rate than CH_4 from fossil fuel extraction and use. There are interventions, mainly focused on increasing the productivity of agricultural production systems, that would allow relatively low-cost interventions to reduce CH_4 but will achieve the same total rate of CH_4 emission reduction from fossil fuel extraction and use.

Where do hard to abate emissions come from and are they non-CO_2 emissions or a mix of CO_2 and non-CO_2 emissions?

36. Hard to abate emissions are largely from industrial processes and sectors, mainly chemical processes and agriculture sectors.

What are the differences among various mitigation pathways (1.5 and 2°C) and what are the opportunities to get onto a more ambitious 1.5°C pathway in terms of CH4 emissions reductions including research needs?

37. By 2050, there are no major differences in the pathways and the main difference lies in how urgently the actions to reduce CH_4, where feasible, are implemented. With this and in the near-term, pathways to limit warming to 1.5 degrees have more rapid reductions but based on available technological options, ending up with the same amount of reduction by 2050. There are some more systemic changes which are typically not modelled but remain as an assumption in modelled studies that could change the total abatement potential, however, since these raise wider questions on feasibility and consistency with development goals, the modelled reductions rely on existing technological options.

38. The F-gas reductions reported in the IPCC assessment are also based on the Kigali amendment and, if greater reductions are achieved, the resulting global heat warming could be lower and the peak warming would also be lower. A fundamental point is that the amount of warming is largely a result of the rate of emissions, therefore the higher the rate of emissions, the higher the amount of peak warming. Conversely, if net CO_2 emissions are achieved globally, then lower amounts of emissions would correspond to a lower amount of peak warming.

39. Australia highlighted efforts to address CH_4 emissions and will launch a dedicated Resource-CH_4 abatement fund to support research organisations to undertake development, prototype, verification and validation of projects. Japan also shared preliminary findings from a research study on reducing CH_4 and in relation with varying vegetation types and ecosystems under different management regimes. Further, Japan also highlighted research initiatives on reducing nitrogen load and use in food production systems,

particularly wheat, to reduce its impact on the environment and plans are underway to promote the seed-based technology.

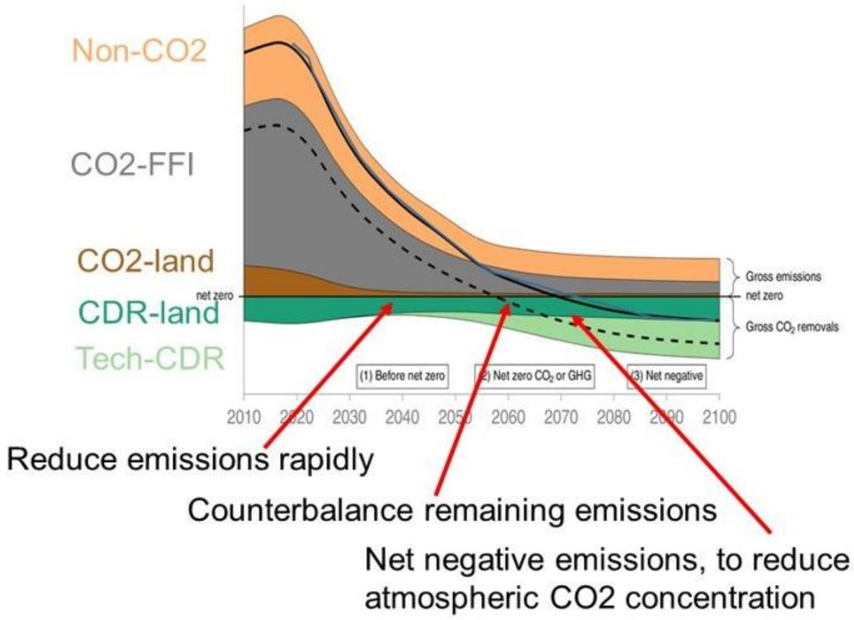
40. During the discussion, there was further interest on the implications of emission metrics choice on climate change policies, understanding safety issues in addressing CH_4 emissions, the role of volatile organic compounds and non-CO_2 mitigation potential across regions, countries and across sectors.

III. Negative emissions technologies, including carbon-dioxide removal

41. Presenters contributing were Oliver Geden and Detlef van Vuuren, lead authors of IPCC AR6 WGIII and Synthesis Report who introduced negative emissions technologies, including CDR, and Professor Hussein Hotein from King Abdullah University of Science and Technology who shared opportunities of CDR in Saudi Arabia. The proceedings are summarized in this section and full recording and presentations are accessible from the RD webpage[10].

42. CDR technologies are essential to reach mitigation targets and keep global temperature rise between 1.5-2^{0}C. CDR is defined in the IPCC WGIII report as anthropogenic activities that remove CO_2 from the atmosphere and durably store it in geological, terrestrial, or ocean reservoirs, or in products, but excludes natural CO_2 uptake. CDR is particularly essential to close the emissions gap of approximately 3000 Gt CO_2 and to maintain a less than 2°C temperature rise. Obstacles to closing the gap and warranting CDR include an insufficient carbon budget of 400-500 Gt CO_2, hard-to-abate CO_2 emissions and persistent emissions from sectors that are unable to reach net zero CO_2 emissions. CDR could, therefore, play an important role with respect to all three conditions, by reducing emissions in the short-term to reach the peak level, counterbalancing remaining emissions, as well as reducing emissions after the peak period, as demonstrated in figure 5.

Figure 5: **Climate Scenarios with CDR**

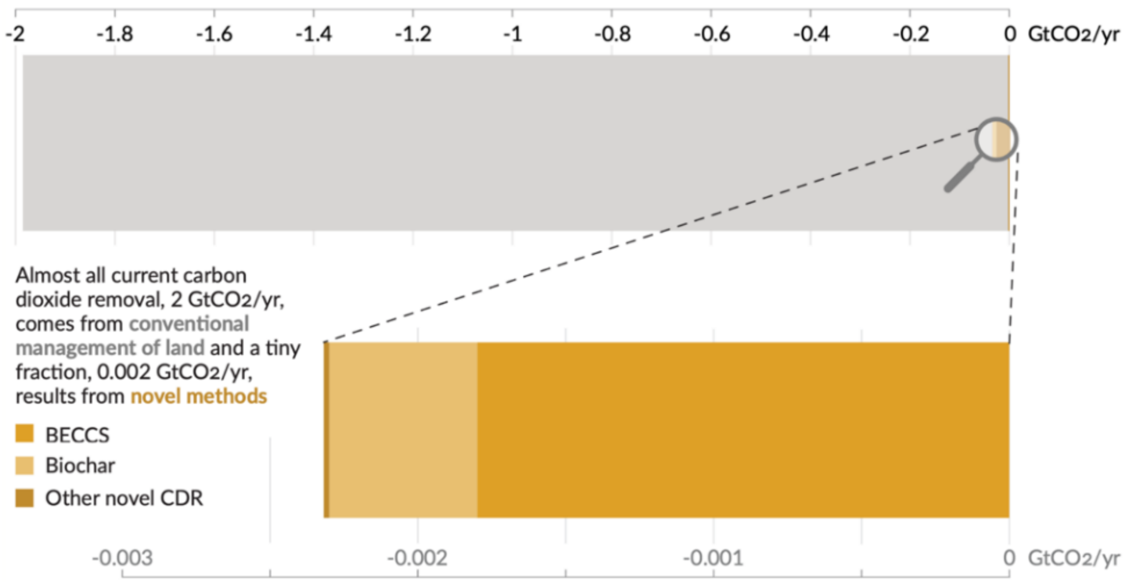


Source: Slide three of Oliver Geden's presentation, Climate Scenarios with CDR

43. According to the State of Carbon Dioxide Removal report, approximately two (2) $GtCO_2$ gross, is removed by CDR per year from conventional management of land, such as reforestation and afforestation, and only 0.1 per cent results from novel methods, including BECCS, biochar, ocean-based CCS methods and others. The IPCC identified different scenarios in relation to the use of CDR- reducing emissions to net zero, such as relying on negative emissions, renewables and combining mitigation strategies and sustainable development.

[10] See Research Dialogue 15 | UNFCCC

Figure 6: **State of CDR**

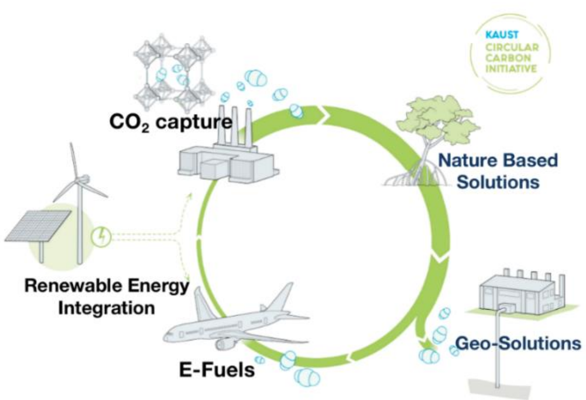


Source: Slide six of Oliver Geden's presentation, The State of CDR

44. There are recent developments around the evolving mechanism of CDR, particularly under methods and pathways, governance arrangements where considerable stress has been placed on regulation, innovation, and achieving negative emissions. There is also interest and progress around certification and accounting, and advances in international cooperation on innovation of novel methods, as demonstrated by the EU, UK, US, Saudi Arabia and others. Selected countries are also exploring targeted incentives, such as Sweden and the U.S. Further, countries have set negative emission targets, such as Denmark's target of 110 per cent emissions reduction by 2050, and such targets and examples are significant for global pathways that will require collective emissions reduction and novel technologies.

45. A presentation on the Circular Carbon Initiative (CCI) of Saudi Arabia was shared to demonstrate examples of CDR initiatives aimed at net-zero emissions by 2060 in accordance with national plans. Broadly, the initiative is a cumulation of multiple thrusts on CDR, including CO_2 capture technologies, nature-based solutions, geo-based solutions, electro-fuels such as hydrogen and ammonium and cross-cutting solutions that integrate renewable energy. The initiative maps global nature-based solutions' resources and their potential, assesses carbon removal capacity of the Saudi Arabian ecosystems, quantifies carbon storage and removal rates in various ecosystems and explores enhancement strategies such as microbial activity. Geo-based solutions under the initiative focus on developing a geological storage atlas for Saudi Arabia, which includes data on emissions from various sources and assessing the capacity, feasibility and readiness of various technologies and solutions on CCS.

Figure 7: **Features of the Carbon Capture Initiative (CCI)**



Source: Slide of Professor Hussein Hoteit, the Carbon Capture Initiative

46. CCI also focuses on CO_2 mineralization in basalts and mafic rocks, which are mineral-rich and facilitate carbon mineralisation, a natural entrapment of CO_2. The technology has also been piloted in the

U.S. and Iceland. In Saudi Arabia, the initiative is particularly working on carbon mineralisation in basalt, which is abundant on the western side of the country and along the red sea; and will also include additional experiments, modelling, and field trials.

47. There are multiple common challenges in research and development and field deployment of CDR faced across the globe. The major challenges include the lack of reliable and vetted data, difficulty of streamlining efforts of academia, industry and government agencies, as well as international collaboration. In terms of field deployment, challenges exist in policy gaps in addressing risk assessments, particularly for untested technologies, management and monitoring within and across borders, responsibility for short- and long-term liability, mitigation plans and licensing and permits.

48. Associated risks with CDR also relate to sustainability; for example, where technologies on CCS could compete for land use with food production and reforestation efforts and climate risks from overshoot. These risks vary in accordance with volume and geographic placement; hence calling for further research and development of the technologies. There are also recommended strategies to reduce reliance on CDR, and reduce exposure to such risks, including lifestyle changes and early, steep emissions reduction.

As the overall cost of CCS remains on the increase, what are the three largest cost components and overall challenges to be addressed to make technologies cost-effective and scalable? What are associated costs, of energy and water use, for one ton of capture and storage of CO_2?

49. CCS technology is relatively costly, unless combined with other technologies such as geothermal, as demonstrated in Iceland. The current estimates stand at 20-30 US dollars per ton, of which capture processes alone represent up to 70 per cent to 80 per cent of the total cost. Currently, a ton of CO_2 requires approximately 25-35 tons of water, depending on the salinity levels of the water and there is ongoing research on use of saline water. The technology has currently only been demonstrated at pilot scale and small field scale with no references to major scale, up to gigatonne levels, translating to a lack of understanding of risks and challenges related to scaling up, such as leakage.

CDR technologies may be misused to compensate for avoidable and delay immediate emissions reduction. How does the potential of immediate emissions reduction including the realization of overall energy transition compare with the deployment of negative emissions technologies?

50. It is emphasized that CDR is additional to and not a replacement for mitigation in addressing emissions reductions. Mitigation measures stand as the main avenue to reach climate goals, and CDR can be additional to these efforts. CDR related risks and sustainability are valid concerns but can be mostly overcome with countermeasures such as consideration of food security implications. The IPCC also lists alternative holistic mitigation pathways that demonstrate means to limit CDR use, such as low consumption levels.

Are other novel CDR methods beside Direct Air Carbon Dioxide Capture and Storage (DACCS) and BECCS considered in climate scenarios and what are the implications of pathways that consider varying CDR technologies including potential future effects? How will global warming affect the potential of ecosystem-based CDR methodologies?

51. Afforestation and reforestation are also widely considered, besides BECCS and DACCS; however, there are reporting and methodology variations such as only providing the net-flux which are lower in some methods. The State of Carbon Dioxide Removal report utilised data and methodologies from IPCC AR6 WGIII's database in gross numbers.

52. Further, carbon removed from soil and vegetation are prone to reversals and according to the current models, CDR from afforestation and reforestation will continue to rise, levelling in 2050 and from then on CDR will mainly be contributed by applying novel technologies.

How large are the existing capture rates for different applications of CDR and what are the scenarios in understanding the risks, potential and needs to limit warming to 1.5 per cent with varying CDR considerations?

53. There are knowledge and observational gaps for establishing realistic potential and verification on the long-term sustainability in relation to CDR, hence the need for further research remains critical including estimating costs for such. In the matter of scalability, the technology has not been demonstrated at a large scale and there is a lack of understanding of risks related to its application at scale.

Abbreviations and acronyms

AR	IPCC Assessment Report	**SDGs**	Sustainable Development Goals
AU	African Union	**SEI**	Stockholm Environment Institute
BECCS	Bio-energy with carbon capture and storage	**SH_6**	sulphur hexafluoride
CCS	Carbon Capture and Storage	**SPM**	Summary for Policymakers
CDR	Carbon Dioxide Removal	**UK**	United Kingdom
CH_4	Methane	**UNFCCC**	United Nations Framework Convention on Climate Change
CO_2	Carbon Dioxide	**US**	United States of America
DACCS	Direct Air Carbon Dioxide Capture and Storage	**WG**	IPCC Working Group
EU	European Union	**Yr**	Year
EWS	Early Warning System		
F-Gases	Fluorinated gases		
GHG	Greenhouse Gase		
$GtCO_2$	Gigaton Carbon Dioxide		
IMP	Illustrative Mitigation Emission Pathways		
IPCC	Intergovernmental Panel on Climate Change		
LDCs	Least Developed Countries		
NF_3	Nitrogen trifluoride		
N_2O	Nitrous Oxide		
PFC	Perfluorocarbons		
SBSTA	Subsidiary Body for Science and Technological Advice		