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Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer
Forty-third meeting
Online, 22 and 24 May and 14–17 July 2021

Report of the forty-third meeting of the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

Addendum

Online session on the unexpected emissions of trichlorofluoromethane (CFC-11)

Introduction

1. Owing to the continuing coronavirus disease (COVID-19) pandemic and related travel restrictions, the forty-third meeting of the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer could not be held in person in Bangkok as had been planned. Instead, a number of issues were selected from the provisional agenda for online work, including the unexpected emissions of trichlorofluoromethane (CFC-11).

2. Accordingly, an online session on the unexpected emissions of trichlorofluoromethane (CFC-11) was convened, on 14 and 15 July 2021, to consider the technical aspects of the following two reports: (a) The report by the Scientific Assessment Panel entitled "Report on the Unexpected Emissions of CFC-11", issued in April 2021;[1] and (b) The report by the Technology and Economic Assessment Panel task force on CFC-11, contained in volume 3 of the Panel's 2021 report, entitled "Decision XXXI/3 TEAP Task Force Report on Unexpected Emissions of Trichlorofluoromethane (CFC-11)", issued in May 2021.[2]

I. Opening of the meeting

3. The session was co-chaired by Mr. Martin Sirois (Canada) and Ms. Vizminda Osorio (Philippines).

4. The session was opened by Ms. Osorio at 9 a.m. (Nairobi time (UTC + 3))[3] on Wednesday, 14 July 2021.

[1] https://ozone.unep.org/system/files/documents/SAP-April-2021-report-on-the-unexpected-emissions-of-CFC-11.pdf.

[2] https://ozone.unep.org/system/files/documents/Final_TEAP-DecisionXXXI-3-TF-Unexpected-Emissions-of-CFC-11-may2021.pdf.

[3] All times mentioned are Nairobi time (UTC + 3).

5. The Co-Chair welcomed representatives to the online session on the unexpected emissions of CFC-11, which constituted the second online session of the forty-third meeting of the Open-ended Working Group. During the first session, held in May 2021, participants had considered the replenishment of the Multilateral Fund for the Implementation of the Montreal Protocol.

6. An opening statement was delivered by Ms. Megumi Seki, Executive Secretary of the Ozone Secretariat.

7. Ms. Seki, in her statement, said that the meetings that had taken place during 2021 on issues associated with the replenishment of the Multilateral Fund had been perfect examples of the cooperation, compromise and decisiveness that made the Montreal Protocol a beacon of hope for multilateralism, and expressed the hope that the same principles would be applied to all the upcoming meetings. The Secretariat appreciated the support that parties had demonstrated throughout the period of the COVID-19 pandemic in adapting to online meetings and continuing the implementation of the Montreal Protocol despite the difficult prevailing circumstances.

8. On the theme of the present online session, namely the issue of unexpected emissions of CFC-11, she recalled that, in 2018, scientific findings had shown that, instead of the projected steady decline of CFC-11 in the atmosphere, unexpected emissions were emanating from unreported sources. In response, parties had taken decisions in 2018 and 2019 requesting the Scientific Assessment Panel and the Technology and Economic Assessment Panel to assess the situation and provide parties with information on atmospheric monitoring and modelling, including underlying assumptions, and on all possible sources of emissions from production, uses and banks. The panels would present their latest findings at the present online session. Those findings showed that the unexpected emissions had dropped sharply in 2018 and 2019, and that the recovery of the ozone layer would not be substantially delayed owing to the increased emissions that had occurred.

9. While that was positive news, the parties needed to consider the institutional processes of the Montreal Protocol with a view to strengthening implementation and enforcement. In addition, there was a need to identify gaps in the atmospheric monitoring of controlled substances, as recognized by the parties in decision XXXI/3, in which the Scientific Assessment Panel had been requested to work with the Ozone Research Managers on the matter. The European Union had approved a pilot project under the Ozone Secretariat to identify locations where additional monitoring would be most useful. Progress would be reported to the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer at its twelfth meeting and the Thirty-Third Meeting of the Parties to the Montreal Protocol in October 2021.

10. In conclusion, she thanked the Scientific Assessment Panel, the broader scientific community and the Technology and Economic Assessment Panel for their work and vigilance, which had enabled the detection and early warning of the issue of unexpected emissions of CFC-11, and commended the parties for their successful cooperation and swift handing of the situation. She expressed the hope that the discussion at the present online session would provide further information on technical issues that would set the basis for policy matters that would be taken up by the Conference of the Parties to the Vienna Convention and the Meeting of the Parties to the Montreal Protocol.

II. Organizational matters

A. Attendance

11. The following parties to the Montreal Protocol were represented: Albania, Algeria, Antigua and Barbuda, Argentina, Australia, Austria, Azerbaijan, Bahrain, Barbados, Belarus, Belgium, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cabo Verde, Cambodia, Canada, Chile, China, Colombia, Costa Rica, Cuba, Czechia, Democratic People's Republic of Korea, Denmark, Dominican Republic, Ecuador, Egypt, Estonia, Eswatini, European Union, Finland, France, Gabon, Gambia, Germany, Ghana, Greece, Guinea, Hungary, Iceland, India, Indonesia, Iran (Islamic Republic of), Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kuwait, Latvia, Liberia, Libya, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mauritius, Mexico, Micronesia (Federated States of), Montenegro, Morocco, Netherlands, New Zealand, Nicaragua, Nigeria, North Macedonia, Norway, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Republic of Korea, Romania, Russia, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Saudi Arabia, Senegal, Serbia, Sierra Leone, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Timor-Leste, Trinidad and Tobago, Tunisia, Uganda, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland, United States of America, Uruguay, Venezuela (Bolivarian Republic of), Viet Nam, Zimbabwe.

12. The following United Nations entities, organizations and specialized agencies were represented: United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO), World Meteorological Organization (WMO). The Montreal Protocol assessment panels and the secretariat of the Multilateral Fund for the Implementation of the Montreal Protocol were also represented.

13. The following intergovernmental, non-governmental, industry, academic and other bodies and organizations were represented: Carrier, Daikin, Environmental Investigation Agency, German Agency for International Cooperation, Industrial Technology Research Institute, Institute for Governance and Sustainable Development, Natural Resources Defense Council, Nolan Sherry and Associates.

B. Adoption of the agenda

14. The Working Group adopted the following agenda for the online session on the basis of the full provisional agenda for the forty-third meeting of the Open-ended Working Group set out in document UNEP/OzL.Pro.WG.1/43/1 and the shortened provisional agenda specific to the online session on unexpected emissions of CFC-11 set out in document UNEP/OzL.Pro.WG.1/43/2/Add.2:

1. Opening of the meeting.
2. Organizational matters:
    (a) Adoption of the agenda;
    (b) Organization of work.
3. Unexpected emissions of CFC-11:
    (a) Presentation of the Scientific Assessment Panel report on unexpected emissions of CFC-11;
    (b) Presentation of the Technology and Economic Assessment Panel task force report on unexpected emissions of CFC-11;
    (c) Discussion session.
4. Closure of the meeting.

C. Organization of work

15. The Working Group agreed to the organization of work proposed by the Co-Chair, namely, to focus exclusively on item 4 of the agenda for the forty-third meeting of the Open-ended Working Group, on unexpected emissions of CFC-11. Presentations would be made by the Scientific Assessment Panel and the Technology and Economic Assessment Panel task force, to be followed by a discussion session.

III. Unexpected emissions of CFC-11

16. Introducing the item, the Co-Chair drew attention to documents UNEP/OzL.Pro.WG.1/43/2 and UNEP/OzL.Pro.WG.1/43/2/Add.2, which summarized the background to the issue. She recalled that following the global phase-out of the production and consumption of CFC-11 in 2010, global CFC-11 emissions and atmospheric abundances had been expected to decrease steadily; however, scientific research published in early 2018 had provided evidence of an unexpected increase in global CFC-11 emissions from around 2012. By decisions of the parties, the Scientific Assessment Panel (decision XXX/3) and the Technology and Economic Assessment Panel (decision XXXI/3) had been mandated to produce reports on the matter for consideration by the Thirty-Second Meeting of the Parties, in 2020. However, as a consequence of the COVID-19 pandemic, consideration of the matter had been deferred to 2021. In the meantime, both reports had been revised to accommodate new findings on the unexpected emissions of CFC-11. The findings of those reports would now be considered at the present online session, while associated policy issues would be considered at the combined twelfth meeting of the Conference of the Parties to the Vienna Convention and the Thirty-Third Meeting of the Parties to the Montreal Protocol, in October 2021.

17. The Secretariat had established a dedicated online forum on the issue of the unexpected emissions of CFC-11 to enable parties to post questions and comments on the reports by the Scientific Assessment Panel and the Technology and Economic Assessment Panel prior to the online session. Parties would also have the opportunity to pose further questions and make further comments during the session.

A Presentation of the Scientific Assessment Panel report on unexpected emissions of CFC-11

18. In a pre-recorded video, Mr. Paul A. Newman, co-chair of the Panel, presented the Scientific Assessment Panel's 2021 report on the unexpected emissions of CFC-11. A summary by the Panel of its presentation is set out in section A of the annex to the present report, without formal editing.

B. Presentation of the Technology and Economic Assessment Panel task force report on unexpected emissions of CFC-11

19. Also by means of a pre-recorded video, the co-chairs of the Technology and Economic Assessment Panel task force, Mr. José Pons, Ms. Helen Walter-Terrinoni and Ms. Helen Tope, presented the report of the decision XXXI/3 task force on the unexpected emissions of CFC-11, as set out in volume 3 of the Technology and Economic Assessment Panel's May 2021 report. A summary by the task force of its presentation is set out in section B of the annex to the present report, without formal editing.

C. Discussion session

20. Representatives who took the floor thanked the two panels for their presentations and informative reports.

21. Members of the panels responded to a number of questions posted by parties in the online forum or raised during the online sessions.

22. Responding to questions about whether the issue of the unexpected emissions of CFC-11 was under control and whether the potential unreported production and renewed use of CFC-11 had ended, Mr. Newman said that the drop in CFC-11 emissions to pre-2012 levels suggested that the issue was being controlled, but further years of observation and more data were required before it would be possible to ascertain whether the situation was under control. The substantial decline in emissions, such that global CFC-11 emissions in 2019 were similar to those during the period 2008–2012, implied that there had been a considerable decline in unreported production, but the top-down estimates from observations could not apportion the emissions among new production and usage, old, pre-2010 bank emissions and emissions from new banks. It was not possible, therefore, to say unequivocally that unreported production and renewed use had ended. Ms. Walter-Terrinoni agreed that the drop in CFC-11 emissions to pre-2012 levels suggested that the issue was being controlled and that the observations were consistent with a significant reduction in unreported CFC-11 production for use in foams. She recalled that parties had taken action to enhance the monitoring and reporting of the production of carbon tetrachloride, which should reduce the potential for illegal CFC-11 production. There had also been commitments made to strengthen laws and enforcement programmes as legal deterrents.

23. The 2022 assessment reports of both the Scientific Assessment Panel and the Technology and Economic Assessment Panel would contain new information on the emissions in 2020 and 2021. Mr. Newman confirmed that the preliminary estimates for 2020 had been done, but said that they still needed to be adjusted for year-to-year variability; they were generally comparable with 2019. Mr. Newman nevertheless pointed out that vast regions of the globe, including much of Africa, all of South America and much of South and South-East Asia, northern Australasia, the Middle East and the Russian Federation were not covered by the observational network. It was not possible to identify specific new uses or production, only to identify the emissions and their possible deviation from expectations. He recalled, however, the work on identifying gaps in atmospheric monitoring of controlled substances being undertaken by the Ozone Research Managers and said that an additional 20 to 24 stations spread across the aforementioned regions would enable the Scientific Assessment Panel to vastly improve its estimates.

24. Mr. Newman confirmed that there was a monitoring station north-east of Beijing that had been reporting data on CFC-11 in the past. About a decade previously, it had been found that the building in which the instruments were installed had been built using CFC-11 foam insulation and thus there was contamination that would last for a long time. China was making major efforts to measure CFC-11 and

the Scientific Assessment Panel looked forward to seeing the data. Mr. Newman expressed the hope that the observations would be cross-calibrated with other international networks and included in open data sources. He confirmed that the station had also collected measurements of dichlorodifluoromethane (CFC-12) and carbon tetrachloride, adding he had not seen the results of the observations.

25. The Panel responded to a question about the paper, published in *Nature Communications* in May 2021, by Lickley and others, entitled "Joint inference of CFC lifetimes and banks suggests previously unidentified emissions", in which it was proposed that the lifetimes of CFC-11, CFC-12 and trichlorotrifluoroethane (CFC-113) were shorter than had previously been thought and that unexplained emissions were therefore larger. Mr. Newman explained that the study was a Bayesian analysis that inferred a lifetime in order to better fit the observations and pointed out that the uncertainties in the paper's lifetime reports overlapped with those in the 2018 assessment of the Scientific Assessment Panel. The paper by Lickley and others was just one of various pieces of evidence to be used for the calculation of lifetimes. It did not demonstrate that previously assessed lifetimes from laboratory, satellite, aircraft, ship and ground information and modelling were incorrect, but the Panel would consider anew the issue of lifetimes in its 2022 assessment report.
Ms. Walter-Terrinoni explained that the Bayesian probabilistic modelling technique used by Lickley and others provided a very broad range of bank quantities, of 878 to 2,264 gigagrams, for 2018. Both the modelling approach used by Lickley and others and that used by the Technology and Economic Assessment Panel broadly concluded, however, that the emissions detected were from unreported new production and not from pre-existing banks. The Technology and Economic Assessment Panel had been able to narrow down the range for the banks on the basis of the technical and economic realities assessed by its task force on CFC-11. The difference between inventory-based emissions and emissions derived from atmospheric measurements was due to the unreported production and it suggested that there had been 15 to 40 kilotonnes of new production or use from recent inventories.

26. Explaining more about the uses of CFC-11, Ms. Walter-Terrinoni said that, although there had been various uses for CFC-11 in the past, such as for chillers, open-cell phones, aerosols and cleaning uses, the Technology and Economic Assessment Panel had determined that it was unlikely that additional production would be used for those products for economic and other reasons. It was likely that new CFC-11 production had been used for the production of closed-cell foam, employed, for example, in insulation for construction and refrigeration. In terms of the emissions from the foams, Ms. Walter-Terrinoni said that a small amount of steady emissions would be expected across the lifetime of the various foam products, for example 7–25 years for refrigeration foam or 30–75 years for insulation foam in buildings, with an increase at the time of decommissioning.

27. Responding to questions about banks of CFC-11, Ms. Walter-Terrinoni said that the Technology and Economic Assessment Panel had estimated that 300 kilotonnes, plus or minus 34 kilotonnes, or 1.4 gigatonnes of carbon dioxide-equivalent, had been added to the active bank of CFC-11 from unreported CFC-11 production and use during the period 2007–2019. More information would be available for the 2022 assessment report of the Technology and Economic Assessment Panel. It was estimated that the closed-cell foam bank had increased by approximately 20 per cent. The overall active bank had increased by a larger percentage, some 30 to 40 per cent. If enclosed in landfills at the end of its life, which was the worst-case scenario and the most common disposal method for CFC-11 globally, all the CFC-11 would be emitted over time, assuming that there was no anaerobic degradation in the landfill.

28. Commenting on queries about the difference between the estimates of emissions from banks in the 2021 assessment report of the Technology and Economic Assessment Panel and those in the 2019 assessment report, Ms. Walter-Terrinoni explained that, in the model in the 2019 report, the concept of average lifetimes of foams had been used, whereas, in reality, lifetimes tended to be within a range. In the 2021 report, the Panel had used a Weibull distribution, which was employed largely by regulators and other individuals dealing with building stock and the lifetimes of building stock. Using the lifetimes of various types of equipment and buildings found through research and in literature, the Panel had been better able to demonstrate a curve around the timing of the decommissioning of buildings and the foams associated with them, and the various types of equipment using foams, such as chillers and refrigerators. Even though in the period 2007–2012 there had been a peak in decommissioning, the Panel considered that it was not sufficient to provide enough emissions to support the atmospherically derived estimates, so it was unlikely that that would support estimates of overall emissions. It would therefore be likely that additional production had been taking place within that period.

29. The Technology and Economic Assessment Panel had also looked at recovery practices in relation to refrigerants and had conducted interviews, held discussions and carried out related research. All the findings had also been incorporated into the model in the 2021 report and had influenced the outcome. In its 2022 assessment report, the Panel intended to refine the models further, looking more closely at some of the regional models that included atmospherically derived data, in order to cross-check them.

30. In response to a question about the information required to further refine the estimates of the CFC-11 banks, given their importance in assessing the magnitude of any unreported production, and associated emissions, Ms. Walter-Terrinoni said that, in the past, data for the Alternative Fluorocarbons Environmental Acceptability Study had been reported by sector type, and therefore use, as different products had different emissions associated with them. Such information would help reduce the uncertainty related to the estimates. Mr. Newman confirmed that any new data that helped the Technology and Economic Assessment Panel to refine the expectations for emissions would be extremely helpful for the Scientific Assessment Panel.

31. In terms of whether emissions from banks could contribute to delaying the recovery of the ozone layer, Mr. Newman explained that there was a linear relationship between the cumulative emissions and the total impact. The 1.3-year delay in the report of the Scientific Assessment Panel was based on 440 gigagrams of cumulative emissions, so, in the event that there were an additional 440 gigagrams, that would lead to additional 1.3 years of delay. The 440 gigagrams of unreported production would lead to a 3 Dobson-unit change in the Antarctic ozone hole. On the basis of the estimate of the Technology and Economic Assessment Panel of total production of up to 700 kilotonnes, there would be up to 6 Dobson units of Antarctic ozone depletion. That kind of depletion would not be particularly detectable within the year-to-year variability of the ozone hole, and it would not reverse the improvement seen. Consideration of the banks, therefore, did not change the conclusion that the impact of the unexpected emissions of CFC-11 was small. Nevertheless, on the basis of the upper limit of the estimate of total production by the Technology and Economic Assessment Panel of 700 kilotonnes, the delay could be between two and three years. In response to the surprise expressed that the potential delays in recovery caused by the unexpected emissions had been described as not being significant by the Scientific Assessment Panel in its presentation, Mr. Newman explained that, for scientists, “statistically significant” meant a detectable signal that was outside usual interannual variability. The current estimates of emissions from unreported CFC-11 production would not have a statistically significant impact on the Antarctic ozone hole and global ozone-layer recovery.

32. Responding to questions about the decline in CFC-12 and carbon tetrachloride emissions as of 2017 and their relationship with CFC-11, Mr. Newman referred to the corresponding sections of the report by the Scientific Assessment Panel, namely section 3.3 on CFC-12, section 3.4 on carbon tetrachloride and section 4.3 on CFC-11. He said that regional emissions of carbon tetrachloride from eastern China had increased after 2012 and declined after 2017, and that regional emissions of CFC-12 from eastern China had not increased after 2012, remaining close to 3 gigagrams, plus or minus 1.2 gigagrams, per year until 2016. CFC-12 emissions had declined substantially after 2016, reaching levels indistinguishable from zero during the period 2017–2019. Taken together, the trends of CFC-12 and carbon tetrachloride emissions from eastern China could be consistent with unreported CFC-11 production occurring in that region, increasing substantially after 2012 and declining one or two years before the CFC-11 emissions had declined. Ms. Tope said that the trends in CFC-12 emissions were more consistent with emission releases during production than with non-emissive uses, although such uses could not be ruled out. The Technology and Economic Assessment Panel was of the opinion that the CFC-12 had been coproduced as a by-product rather than being produced specifically. Explaining further the relationship between CFC-11 and carbon tetrachloride emissions despite the latter being a feedstock for the former and therefore consumed, she said that the increase in emissions of carbon tetrachloride were assumed to come from increased production thereof for the production of CFC-11. In 2019, the total production of carbon tetrachloride reported globally was 316 kilotonnes, which would be a substantial proportion of the 45–120 kilotonnes estimated to be required to achieve the amounts of CFC-11 that was estimated to have been produced.

33. In response to a comment about the assertion by the Technology and Economic Assessment Panel that only China had the spare annual capacity in chloromethane plants that might allow carbon tetrachloride production to supply the amounts required for large-scale CFC-11 production, Ms. Tope said that there had been various studies on the range of carbon tetrachloride emissions from industrial sources compared with emissions derived from atmospheric measurements, but there remained a great deal of uncertainty. It was known that reported carbon tetrachloride production in China had increased by about 100 per cent from 2013 to 2019. Over the period 2015–2019, the growth in reported carbon tetrachloride production in China had been almost twice that of the growth in chloromethane

production. The increasing quantities of chloromethane and reported carbon tetrachloride production in China ran counter to the reduction in carbon tetrachloride emissions observed in eastern China as of 2017. The reduction could be consistent with a reduction in unreported carbon tetrachloride production and associated emissions. Nevertheless, it was important to remember that there were other unrelated industrial sources of carbon tetrachloride, for example chlorine production and usage and legacy emissions such as landfills, that made it difficult to draw robust conclusions. It was worth noting that, for its 2022 assessment report, the Medical and Chemicals Technical Options Committee planned to review and update the previous inventory of industrial sources of carbon tetrachloride emissions.

34. Clarifying her remarks further, Ms. Tope confirmed that carbon tetrachloride was also produced and processed in perchloroethylene plants and that there were five such plants operating in Europe and the United States and at least nine operating in China. There, too, there was spare global capacity of 50–100 kilotonnes per year, mainly within the European Union. It was therefore in relation to chloromethane plants that the report stated that only China had the spare capacity to produce the carbon tetrachloride in the quantities required for large-scale CFC-11 production.

35. The representative of China said that her Government had been strictly regulating carbon tetrachloride in recent years and had established an online monitoring system to strengthen controls. Furthermore, as carbon tetrachloride was a feedstock for CFC-11 and CFC-12, the production and emissions data should correlate closely. The top-down results, however, indicated that emissions of carbon tetrachloride had been largely stable since 2010. She recalled that the report by the Technology and Economic Assessment Panel had concluded that uncertainties and variability associated with annual estimates and year-to-year changes of carbon tetrachloride emissions precluded any robust conclusions about global carbon tetrachloride emission changes being directly linked to CFC-11.

36. In response to questions about it being possible to explain only 60 per cent of the increase in CFC-11 emissions, Mr. Newman said that even that 60 per cent included a large degree of uncertainty, which could feasibly account for the remaining 40 per cent. He nevertheless recalled that there were vast regions of the world that were not measured. The fact that 2019 measurements showed that emissions rates had returned to more or less pre-2014–2018 levels had provided some insights, but future years of estimates would provide even better understanding. Mr. Newman confirmed that there had been no recent changes of note in observed CFC-11 emissions in regions other than in eastern China that could explain the total global unexpected emissions, but he reiterated that monitoring was not conducted globally. Ms. Tope said that available observations from the current network of stations and the uncertainty related to emission estimates precluded the identification of the region associated with the remaining 40 per cent.

37. Responding to comments about the availability of data, Mr. Newman confirmed that there were no updated publications about trends in CFC-11 emissions in the United States after 2014. Some work was being undertaken in that regard and the outcome would appear in the 2022 assessment report of the Scientific Assessment Panel. Preliminary data, however, showed that emissions in subsequent years were below those inferred for 2014. Similarly, there were efforts to obtain more data from India, as there was one only data point for the country, which had been obtained from a flask sampling campaign for a study by Mr. Daniel Say,[4] combined with regional emissions modelling. Mr. Newman confirmed that a high-quality sampling station in the region would provide much better insight and that a new focus campaign repeating the study by Mr. Say could help with estimates of emissions in future years.

38. One representative drew attention to studies on the impact of the oceans on global CFC-11 emissions and on atmospheric concentrations of CFC-11. Mr. Newman said that it was indeed recognized that CFC-11 was taken up by the ocean and could be used as a tracer to check the age of ocean water. Although the impact of the oceans was not thought to be significant, the Scientific Assessment Panel would consider the matter in the 2022 assessment report.

39. Following the responses, one representative, thanking the Panel members for their answers, especially to the questions posted in the online forum, added that they had nevertheless been brief and that she would appreciate additional written responses, if possible, to any questions remaining unanswered or requiring further clarification.

[4] Say, D., A. L. Ganesan, M. F. Lunt, M. Rigby, S. O'Doherty, C. Harth, A. J. Manning, P. B. Krummel and S. Bauguitte, Emissions of halocarbons from India inferred through atmospheric measurements, *Atmos. Chem. Phys.* 19 (15), 9865–9885, doi:10.5194/acp-19-9865-2019, 2019.

40. A number of representatives took the floor to make general statements. All began by thanking the members of the assessment panels for their work in producing the reports and presentations during a particularly challenging period.

41. Most of the representatives who spoke said that they were encouraged by the recent positive trend in CFC-11 emissions. They also welcomed the assessment that the unexpected emissions of CFC-11 seen to date would not significantly delay the recovery of the ozone layer, although one observed that the delays estimated were within the range of impact associated with potential policy measures identified by the Scientific Assessment Panel in its quadrennial assessments and were therefore not insignificant. A number of them also cautioned that more work was still needed, notably on monitoring, including monitoring of onsite flow of precursor substances, such as carbon tetrachloride, to identify potential risks for ozone layer recovery at an early stage; and on assessment of the impact of emissions from CFC banks, including the additional banks arising from unreported production. One representative pointed out that almost all Article 5 parties had eliminated the use of CFC-11 and appealed to those producing carbon tetrachloride to exercise careful control, avoid CFC production and preserve the recovery of the ozone layer.

42. A number of representatives said that the global monitoring system gaps identified by the Scientific Assessment Panel were significant and should be filled. One called for a system that would enable the scientific and technical bodies of the Montreal Protocol to identify issues in time to enable corrective action without adding to the burden on parties. Another said that monitoring gaps in areas with no significant history of production or consumption could be considered less important when considering which gaps to fill, while a third urged coverage of all substances with a high ozone-depleting or climate impact and called on parties in a position to do so to continue sharing data and strengthening monitoring capacity in an attempt to close gaps.

43. The representative of the European Union provided additional information on the joint initiative being undertaken with the Ozone Secretariat on identifying gaps in atmospheric monitoring. Describing the European Union's contribution as a relatively modest one that should be viewed as seed funding, he suggested that the Secretariat make a summary of the initiative's technical parameters available to Parties so that they could consider contributing, not just financially but also by allowing for sampling and monitoring in areas that were considered important.

44. One representative noted that his delegation was drafting a conference room paper on a framework for work on atmospheric monitoring, to be introduced at the Thirty-Third Meeting of the Parties, and invited other parties to contribute by participating in intersessional consultations on the matter.

45. Another representative, noting that the Technology and Economic Assessment Panel's technical and policy-related suggestions to parties were aimed at enabling the Panel to improve its estimates and modelling, said that it was now up to the parties to reflect on the information provided and decide on the actions to be taken, both individually and collectively. The Thirty-Third Meeting of the Parties would provide an opportunity to consider the matter further.

IV. Closure of the meeting

46. Following the customary exchange of courtesies, the forty-third meeting of the Open-ended Working Group was adjourned and the online session on unexpected emissions of CFC-11 was declared closed at 6.55 p.m. on Thursday, 15 July 2021.

Annex

Presentations by the Technology and Economic Assessment Panel*

A. Summary of the presentation by the Scientific Assessment Panel on the "Report on unexpected emissions of CFC-11" at the online session on unexpected emissions of trichlorofluoromethane (CFC-11) of the forty-third meeting of the Open-ended Working Group, held on 14 and 15 July 2021

1. Paul A. Newman, David W. Fahey, John A. Pyle, and Bonfils Safari (SAP co-chair) gave a presentation on the "Report on Unexpected Emissions of CFC-11", highlighting the main findings of the published WMO [2021].

2. The Report was mandated under Decision XXX/3: Unexpected emissions of trichlorofluoromethane (CFC-11) November 2018, 30th MOP. The Report authors were assembled in August 2019 and three report drafts were completed and peer-reviewed. The Report was finalized in March 2021 and the final draft was delivered to the Parties on 5 April 2021. The WMO Report was published in July 2021. The Report included contributions from 53 persons from 15 different countries. The CFC-11 Report Advisory Group was composed of Paul Fraser (Australia), Neil Harris (UK), Jianxin Hu (China), Michelle Santee (USA), David W. Fahey (SAP), Paul A. Newman (SAP), John A. Pyle (SAP), and Bonfils Safari (SAP).

3. The Report is divided into seven sections. The sections and authors are:

    1. Executive Summary: All
    2. Introduction: All
    3. Observations: Stefan Reimann (Switzerland), Bo Yao (China)
    4. Global emissions: Steve Montzka (USA), Sunyoung Park (South Korea)
    5. Regional emissions: Matt Rigby (UK), Andreas Stohl (Norway).
    6. CFC-11 Scenarios and Sensitivity Cases: Guus Velders (Netherlands), Helen Walter-Terrinoni (USA).
    7. Modelled Impact on the Stratospheric Ozone Layer: Martyn Chipperfield (UK), Michaela Hegglin (UK)

4. The findings included a full description of observationally derived CFC-11 emissions beginning with the Montzka et al. (2018) paper that first reported the unexpected increase of CFC-11 emissions. More recent data showed that the global emissions substantially declined in 2019 (Montzka et al., 2021). A cumulative global emission enhancement of 440 Gg is estimated up to 2019 due to the unreported production, calculated relative to the TEAP modeled emissions from the preexisting CFC-11 bank. The emissions in 2019 include contributions from: 1) the pre-existing bank in 2010, 2) the post-2010 increase of the bank due to unreported emissions, and 3) any continued unreported production and use. The report concludes that there is insufficient quantitative information to attribute the current emissions amongst these three terms.

5. A detailed explanation was included on regional emission estimates. Using inverse modeling techniques on the Gosan and Hateruma station data allows regional emissions to be estimated for Eastern Asia. CFC-11 mixing ratios during pollution events at the stations increased between 2013 and 2017, with episodic enhancements as large as 50-70 ppt. Using these data, Rigby et al. (2019) showed an emissions increase from Eastern China. CFC-11 emissions decreased substantially between this 2014-2017 period and 2019 (Park et al. 2021).

6. While the observations network is adequate to monitor global CFC-11 levels and the inter-hemispheric differences, our ability to monitor regional emissions is limited by the small number of irregularly spaced ground stations. In this presentation, we specifically reference the 11th ORM meeting's presentation: "Identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options to enhance such monitoring". https://ozone.unep.org/meetings/11th-meeting-ozone-research-managers-part-i/pre-session-documents

* The presentations have not been formally edited.

7. Regional CFC-11 emission estimates were shown for various measured regions. Australia, Western Japan, and India (2016 only) had modest emissions in the 2008-2017 period. Western European emissions have had a modest negative trend since 2008. United States emissions have trended downward over 2011-2014 and preliminary data suggest they are still relatively low. As noted earlier, Eastern China emissions increased after 2012, and decreased in 2018-19.

8. Global CFC-11 emissions have decreased substantially since they peaked in the late-1980s. Current and future CFC-11 emissions are dependent on bank magnitudes, release rates, and compliance (TEAP, 2019). Estimates from previous SAP ozone depletion assessments have assumed full compliance with the Montreal Protocol and therefore project decreased emissions through this century. Derived CFC-11 emissions up to 2016 include declining direct emissions from early CFC-11 production and products manufactured with CFC-11, augmented by any emissions from the new bank associated with unreported CFC-11 production. Projected future emissions are made with no quantitative information on bank augmentations. The anticipated recovery of stratospheric ozone will be delayed if substantial amounts of the unreported CFC-11 production were added to foam banks after 2010. Quantifying unreported CFC-11 production in the last decade and its future impact on emissions more precisely requires an improved understanding of present-day bank emissions from pre-2010 production and the likely enhancement from unreported production since 2010.

9. Atmospheric models have shown that additional ozone depletion and recovery delays result from the additional CFC-11 emissions. For every 1000 Gg of equivalent CFC-11 emissions, there is an additional 6 DU of Antarctic ozone depletion. Thus, for the 440 Gg of emissions estimated from the observations and TEAP bottom-up analysis (higher end estimate), there will be about 3 DU of additional Antarctic ozone hole depletion by 2050. This 3 DU of additional depletion will not be attributable to increased CFC-11 emissions against the improving Antarctic conditions and year-to-year variability of ozone depletion. A delay in ozone recovery from enhanced CFC-11 emissions will not be substantial because emissions were significantly elevated only for a brief period (2014– 2019).

10. CFC-12 is co-produced with CFC-11 production and CCl_4 is used as a feedstock for this process. Global CFC-12 emissions have declined since the mid-1990s. The rate of decline was slower in the 2010-2017 period than in the 2000-2009 period and there was a significant reduction in emissions after 2017. Emissions from Eastern China increased from 6.0 Gg yr^{-1} (2011-2012) to 10.9 Gg yr^{-1} (2014-2017). Emissions declined to levels indistinguishable from zero (0.8 ± 0.9 Gg yr^{-1} 2017-2019). Global CCl_4 emissions did not decline in the 2010-2019 period. Inverse analysis suggests that CCl_4 emissions from Eastern China increased after 2012 and subsequently decreased in around 2017.

B. Summary of the presentation by the decision XXXI/3 task force of the Technology and Economic Assessment Panel at the online session on unexpected emissions of trichlorofluoromethane (CFC-11) of the forty-third meeting of the Open-ended Working Group, held on 14 and 15 July 2021

11. On behalf of the Decision XXXI/3 TEAP Task Force on Unexpected CFC-11 Emissions, Mr Jose Pons, co-chair of the Task Force, summarised decision XXXI/3 paragraph 7, which requested the TEAP to provide parties with an update to the information provided in response to decision XXX/3 as well as an analysis of CFC-11 banks by geographic location and by market sector, of the linkages between the level of production of anhydrous hydrogen fluoride and carbon tetrachloride and unexpected emissions of CFC-11, of the types of products made with CFC-11, their final disposition, how to detect them, how to recover the CFC-11 that they contain, and identify possible reasons for illegal production of CFC-11 based on an assessment of alternatives to CFC-11 and those of its replacement HCFC-141b. Mr Pons highlighted the background to the decision, including the science findings, TEAP's earlier response to decision XXX/3 in 2019, that the TEAP response to decision XXXI/3 coincides with the response to decision XXX/3 from the Science Assessment Panel and its new science findings, and reminded parties that they agreed to extend the timeline for reporting until OEWG-43. Mr Pons outlined the membership of the newly formed TEAP Task Force, which built on the membership of the first Task Force, providing balanced industrial expertise and coordination with scientists from the SAP as consulting experts.

12. Mr Pons summarised the key conclusions of the earlier TEAP Task Force report in response to decision XXX/3 in 2019, namely the resumption of production of CFC-11 for use in closed cell foams as the most likely explanation for the unexpected increase in CFC-11 emissions, and that emissions cannot be explained by reported production and related usage, including emissions from pre-2010 foam banks, that reported atmospheric-derived emissions of CFC-11 from eastern mainland China

cannot be explained by expected emissions from local foam banks, and that it is unlikely that newly produced CFC-11 was used in applications other than closed-cell foams. Mr Pons reminded parties of the earlier conclusion that the most likely CFC-11 production routes were using CTC on an existing large-scale liquid phase plant with the capacity to produce different chemicals other than CFC-11, such as HCFC-22 and/or HFC-32, and also using CTC on micro-scale plants to produce low-grade CFC-11 for foam blowing use. Mr Pons provided an overview of the recent report in response to decision XXXII/3.

13. Ms Helen Walter-Terrinoni, co-chair of the Task Force, continued by outlining the CFC-11 production and market usage data critical for responding to parties' questions about the unexpected emissions. Ms Walter-Terrinoni explained that usage data was available through the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) for 1930s to 2003, which was available because of voluntary industry reporting at the time, and that market data is critical in allowing the allocation of production quantities to usage, and hence provides a quantitative understanding of banks and emissions. She described that Article 7 data reported by parties provided production data from 1989 onwards but does not include such market sector information. Ms Walter-Terrinoni reinforced the serious need for more detailed current and future global production data by market sector, which she explained is critical to the Montreal Protocol's ability to better understand expectations of emissions and to answer future questions about emissions discrepancies as a global check on compliance.

14. Ms Walter-Terrinoni explained that the inventory-based model used for the Task Force's analysis is a representation of historic reported global CFC-11 production and use that estimates CFC-11 emissions and banks over time. Ms Walter-Terrinoni outlined the refinements made to the global and regional inventory-based modelling of CFC-11 production and usage for this report, including using a Weibull distribution to better represent a range of lifetimes for chillers and foams in the active bank, incorporating new information about refrigerant management practices, and using regional and product-based models to inform bank behaviours. Ms Walter-Terrinoni explained that a compilation of emissions from different products at different life cycle stages from the model produced the estimated expected total CFC-11 emissions profile on a yearly basis, and that these were then compared with global emissions derived from CFC-11 atmospheric concentration measurements and an adopted CFC-11 atmospheric lifetime. She noted a previously identified unresolved difference that remains between observed CFC-11 emissions from foams in situ and emissions derived from regional atmospheric measurements.

15. She presented the results of the Task Force's analysis, which concludes that emissions from the pre-2010 CFC-11 bank alone cannot explain the derived CFC-11 emissions during 2013-2018. She also highlighted that unreported CFC-11 production and use would seem to have started before 2013, in the period 2007-2012, noting this is the first time that this observation had been reported by TEAP and was based on the refined inventory-based model analysis. She summarised the additional CFC-11 production that was necessary for inventory-based expected emissions to explain the derived emissions, which were 10 to 40 kilotonnes per year between 2007-2012, 40 to 70 kilotonnes per year between 2013-2018, and, for the year 2019, 15-40 kilotonnes of new production or use from recent inventory. She noted that the estimated cumulative total of unreported CFC-11 production was 320-700 kilotonnes during the period 2007-2019, and that assuming usage was in closed-cell foam production, that this leads to an estimated increase in the magnitude of the CFC-11 bank of 300 (266-333) kilotonnes by the end of 2019. Ms Walter-Terrinoni then presented the Task Force's analysis of pre-2010 CFC-11 banks by region and market sector, noting that before 2010, the majority of reported global CFC-11 production and use in closed-cell foams was in non-Article 5 parties, specifically in North America and Europe, with the quantities for Article 5 parties much smaller. She elaborated that the majority of pre-2010 CFC-11 foam banks was in closed-cell insulating foams for construction and refrigeration, with most of the active bank of about 750 kilotonnes remaining in building insulation foams in North America and Europe, and an estimated 700 kilotonnes in inactive foam banks in landfills. She noted that most foams used in refrigeration appliances had already been decommissioned and either landfilled or destroyed. Regarding centrifugal chillers, she noted that the pre-2010 active bank of CFC-11 is estimated to be relatively small. Ms Walter-Terrinoni explained that there was likely a combination of possible drivers for illegal CFC-11 production and trade. For blowing agent use for closed cell foams, possible drivers included higher pricing and a lack of availability of HCFC-141b owing to its phase-out, the economic attractiveness and technical ease of reverting to CFC-11, the belief that flammability might be reduced by using CFC-11 as a blowing agent without the need for expensive fire retardants, and challenges with the HCFC-141b phase-out in the spray foam sector and for SMEs, including with the adoption of alternatives.

16. Ms Helen Tope, co-chair of the Task Force, continued by outlining possible drivers for the production sector relating to technical opportunity and economics. She explained that purpose-built liquid phase swing plants could produce a range of CFC-11/12, HCFC-22, HFC-32, and swing to produce one or the others, that they have a larger range of allowable operating parameters that allow them to make a large range of products and are designed to minimise economic impacts when swinging between products. She further explained that, on the other hand, large plants built for production of a single product are technically capable of swinging to another product but at the cost of reduced capacity and product quality and being economically less suited to swinging. Micro-scale plants on the other hand would be low tech, low cost, easy to relocate, hard to detect but are limited economically by their small annual production capacity, and more than 20 and up to 700 plants would be needed to meet the large-scale unreported CFC-11 production. Ms Tope reported on the linkages between raw material production of hydrogen fluoride and carbon tetrachloride and the unexpected CFC-11 emissions, saying that, given the most likely production route, there are direct linkages. She noted, however, that there are important differences between the hydrogen fluoride and carbon tetrachloride production linkages associated with their different regulation, global demand and use that make carbon tetrachloride production the most important linkage in tracking potential CFC-11 production. She elaborated that 45 to 120 kilotonnes of carbon tetrachloride would be required to supply 40 to 70 kilotonnes CFC-11 production annually in the period 2013-2018, depending on the proportion of co-produced CFC-12, which could be between 0 and 30 percent. She noted that the quantities of carbon tetrachloride required were expected to be at the lower end of that range. She further noted that the cumulative quantity of carbon tetrachloride required to produce the estimated cumulative 320-700 kilotonnes of CFC-11 would be at least 360 kilotonnes and could be considerably higher depending on CFC-11 selectivity. She explained that given the scale and logistics of production, and that carbon tetrachloride supply for unreported CFC-11 production went undetected, it seems more likely that CFC-11 production occurred within the same country, and even on the same site, as carbon tetrachloride production. She stated that any additional unexpected emissions of CFC-12 are likely to be as a co-product associated with the production of CFC-11, rather than from any specific production initiated to supply CFC-12 in its own applications, with emissions trends more consistent with emissions releases during production than non-emissive uses, although CFC-12 uses could not be ruled out.

17. Ms Tope reported on the fate of CFC-11 products and the CFC-11 contained therein, stating that opportunities to recover CFC-11 are limited to active banks of mainly insulation foams and to a lesser extent of centrifugal chillers. She explained that landfill is the most common disposal practice for foams, with nearly all CFC-11 emitted over time. She further noted that only a few countries recover and destroy foams and their blowing agents, a practice where economies of scale are important. She elaborated that combining foam wastes containing ozone-depleting substances and hydrofluorocarbons would realise the largest economies of scale and accrue the greatest benefits in recovery and destruction. She stated that the few CFC-11 centrifugal chillers remaining mostly in the United States are likely to continue to operate for the next 10-20 years and leak very little, and that, if recovered, CFC-11 is either destroyed or reclaimed for re-sale and reuse. She stated that up to about 1,100 kilotonnes (5.2 Gigatonnes CO_2eq.) of CFC-11 from active banks are available for recovery, including about 800 kilotonnes from pre-2010 active banks and 300 kilotonnes from active banks resulting from unreported CFC-11 production and use during 2007-2019. She explained that the global peak of decommissioned CFC-11 from active banks, when dismantled at end-of-life, is estimated to have occurred around 2010, at about 45 kilotonnes per year, then slowly decreases over time. She added that there are underlying variations to the timing of the regional peaks in CFC-11 foam decommissioning, where some regions and foams types are likely yet to have reached their decommissioning peaks, such as building foam panels in Europe. She presented new information showing the impact of the unreported CFC-11 production and use on active bank decommissioning over time, which results in a slower rate of decline in CFC-11 decommissioning after the 2010 peak and higher annual decommissioned quantities and changed underlying variations in foam types based on usage assumptions.

18. Ms Tope summarised the challenges and opportunities to recovery and destroy CFC-11, noting the SAP conclusion from the 2018 Assessment that future emissions from ODS banks continued to be a slightly larger contributor than future ODS production to ozone layer depletion over the next four decades. She explained that the opportunities for CFC-11 recovery and destruction lie in the higher management of active foam banks at end-of-life, with potential diversion of foam wastes away from landfill towards destruction, thereby mitigating emissions. She noted that investment and operating costs in ODS waste recovery and destruction present a challenge compared with relatively cheaper forms of disposition through venting and landfill disposal. She explained that destruction costs represent a minor portion and recovery costs represent the major portion of total costs. She noted that venting and landfill costs do not reflect the true cost of these forms of disposal because they do not

include the costs to society of future health and environmental impacts of associated emissions. She suggested that with long building lifetimes the drivers for recovery and destruction of CFC-11 building insulation foams might change over time and that end-of-life choices might improve with the evolution of net zero carbon requirements and the circular economy. Ms Tope explained that while sampling and detection methods and technologies are available, parties may wish to consider strengthening enforcement and training to ensure opportunities are not being overlooked to detect CFC-11, or any controlled substance, and to alert authorities to illegal marketing or use. Mr Pons continued by summarising the key conclusions.