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Technical note: A method for calculating offsets to ozone depletion and climate impacts of ozone-depleting substances

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The usage of different ozone-depleting substances has implications on estimating the magnitude of impacts to be offset. We summarize below some of the usage considerations by substance.

S.1 CFC-11 and CFC-12

Historically, CFC-11 was manufactured using CCl_4 as a feedstock and was typically co-produced with CFC-12 to optimize chemical process efficiency. One implication is that detection of unexpected CFC-11 production is likely to be also associated with unreported production of CFC-12, although large uncertainties in annual estimates of global CFC-12 emissions (4–10 Gg yr^{-1}) have confounded efforts to detect unusual enhancement in CFC-12 emissions in recent years (Montzka et al., 2021; Park et al., 2021). Furthermore, if there is no clandestine market for unavoidable production of either substance, the substance will likely eventually be discharged and escape to the atmosphere, since destruction would involve added cost and complication.

Prior to phaseout under the Montreal Protocol, CFC-11 was principally used as a foam blowing agent and as a low-pressure refrigerant. If used for manufacturing flexible foam, emissions of CFC-11 are immediate. If used for manufacturing rigid foam or as a refrigerant, emissions of CFC-11 are distributed over the life of the product whether in its product application or in disposal unless incinerated. The 2019 Montreal Protocol Technology and Economic Assessment Panel (TEAP) Task Force concluded that "it is likely that a resumption of newly produced CFC-11 usage in closed-cell foams in some regions was the dominant cause for the emission increase after 2012, due to technical ease and economic advantage of its use." (TEAP, 2019) The implication is that a good fraction of the emissions will lag production by many years, so the CFC-11 contained in these newly produced foams will continue to escape to the atmosphere and enhance CFC-11 emissions for many years into the future. The TEAP conclusion does not rule out increases in other historic CFC-11 uses adding to the unexpected emission increase after 2012, such as drug manufacture, uranium enrichment by gaseous diffusion, wind chambers, and other specialized experimental, analytical, and laboratory uses. The Montreal Laboratory and Analytical Use Exemption allows the continued production and import of small amounts of class I ODSs (CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide, and bromochloromethane) (but not class II ODSs, e.g., HCFCs) for such uses as equipment calibration and biochemical research; as an extraction solvent, diluent, or carrier for chemical analysis; as inert solvent for chemical reactions; and other critical analytical and laboratory purposes (United Nations, 1994).

CFC-12 was principally used prior to phaseout as a propellant in aerosol products and as refrigerant. Propellent emissions are coincident with product use, while refrigerant emissions are small during manufacture of refrigeration and air conditioning appliances (McCulloch et al., 2003). While a larger fraction of CFC-12 refrigerant emissions are associated with leakage during installation, servicing, use, and disposal at end of the refrigeration and air conditioning appliance life than is true for CFC-11 in its main uses, there will still be significant emissions from air conditioning and refrigeration equipment long after that equipment was produced (Andersen et al., 2007).

S.2 CFC-113, CFC-113a, CFC-114a, and CFC-115

CFC-113 was predominantly used prior to phaseout as an electronics and aerospace solvent, with ongoing use as a feedstock. Prior to phase out, the annual emissions were roughly equivalent to production (adjusted for quantities held in inventory). While CFC-113 production has been phased out by the Montreal Protocol, CFC-113 and other ODSs, when used as feedstocks and entirely consumed, are currently exempted from calculations of controlled substances produced and consumed under the Montreal Protocol (Andersen et al., 2021). Ongoing substantial use of CFC-113 as a feedstock likely results in annual emissions in the amount of production that is not chemically converted into new chemicals. Early in the history of the Montreal Protocol, parties assumed that feedstock emissions would be *de minimis,* but they are now realized that they can be significant, arising from the manufacturing of chemicals and products such as plastics (Andersen et al., 2021). While products made with or containing CFC-11 and CFC-12 are typically easily identified, products made using CFC-113 solvent are almost impossible to identify due to evaporation of the solvent with no discernible residue.

Emissions of other CFCs allowed for production when used as feedstocks have been growing, with CFC-113a growing the fastest with 244% increase in emissions between 2010–2020, CFC-112a emissions growing by 169%, and CFC-114a growing 108% over the same period, although there are no known current uses for CFC-13 and CFC-112a (Western et al., 2023).

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