Decision XXX/3 TEAP Task Force on Unexpected Emissions of CFC-11

Preliminary Report May 2019

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41st OEWG
Bangkok, 1-5 July 2019

Decision XXX/3: Unexpected Emissions of CFC-11

Noting the recent scientific findings showing that there has been an unexpected increase in global emissions of trichlorofluoromethane (CFC-11) since 2012, after the consumption and production phase-out date established under the Montreal Protocol…

2. To request the Technology and Economic Assessment Panel to provide the parties with information on potential sources of emissions of CFC-11 and related controlled substances from potential production and uses, as well as from banks, that may have resulted in emissions of CFC-11 in unexpected quantities in the relevant regions; a preliminary report should be provided to the Open-ended Working Group at its forty-first meeting and a final report to the Thirty-First Meeting of the Parties;

3. To request parties with any relevant scientific and technical information that may help inform the Scientific Assessment Panel and Technology and Economic Assessment Panel reports described in paragraphs 1 and 2 above to provide that information to the Secretariat by 1 March 2019;

- A submission was received from one party.

TEAP Task Force

Members	Affiliation	Party	Members	Affiliation	Party
Jose Pons	MCTOC member	Venezuela	Miguel Quintero	FTOC member	Colombia
Helen Tope	MCTOC co-chair	Australia	Enshan Sheng	Huntsman	Singapore
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Rabinder Kaul	SRF Limited	India	Archie McCulloch	Retired private consultant	UK
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Richard Lord	Carrier	USA	Matt Rigby	University of Bristol	UK
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Keiichi Ohnishi	MCTOC co-chair	Japan	Guus Velders	Utrecht University	Netherlands
Fabio Polonara	RTOC co-chair	Italy	Dan Verdonik	HTOC	USA

Overview of Preliminary Report

- Preliminary Report addresses elements of response:
  - Production of CFC-11 and related controlled substances
  - Aerosols, solvents and miscellaneous uses
  - Refrigerant uses
  - Foams uses
  - Emissions modelling and analysis, including banks
- Preliminary Report analyses, at the global level, the likelihood of potential sources of emissions, eliminates unlikely sources, and identifies remaining potential sources for further consideration for the Final Report, and additional information needed.
- Final Report to be completed mid-September for 31st MOP.

Background (1)

- CFC-11 was used as a foam-blowing agent (for open and closed cell foams), aerosol propellant, refrigerant (for centrifugal chillers), and in smaller uses, e.g., asthma inhalers, tobacco expansion. Alternatives replaced former uses.
- CFC-11 production/consumption in non-A5 parties was phased out in 1996, and in A5 parties in 2010, with some limited exceptions, e.g., for basic domestic needs.
- A bank of CFC-11 remains in closed cell foams and centrifugal chillers, from which CFC-11 is released into the atmosphere over time.

Background (2)

- Montzka *et al.* (Nature, May 2018) reported an unexpected, global increase in CFC-11 emissions of 13,000 ± 5,000 tonnes/ year after 2012. The study suggests:
  - A concurrent increase in CFC-11 emissions from eastern Asia, although the regional contribution to the global increase was not quantified.
  - The CFC-11 emissions increase arises from new production that has not been reported to the Ozone Secretariat.
- Rigby *et al.* (Nature, May 2019) provides additional quantification and investigation of regional emissions, published after the Preliminary Report was completed.

Production: Options for CFC-11

- Task Force considered the technical and economic feasibility of 20 potential CFC-11 production routes.
- Main manufacturing process routes to CFC-11 use carbon tetrachloride (CTC) as feedstock.
- A range of potential CFC-11 production quantities annually were considered from small-scale production (≤ 10,000 tonnes per year) to large-scale production (≥ 50,000 tonnes per year).
- The most likely CFC-11 production routes are:
  - CTC to CFC-11 on micro-scale plants using minimal equipment (to make low-grade CFC-11 for foam blowing use); and/or,
  - CTC to CFC-11/12 on a large-scale in an existing liquid-phase plant (HCFC-22 plant).
- If CFC-11 production is ≥ 50,000 tonnes/yr, then it seems less likely that a large number of micro-scale plants would be solely responsible, although some micro-scale plants could also be contributing to production.

Production: Relationship to CFC-12

- Using traditional process routes, a mix of CFC-11 and -12 is produced, with the proportion controlled by varying operating conditions.
  - 100% CFC-12 is achieved relatively easily.
  - 100% CFC-11 is more difficult to achieve, but not impossible in well-operated facilities.
  - Operating range of 30:70, either way, can be comfortably achieved.
  - More than 90% CFC-11 is possible with process modifications.
  - Emissions from production are low (average 0.5%).
- Near 100% CFC-11 production is possible in purposefully designed and operated micro-scale plants, with emissions likely higher (up to 10%).
- With economics of destruction and venting, it is more likely that a small co-production of CFC-12 would be sold into limited uses.

Production: Spare Capacity in Existing HCFC-22 Plants

- Production of CFC-11 (and CFC-12) is possible in existing HCFC-22 plants.
- Spare annual capacity to produce CFC-11 in an existing HCFC-22 plant is estimated to be available in the following countries:
  - Argentina, Mexico, Russia, and Venezuela for small-scale CFC-11 production (≤ 10,000 tonnes);
  - European Union and United States for medium-scale CFC-11 production (between 10,000 and 50,000 tonnes);
  - China for large-scale CFC-11 production (≥50,000 tonnes).

Production: Options for CTC

- CTC is produced in:
  - Chloromethanes (CMs) plants as an unavoidable part of the production of dichloromethane and chloroform, or
  - Perchloroethylene (PCE)/CTC plants, according to demand.
- In 2016, the global maximum amount of potential CTC available from CMs production was 305,000 tonnes, after existing local supply commitments had been met.
  - A number of regions have spare annual capacity that might allow CTC production in the amounts required for small-scale CFC-11 production.
  - China, European Union, and United States have largest CMs capacities, and also largest potential CTC availability.
  - Only China has the spare annual capacity that could supply the larger amounts of CTC required for large-scale CFC-11 production.
- Five PCE/CTC plants operative in EU and US.
  - Spare global capacity to produce CTC by this process is estimated to be between 50,000-100,000 tonnes per year, existing mainly in the European Union.

Production: Illicit International Trade

- The Task Force has not found or received evidence, from customs or other agency activities, that illicit international trade in significant quantities of CFC-11 or CTC has occurred after the phase-out.
- However, there have been indications of marketing of CFC-11 for use in foams in recent years (2016-2018).

Aerosols, Solvents and Miscellaneous

- The main use of CFCs was as a pressurized liquid in aerosols, which is an emissive use.
- CFC-11 worked very well in combination with CFC-12. CFC-11 cannot be used alone as a propellant due to its physical properties.
  - Mixtures of hydrocarbon propellants and CFC-11 are technically feasible.
- It is **unlikely** that CFC-11 would be produced or used for aerosols; hydrocarbon propellants are much cheaper than CFCs.
- It is **unlikely** that CFC-11 would be used:
  - In a newly established plant as a process agent in manufacturing synthetic fibre sheet.
  - As a solvent.
  - For tobacco expansion or the processing of uranium.

Refrigeration and Air Conditioning

- A small number of CFC-11 chillers are still in operation and expected to reach their end of life in the next 1 to 5 years. It is **unlikely** that CFC-11 production would be employed to maintain the very small number of operating CFC-11 chillers.
- Based on estimates of CFC-11 chiller banks and emissions, it is **highly unlikely** that emissions from CFC-11 chillers are the cause of the sudden increase of global CFC-11 emissions.
- There might be a small CFC-12 demand for a limited number of CFC-12 mobile ACs in some vehicles built before 2002 in A5 parties.
- It is **unlikely** there is significant resumption of CFC-12 usage in R/AC sub-sectors in both non-A5 and A5 parties, implying no significant new CFC-12 production is needed.

Foams Background

- CFC-11 was used mainly in open-celled flexible polyurethane (PU) foams (e.g., bedding and other uses) until the mid-1960s.
- CFC-11 was then primarily used in closed-cell rigid insulating polyurethane (PU) foams for appliances and construction, with CFC-11 usage peaking in the late 1980s.
- CFC-11 is low cost and easy to use in closed-cell PU foam.
- Recent indications of CFC-11 marketing and technical activity in foams after phase-out:
  - FTOC was provided with a copy of an offer for sale of CFC-11 through distribution, has seen offers for sale on internet websites (since removed), and learned more through industry discussions.
    - One example of minimum orders was 15.5 tonnes CFC-11
    - One example quoted 2,200 USD per tonne CFC-11 (Jan. 2018)
  - Patent applications filed for foam products.

Foams: Potential Drivers and Feasibility

- Conversion from HCFC-141b back to CFC-11 in PU foams and pre-blended systems would be low-cost with almost no technical changes needed.
  - Single quoted CFC-11 price is lower than market price of HCFC-141b.
- The phase-out of HCFC-141b in the spray foam sector and in SMEs has created technical and economic challenges that might promote the use of CFC-11, although actual usage has not been confirmed.
  - Lack of available HCFC-141b supply due to production phase-out.
  - Increasing price of HCFC-141b due to the allocation-based supply and demand imbalance.
  - Negative aspects to alternatives:
    - Flammability of hydrocarbons and associated conversion investment
    - Higher cost of HFCs and HFOs
  - Not all companies in A5 parties are funded by MLF. Single year of MLF funding for HCFC-141b conversions for funded companies.

Foams Findings

- Based on its current assessment (including modelling), the Task Force finds that production of closed-cell foam products using CFC-11 may be a potential source of the increased emissions, as it is technically and economically feasible.
- If the observed increased CFC-11 emissions are due to new CFC-11 production used in closed-cell foams, actual CFC-11 production would be significantly larger than the increased emissions detected to date.
  - The non-emitted CFC-11 would accumulate in the foam banks, from which it would be slowly released over time.
- In open-cell foams, although technically feasible, there is little economic incentive in replacing very low cost dichloromethane with CFC-11. Nevertheless, the Task Force will consider regulatory limitations on the use of dichloromethane in flexible foams.

Foams: End-of-Life Emissions

- There is a difference between the projected estimated CFC-11 emissions rates from foams banks (including landfills) (< 1.5%) and atmospheric derived emissions rates (3-4%), including in regions where CFC-11 has not been used in foams in decades.
  - This difference could be partly explained by handling losses during dismantling and disposal practices that are not best practice.
- The increased CFC-11 emissions are unlikely to come from traditional handling of foams at end-of-life alone.
- The Task Force found no evidence for a significant change in end-of life foam processes.
- Further investigation into emission rates from foams banks is warranted to differentiate these background emissions from other potential new sources, in order to better quantify these other potential sources.

Emissions and Banks Modelling:
IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System (the "SROC" report)

- The 2005 SROC report included scientific and technical information regarding alternatives to ODSs that may also affect the global climate system. It was published in 2005 before the sudden increase in CFC-11 emissions.
- SROC estimated bank sizes and maximum possible emissions in business as usual (BAU) and mitigation scenarios from 2002-2015.
- The Task Force analysis concludes that emissions associated with banks, as calculated in the SROC report, cannot explain the increased atmospheric derived CFC-11 emissions in recent years.

Emissions and Banks Modelling: New Emissions Model and Sensitivity Analysis

- The Task Force developed a new “bottom-up” global CFC-11 emissions model followed by a sensitivity analysis.
- The analysis evaluated the impact of specific variables (e.g., emissions from potential CFC-11 production, installation into foams or chillers, existing banks, or end-of-life disposal) on the estimated “bottom up” emissions.
- These were compared with the atmospheric derived global emissions (“top-down”).
- The Task Force determined that past production, historic usage, and the resulting bank, are **unlikely** to account for the increased global CFC-11 emissions.

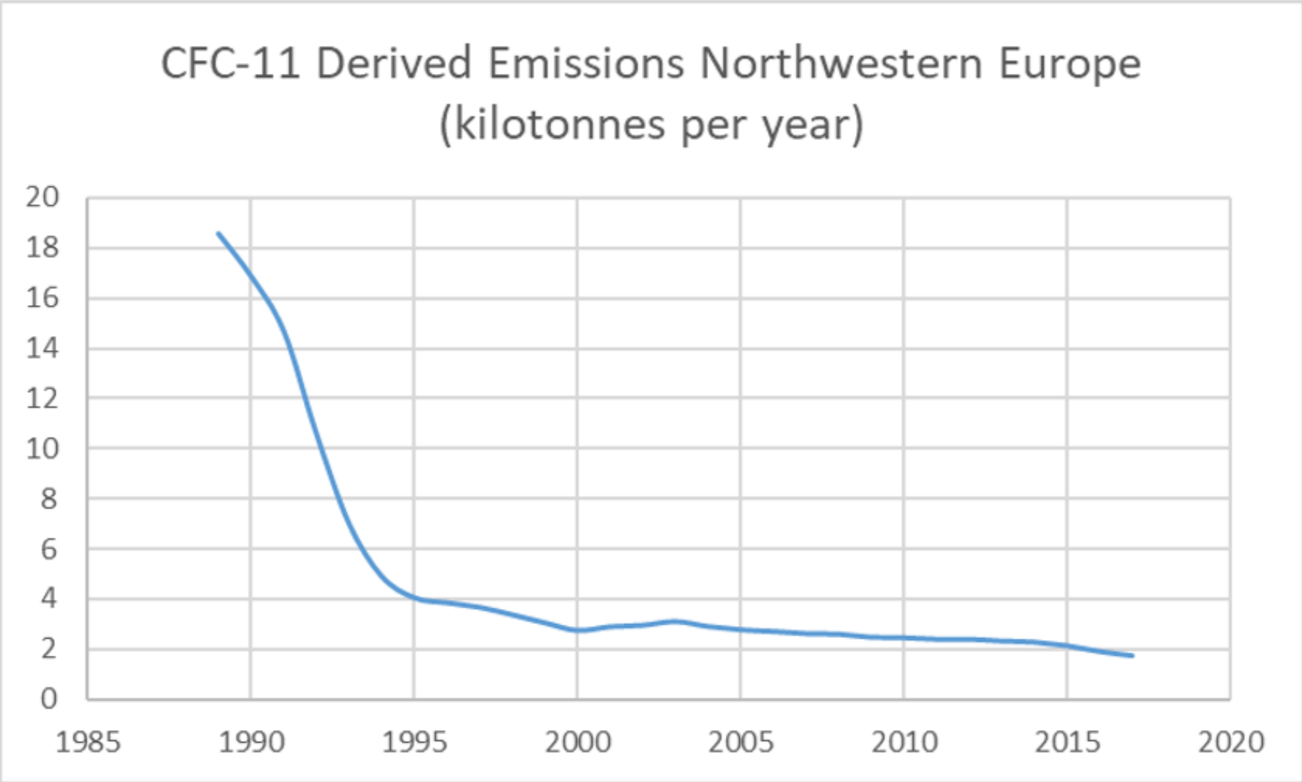
Emissions and Banks Modelling:

Emissions Rates from Banks in Western Europe

- Another approach to exploring emissions from CFC-11 banks is to examine localised CFC-11 emissions in different regions of the world ("top-down").
- The majority of CFC-11 in banks are contained in foams. Foam banks are mostly landfilled or destroyed. There are generally very low emissions rates from these processes.
- Emissions from banks in Western Europe (derived from atmospheric measurements), where CFC-11 has not been consumed for several decades, continue to decline generally.
- Unless banks are treated very differently in other regions, which is unlikely, the Western Europe bank emissions rates can be considered typical and extrapolated to estimate global bank emissions rates.
- The overall decline in emissions shown by this regional CFC-11 bank once again demonstrates that the unexpected increased CFC-11 emissions cannot be explained by the global CFC-11 bank.

CFC-11 Atmospheric Emissions from Northwestern Europe

Figure 6.6 CFC-11 atmospheric emissions in northwestern Europe (in kilotonnes or gigagrams) as derived from the Mace Head monitoring site in Ireland (UK NIR)[107]



Emissions and Banks Modelling:

Derived Atmospheric Emissions of Foam Blowing Agents

- Observed global HCFC-141b atmospheric emissions have started to decline in recent years, as expected with the production freeze and phase-down.
- The sum of derived global emissions from higher boiling, fluorocarbon blowing agents for PU closed-cell foams (CFC-11, HCFC-141b, HFC-245fa, HFC-365mfc) have been gradually increasing since 2004, in parallel with increased PU foam use.
- Derived global CFC-11 emissions have increased while HCFC-141b emissions decreased. This is not conclusive; however it is consistent with some replacement of HCFC-141b with CFC-11 in closed-cell PU foams.

Emissions and Banks Modelling: Emission Source Scenarios (1)

- The Task Force tested additional hypothetical scenarios beyond the scope of the sensitivity analysis in an attempt to duplicate the derived increased atmospheric emissions.
- Some extreme hypothetical assumptions **did not align** with derived increased emissions:
  - Increasing CFC-11 bank emissions rates by 50%
  - Decreasing CFC-11 bank emissions rates by 50%
  - 35 kilotonnes per year of CFC-11 used to charge chillers

Emissions and Banks Modelling: Emission Source Scenarios (2)

- Some extreme hypothetical assumptions **aligned** with derived increased emissions, **but are implausible**:
  - Increases in CFC-11 bank emissions rates, changing in different time periods. There is no known reason that global foam bank emissions rates would increase from less than 2% per year to much larger rates of 8% to 24% per year after 2012.
  - New CFC-11 used in open-cell foam seems unlikely because dichloromethane is much cheaper ($0.7/kg).
  - Direct release of 25-50 kilotonnes/year of newly produced CFC-11.

Emissions and Banks Modelling: Emission Source Scenarios (3)

- Only one category of extreme hypothetical assumptions **aligned** with the derived increased emissions **and remains plausible**:
  - 35-70 kilotonnes per year of CFC-11 used in closed-cell foams.

Summary Conclusions

- The Task Force evaluated a number of scenarios and eliminated most of them because:
  - They do not explain the unexpected emissions;
  - They are technically infeasible;
  - They are economically infeasible.
- The only remaining plausible scenario is the use of newly produced CFC-11 in closed-cell PU foams.
- CFC-11 production would also require CTC production.
- The Task Force will continue to refine its analysis for the Final Report.

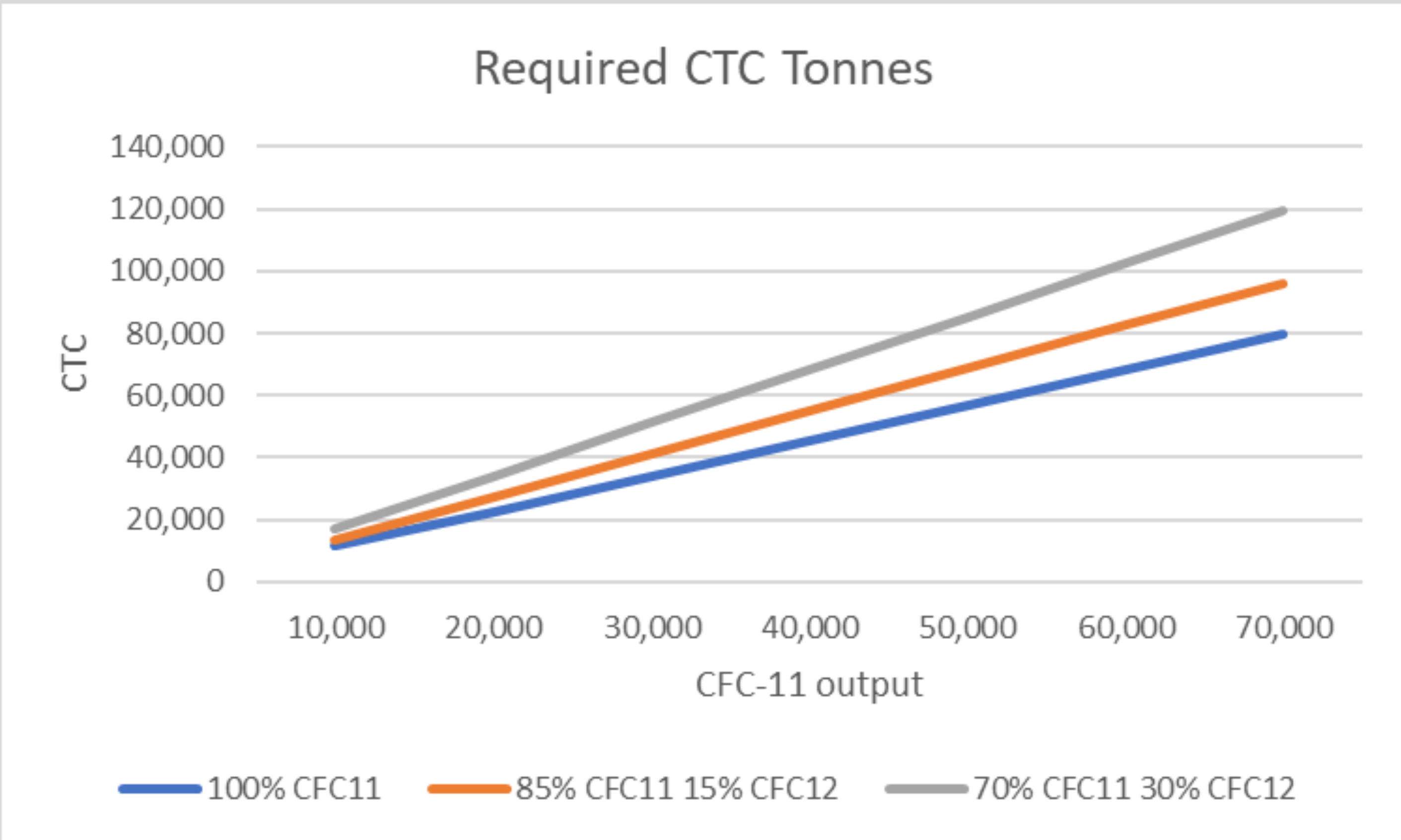
Thank You

Estimated Spare Capacity of HCFC-22 Available to Produce CFC-11 or Other Products (kilotonnes per annum)

Region/Country	Estimated Spare Capacity
Argentina	<10
China	>50
EU	<50
India	0
Japan	0
Mexico	<20
Russia	<10
USA	<50
Venezuela	<10

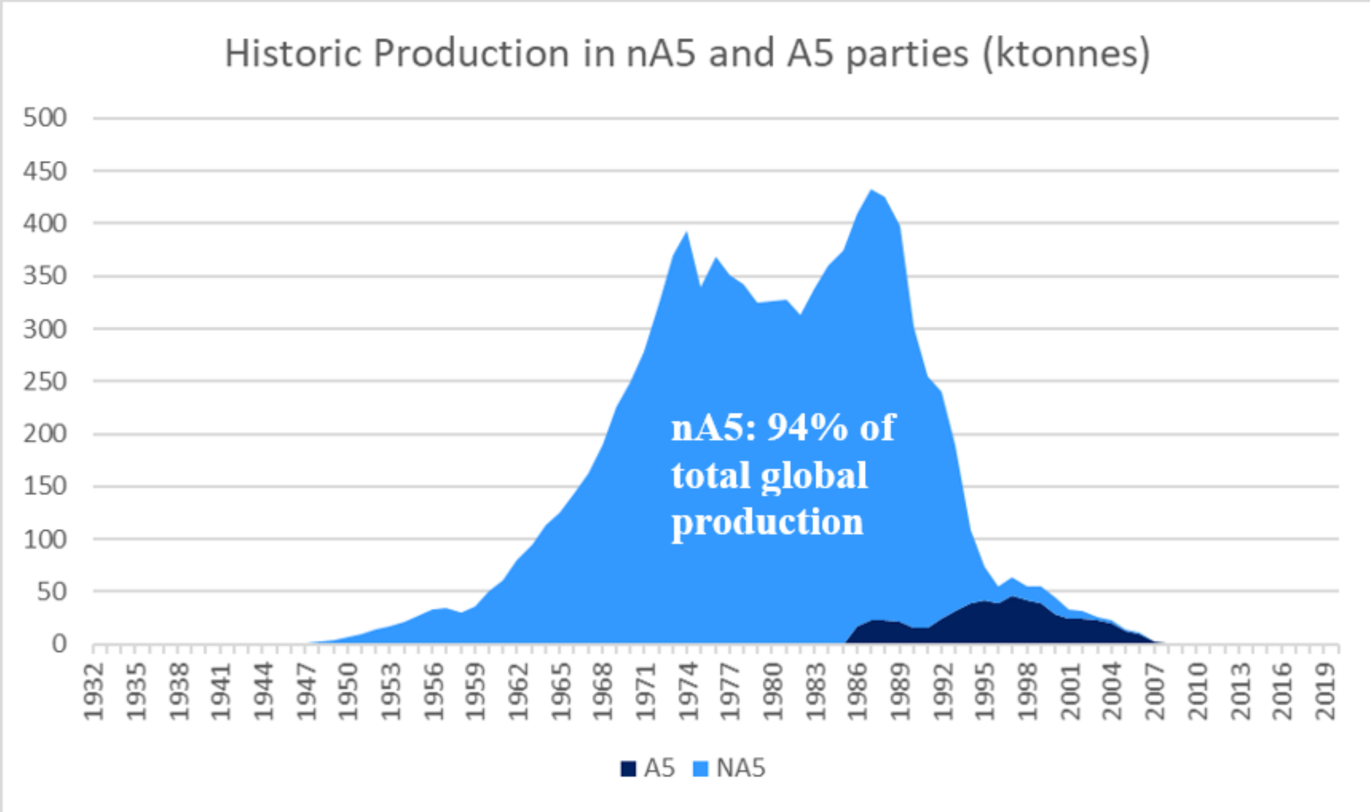
CTC Quantity Required for CFC-11 Output (tonnes)

Figure 2.3 CTC quantity required for CFC-11 output



CFC-11 Production in nA5 and A5 Parties

Figure 6.2 Historic production in non-Article 5 and Article 5 parties

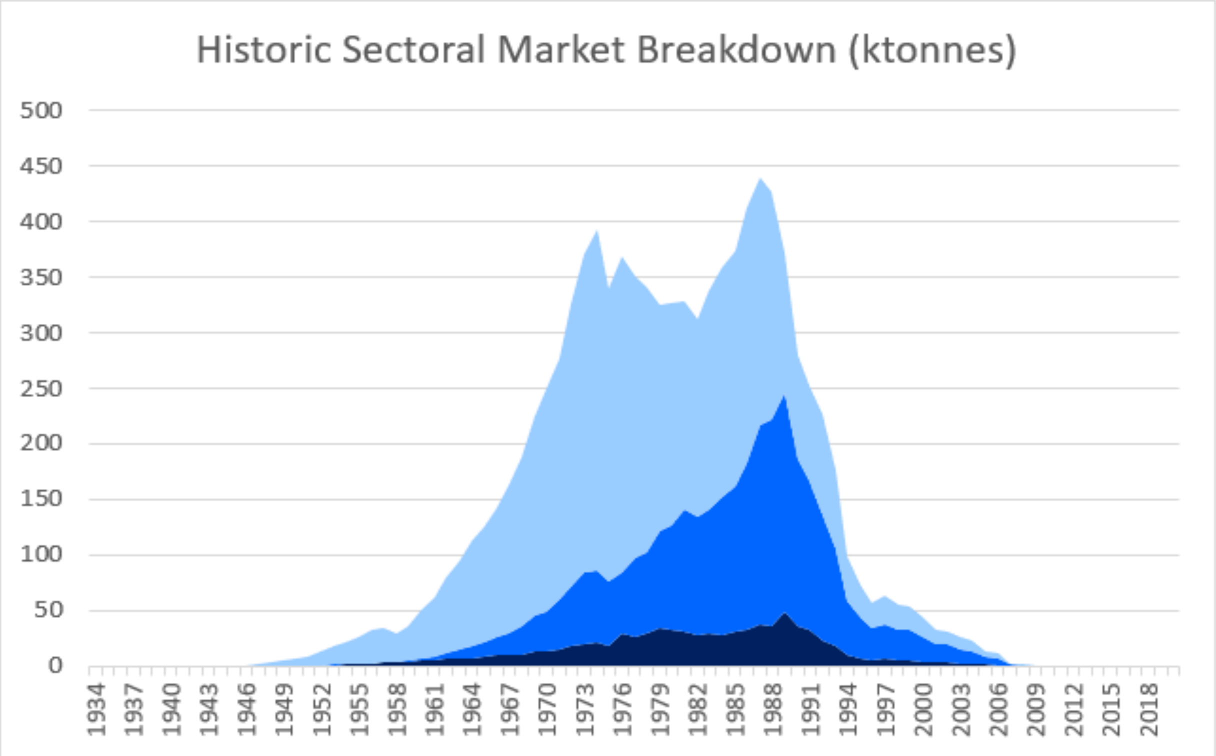


Note: Production shifted to Article 5 parties in the 1990s. Of the 9.7 billion tonnes of CFC-11 produced, 6% of the total was produced in Article 5 parties and the other 94% was produced in non-Article 5 parties.

*AFEAS and Article 7 reported production

Historic CFC-11 Sales into Market Sectors

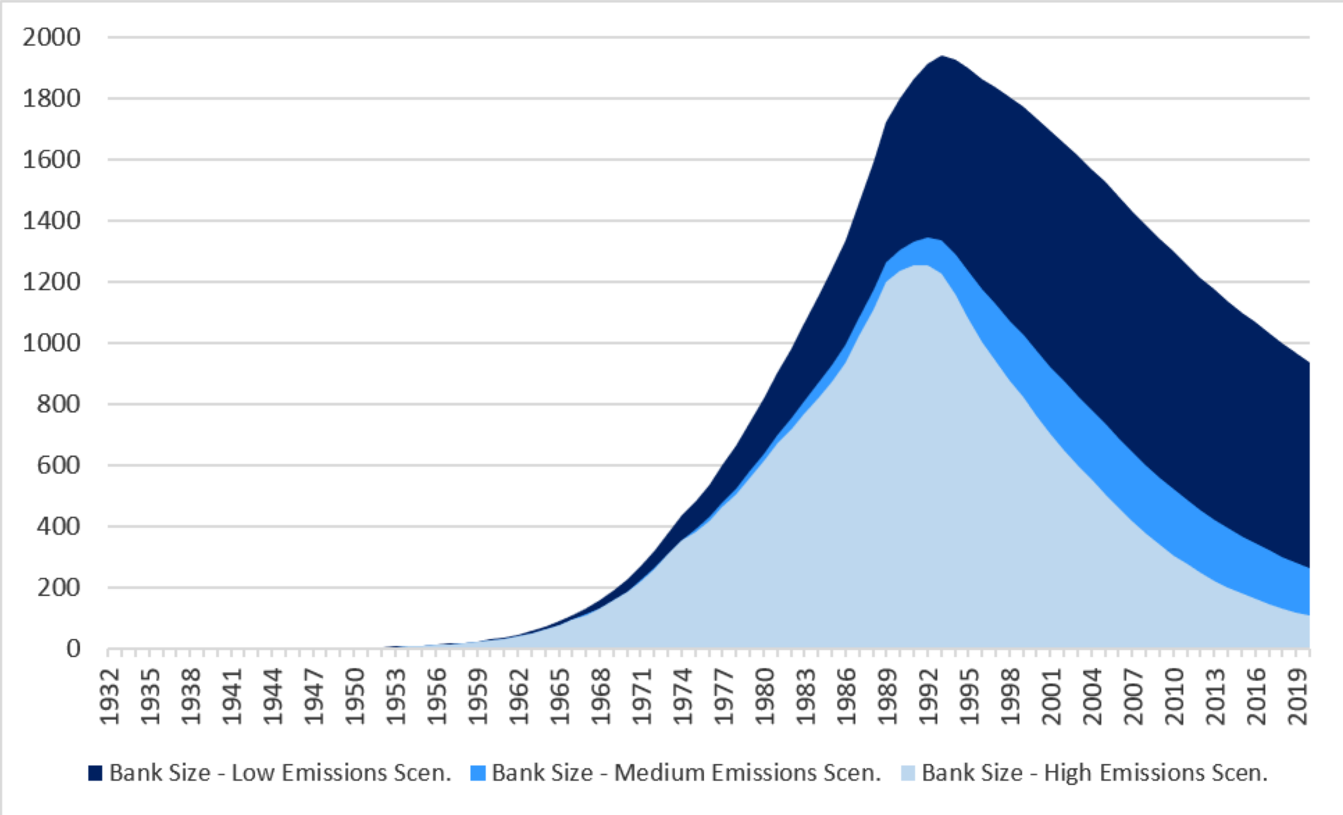
Figure 6.1 Historic sales sectoral market breakdown based on AFEAS data



Note: Sales sectoral breakdown was reported in the AFEAS data. From 1989 onwards when data was consistently reported to UNEP, the sectoral breakdown was no longer reported, and the assumption made is that the market comprised of 10% R/AC, 50% rigid foam and 40% emissive uses.

CFC-11 Bank Sensitivity Analysis

Figure 6.5 Range of "bottom-up" bank sizes as derived from the scenarios shown in Table 6.1



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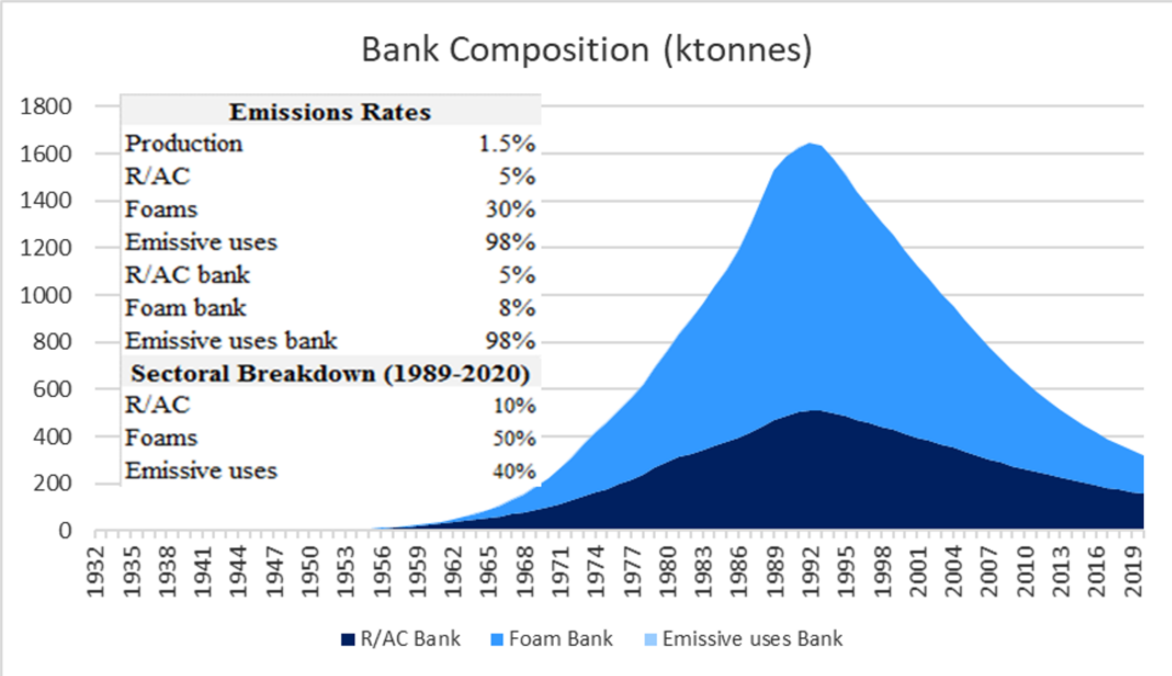
Historic CFC-11 Bank Composition*

Figure 6.3 Historic bank composition



Note: CFC-11 banks are mostly comprised of R/AC equipment and the rigid foams. Emissive uses contribute minimally to the bank and thus are barely visible. Data started being consistently reported to UNEP[101] in 1989. The sectoral breakdown of CFC-11 uses is not included in the UNEP reporting so assumptions were made (see Table).

A number of scenarios were developed using a range of emissions rates resulting in a range of bank sizes and compositions.

*Estimated emission rates are percentage per year

Range of Dependent Variables Used in the CFC-11 Sensitivity Analysis

Table 6.1 Range of dependent variables used in the sensitivity analyses resulting in the calculated CFC-11 "bottom-up" emissions and banks shown in Figures 6.4 and 6.5

Variables	Low	Medium	High
Production & Distribution Emissions Rate	0.5%	1.5%	5%
Refrigeration Installation Emissions Rate	2%	5%	10%
Foam Emissions Installation Rate	25%	30%	35%
Emissive Uses Installation Emissions Rate[103]	98%	98%	98%
Refrigeration Banks Emissions Rate	2%	5%	10%
Foam Banks Emissions Rate	4%	8%	10%
Emissive Uses Bank Emissions Rate	98%	98%	98%
Sectoral Breakdown: Refrigeration/Closed cell/Emissive	13/53/34	10/50/40	10/40/50
Reported Production[104]	100%	110%	120%

Note: Production data as reported to AFEAS and UNEP.[105]

Emission Source Scenarios Attempting to Duplicate Derived Atmospheric Emissions of CFC-11

Table 6.2 Emission source scenarios attempting to duplicate derived atmospheric emissions of CFC-11

Emissions Source Scenario[117]	Aligned with Derived Emissions?	Extreme Assumptions		Conclusions and any Additional Recommendations
Bank Emissions Rate Increases or Decreases	No	Emissions rate increase or decreased by 50%		No known practical emissions source or evidence of sufficient volumes to explain the unexpected emissions
Bank Emissions Rate Increases for foams and chillers as per table	Yes	Range of years 1934 to 2002 2003 to 2006 2007 to 2011 >2012	Chiller/Foam emissions rates per year 5%/8% 7%/11% 10%/16% 15%/24%	No known practical emissions source Especially for foams
New CFC-11* used in chillers	No	35 ktonnes per year in 2002-2010 70 ktonnes per year >2010		Commercially unlikely
New CFC-11 used in Closed Cell Foam	Yes	35 ktonnes per year in 2002-2009 70 ktonnes per year >2009		Additional exploration recommended
New CFC-11* used in Open Cell Foam	Yes	25 ktonnes per year 2002-2010, 50 ktonnes per year >2010		Commercially unlikely and overall balance of foam blowing agents inconsistent
New CFC-11* released	Yes	25 ktonnes per year 2002-2010 50 ktonnes per year >2010		Commercially unlikely

* New CFC-11 could come from new production and/or previously stockpiled inventory

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