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In-session technical workshop on findings on emission metrics contained in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

Technical report by the secretariat

Summary

This technical report provides a summary of the in-session technical workshop on findings on emission metrics contained in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, which was held on 7 June 2023 during the fifty-eighth session of the Subsidiary Body for Scientific and Technological Advice. At the workshop, representatives of Intergovernmental Panel on Climate Change Working Groups I and III provided information on the key findings on emission metrics and participants from Parties shared views on experience with and open questions about the applications of emission metrics.

Abbreviations and acronyms

AFOLU	agriculture, forestry and other land use
AR	Assessment Report of the Intergovernmental Panel on Climate Change
CGTP	combined global temperature change potential
CH_4	methane
CO_2	carbon dioxide
GHG	greenhouse gas
GTP	global temperature change potential
GWP	global warming potential
GWP*	quantity that combines the pulse (emissions) and step (changes in emission levels) approaches
IPCC	Intergovernmental Panel on Climate Change
N_2O	nitrous oxide
SBSTA	Subsidiary Body for Scientific and Technological Advice

I. Introduction

A. Mandate

1. SBSTA 30 initiated consideration of common metrics to calculate the CO_2 equivalence of anthropogenic GHG emissions by sources and removals by sinks.

2. SBSTA 57 invited the IPCC to present the findings on emission metrics contained in the AR6 at an in-session technical workshop at SBSTA 58 and requested the secretariat to prepare a technical report as an outcome of that workshop.[1]

3. The SBSTA agreed to continue consideration of common metrics at SBSTA 66.[2]

B. Scope of the note

4. This technical report contains information on the proceedings of and discussions during the workshop referred to in paragraph 2 above. It may be used to inform the continued consideration at SBSTA 66 of common metrics under the agenda item on methodological issues under the Convention.

II. Proceedings

5. The technical workshop was organized by a scientific steering committee on behalf of the IPCC, which comprised IPCC bureau members and representatives of the IPCC, with the support of the secretariat and held on 7 June 2023 during SBSTA 58. Harry Vreuls, the SBSTA Chair, opened the workshop and highlighted its importance as a step forward in providing the latest scientific information for the consideration of common metrics under the Convention and fostering dialogue between the scientific community and Parties, which will facilitate the continued consideration of this matter under the SBSTA, recognizing its relevance to climate change policies. The SBSTA Chair underlined that the workshop would provide the scientific community with insights into research needs for the work of the IPCC on emission metrics for the AR7.

6. Hoesung Lee, the IPCC Chair, in his address to participants highlighted the priority objectives of the workshop as disseminating the key findings on emission metrics contained in the AR6, presenting the best available science as assessed by the IPCC and identifying the benefits and shortcomings of the use of different metrics. The IPCC Chair noted that metrics continued to play a crucial role as quantitative measures in the cause and effect chain from emissions to climate change and are widely used to quantify the equivalence between CO_2 emissions and emissions of other gases. He underlined that this equivalence can relate to various consequences of emissions, including climate forcing, temperature change and other climate impacts, as well as to mitigation or damage costs over time.

7. The IPCC Chair emphasized that representatives of IPCC Working Groups I and III would present during the workshop the key issues related to emission metrics, such as the existing types and uses, uncertainties and gaps in current understanding. He indicated that experts would elaborate on the different types of metric, including purely physical metrics and more comprehensive metrics that account for both physical and economic dimensions of the climate change challenge.

8. The IPCC Chair underlined that the workshop was an excellent opportunity to establish a better understanding of what Parties consider to be relevant information concerning emission metrics for the UNFCCC process, including possible limitations or shortcomings that deserve further consideration by the scientific community, which would contribute to the identification of research needs and increase of scientific knowledge on

[1] FCCC/SBSTA/2022/10, para. 69.
[2] FCCC/SBSTA/2022/10, para. 70.

emission metrics, which will in turn be assessed in the AR7. Finally, the IPCC Chair invited Thelma Krug, IPCC Vice-Chair, to moderate the workshop on his behalf.

9. The workshop was divided into five parts. Representatives of the IPCC and the secretariat made presentations during the relevant parts of the workshop.[3] In the first part, the secretariat made an introductory presentation covering a brief history of the consideration of common metrics under the UNFCCC and presenting the mandate for and scope of the workshop. In the second part, representatives of the IPCC presented an overview of the scientific evolution of emission metrics from the AR1 to the AR6, the key issues related to the choice of different emission metrics and their relationship to net zero GHG emissions, and an introduction to the assessments of emission metrics in the contributions of Working Groups I[4] and III[5] to the AR6. The presentation was given by Jan Fuglestvedt, IPCC Working Group I Vice-Chair, co-authored by Andy Reisinger, IPCC Working Group III Vice-Chair, and Diriba Korecha Dadi, IPCC Working Group III Vice-Chair.

10. The third part of the workshop consisted of two presentations, the first introducing the findings on emission metrics of Working Group I, covering the physical assessment of metrics, and the second the findings on emission metrics of Working Group III. The first presentation was given by William Collins, lead author of chapter 7 of the contribution of Working Group I to the AR6, co-authored by David Frame, lead author of chapter 7 of the contribution of Working Group I to the AR6. The second presentation was given by Andy Reisinger, IPCC Working Group III Vice-Chair. A question and answer panel session followed, where representatives of Working Groups I and III answered questions from participants and clarified relevant aspects of the IPCC findings on emission metrics.

11. The fourth part of the workshop comprised presentations by representatives of the scientific community, addressing additional perspectives on the findings in the AR6 on GHG emission metrics that were outside the mandate for and scope of the workshop given by the SBSTA and are, as such, not reflected in this technical report. The fifth part of the workshop comprised an open floor discussion among participants on experience and open questions from users on the applications of emission metrics. The discussion was facilitated by Thelma Krug and Youba Sokona, the IPCC Vice-Chairs.

12. At the end of the workshop, Valerie Masson-Delmotte, IPCC Working Group I Co-Chair, and Jim Skea, IPCC Working Group III Co-Chair, provided concluding remarks. The former highlighted that the AR6 provides an assessment of emission metrics based on physical understanding and that scientific evidence informs decision-making grounded in physical understanding. She referred to new dimensions in this understanding, such as the consequences of CH_4 emissions as a precursor of ozone formation and its implications for health and plant growth, and the consequences of CO_2 emissions for ocean acidification and its implications for marine life fisheries, including irreversible consequences for the deep ocean. These new dimensions are not fully covered in the assessments in terms of purely mitigation cost-effectiveness, and advances in science are needed in these fields. She highlighted the importance of the workshop for providing informing on the use of metrics depending on purpose and context, and for identifying the knowledge advances required to inform decision-making.

13. The Working Group III Co-Chair highlighted the policy relevance of this topic and that interaction between science and policy has led to convergence on the use of 100-year time-horizon GWP values, as evidenced in the procedural and scientific reasons presented during the workshop on why Working Group III decided to use 100-year time-horizon GWP

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[3] The presentations are available at https://unfccc.int/event/ipcc-in-session-technical-workshop-on-findings-on-emission-metrics-contained-in-its-sixth-assessment.

[4] IPCC. 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. V Masson-Delmotte, P Zhai, A Pirani, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg1/.

[5] IPCC. 2022. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. P Shukla, J Skea, R Slade, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg3/.

values in its contribution to the AR6 and used in the most recently adopted decision on common metrics.[6] He recalled that other metrics may be used in addition to GWP, with a clear line of sight to underlying IPCC assessment reports. He stressed that the report on the current workshop will be read not only by policymakers but also by the scientists who will be producing the papers that the IPCC will consider in future assessment cycles.

14. The SBSTA Chair provided closing remarks, thanking the IPCC experts for making a significant effort to bring and successfully summarize their assessment of emission metrics as contained in the contributions of Working Groups I and III to the AR6. He highlighted that the workshop was a very important step forward in providing information for the future consideration of common metrics under the Convention and promoting a space for Parties and the scientific community to exchange views and identify research needs on this topic, including in relation to key issues such as the choice of emission metrics and their relationship to net zero GHG emissions.

III. Presentations and discussions

A. Overview of greenhouse gas emission metrics in Intergovernmental Panel on Climate Change assessment reports

15. The IPCC representative introduced the work on emission metrics since the AR1 in 1990. In that report it was indicated that no universally accepted methodology for combining all the relevant factors into a single metric was available and a simple approach (that is, GWP) had been adopted to illustrate the difficulties inherent in the concept. GWP considers pulse emissions of individual gases and integrates the radiative forcing up to a chosen time-horizon. The AR1 presented three time-horizons (20, 100 and 500 years) as candidates for discussion that should not be considered as having any special significance. A few years later, 100 years was chosen as the time-horizon to be used under the Kyoto Protocol. In 2007, the AR4 stated that GWP remained the recommended metric to compare future climate impacts of emissions of long-lived gases, despite several known shortcomings. However, the IPCC expert meeting on the science of alternative metrics in 2009, among its key conclusions and recommendations, indicated that the effectiveness of the use of a given metric depends on the primary policy goal and that GWP was not designed with a particular policy goal in mind. Depending on the specific policy goal or goals, alternative metrics may be preferable.

16. The AR5 indicated that the most appropriate metric and time-horizon will depend on which aspects of climate change are considered most important to a particular application. No single metric can accurately compare all consequences of different emissions, and all have limitations and uncertainties. In that report, a new metric, namely GTP, was reflected, which considers the temperature response for the chosen time-horizon. The values of this metric also depend on the time-horizon. CO_2 has a very long response time in the climate system, and, when using a time-horizon of 100 years, the long tail of response from CO_2 is lost, which is one of the challenges when short-lived gases are compared with long-lived gases like CO_2. In the AR5, Working Group III considered emission metrics and provided a conceptual overview of and links between physical metrics, like GWP and GTP, and global damage potential and global cost potential, relating physical aspects of metrics to economic aspects.

17. The values of GWP and other metrics change between IPCC assessments, because there are updates to the direct radiative forcing of the gases under consideration and the reference gas CO_2, as well as improvements in understanding of physical aspects. Changes in background concentrations affect both the lifetime and the radiative forcing and the behaviour of the gases in the atmosphere. Lifetime changes can be due to new knowledge or physical changes in the system, and the response time of the reference gas CO_2. Also, the indirect effects of the emission of gases are updated. For instance, CH_4 has several indirect effects through chemical processes in the atmosphere and through climate–carbon cycle

[6] Decision 7/CP.27.

feedbacks (increased temperatures resulting from the emissions of a non-CO_2 gas may affect the carbon cycle, which results in further warming).

18. In the sixth assessment cycle, metrics were discussed briefly in the IPCC Special Report on Global Warming of 1.5 °C,[7] in the contribution of Working Group I to the AR6 and its supplementary material, and in the contribution of Working Group III to the AR6 and its supplementary material. Both contributions include assessment of new metric concepts. Recognizing that all metrics have shortcomings and limitations, an effort was made in the sixth assessment cycle to provide information by gas wherever possible.

19. The common glossary of the AR6, which harmonized concepts across the Working Groups, defined emission metrics as a simplified relationship used to quantify the effect of emitting a unit mass of a given GHG on a specified key measure of climate change. A relative GHG emission metric expresses the effect from one gas relative to the effect of emitting a unit mass of a reference GHG on the same measure of climate change. The definition indicated that there are multiple emission metrics and the choice of the most appropriate metric depends on the application. Emission metrics may differ with respect to the key measure of climate change they consider (e.g. radiative forcing, temperature or precipitation); whether they consider climate outcomes for a specified time point in time or integrated over a specified time-horizon; the time-horizon over which the metric is applied; whether they apply to a single emission pulse, emissions sustained over a time period or a combination of both; and whether they consider the climate effect from an emission compared with the absence of that emission or compared with a reference emission level or climate state.

20. A note in the common glossary emphasizes that a metric that establishes equivalence regarding one key measure of the climate system response to emissions does not imply equivalence regarding other key measures, and that the choice of metric, including its time-horizon, should reflect the policy objectives for which the metric is applied.

21. Regarding how emission metrics relate to the concept of net zero GHG emissions, the AR6 defines net zero GHG emissions as a condition in which metric-weighted anthropogenic GHG emissions are balanced by metric-weighted anthropogenic GHG removals over a specified period. The quantification of net zero GHG emissions depends on the emission metric chosen to compare emissions and removals of different gases, as well as the time-horizon chosen for that metric. The quantification of net zero GHG emissions is therefore dependent on the metric used, and the choice of metric will have an impact on when net zero is achieved and the temperature response to net zero GHG emissions.

B. Key findings on emission metrics in the Sixth Assessment Report

1. Working Group I perspective

22. The representative of Working Group I indicated that the key messages contained in the Summary for Policymakers of the contribution of Working Group I to the AR6[8] mainly focus on the net zero implications. In the Summary for Policymakers it is stated that limiting warming requires at least net zero CO_2 emissions and strong reductions in other GHG emissions. Emissions of non-CO_2 gases do not have to be zero, but limited or declining emissions of non-CO_2 gases would be sufficient to limit human-induced warming. It is also stated that the emission metric used to define net zero affects when aggregated GHG emissions are calculated to be net zero. It is important to note that when 100-year time-

[7] IPCC. 2018. *IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. V Masson-Delmotte, P Zhai, H-O Pörtner, et al. (eds.). Geneva: World Meteorological Organization. Available at https://www.ipcc.ch/sr15/.

[8] IPCC. 2021. Summary for Policymakers. *In*: V Masson-Delmotte, P Zhai, A Pirani, et al. (eds.). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg1/.

horizon GWP is used to define net zero, provided that CO_2 is mitigated more strongly than CH_4, this leads to a declining surface temperature.

23. The Technical Summary of the contribution of Working Group I to the AR6[9] provides a few messages on new emission metrics (e.g. GWP*). The underlying physics of these new metrics is based on the concept that warming is proportional to the cumulative emissions of CO_2, while warming from short-lived gases is related to their rate of emissions. Therefore, to convert emissions of short-lived gases into cumulative emissions of CO_2, the emission rate of short-lived species can be used to quantify the warming response of these short-lived species. In contrast, when using standard metrics, such as GWP or GTP, to convert emissions of short-lived species to cumulative CO_2 equivalent emissions, these cumulative emissions are not necessarily related to the future warming. When the new metrics such as GWP* are used to quantify net zero emissions, this leads to an approximate temperature stabilization, rather than a temperature decline as with 100-year time-horizon GWP.

24. GWP values change in each IPCC assessment report because of changes in the background concentration of CO_2, which generally increases the relative effect of non-CO_2 gases, updates in the understanding of the physical effects of radiative forcing, new understanding of the chemical effects, particularly effects on ozone and stratospheric water vapour, and new assessments of the budgets for CH_4 and N_2O, leading to decreases in their estimated lifetimes. Overall, the GWP value for CH_4 decreased slightly in the AR6, whereas the value for N_2O stayed more or less the same, compared with the values in the AR5. The presenter stressed the uncertainties in these metrics (in the order of 40 per cent) and that changes in the GWP values across the IPCC assessment reports lie within the uncertainties for this metric.

25. Metrics have to take into consideration the response of the carbon cycle to emissions. The decay rate of CO_2 that has been used for the last two IPCC Assessment Reports is based on a multi-model assessment that included the impacts of the carbon cycle and temperature response to CO_2 emissions. Hence, carbon cycle responses also need to be considered for emissions of non-CO_2 gases, given that the carbon cycle response affects both the numerator and denominator of the calculation of GWP. In the AR6, the carbon cycle response to non-CO_2 species is included by default, and the treatment of carbon cycle responses is more robust than in the AR5.

26. Regarding GWP values for fossil versus non-fossil CH_4, the non-fossil value is used when the carbon contained in CH_4 is already accounted for elsewhere in the system, and the fossil value is used if the carbon is not accounted for elsewhere in the system. The presenter illustrated the consistency of these different approaches to dealing with fossil CH_4 emissions.

27. The new emission metrics discussed in the AR6 are based on the idea that the climate impact of a step change in the rate of CH_4 emissions behaves similarly to the climate impact of a one-off pulse emission of CO_2. One of the new metrics discussed is CGTP, which relates to a step change in CH_4 emissions over a given time period with a one-off emission pulse of CO_2. Another new metric is GWP*, which is a combination of the pulse and step approach. For a scenario of roughly constant change (step change) in CH_4 emissions over a 100-year timescale, use of all three metrics (100-year time-horizon GWP, CGTP and GWP*) leads to approximately the same result. Therefore, using 100-year time-horizon GWP is not inconsistent in such a case.

28. In a scenario of CH_4 emissions constantly increasing, whether using 100-year time-horizon GWP, CGTP or GWP*, they all roughly correlate on the warming caused by CH_4. In a scenario of emissions decreasing, for instance after mid-century in a mitigation scenario, 100-year time-horizon GWP does not track declining warming due to CH_4 but suggests that the warming contribution of CH_4 increases. This contrasts with new metrics like GWP*, which do correlate with the decline in warming due to CH_4.

[9] IPCC. 2021. Technical Summary. *In*: V Masson-Delmotte, P Zhai, A Pirani, et al. (eds.). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg1/#TS.

29. When GWP is used to define net zero GHG emissions, it results in a decline of surface temperature; whereas, if GWP* is used to define net zero GHG emissions, this leads to roughly constant temperature. However, it would be possible to use new metrics to provide a specific decline in temperature, whereas the rate of this decline when using 100-year time-horizon GWP depends on the balance of CO_2 and CH_4 mitigation.

30. The assessment of Working Group I focuses on the physical science and does not address equity or fairness, as that will be a function of the use of the metric, rather than of the physics of the metrics.

31. The presenter summarized that metrics have been updated since the AR5 and account more robustly for carbon cycle responses. The key result contained in the Summary for Policymakers is that, if 100-year time-horizon GWP is used to define net zero GHG emissions, this could lead to declining temperatures. If new metrics (GWP* or CGTP) are used to define net zero GHG emissions, they would lead to approximately stable temperatures, and, for this, gradually declining CH_4 emissions are sufficient. The presenter emphasized the uncertainties in all metrics and that reporting long- and short-lived gases separately would allow much more transparency in the ultimate quantification of temperature projections and net zero GHG emission calculations.

2. Working Group III perspective

32. The representative of Working Group III presented on the performance of metrics with regard to cost–benefit and cost-effectiveness approaches to mitigation, the use of metrics in life cycle assessment, key differences in recent applications of step change and pulse metrics, the interaction between net zero emission targets and different metrics, and use of 100-year time-horizon GWP in the contribution of Working Group III to the AR6.

33. The presenter indicated that approaching mitigation from a cost–benefit perspective implies weighting each emission based on the economic damages that it will cause over time, or conversely the damages avoided by avoiding that emission. This approach relies on the damage function and discount rate. A key conclusion in the AR6 is that GWP is conceptually consistent with a cost–benefit approach to mitigation. GTP, which only considers a particular endpoint in time, does not reflect a cost–benefit framework. More importantly, work has been undertaken to link the time-horizon of GWP to the discount rate that reflects how much value is placed on near-term versus longer-term damages, which concluded that 100-year time-horizon GWP is consistent with a discount rate of 3–5 per cent across a wide range of different damage functions, whereas 20-year time-horizon GWP would imply a discount rate of more than 10 per cent. This information does not help to identify which time-horizon or discount rate to use, but can inform the internal consistency of how climate change mitigation is approached.

34. A cost-effectiveness approach to mitigation would weight each emission based on the contribution of that emission to temperature in the year that a specified temperature target or limit is reached. This can be used to inform least-cost abatement choices for achieving a given temperature target or limit. A cost-effectiveness approach inherently requires the metric values to change over time because the value of abating short-lived climate forcers changes as the target is approached.

35. A key conclusion is that dynamic GTP is conceptually consistent with a cost-effectiveness approach to mitigation. Dynamic GTP means that the time-horizon is aligned with the target year, when global temperature is expected to peak on an intended mitigation pathway. For example, purely hypothetically, if peak warming is expected to occur in 2070, dynamic GTP would use 40-year time-horizon GTP emissions in 2030, but 30-year time-horizon GTP emissions in 2040, and 20-year time-horizon GTP emissions in 2050. GTP and GWP with fixed time-horizons are not conceptually consistent with a cost–benefit framework because they always give the same weighting to emissions no matter how close the intended target is.

36. A second key finding is that, despite GWP not being designed or matching a cost-effectiveness framework, in modelled mitigation pathways of limiting warming to 2 °C (with a chance of more than 67 per cent) and lower, if they are informed by 100-year time-horizon GWP, they are quite close to least global cost within a few per cent. The use of dynamic GTP

could reduce these global mitigation costs by a few per cent at the global scale, but this very much depends on the temperature limits on the policy foresight and the flexibility in abatement choices, that is the extent to which decisions on mitigation can actually respond to the rapidly changing weighting that would be given to CH_4 under dynamic GTP.

37. With regard to why 100-year time-horizon GWP performs relatively well in terms of global cost-effectiveness even though it is not designed for this, there are two strands to the answer. The numerical metric values are not too different for temperature limits of 2 °C and below. 100-year time-horizon GWP and dynamic GTP for the next few decades are at the same order of magnitude. The other strand is the shape of the marginal abatement cost curve, which implies that there is a large amount of CH_4 that can be abated at relatively low cost, and there is some CH_4 that will not be abated, even at very high cost, especially in agriculture. Therefore, in the mid-range, most of the CH_4 will be abated and it does not matter so much precisely which metric value is used.

38. The presenter indicated that life cycle assessment using different metric values can pose a real problem. The justification of the use of different metrics is challenging because life cycle assessment often does not have a single clear policy objective, yet one of the core principles is that the metric has to match the policy goal. One of the conclusions from the literature is that one can conduct sensitivity tests, by undertaking life cycle assessment with different metrics, and see how much of a difference it makes (e.g. for the comparison of the carbon footprint of different products).

39. Costs and benefits and preferences for metrics may well differ between the global, national and sectoral level and that also apply to the cost–benefit and cost-effectiveness choices. For example, globally, 100-year time-horizon GWP is more cost-effective than 100-year time-horizon GTP, but nationally or sectorally the costs may well be greater for some particular emitters at 100-year time-horizon GWP than at 100-year time-horizon GTP. Step-change metrics are not well suited to life cycle assessment of products or events because they refer to individual pulses and not sustained activities. But there have been some uses of step-change metrics for assessing long-term effects such as lifetime dietary change.

40. The presenter referred to the question of why use of GWP* in some cases gives radically different results compared with 100-year time-horizon GWP. Specifically, a declining rate of CH_4 emissions may be stated as having a climate impact that is equivalent to negative CO_2 emissions (using GWP*) but to positive CO_2 emissions (using 100-year time-horizon GWP). Looking at historical emissions of CO_2 and CH_4 at the global scale, historical CO_2 emissions result in long-term committed warming, whereas the warming from historical CH_4 emissions declines quite rapidly because CH_4 is short-lived. Future emissions of those gases in both cases would lead to increased warming compared with the warming from historical emissions, and on deep mitigation pathways the amount of additional warming from future emissions turns out to be quite similar (about 0.2 °C) for both gases. This is because net CO_2 on this pathway is reducing very rapidly. In the assessment of Working Group III, this type of warming is referred to as “marginal”, which is the warming that occurs from an emission compared with the absence of that emission, everything else being equal. The CO_2 equivalent using GWP or GTP is always greater than zero because those metrics measure marginal warming and are not taking into account the climate effect of historical emissions.

41. With declining future CO_2 emissions, warming still increases compared with that in 2020, whereas declining future CH_4 emissions would lead to reduced warming compared with that in 2020. This, for lack of a better word, is referred to in the Working Group III assessment as “additional” warming. In this case, GWP* would give to CO_2 emissions a negative value, because CO_2 can only reduce warming at negative CO_2 emissions. For CH_4 emissions from 2020 onward, additional warming is negative. The key message is simply that, for long-lived gases, additional warming and marginal warming are approximately the same, whereas for short-lived gases, such as CH_4, they are very much not the same. The question, therefore, is what warming information is relevant for informing policy.

42. Marginal warming has the fundamental starting point of every emission of every GHG making the Earth warmer than it would have been otherwise. Additional warming refers to the fact that even declining CO_2 emissions make the Earth being warmer than it is already,

whereas declining CH_4 emissions would lead to reduced warming. Marginal warming focuses on warming resulting from an emission or a time series of emissions, compared with the absence of that emission, and this can help to quantify the benefit of avoided emissions, for example avoiding 1 t CH_4 has the same benefit as avoiding X t CO_2. But X depends very much on the perspective taken, whether cost–benefit or cost-effectiveness, and what time-horizon is taken into account for the policy, which is where the choice of GWP or GTP becomes relevant.

43. Additional warming focuses on warming resulting from a time series of emissions compared with warming from past emissions at the start of the time series, which means that there is a reference level involved. This is very useful for quantifying the benefit of more or less mitigation of short-lived climate forcers relative to a reference scenario and expressing that as emitting or removing CO_2. But the choice of reference (more or less emissions of short-lived climate forcers compared with what) really matters. In this context, Working Group III noted that the different focuses of these metrics can have important distributional consequences, but this is only beginning to be explored in the scientific literature.

44. Regarding the timing of net zero GHG emissions, Working Group I concluded that actual warming depends on the actual emissions of the gases on an emission pathway, whereas the metric indicates when the reported aggregate CO_2 equivalent emissions would reach net zero. The climate outcome for aggregate emissions using different metrics for a given mitigation pathway is exactly the same because the emissions are unchanged, but the timing of when net zero would be reached, in effect whether it is reached at all, depends very much on the metric that is chosen. An important consequence of this is that changing the GHG emission metrics, but retaining the same numerical CO_2 emission target, such as net zero, would result in different climate change outcomes. Therefore, changing the GHG emission metrics used to monitor achievement of existing emission targets could inadvertently change the intended climate outcomes or ambition, unless existing emission targets are re-evaluated at the same time. This means that targets and metrics do not exist in isolation, and the metric depends on what is intended to be achieved for the emission target and what policy principles the target intended to reflect.

45. The presenter explained why Working Group III chose to use 100-year time-horizon GWP in the AR6 for two main clusters of reasons. It is the dominant metric in the literature that was assessed by Working Group III and is consistent with past IPCC assessment reports and with decisions taken under the Paris Agreement rulebook. But there are also scientific reasons, as it approximates the relative damage due to CH_4 emissions under social discount rates, and results in close to global least-cost mitigation pathways for temperature increase limits of 2 °C (with a probability of more than 66 per cent) or lower, even if only accidentally so. However, there is ambiguity if emissions are only expressed in CO_2 equivalent with 100-year time-horizon GWP; therefore, IPCC authors were requested to report individual gases where possible. Also, there are some important limitations when working with literature that uses 100-year time-horizon GWP so pervasively. As a result, it is really difficult to change the metric fundamentally because often there is no detailed information on individual gases.

46. The Working Group III assessment of GHG emission metric performance is largely based on economic principles, and there may be other policy-relevant principles that need more consistent frameworks. The choice of the right metric depends very much on the policy objective, the policy principles and how the metric is applied. Therefore, metrics very much sit at the interface between science and policy, and their use relies on a continued dialogue between the scientific community and policymakers and on mutual learning.

3. Question and answer panel session

47. This part of the workshop focused on providing clarification of issues raised by participants on technical information and findings presented by the representatives of the IPCC, including various technical aspects.

48. A participant requested the IPCC experts, taking into account the global policy goal of limiting warming to 1.5 °C, to share their views on whether there is a need to amend the agreed metric of 100-year time-horizon GWP; and, in reference to the gases included in the AR6, whether fugitive emissions and indirect impacts on climate change from the use of

hydrogen could be relevant to be included in future IPCC assessments, or whether it does not matter because the scale of the hydrogen use activities would not have an impact on achieving the goal. The IPCC experts indicated that, under pathways to 1.5 °C, global mean temperature is expected to peak in around 2050, which is 27 years from now. If weighting today's emissions so that they cost-effectively contribute to reaching the objective of temperature peaking in 2050, then a 27-year time-horizon GTP would be needed, and next year a 26-year time-horizon GTP, etc. But the Working Group III assessment has shown that current commitments and targets are not consistent with reaching the goal of 1.5 °C. Therefore, this is a question that goes beyond the science, and refers more to answering the question of what to do when current targets and commitments are not consistent with that objective. In reference to hydrogen use, the IPCC experts indicated that Working Group I assessed only changes in metrics for which literature was already published and literature related to hydrogen was not available. Since then, literature has been published on emission metrics for hydrogen and it could be that the AR7 would consider metrics for hydrogen.

49. Another participant indicated that in general the concept of GWP* is not intuitive, and requested the IPCC experts to explain qualitatively what the differences are between GWP* and 100-year time-horizon GWP, what use of GWP* is aimed at achieving and how that relates to atmospheric lifetimes and time-horizons. The IPCC experts indicated that GWP, in particular, varies quite strongly with time-horizon and, if the question is about what would happen in 2050, it might be necessary to use a different time-horizon than that showing what would happen in 2100. Whereas GWP* is much less dependent on time-horizon, being almost like a fixed number, because effectively the climate impact of a pulse of CO_2 is equivalent to a rate of change of CH_4 emissions and that is not really dependent on the time-horizon chosen for the analysis.

50. One participant, when referring to the finding presented that decreasing CO_2 emissions are still increasing warming, while decreasing CH_4 emissions are decreasing warming, requested implications for the CH_4 emissions from the AFOLU sector to be drawn from this. Also, indicating that eventually CH_4 emissions are steady in the AFOLU sector and constitute a closed cycle, and therefore, similar to the carbon cycle, they do not really contribute to the warming, the participant questioned whether this is not the right interpretation for this issue. The IPCC experts indicated that this is correct if considering constant or near-constant CH_4 emissions from the AFOLU sector, which are biogenic. Therefore, if the decline in CH_4 emissions is about 0.3 per cent/year, that would result in no additional warming. That is as far as the science goes, but there can be a large amount of marginal warming in the sense of the warming that would not occur if those emissions did not continue. If a hypothetical country is a very large CH_4 emitter and continues as such emitting CH_4, it is making the Earth a lot warmer than it would be if it stopped those emissions, which is the marginal warming. It is true that the country is not causing any more warming than that it was already, but the warming that the country contributes is on top of the warming caused by every other emitter.

51. In response, the participant highlighted that there is no additional warming and that, if CO_2 emissions are reducing but still contributing to warming, the temperature continues to rise. The participant requested clarification of whether, when the level of CH_4 emissions is constant, it leads to temperature increase or there is no additional warming and no further temperature increase takes place. The IPCC experts clarified that, as long as CH_4 emissions decline by about 0.3 per cent/year, there would be no additional warming. As CH_4 has already led to about 0.5 °C warming, as reported in the assessment of Working Group I, that 0.5 °C warming will still be there unless something is done about it. Therefore, when referring to warming, it is starting from 0.5 °C for CH_4.

52. Another participant indicated that it was clear from the presentations that the choice of metrics has a very huge impact on climate change policy, and that the quantification of net zero GHG emissions depends on the GHG emission metric chosen. He referred to the finding in chapter 1 of the AR6 that the cumulative emissions calculated using 100-year time-horizon GWP are performing well when emissions are increasing, but not when they are stable or decreasing. He indicated that, considering the relationship between net zero and the metrics chosen, it could be understood that, for achieving a net zero target and bearing in mind that emissions are going to be stable or decreasing, GWP might not be the most appropriate metric

for use. In reference to the definition of emission metrics included in the common glossary of the AR6, the participant noted that, on the policy side, there is a SBSTA agenda item on common metrics, and requested the IPCC experts to elaborate on the difference between common metrics from the policy side and emission metrics. The IPCC experts clarified that the finding that cumulative 100-year time-horizon GWP ‘responds well’ when emissions are rising depends on the understanding of what is meant by ‘responding well’. Working Group I assessed what the physical temperature response to that would be, and cumulative emissions based on GWP did not correlate well with warming when emissions are falling. However, if using 100-year time-horizon GWP in relation to mitigation of various gases, then it can perform reasonably well. Therefore, it is really about what the intended use of the metric is and that depends on whether it is appropriate for quantifying cumulative CO_2.

53. Finally, the same participant recalled that, at a 2009 expert meeting on the science of alternative metrics, the IPCC provided recommendations to the UNFCCC and the scientific community, and that the technical report on the current workshop, considering the Convention and the Paris Agreement, could provide elements for consideration by the scientific community as well as elements for the scoping of the AR7. The IPCC experts recalled that those recommendations were very useful as input to the scoping of the AR5. They indicated that the report on the current workshop could serve as input to the next IPCC assessment cycle. However, they warned that it is too early to say how to relate to that, as this is a task for the next IPCC bureau. Nevertheless, they indicated that the report will be available to the next IPCC bureau and set of authors.

54. Another participant requested clarification in order to better understand the implications of the speed of increase in temperature for the design of metrics, taking into account that the information available indicates that the increase in temperature was around 0.1 °C per decade and has already reached 0.2 °C and will potentially reach a higher level in this crucial decade. In that sense, the participant asked what the implications would be, if already assessed, or otherwise what the views of the IPCC experts are on the implications for metrics. Further, the participant noted that, while the presenters from the IPCC indicated that changing the metric used would be complicated, in fact the metrics have been already changed. He recalled that, since Parties in their reporting initially started using metrics from the AR2, at this stage developing and developed countries have already used different metrics for their nationally determined contributions and GHG inventories, and now countries are moving to using metrics from the AR5, so a change in the numbers is already happening. In that context, he asked the IPCC experts their views on the implications of changing the metrics used from those in the AR5 to those in the AR6 or to another metric.

55. The IPCC experts indicated that metric values have changed since the AR2, but these changes and updates are relatively small compared with their uncertainty ranges. It is necessary to distinguish between the changes in values and the change in concept, because, if there is a change in concept, it is necessary to think differently about how targets are set and defined. Therefore, changing values is different from changing concept. They recalled that, in the figures included in the supplementary material of the contribution of Working Group III to the AR6, it is possible to see that the difference in net zero data from different vintages of 100-year time-horizon GWP is relatively minor. A change to a different type of metric would have a much bigger impact and imply a more systematic change. Therefore, if there was a change to a fundamentally different metric, the climate outcome would change more fundamentally, and, of course, different emitters would be differently affected by such a change.

56. Finally, one participant recalled that, during the presentations on net zero, it was indicated that reaching net zero CO_2 and declining emissions of non-CO_2 GHGs will be sufficient to limit warming, and that conceptually this is true for CH_4, but not for N_2O as it has a long atmospheric lifetime. He indicated that it is unclear how that adds up in terms of N_2O still accumulating and increasing in the atmosphere, even if it is declining. Regarding the concepts of additional warming and marginal warming, he indicated that essentially this refers to reducing atmospheric concentration of CO_2. Net zero, which is designed to reduce concentrations in the atmosphere, can be reached by reducing CH_4 emissions and, owing to its shorter atmospheric lifetime, the concentration in the atmosphere will decline. Therefore, it may be an easier way to communicate the physical changes considered, rather than using

complex vocabulary. The IPCC experts noted that the meaning of net zero in relation to gases other than CH_4 or CO_2 comes from the requirement for the radiative forcing from those gases to decline by about 0.3 per cent/year. Whether this is coincidence or not, when stopping emissions of CO_2, the decline in the radiative forcing is about 0.3 per cent/year; hence, net zero CO_2 does that, but for CH_4 it is not necessary to stop the emissions but just to reduce them by roughly 0.3 per cent/year. For N_2O this was not specifically assessed by Working Group I, but the N_2O concentration could be related to the emission change, and roughly a two-thirds reduction in N_2O emissions would be needed to achieve the 0.3 per cent/year decline in N_2O emissions, instead of zero N_2O.

C. Open floor discussion on experience and open questions from users on the applications of emission metrics

57. The objective of the open floor discussion was to provide the workshop participants the opportunity to exchange views taking into account the evolution in the science of emission metrics from the AR5 to the AR6 and discuss related open research questions. As users of emission metrics, they were invited to share their experience and/or expectations for the next IPCC assessment report in order to provide information that may be policy relevant for Parties. Participants, as in previous interventions during the workshop, expressed their satisfaction with the high level of the presentations and materials presented and expressed appreciation to the IPCC for providing relevant information on emission metrics.

58. In providing his perspective as a user of the applications of emission metrics, one participant indicated that, in the light of decisions 18/CMA.1 and 7/CP.27 stating that Parties may, in addition, also use other metrics to report supplemental information on aggregate GHG emissions and removals, it could be necessary to ask whether Parties should be encouraged to use other metrics as supplementary information in their reports in addition to using the GWP values.

59. Referring to the choice of metrics in relation to limiting warming to 1.5 °C, another participant indicated that some new scientific papers showed that, if countries are steering the temperature towards limiting warming to 1.5 °C, then the consequences of the choice of metrics for the resulting global mean temperature need to be understood. Steering towards a more ambitious temperature goal, without knowing the consequences of decisions on choice of metrics for global mean temperature, may lead to unexpected results. He indicated that there is evidence presented in the AR6 that aggregate emissions calculated using 100-year time-horizon GWP do not provide information on consequences for global mean temperature.

60. Another participant indicated that one of the shortcomings in the scientific knowledge relates to some intermediate forcers that have an even shorter lifetime, for instance black carbon, which has never been included in the set of metrics provided by the IPCC, because intermediate forcers are even further from being possible to merge into some kind of aggregate metric. He also indicated that he was not aware of whether the IPCC had been able to move forward on finding solutions for or approaches to this issue. A representative of the IPCC clarified that the IPCC did not specifically quantify a metric for black carbon in the AR6.

61. One participant mentioned that one presentation during the workshop indicated that 100-year time-horizon GWP is a good approximation of a cost-effective metric for the coming decades, but another presentation indicated that GWP is not perfect because no metric is. Therefore, it would be good to have a summary of the perspectives on and reasons for this.

62. Another participant stressed that the use of known metrics has different implications on the global and national scale, so they affect the assessments that Parties make at different scales. At the same time, she considered that it seems that there is some freedom to use different metrics. Therefore, in the context of the global stocktake, it is necessary for Parties to discuss the need to harmonize the use of metrics in the process of assessing progress towards the global goal. She questioned whether there is a need to consider harmonization in the light of GWP seeming to be the best metric that Parties currently have, but noted that it is important to explore the best approach going forward.