CHAPTER 4

Strengthening the Global Regulation of Hydrofluorocarbons under the Montreal Protocol

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1 Introduction

The production and consumption of hydrofluorocarbons (HFCs) have increased significantly as a result of actions taken by member parties under the Montreal Protocol on Substances that Deplete the Ozone Layer (1987).[1] While HFCs have a low potential to deplete stratospheric ozone and remain in the atmosphere for significantly less time than carbon dioxide (CO_2),[2] many are potent greenhouse gases and, together with methane, black carbon, and tropospheric ozone, are classified as short-lived climate pollutants (SLCPs).[3] Reducing emissions of HFCs is thus important in regard to climate change mitigation. In a significant move, the Parties to the Montreal Protocol, in 2016, agreed to the addition of HFCs to the list of substances controlled by the Montreal Protocol.

This chapter first provides an overview of HFCs and emphasises their contribution to climate change. The section following discusses the international law regime for stratospheric ozone depletion and its application to HFCs. In doing so, it considers the events leading up to the development of the international ozone regime and provides an overview of this regime, focusing particularly on the Montreal Protocol. It also discusses the effectiveness of the ozone regime generally, as well as gaps that have been identified in relation to HFCs, and highlights potential ways in which these gaps could be addressed. The

1 Montreal Protocol on Substances that Deplete the Ozone Layer (signed 16 September 1987, entered into force 1 January 1989) 1522 UNTS 3.
2 While the average lifetime of HFCs is generally relatively short, the lifetime of HFC-23 (a by-product of the manufacture of HCFC-22) is 228 years: World Meteorological Organisation (WMO), 'Scientific Assessment of Ozone Depletion: 2018' (Global Ozone Research and Monitoring Project – Report No. 58, 2018) <https://www.esrl.noaa.gov/csl/assessments/ozone/2018/> accessed 10 December 2021, Appendix A.
3 CCAC, 'Short-lived Climate Pollutants (SLCPs)' <https://www.ccacoalition.org/en/content/short-lived-climate-pollutants-slcps> accessed 10 February 2022.

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chapter goes on to explore how the global regulation of HFCs under the ozone regime could be further strengthened. Concluding thoughts are provided in the final section.

2 HFCs

HFCs are a group of chemicals that contain hydrogen, fluorine and carbon. They are used in various applications including in air conditioning, refrigeration and fire protection systems and in metered dose inhalers. Their use in air conditioning and refrigeration accounts for over 80 per cent of total HFC consumption.[4] In contrast to other substances controlled by the Montreal Protocol, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), HFCs do not contain chlorine, which is implicated in the destruction of stratospheric ozone.[5] Thus, HFCs do not deplete stratospheric ozone. However, many HFCs are potent greenhouse gases, with a global warming potential (GWP)[6] hundreds to thousands of times greater than that of CO_2.[7] The most abundant HFC, HFC-134a, is used in mobile air conditioning, foam blowing, and domestic refrigerators,[8] and has a GWP of 1 360.[9] The next most abundant HFCs are HFC-23, HFC-32, HFC-125, and HFC-143a.[10] Their respective GWPs are 12 690, 705, 3 450, and 5 080.[11] Reducing emissions of HFCs is thus important to climate mitigation efforts, especially efforts to limit the global temperature increase to just 1.5° Celsius.[12] In 2021, the top consumer of

4 CCAC, 'Hydrofluorocarbons (HFCs)' <https://www.ccacoalition.org/en/slcps/hydrofluorocarbons-hfcs> accessed 3 December 2021.

5 Mario Molina and Frank Rowland, 'Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom-catalysed Destruction of Ozone' (1974) 249 Nature, 810–812.

6 The GWP is 'a metric for determining the relative contribution of a substance to climate warming'; see WMO (n2), ES.13.

7 ibid, Appendix A.

8 Sergey Gulev and others, 'Changing State of the Climate System' in V Masson-Delmotte and others (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* (2021), 2–22.

9 ibid.

10 ibid; Gulev and others (n8), Table 2.2, pp. 2–19.

11 WMO (n2), Appendix A.

12 Valerie Masson-Delmotte and others (eds), *Global Warming of 1.5°C: An 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* (Intergovernmental Panel on Climate Change 2018), 118.

HFCs was China, followed by the European Union, Brazil, Mexico and India respectively.[13]

In turn, global warming due to the increasing emission of greenhouse gases may lead to stratospheric cooling and the formation of polar stratospheric clouds, which play a critical role in the formation of the ozone hole.[14] Furthermore, research shows that increasing greenhouse gas concentrations have caused the stratosphere to contract, with stratospheric contraction of 1.3 kilometres projected by 2080.[15] This highlights the interconnections between different planetary processes.[16] In light of these interconnections, it is important to ensure that introducing solutions to one problem does not shift the problem elsewhere.[17]

It is notable that since HFCs were only commercialised in the early-1990s, their presence in the atmosphere is currently low.[18] However, their abundance is increasing. From 2011 to 2019, levels of the most prevalent HFCs increased by more than 140 per cent.[19] Reasons for the increase in HFC emissions include the fact that HFCs are replacing HCFCs, which have been almost completely phased out in developed country Parties,[20] except in regard to essential uses and for the servicing of existing refrigeration, air conditioning, fire suppression and fire protection equipment and in further specific applications.[21] Rising

13 United Nations Environment Programme (UNEP) Ozone Secretariat, 'Country Data' (2023) <https://ozone.unep.org/countries/data-table> accessed 1 August 2023.

14 Susan Solomon, 'Stratospheric Ozone Depletion: A Review of Concepts and History' (1999) 37 Reviews of Geophysics, 286.

15 Petr Pisoft and others, 'Stratospheric Contraction Caused by Increasing Greenhouse Gases' (2021) 16 Environmental Research Letters 064038.

16 Johan Rockström and others, 'A Safe Operating Space for Humanity' (2009) 461 Nature 24, 472–475; Johan Rockström and others, 'Planetary Boundaries: Exploring the Safe Operating Space for Humanity' (2009) 14 Ecology and Society 32; Will Steffen and others, 'Planetary Boundaries: Guiding Human Development on a Changing Planet' (2015) 347 Science 6223, 736.

17 On problem shifting, see Rakhyun Kim and Harro van Asselt, 'Global Governance: Problem Shifting in the Anthropocene and the Limits of International Law' in E Morgera and K Kulovesi (eds), *Research Handbook on International Law and Natural Resources* (Edward Elgar 2016) 473–495.

18 CCAC (n4).

19 This percentage has been calculated based on the figures provided in Gulev and others (n8), Table 2.2, p. 2–19).

20 Hannah Flerlage, Guus Velders, and Jacob de Boer, 'A Review of Bottom-up and Top-down Emission Estimates of Hydrofluorocarbons (HFCs) in Different Parts of the World' (2021) 283 Chemosphere 131208, 1–2.

21 Montreal Protocol on Substances that Deplete the Ozone Layer (adoped 16 September 1987, entered into force 1 January 1989) 1522 UNTS 3, Art. 2(f).

HFC emissions can also be explained by growing demand for motor vehicles, air conditioners and refrigerators – primarily due to economic growth in developing countries.[22] It is projected that the combination of increased warming and growing populations will further increase demand for refrigeration and air conditioning,[23] which will contribute to further increases in HFC emissions.[24] It has been projected that 'the global stock of air conditioners in buildings will grow to 5.6 billion by 2050',[25] and it is estimated that annual HFC emissions could increase to 4.3 gigatonnes (Gt) of CO_2 equivalent by 2050.[26]

The following section outlines the regulation of HFCs at the global level.

3 The Global Regulation of HFCs under the Ozone Regime

HFCs are included as a controlled substance under the Montreal Protocol; and they are also listed as a greenhouse gas under the 1997 Kyoto Protocol[27] and included under the 2015 Paris Agreement.[28] The role of HFCs under the international climate change regime is dealt with in chapter 3 and, therefore, this section focuses on HFC regulation under the ozone regime, with a particular emphasis on the Montreal Protocol. First, the background to the development of the ozone regime is traced.

3.1 *Events Leading to the Development of the Ozone Regime*[29]

Chlorofluorocarbons (CFCs) were invented in 1928 as a safer and more stable alternative to other substances, such as sulfur dioxide and ammonia, for use

22 Flerlage, Velders, and de Boer (n20) 2.
23 Paul Newman, 'The Way Forward for Montreal Protocol Science' (2018) 350 Comptes Rendus Geoscience, 442–447.
24 CCAC (n4).
25 ibid.
26 Pallav Purohit and others, 'Electricity Savings and Greenhouse Gas Emission Reductions from Global Phase-down of Hydrofluorocarbons' (2020) 20 Atmospheric Chemistry and Physics 11305–11327, 11320.
27 Kyoto Protocol to the United Nations Framework Convention on Climate Change (adopted 11 December 1997, entered into force 16 February 2005) 2303 UNTS 162.
28 Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016) 3156 UNTS 54113.
29 This section draws on my earlier research; see Louise Du Toit, 'Stratospheric Ozone Depletion' in French, D and Kotzé, LJ (eds) *Research Handbook on Law, Governance and Planetary Boundaries* (Edward Elgar 2021) 261–277.

as home refrigerants.[30] Their use on a large scale began in the 1930s[31] and, by 1985, total CFC production exceeded 1 million tons.[32] During this time, there was growing concern regarding increasing CFC emissions and their potential role in depleting stratospheric ozone. Destruction of stratospheric ozone allows ultraviolet (UV) radiation, primarily UV-B, to reach the Earth's surface. Excessive UV-B radiation can cause skin cancer and cataracts in humans, stunting in plants, and harm to animals integral to the marine food chain.[33] In 1974, Mario J Molina and FS Rowland noted that CFCs had been added to the atmosphere in increasing amounts over the past few decades and proposed that when CFCs are released into the atmosphere, they are broken down by UV radiation, resulting in the release of chlorine.[34] Chlorine then reacts with ozone, leading to the destruction of ozone in the atmosphere.[35] It should be noted that this process had not actually been observed outside of the laboratory, nor had actual environmental harm due to this process.[36]

Over the following years, further research on the impacts of CFCs was carried out by other scientists and bodies, including the US National Academy of Scientists and the United Nations Environment Programme (UNEP), which supported the 'Molina–Rowland hypothesis'.[37] Velders et al argue that the early warning provided by Molina and Rowland led to citizen action and national regulations to restrict ozone-depleting substances (ODSs).[38] For example, in the US, the Clean Air Act was amended in 1977 to empower the Environmental Protection Agency (EPA) to regulate substances that were

30 Lani Sinclair, 'The Science of Ozone Depletion: From Theory to Certainty' in Andersen, SO and Madhava Sarma, K (eds) Protecting the Ozone Layer: The United Nations History (Earthscan 2002) 4.

31 Rishav Goyal and others, 'Reduction in Surface Climate Change Achieved by the 1987 Montreal Protocol' (2019) 14 Environmental Research Letters 124041, 1.

32 Alexander Gillespie, *Climate Change, Ozone Depletion and Air Pollution: Legal Commentaries with Policy and Science Considerations* (Martinus Nijhoff Publishers 2006) 21.

33 Ved Nanda, 'Stratospheric Ozone Depletion: A Challenge for International Environmental Law and Policy' (1989) 10 Michigan Journal of International Law, 489–490.

34 Molina and Rowland (n5).

35 The chemical reactions involved in this process are set out in Molina and Rowland (n5). See also Frank Rowland, 'Chlorofluorocarbons and the Depletion of Stratospheric Ozone' (1989) 77 American Scientist 36–45.

36 Elizabeth DeSombre, 'The Experience of the Montreal Protocol: Particularly Remarkable, and Remarkably Particular' (2000) 19 Journal of Environmental Law, 50.

37 Sinclair (n30) 11–13.

38 Guus Velders and others, 'The Importance of the Montreal Protocol in Protecting Climate' (2007) 104 PNAS 12, 4814.

reasonably anticipated to impact the stratosphere and adversely affect public health or welfare.[39]

In 1985, Farman and colleagues publicly confirmed that spring-time levels of ozone in Antarctica had fallen considerably.[40] Although a link between the concentration of chlorine-containing substances in the atmosphere and ozone depletion had not yet been conclusively proven, Farman et al suggested that CFCs were the likely cause.[41] Following the discovery of the Antarctic ozone hole, it took several more years for the link between CFCs and ozone depletion to be conclusively established. In August 1987, data obtained during an Antarctic expedition revealed the lowest levels of ozone that had ever been recorded and directly implicated CFCs in the enormous loss of ozone over Antarctica.[42]

Against this background of uncertainty, as well as disagreement over whether a precautionary approach should be followed, or whether conclusive evidence of ozone depletion should first be required,[43] there was no coordinated international response for several years. Since the science was not certain, there was significant resistance[44] and scepticism.[45] Nevertheless, there were several initiatives in the 1970s, including a 1976 tripartite agreement regarding the monitoring of the stratosphere between the governments of the United States, France and the United Kingdom, as well as the 1977 World Plan of Action on the Ozone. Discussions on a draft international convention to address stratospheric ozone depletion began in 1981.[46]

39 Gillespie (n32) 155.

40 Joseph Farman, Brian Gardiner, and Jonathan Shanklin, 'Large Losses of Total Ozone in Antarctica Reveal Seasonal ClO_x/NO_x Interaction' (1985) 315 Nature, 207–210.

41 Susan Solomon, 'Stratospheric Ozone Depletion: A Review of Concepts and History' (1999) 37 Reviews of Geophysics, 283.

42 Sinclair (n30) 22.

43 Gillespie (n32) 152–157.

44 Stephen Andersen, Marcel Halberstadt, and Nathan Borgford-Parnell, 'Stratospheric Ozone, Global Warming, and the Principle of Unintended Consequences – An Ongoing Science and Policy Success Story' (2013) 63 Journal of the Air & Waste Management Association, 613.

45 Ben Lieberman, 'Stratosperic ozone depletion and the Montreal Protocol: A critical analysis' (1994) 2 Buffalo Environmental Law Journal, 1–32; Robert Falkner, 'The Business of Ozone Layer Protection: Corporate Power in Regime Evolution' in DL Levy and PJ Newell (eds), *The Business of Global Environmental Governance* (MIT Press 2005) 105–134.

46 The international process leading to the finalisation of the Vienna Convention is discussed in detail in Stephen Andersen and K Madhava Sarma (eds), *Protecting the Ozone Layer: The United Nations History* (Earthscan 2002).

3.2 *The Vienna Convention*

In view of this uncertainty, it was significant that the Vienna Convention for the Protection of Ozone[47] was agreed to in March 1985. Parties to the Vienna Convention, in the Preamble, noted the potentially harmful impact of the modification of the ozone layer on human health and the environment, and the importance of international co-operation and action as well as scientific and technical considerations in developing measures to protect the ozone layer from human-caused modifications. Parties resolved to protect human health and the environment from adverse effects arising from the ozone layer's modification. 'Adverse effects' are defined to include 'changes in the physical environment or biota, *including changes in climate*, which have significant deleterious effects on human health or on the composition, resilience and productivity of natural and managed ecosystems, or on materials useful to mankind'.[48]

The prevailing uncertainty is reflected in the language of the Vienna Convention, which obliges Parties to take appropriate measures to protect human health and the environment against adverse effects 'resulting or likely to result from human activities which modify or are likely to modify the ozone layer'.[49] The Vienna Convention sets out several general obligations for Parties,[50] including undertaking research and scientific assessments (article 3 read with Annex I) and specifically acknowledges the potential impacts of the modification of ozone on the climate.[51] It furthermore requires Parties to continually review the implementation of the Convention and to consider and undertake additional actions that may be necessary to achieve the Vienna Convention's purposes.[52]

Despite not providing for any controls on ODSs, it was considered 'a promising first step, for it signified recognition by the world community that it must act promptly on this environmental challenge before the occurrence of any actual damage'.[53]

47 Vienna Convention for the Protection of the Ozone Layer (agreed 22 March 1985, entered into force 22 September 1988) 1513 UNTS 293.
48 ibid, Article 1(2), own emphasis.
49 ibid, Article 2 (1).
50 ibid, Articles 2–5.
51 ibid, Articles 2–3 read with Annex I.
52 ibid, Article 6(4).
53 Nanda (n33) 500.

3.3 *The Montreal Protocol*

3.3.1 Introduction

The Montreal Protocol was signed two years later in September 1987. The negotiation process – with regard to both the Vienna Convention and the Montreal Protocol – has been described as 'particularly impressive' since negotiations were carried out (and agreement reached) 'under conditions of uncertainty, both over the existence and extent of environmental harm and the costliness of taking action to mitigate it'.[54] It should be noted that while there were initially only 23 state Parties to the Montreal Protocol, following its continual strengthening and refinement (elaborated on below), the Montreal Protocol became the first international treaty to be universally ratified in 2010.[55]

3.3.2 Overview of the Main Provisions of the Montreal Protocol

Parties to the Montreal Protocol, in the Preamble, recognised that global emissions of certain substances can significantly deplete and modify the ozone layer so as to result in adverse effects to human health and the environment, and noted the potential climatic effect of such emissions. Parties were furthermore '[d]etermined to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination'.[56]

The Montreal Protocol sets out control measures for Parties in relation to their consumption and production of the various controlled substances included under the Montreal Protocol. Controlled substances are defined as 'substance[s] in Annex A, Annex B, Annex C, Annex E or Annex F to this Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, *but excludes any controlled substance or mixture which is in a manufactured product* other than a container used for the transportation or storage of that substance'.[57] 'Consumption' is defined as 'production plus imports *minus exports of controlled substances*'.[58] 'Production' is defined as 'the amount of controlled substances produced, minus the amount destroyed by technologies to be approved by the Parties and *minus the amount entirely used as feedstock in the*

54 DeSombre (n36) 49.

55 Sophie Godin-Beekmann, Paul Newman and Irina Petropavlovskikh, '30th anniversary of the Montreal Protocol: From the safeguard of the ozone layer to the protection of the Earth's climate' (2018) 350 *Comptes Rendus Geoscience*, 331.

56 Montreal Protocol (n1) Preamble.

57 ibid, Article 1(4), own emphasis.

58 ibid, Article 1(6), own emphasis.

manufacture of other chemicals. The amount recycled and reused is not to be considered as "production"'.[59]

The Montreal Protocol originally set out control measures in relation to the consumption and production of only CFCs and halons,[60] as these were the only substances that had been identified as being ozone-depleting. However, over time, more chemicals were identified as being responsible for ozone depletion.[61] As a consequence, the Montreal Protocol has been continually strengthened since it came into effect in 1989 through numerous adjustments and amendments.[62] Adjustments are a noteworthy feature of the Montreal Protocol, and they allow for binding adjustments to be made – for example, of the reductions of controlled substances – with the consent of only two-thirds of the Parties.[63] These adjustments and amendments have had the effect of, firstly, accelerating phase-out schedules – for instance, the Montreal Protocol originally called for the consumption of CFCs to be decreased to 50 percent of 1986 levels by 1999, but this was adjusted to require a complete phase-out by 1996; and, secondly, bringing more chemicals under the control of the Montreal Protocol.[64]

CFCs and halons were gradually replaced by hydrochlorofluorocarbons (HCFCs).[65] Since HCFCs are still ozone-depleting, they were included under the Montreal Protocol in 1992, as noted in Table 4.1 below. As a consequence, HCFCs are being replaced by HFCs.[66] While HFCs are not ozone-depleting, they have a high potential to warm the climate, and their GWPs range from 53 to 14 800. This is taken up further below. The additional chemicals that have been brought under the Montreal Protocol, together with their ozone-depleting potentials (ODPs)[67] and global warming potentials (GWPs) are depicted in Table 4.1 immediately below.

59 ibid, Article 1(5), own emphasis.
60 ibid, Article 2.
61 Gillespie (n32) 164; Mark Roberts, 'Finishing the Job: The Montreal Protocol Moves to Phase Down hydrofluorocarbons' (2017) 26 RECIEL, 221.
62 Adjustments may be made in terms of article 2(9)(a) read with article 6; while substances may be added to (or removed from) any annex in terms of article 2(10) read with article 6. See also DeSombre (n36) 54.
63 Montreal Protocol (n1) Article 2(9)(c) and (d).
64 Tina Birmpili, 'Montreal Protocol at 30: The Governance Structure, the Evolution, and the Kigali Amendment' (2018) 350 Comptes Rendus Geoscience, 427.
65 Godin-Beekmann, Newman and Petropavlovskikh (n55) 332.
66 ibid.
67 The ODP is 'a metric for determining the relative strength of a chemical to destroy ozone': WMO (n2) ES.13.

TABLE 4.1 Substances brought under the control of the Montreal Protocol[a]

Year	Amendment	New substances brought under the control of the montreal protocol	ODP	GWP
1990	London Amendment[b]	Other fully halogenated CFCs	1.0	4 370 – 13 900
		Carbon tetrachloride	1.1	2 110
		Trichloroethane	0.1	153
1992	Copenhagen Amendment[c]	Hydrochlorofluorocarbons (HCFCs)	0.001–0.52	77 – 2 310
		Hydrobromofluorocarbons	0.02–7.5	
		Methyl bromide	0.57	2
1999	Beijing Amendment[d]	Bromochloromethane	0.12	4.7
2016	Kigali Amendment[e]	Hydrofluorocarbons (HFCs)	0	53 – 14 800

a The values contained in this table have been obtained from the Montreal Protocol and WMO (n2).
b United Nations Environment Programme (UNEP), *Report of the Second Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.2/3, 1990) <https://ozone.unep.org/Meeting_Documents/mop/02mop/MOP_2.shtml> accessed 5 May 2022.
c UNEP, *Report of the Fourth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.4/15, 1992) <https://ozone.unep.org/sites/default/files/2019-04/MOP-4-15E.pdf> accessed 5 May 2022.
d UNEP, *Report of the Eleventh Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.11/10, 1999) <https://ozone.unep.org/sites/default/files/2019-04/MOP-11-10E.pdf> accessed 5 May 2022.
e UNEP, *Report of the Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.28/12, 2016) <https://ozone.unep.org/sites/default/files/2019-08/MOP-28-12E.pdf> accessed 5 May 2022.

Article 4 of the Protocol deals with trade in ODSs. While it deals separately with each of the groups of controlled ODSs, it essentially prohibits the export and import of controlled substances to and from countries that are not Parties to the Montreal Protocol. Article 4 also prohibits the import of products either containing or produced with controlled substances. It furthermore discourages the export of technologies to either produce or utilise certain controlled substances.

Article 5 of the Montreal Protocol deals with the special situation of developing countries and entitles developing countries (also referred to here as article 5 countries), whose annual consumption of controlled substances was less than 0.3 kilograms per capita after the entry into force of the Montreal Protocol (and until 1 January 1999) – in order to meet their basic domestic needs – to delay their compliance with the control measures of the Montreal Protocol.[68] The special situation of developing countries is discussed in further detail in Section 3.3.3 below.

Article 6 of the Montreal Protocol makes provision for the assessment of the control measures contained in article 2 and articles 2A–2J and it provides for Parties to convene panels of experts which will report their conclusions to the Parties. The Montreal Protocol requires Parties to report to the Secretariat on their annual emissions of all controlled substances (including HFCs) 'and, separately, for each substance, … [a]mounts used for feedstocks'.[69] In relation to HFC-23 specifically (also dealt with below), the Montreal Protocol provides that Parties shall report to the Secretariat on their annual emissions of HFC-23 per facility.[70] Article 8 makes provision for the development of procedures and institutional mechanisms to deal with instances of noncompliance. Cooperation in regard to research, development, public awareness and exchange of information is addressed in article 9. Article 10, which was inserted in 1990, provides for the establishment of a financial mechanism. This financial mechanism is elaborated on in Section 3.3.3 below. Furthermore, article 10A provides for the transfer of environmentally safe substitutes and related technologies to developing country Parties.

These provisions are reflected on in more detail in Section 4 below.

3.3.3 Facilitating the Participation of Developing Countries

At the outset, only three developing countries – Egypt, Mexico, and Uganda – signed the Montreal Protocol. At the time, the consumption and production of ODSs in developing countries was insignificant, but was expected to increase substantially. The Montreal Protocol did not initially provide for a financial mechanism and, as DeSombre argues, without 'sufficient incentives to join the agreement, developing countries showed every sign of remaining outside the regulatory system'.[71] Consequently, provision for a financial mechanism was made in 1990 in terms of the London Amendment, and the Multilateral

68 Montreal Protocol (n1) Articles 5(1) and 5(8 *bis*) – 5(8 *qua*).
69 ibid, Article 7.
70 ibid, Article 7(3ter).
71 DeSombre (n36) 69.

Fund (which receives contributions from developed country Parties)[72] was established in 1991. Consequently, China, India and Brazil joined the Montreal Protocol, followed by almost all other developing countries.[73]

Further provisions have arguably facilitated the participation of developing countries. The Multilateral Fund is managed by an Executive Committee, which has equal numbers of developing and developed country Parties.[74] Where it is not possible to take decisions by consensus, the Protocol requires that decisions are taken by a two-thirds majority vote, representing a majority of developing and developed country Parties.[75] The Montreal Protocol also provides that developing country compliance with the control measures of the Protocol depends on the effective implementation of the Multilateral Fund and the transfer of technology.[76] The Montreal Protocol allows a certain amount of production of controlled substances to 'satisfy the basic domestic needs' of developing country Parties.[77]

It has been argued, on the basis of these provisions, that the Montreal Protocol has given effect to the principle of common but differentiated responsibilities.[78] Since developed countries were responsible for the bulk of the production and consumption of ODSs, it was essential that they took responsibility by starting first while allowing developing countries to address their development priorities.[79]

3.3.4 The Role of Industry

While, initially, there was significant resistance from ODS producers and even attempts to discredit the ozone depletion hypothesis,[80] industry came to play a very important role in the success of the ozone regime. As highlighted above, prior to the agreement on the Vienna Convention, national regulations regarding the limitation of ODSs had already been developed in some countries, including the United States, which 'strongly influenced the role industry

72 Multilateral Fund for the Implementation of the Montreal Protocol <http://www.multilateralfund.org/default.aspx> accessed 20 December 2022.

73 ibid, 71.

74 Montreal Protocol (n1) Article 10(5).

75 ibid, Article 10(9).

76 ibid, Article 5(5).

77 ibid, Articles 2(d)–2(j).

78 Marco Gonzalez, Kirsten Taddonio, and Nancy Sherman, 'The Montreal Protocol: How Today's Successes Offer a Pathway to the Future' (2020) 5 Journal of Environmental Studies and Sciences, 124–125.

79 DeSombre (n36).

80 Falkner (n45) 108.

played in the process'.[81] For example, the strict domestic regulation in the US incentivised US CFC industries to call for international regulation so that they would not be at a disadvantage in comparison to CFC industries in other countries subject to less stringent domestic regulation. Furthermore, the hefty excise tax that was imposed on ODSs in the US motivated industry to develop substitutes. Indeed, after the Montreal Protocol was adopted, ODS producers such as AT&T and DuPont swiftly developed substitute substances.[82] Industry was further incentivised by the prospect of capturing an emerging market for ODS substitutes.[83] Following the adoption of the Montreal Protocol, industry has continued to play a positive role, including by undertaking joint research programmes.[84]

3.3.5 Governance under the Montreal Protocol

Several institutions established under the ozone regime have been integral to its success. The Ozone Secretariat, which was established under the Vienna Convention, also administers the Montreal Protocol. Amongst other things, it organises Conferences of the Parties under the Vienna Convention and Meetings of the Parties under the Montreal Protocol and manages the implementation of decisions arising from such conventions and meetings. Three assessment panels – the Environmental Effects Assessment Panel (EEAP), the Scientific Assessment Panel (SAP) and the Technology and Economic Assessment Panel (TEAP) – have been established under the Montreal Protocol. The EEAP assesses the effects of ozone depletion and advises the Parties on new developments. The SAP assesses relevant atmospheric science issues and the status of ozone depletion and prepares regular reports and highlights scientific issues of importance for consideration at the Meetings of Parties under the Montreal Protocol. The TEAP provides technical information regarding alternative technologies. As noted above, the Multilateral Fund provides financial assistance to developing countries. The Executive Committee of the Multilateral Fund has played an important role in facilitating the phase-out of ODSs in developing countries. For example, following China's continued construction of plants to produce halons while also applying for funding to retrofit one halon plant, the Executive Committee decided to restrict funding for the phase-out of ODS production while other ODS production was ongoing.[85]

81 DeSombre (n36) 57.
82 ibid, 57–60.
83 ibid, 60; Falkner (n45) 105.
84 Falkner (n45) 109–110; see also The Alliance for Responsible Atmospheric Policy <https://alliancepolicy.org/> accessed 20 December 2022.
85 DeSombre (n36) 74.

3.4 *The Kigali Amendment*

3.4.1 Events Leading to the Adoption of the Kigali Amendment

As HFCs were developed to replace HCFCs (discussed above), the consumption of HFCs increased from almost zero in 1990 to more than 1 200 million tonnes of CO_2 equivalent by 2010; and the replacement of HCFCs by HFCs was therefore contributing to climate change.[86] Already in 2009, the G8 countries at the time (France, Germany, Italy, Japan, Russia, the United Kingdom, and the United States) recognised that the phase-out of HCFCs was leading to rapidly rising HFC use and undertook to 'work with [their] partners to ensure that HFC emissions reductions are achieved under the appropriate framework'.[87] Furthermore, in 2009, a proposal to amend the Montreal Protocol to include HFCs was submitted by the Federated States of Micronesia and Mauritius.[88] However, there was resistance particularly from other developing countries, including China, India, Malaysia and the Dominican Republic, who, *inter alia*, argued that HFCs should be dealt with under the climate change regime and that implementation issues relating to the phase-out of HCFCs should first be resolved.[89] In 2010, further proposals were submitted by the Federated States of Micronesia as well as by Canada, Mexico, and the United States and significant debate ensued.[90] Those supporting the inclusion of HFCs under the Montreal Protocol (including Canada, the Federated States of Micronesia, Kenya, Macedonia, Mexico, the Philippines, Tuvalu (on behalf of Pacific Island countries), and the United States) argued, *inter alia*, that there was a legal and moral responsibility to address HFCs under the Montreal Protocol and that such efforts would not diminish responsibility under the UNFCCC. Arguments

86 Roberts (n61) 224; Rakhyun Kim and Klaus Bosselmann, K 'Operationalising Sustainable Development: Ecological Integrity as a *Grundnorm* of International Law' (2015) 24 RECIEL 194–208, 200.

87 Group of Eight (G8), 'Responsible Leadership for a Sustainable Future' (2009) <http://www.g8.utoronto.ca/summit/2009laquila/2009-declaration.pdf> accessed 22 December 2022.

88 International Institute for Sustainable Development (IISD), 'Summary of the Twenty-eighth Meeting of the Parties to the Montreal Protocol: 10–14 October 2016' (2016) <https://enb.iisd.org/events/montreal-protocol-mop-28/summary-report-10-14-october-2016> accessed 5 May 2022, p. 15.

89 IISD, 'Summary of the Twenty-seventh Meeting of the Parties to the Montreal Protocol: 1–5 November 2015' (2015) <https://enb.iisd.org/events/montreal-protocol-mop-27/summary-report-1-5-november-2015> accessed 5 May 2022, pp. 12–13; Arunabha Ghosh, 'Making Sense on its Own Terms: India in the HFC and Aviation Negotiations' in NK Dubash (ed), *India in a Warming World* (Oxford University Press 2019) 232.

90 IISD, '28th Meeting' (n89) 15.

by those opposing the inclusion of HFCs (including Argentina, Brazil, China, Cuba, India and Malaysia) included that HFCs lay outside the scope of the Montreal Protocol, resources under the Montreal Protocol are limited, and, furthermore, that any decision on HFCs under the Montreal Protocol should await the finalisation of discussions under the UNFCCC regarding whether HFCs would be included in the new commitment period under the Kyoto Protocol.[91] It is notable that under the Clean Development Mechanism, established under the Kyoto Protocol, developing countries were able to claim carbon credits to destroy emissions of HFC-23. This created a 'perverse incentive' to produce more HFC-23 (as a by-product of HCFC-22 production) which could then be destroyed to earn more carbon credits. China and India were major producers of HCFC-22. However, the European Union banned HFC-23 carbon credits in the European Trading Scheme in 2013.[92]

Further discussions were held in 2014, and in 2015 the Parties to the Montreal Protocol agreed to establish a contact group to consider the feasibility of and ways to manage HFCs.[93] Resistance began to diminish. For example, in 2016, India and the United States issued a joint statement regarding their intention 'to work to adopt an HFC amendment in 2016 with increased financial support from donor countries to the Multilateral Fund to help developing countries with implementation'.[94] While it is not possible to point to a single factor in the shift or the eventual agreement on the Kigali Amendment, the proactive and behind-the-scenes role of the Ozone Secretariat in facilitating discussions

91 IISD, 'Summary of the Twenty-second Meeting of the Parties to the Montreal Protocol: 8–12 November 2010' (2010) <https://enb.iisd.org/ozone/mop22/> accessed 12 September 2022; UNEP, *Report of the Twenty-Second Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.22/9) (2010) <https://ozone.unep.org/Meeting_Documents/mop/22mop/MOP-22-9E.doc> accessed 12 September 2022.

92 Ghosh (n90) 235.

93 UNEP, *Report of the Thirty-fifth Meeting of the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.WG.1/35/6) (5 May 2015) <https://ozone.unep.org/system/files/documents/OEWG-35-6E.pdf> accessed 5 May 2022, para. 126.

94 The White House 'Joint Statement: The United States and India: Enduring Partners in the 21st Century' (7 June 2016) <https://obamawhitehouse.archives.gov/the-press-office/2016/06/07/joint-statement-united-states-and-india-enduring-global-partners-21st> accessed 12 September 2022.

on HFCs (from as early as 2009) has been highlighted.[95] Furthermore, during negotiations, delegates emphasised the historical success of the ozone regime and the potential for an amendment dealing with HFCs to be 'the Montreal Protocol's next success'.[96] Such submissions also appealed to the sense of responsibility and pride of 'the ozone family'.[97] Furthermore, although measures to address HFCs had been introduced in many countries,[98] Parties recognised that a global and holistic response to the problem would be most beneficial.[99] Significantly, in 2016, at the twenty-eighth Meeting of the Parties in Kigali, the Parties agreed to the insertion of article 2J (and Annex F) which provides for the phase-down of HFCs beginning in 2019.[100]

3.4.2 Overview of the Kigali Amendment

Article 2J provides that, commencing on 1 January 2019, Parties shall ensure that their annual consumption of HFCs (or production of HFCs – in respect of Parties producing HFCs), expressed in CO_2 equivalents, shall, by 2036, not exceed 15 per cent of the annual average of their consumption of HFCs for the years 2011, 2012 and 2013, plus 15 per cent of their consumption of HCFCs, expressed in CO_2 equivalents.[101] Notwithstanding these provisions, Parties may decide that a party may commence its phase-down of HFCs from 1 January 2020 so that by 2036 its annual consumption of HFCs (or production of HFCs – in respect of Parties producing HFCs), expressed in CO_2 equivalents, does not exceed 15 per cent of the annual average of its consumption of HFCs for the years 2011, 2012 and 2013, plus 25 per cent of its consumption of HCFCs, expressed in CO_2 equivalents (article 2J(2) and (4)).[102] Annex F lists 18 different

95 Jannah Wijermars, *Facilitation for the Future: The Ozone Secretariat's Role During the Kigali Amendment Negotiations* (MSc thesis, Utrecht University 2022) <https://studenttheses.uu.nl/bitstream/handle/20.500.12932/42445/MScThesis_Wijermars_5717280%20%28for%20online%20publication%29.pdf?sequence=1&isAllowed=y> accessed 12 September 2022.

96 IISD, '28th Meeting' (n89) 5.

97 ibid, 17; Birmpili (n64).

98 e.g. Duncan Brack, 'National Legislation on Hydrofluorocarbons' (11 September 2015) <http://www.igsd.org/documents/NationalLegislationonHydrofluorocarbons_9.11.151.pdf> accessed 20 December 2022.

99 UNEP, *35th Meeting* (n94); UNEP, *Report of the Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP/OzL.Pro.28/12, 2016) <https://ozone.unep.org/sites/default/files/2019-08/MOP-28-12E.pdf> accessed 5 May 2022.

100 UNEP, *28th Meeting* (n100).

101 Montreal Protocol (n1) Article 2J (1) and (3).

102 ibid, Article 2J (2) and (4).

HFCS, including HFC-23, HFC-32, HFC-125, HFC-134a, and HFC-143a (all of the five most abundant HFCS). The Montreal Protocol makes provision for Parties to decide to allow the production or consumption of HFCS in regard to uses that are agreed to be exempted.[103]

HFC-23 – a potent greenhouse gas with a GWP of 12 690 – is produced incidentally as a by-product of the production of HCFC-22.[104] While the Montreal Protocol does not generally include controls in regard to HFCS that are produced as by-products, it does oblige Parties that manufacture HCFCS or HFCS to ensure that HFC-23 emissions generated in production facilities that manufacture HCFCS or HFCS 'are destroyed to the extent practicable',[105] and furthermore requires that Parties provide statistical data to the Secretariat on their annual emissions of HFC-23 per facility.[106]

While article 4, which deals with the control of trade with non-Parties, does not yet explicitly ban or restrict the import or export of HFCS (perhaps because the Kigali Amendment provides for the phase-down, rather than phase-out, of HFCS), it does for example require that to the fullest extent practicable, Parties discourage the export of any technology for producing or using, amongst others, HFCS to States that are not party to the Protocol.[107]

These provisions are reflected on in Section 4 below.

3.4.3 Participation under the Kigali Amendment

In contrast to other amendments to the Montreal Protocol, which have been almost universally ratified, the Kigali Amendment has been ratified by only 151 countries. However, the Kigali Amendment was accepted by China in June 2021; it was ratified by India in September 2021; and it was ratified by the United States and accepted by Brazil in October 2022.[108] Thus, all of the top consumers of ODSS have ratified the Kigali Amendment.[109] It should be noted that Parties that have not yet ratified the Amendment are not bound to phase down their consumption and production of HFCS or report on their HFC consumption to the Ozone Secretariat.

103 ibid, Article 2J (5).
104 WMO (n2), ES. 20.
105 Montreal Protocol (n1) Article 2J (6).
106 ibid, Article 7(3*ter*).
107 ibid, Article 4(5).
108 UNEP Ozone Secretariat, 'All Ratifications' (2022a) <https://ozone.unep.org/all-ratifications> accessed 20 December 2022.
109 ibid; UNEP Ozone Secretariat (n13).

The effectiveness of the ozone regime – in regard to its strengths and weaknesses – is now considered.

4 Evaluating the Effectiveness of the Ozone Regime

4.1 *Strengths of the Ozone Regime*

Overall, the Montreal Protocol has been described as 'a landmark in the ongoing development of international environmental law'[110] and it is widely considered to be one of the most successful international environmental law regimes.[111] By 2018, 99 per cent of ODSs (controlled by the Montreal Protocol) had been phased out.[112] Ozone levels have not declined further since the late-1990s, and are actually beginning to recover, and it has been projected that global ozone will return to 1980 levels by around mid-century.[113]

As the above discussion reveals, one of the strengths of the ozone regime is that its provision for adjustments and amendments has enabled the Montreal Protocol to 'adapt to changing environmental conditions, scientific and technical understanding, and political realities'.[114] As a result, the regime has been continually refined and strengthened, and further ODSs have been brought under its control.

The ozone regime has also had important climate benefits. Velders et al argue that, as of 2007, '[t]he climate protection already achieved by the Montreal Protocol alone is far larger than the reduction target of the first commitment period of the Kyoto Protocol'.[115] In addition, Goyal et al project the avoidance of a global temperature increase of at least 1°C (they state that this estimate is conservative) by 2050 as a result of the Montreal Protocol.[116] In regard to the Kigali Amendment specifically, it has been argued that due to its adoption, the Montreal Protocol 'evolved from strictly an ozone protection agreement into an ozone and climate agreement'.[117] It has further been argued that the

110 Nanda (n33) 510.

111 Stephen Andersen and others, 'Narrowing Feedstock Exemptions under the Montreal Protocol has Multiple Environmental Benefits' (2021) 118 PNAS 49, 1.

112 Birmpili (n64) 427.

113 WMO (n2), ES-1 at ES.16, ES.42.

114 DeSombre (n36) 57; Birmpili (n64) 430; John Dryzek, 'Institutions for the Anthropocene: Governance in a Changing Earth System' (2016) 4 British Journal of Political Science, 943.

115 Velders and others (n38) 414.

116 Goyal and others (n31).

117 Newman (n23) 442; see also Velders and others (n38).

Kigali Amendment will help to 'ensure that the restoration of the ozone layer does not come at the expense of the global climate'[118] and it has been projected that global warming of 0.2°C–0.4°C will be avoided by 2100 due to the Amendment.[119]

Further factors contributing to the success of the Montreal Protocol include, as also noted above, its commitment to the principle of common but differentiated responsibilities;[120] the participation of developing countries;[121] and the positive involvement of industry.[122] Rockström et al argue that '[o]n balance, the case of stratospheric ozone is a good example where concerted human effort and wise decision making seem to have enabled us to stay within [the] planetary boundary [for stratospheric ozone depletion]'.[123]

Despite these strengths, the ozone regime also contains several gaps, which are now outlined.

4.2 *Gaps in the Ozone Regime*

4.2.1 The Montreal Protocol Does Not Regulate Banks of HFCs

In the first place, the Montreal Protocol does not control the 'banks'[124] of ODSs that are contained in, amongst others, air conditioning, refrigeration and fire-fighting equipment, which will eventually leak into the environment.[125] In contrast to CFCs, which were largely used in 'rapid-release applications' such as spray cans and solvents, HFCs are primarily contained in applications that involve containment, particularly refrigerators and air conditioners.[126]

This weakness contributes to the fact that 'once produced, ODSs are in "no treaty territory"'.[127] Velders, Solomon and Daniel[128] demonstrate that HFC

118 Roberts (n61) 220.
119 WMO (n2), ES.3.
120 Gonzalez, Taddonio, and Sherman (n79) 124–125.
121 DeSombre (n36) 69–75.
122 Falkner (n45); Birmpili (n64) 427.
123 Rockström and others, 'Planetary Boundaries' (n16) 12.
124 Banks are 'reservoirs of produced and stockpiled, but not yet emitted, chemicals'; see Benjamin Sovacool and others, 'Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions' (2021) 141 Renewable and Sustainable Energy Reviews 110759.
125 Gonzalez, Taddonio, and Sherman (n79) 123, 127; Megan Lickley and others, 'Quantifying Contributions of Chlorofluorocarbon Banks to Emissions and Impacts on the Ozone Layer and Climate' (2020) 11 Nature Communications 380.
126 Guus Velders, Susan Solomon and John Daniel, 'Growth of climate change commitments from HFC banks and emissions' (2014) 14 Atmos. Chem. Phys. 9, 4564.
127 Gonzalez, Taddonio, and Sherman (n79) 127.
128 Velders, Solomon, and Daniel (n127) 4569.

emissions continue to be released for 20 years after production is phased out and, furthermore, that HFCs continue to contribute to radiative forcing for a further several decades. Thus, 'the buildup of HFC banks [for example, in refrigerators and air conditioners] represents a new challenge to climate change prevention efforts'.[129] Furthermore, developing countries are required to only begin to phase down HFCs from 2029 onwards. In the meantime, the production and consumption of HFCs are increasing, and accumulating in banks, which will leak at unknown future dates.

In response to this concern, it has been proposed that HFCs contained in, *inter alia*, refrigeration and air-conditioning equipment should be recovered and destroyed.[130] However, Velders, Solomon and Daniel[131] point out that many millions of refrigeration and air conditioning units exist, which makes the subsequent recovery and destruction of HFC banks more complex than reducing production in the first place. They, therefore, argue that maximum benefits can be achieved through the destruction of HFC banks combined with the phase-out of HFCs, which would reduce the number of HFC banks.[132]

4.2.2 The Montreal Protocol Does Not Adequately Regulate HFCs Produced as By-Products

As discussed above, HFC-23 is a potent greenhouse gas as well as a by-product of HCFC-22 production. Although the Protocol requires the destruction of HFC-23 to the extent practicable, observations show that HFC-23 emissions are increasing – contrary to countries' reports that HFC-23 is being phased out.[133] Indeed, from 2011 to 2019, the atmospheric abundance of HFC-23 increased by 35 per cent.[134] It has been argued that Parties are not destroying their emissions of HFC-23 and reporting on such emissions as required under the Montreal Protocol.[135] It has been argued that if the emission of HFC-23 does not decline soon, this will undermine the successes of the Montreal Protocol.[136]

129 Gonzalez, Taddonio, and Sherman (n79) 127.
130 ibid, 126.
131 Velders, Solomon, and Daniel (n127) 4565.
132 ibid, 4570; Susan Solomon, Joseph Alcamo, and Akkihebbal Ravishankara, 'Unfinished Business after Five Decades of Ozone-layer Science and Policy' (2020) 11 Nature Communications 4272, 4.
133 Kieran Stanley and others, 'Increase in Global Emissions of HFC-23 Despite Near-total Expected Reductions' (2020) 11 Nature Communications 397, 4570.
134 Gulev and others (n8) 22.
135 Jane Palmer, 'The HFC Challenge: Can the Montreal Protocol Continue Its Winning Streak?' (Mongabay, 5 May 2021) <https://news.mongabay.com/2021/05/the-hfc-challenge-can-the-montreal-protocol-continue-its-winning-streak/> accessed 8 December 2021.
136 Solomon, Alcamo and Ravishankara (n133).

To address this weakness, the Montreal Protocol should arguably restrict the production of HFC-23 in the first place, for example, by 'requiring de minimis HFC emissions from HCFC-22'.[137]

4.2.3 The Montreal Protocol Does Not Control Substances that Are Used as Feedstocks

Related to the above concern, the Montreal Protocol does not control or restrict the production of ODSs, when produced purely to manufacture other substances. As discussed above, 'production' is defined in the Montreal Protocol so as to exclude ODSs that are used entirely as feedstock in the manufacture of other chemicals.[138] HCFC-22, which has a GWP of 1 780[139] and results in the emission of HFC-23 as a by-product, is manufactured and used as a feedstock to produce other substances such as Teflon;[140] and its atmospheric abundance has increased by at least 15 per cent from 2011 to 2019.[141] Other ODSs – including CFC-113, HFC-143a, HCFC-142b, which have GWPs of 6 080, 5 080 and 2 070 respectively[142] – are used as feedstocks to produce various materials, including plastics.[143] While '[t]he feedstock exemptions were premised on the assumption that feedstocks presented an insignificant threat to the environment; experience has shown that this is incorrect'.[144]

In response to this concern, it has been proposed that the scope of feedstock exemptions be narrowed.[145] However, critical uses of feedstocks could still be exempted, such as the production of substances to rapidly replace high-GWP HFCs and the use of HCFC-22 to produce polytetrafluoroethylene (PTFE) for medical applications until appropriate alternatives are found.[146] Andersen et al argue that this is consistent with the approach under the Montreal Protocol 'where requirements are strengthened in response to new scientific findings and technological advances'.[147]

137 Gonzalez, Taddonio, and Sherman (n79) 126.
138 Montreal Protocol (n1), Article 1(5).
139 WMO (n2), Table A-1.
140 Palmer (n136).
141 Gulev and others (n8) Table 2.2, pp. 2–19.
142 WMO (n2) Table A-1.
143 Andersen and others (n112) Table 2, p. 3.
144 ibid, 1.
145 Gonzalez, Taddonio, and Sherman (n79) 126; Andersen and others (n112).
146 Andersen and others (n112) 7.
147 ibid, 6.

Amending the Montreal Protocol to narrow such exemptions would have socio-ecological benefits, arising not only from reduced ozone depletion and greenhouse gas emissions, but also from the reduced production of plastics.[148] This would also contribute to reducing the unauthorised and illegal production of, *inter alia*, HFCs.[149]

This process could be guided by assessments produced by the various assessment panels established under the Montreal Protocol, including the TEAP, the SAP and the EEAP.[150]

4.2.4 Substitute Substances May Give Rise to Other Problems

Although the Montreal Protocol has addressed one case of environmental problem shifting,[151] namely rising greenhouse gas emissions due to the increased uptake of HFCs, there is the potential for further problem shifting to arise as a result of the substances that are used to replace HFCs, such as hydrofluoroolefins (HFOs). While HFOs have low ODPs *and* low GWPs, they degrade to produce trifluoroacetic acid (TFA), a 'persistent toxic chemical'.[152] Their presence has been detected in humans; plants, including crops consumed by humans; and aquatic environments; and may accumulate in sensitive ecosystems like wetlands.[153] TFA has been found to be 'toxic to many organisms and can in principle lead to acidification of water bodies. … These persistent and mobile compounds have been identified as reason for concern, as they lead to irreversible contamination'.[154] Pickard et al also suggest that 'CFC replacements introduced as a result of the Montreal Protocol are likely the major source of TFA to the Arctic'.[155] HFOs also degrade to produce ozone, which contributes to ground-level pollution, particularly in urban areas. Their potential long-term impacts are not yet known,[156] and it has been argued that HFOs 'cannot be

148 ibid, 4–5.
149 ibid, 7.
150 ibid, 5.
151 Kim and van Asselt (n17).
152 Stephen Montzka, 'Hydrofluorocarbons (HFCs)' in WMO (n2) 2.4.
153 Heidi Pickard and others, 'Ice Core Record of Persistent Short-chain Fluorinated Alkyl Acids: Evidence of the Impact from Global Environmental Regulations' (2020) 47 Geophysical Research Letters e2020GL087535, 2.
154 Flerlage, Velders, and de Boer (n20) 12–13.
155 Pickard and others (n154) 7.
156 Montzka and others (n153) 2.34.

regarded as overall sustainable alternatives'.[157] Measurements of atmospheric concentrations reveal that the consumption of HFOs is increasing,[158] and it is projected that the deposition of TFA in the environment will increase further as HFC-134a (used in mobile air conditioners) is replaced by HFO-1234yf.[159]

Steffen et al argue that '[t]he risks associated with the introduction of novel entities into the Earth system are exemplified by the release of CFCs (chlorofluorocarbons), which are very useful synthetic chemicals that were thought to be harmless but had unexpected, dramatic impacts on the stratospheric ozone layer.[160] In effect, humanity is repeatedly running such global-scale experiments but not yet applying the insights from previous experience to new applications'.[161] Arguably, such 'global-scale experiments' are being repeated with the introduction of HFO-1234yf.

In addition, natural refrigerants (which occur naturally in the environment), including hydrocarbons, ammonia, water and CO_2, have been (re-)introduced to some extent in certain sectors. However, they are not necessarily unproblematic. For example, most are flammable, and ammonia is toxic.[162] Furthermore, while CO_2 has a significantly lower GWP than HFCs, it does remain a greenhouse gas.

In response to these concerns, De Graaf et al note that the use of natural refrigerants would require the introduction of appropriate safety measures and trained personnel.[163] More broadly, Flerlage, Velders and De Boer note the importance of considering '[a]dditional safety and environmental concerns beyond global warming' in the analysis of HFC alternatives.[164] Pickard et al recommend that the persistence and mobility of chemicals should be considered before replacing one class of chemicals with another.[165] Similarly, the

157 Daniel de Graaf, 'Hydrofluorocarbon Emission Reduction: A Crucial Contribution to Climate Protection: Proposals to Enhance European Climate Ambition' (2021) <https://www.umweltbundesamt.de/sites/default/files/medien/2546/publikationen/2021-05-04_scientific_opinion_paper_hfcs_climate_protection_contribution_final.pdf> accessed 15 December 2021, 9.

158 Flerlage, Velders, and de Boer (n20) 12.

159 Pickard and others (n154) 7.

160 Will Steffen and others, 'Planetary Boundaries: Guiding Human Development on a Changing Planet' (2015) 347(6223) Science 736.

161 Steffen and others (n16).

162 de Graaf (n158) 8.

163 ibid, 9.

164 Flerlage, Velders, and de Boer (n20) 13.

165 Pickard and others (n154) 7.

importance of examining the '"life-cycle" impacts' of substitute substances – in relation to both society and the environment – has been highlighted.[166]

4.2.5 Obtaining Accurate Data Is Complex

In terms of the Montreal Protocol, as discussed above, Parties are required to report on their production as well as imports and exports of ODSs. Under the climate regime, Parties are required to report on their HFC emissions.[167] However, Parties to the Montreal Protocol that have not ratified the Kigali Amendment are not required to report on their production, imports and exports of HFCs. This means that obtaining a complete picture is challenging.

In regard to HFC-23 specifically, research reveals a large discrepancy (of 24.4 gigagrams (Gg) between 2015 and 2017) between the HFC-23 emissions that were reported and those that were actually observed in the atmosphere.[168] While it is not possible to identify the precise cause, Stanley et al suggest that 'it is highly likely that developing countries have been unsuccessful in meeting their reported emissions reductions. Alternatively, or additionally, there may be substantial unreported production of HCFC-22 at unknown locations resulting in unaccounted-for HFC-23 by-product being vented to the atmosphere'.[169]

Similarly, in regard to HFCs generally, there is a discrepancy between the HFC emissions reported by developed countries and the global HFC emissions that have been estimated based on atmospheric measurement data. Thus, the emission estimates of HFCs provided by Annex I (developed) countries to the UNFCCC account for less than half of the emissions that have been estimated based on atmospheric data.[170] While China's HFC emissions are estimated to account for approximately 56 per cent of the HFC emissions of non-Annex I (developing) countries, there is still an unexplained gap, and '[n]umerous studies … share the conclusion that China is not the only big non-Annex I emitter causing the gap in emissions between reported values from Annex I countries to the UNFCCC and global emissions derived from atmospheric measurements'.[171]

166 UNEP, *HFCs: A Critical Link in Protecting Climate and the Ozone Layer* (2011) <https://www.unep.org/resources/report/hfcs-critical-link-protecting-climate-and-ozone-layer> accessed 9 December 2021, 12.
167 United Nations Framework Convention on Climate Change (UNFCCC) (signed 4 June 1992, entered into force 21 March 1994) 1771 UNTS 107, Articles 4(1) and 12(1).
168 Stanley and others (n134) 4.
169 ibid, 2.
170 Flerlage, Velders, and de Boer (n20) 7.
171 ibid, 13.

The research of Flerlage, Velders and De Boer[172] illustrates the difficulty of obtaining accurate data including due to the use of different methods to estimate emissions, the unavailability of data in certain regions, the inconsistency in reporting, the one-off nature of atmospheric studies, and the seasonal variability of some HFCs. In addition, emissions of certain HFCs are not reported to the UNFCCC due to confidentiality issues (to protect businesses' competitiveness).[173] Furthermore, exports of products or waste containing HFCs are not included in the inventories of exporting (likely developed) countries that are reported to the UNFCCC. 'While the export may be better recorded, it may be that imports into waste processing countries are not accounted for in bottom-up estimates'.[174] While not confirmed, this could partly explain the gap between reported and observed HFC emissions.[175] In addition, since the emissions 'would be accounted for in countries where only the disposal happens but the benefits of the product were not used, this method of accounting raises fairness issues'.[176]

In response to these concerns, it has been proposed that measurement methods be harmonised and, furthermore, that strategically locating measurement stations would enable additional data to be obtained, thereby enabling emissions from further regions to be quantified and decreasing the uncertainty of top-down atmospheric emission estimates.[177]

5 Strengthening the Global Regulation of HFCs: Enhancing Cooperation under International Law

In addition to addressing the gaps identified above, a more substantive shift relates to enhancing the coordination of measures related to HFC regulation under international law. Although HFCs are regulated directly under the ozone regime – which has been the focus in this chapter – 'this does not mean that

172 ibid.
173 Environmental Protection Agency (EPA) 'Revisions and Confidentiality Determinations For Data Elements Under the Greenhouse Gas Reporting Rule' (21 June 2022) <https://www.federalregister.gov/documents/2022/06/21/2022-09660/revisions-and-confidentiality-determinations-for-data-elements-under-the-greenhouse-gas-reporting> accessed 15 September 2022.
174 Flerlage, Velders, and de Boer (n20) 5.
175 ibid, 5–6.
176 ibid, 6.
177 ibid, 13; see also Sovacool and others (n125).

HFCs are outside the scope of the UNFCCC or the Paris Agreement'.[178] Indeed, HFCs are a listed greenhouse gas under the Kyoto Protocol and, importantly, they fall under the enhanced transparency framework established by the Paris Agreement,[179] which includes obligations in regard to reporting. Furthermore, many countries have dealt with HFCs in their nationally determined contributions (see Chapter 3 of this book). This points to the need to coordinate their regulation under both the ozone and climate regimes, including to address the 'no treaty territory'[180] that ODSs, including HFCs, fall into once produced.

There has previously been cooperation between bodies under the climate and ozone regimes. For example, the Intergovernmental Panel on Climate Change and the TEAP under the Montreal Protocol together prepared a Special Report regarding the impacts of ODS substitutes on the global climate system.[181] Furthermore, the TEAP's Energy Efficiency Task Force is exploring the potential coordination of measures to phase down HFCs and enhance energy efficiency, which would also have climate co-benefits. In addition, the Task Force has suggested that developing countries switch directly from HCFCs to low-GWP alternatives, thereby bypassing HFCs.[182]

Furthermore, Parties under the Montreal Protocol explicitly acknowledge the potential climatic effects of emissions of ODSs[183] and have, in several decisions, acknowledged the link between the ozone and climate regimes. For example, already in 2007, Parties agreed that projects that focused on substitutes that 'minimize other impacts on the environment, including the climate, taking into account global-warming potential, energy use and other relevant factors' should be prioritised.[184]

178 Dario Piselli and Harro van Asselt, 'Planetary Boundaries and Regime Interaction in International Law' in French, D and Kotzé, LJ (eds) *Research Handbook on Law, Governance and Planetary Boundaries* (Edward Elgar 2021) 137.

179 Paris Agreement (n28) Article 13.

180 Gonzalez, Taddonio, and Sherman (n79) 127.

181 Bert Metz and others (eds), *Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons* (Cambridge University Press 2005).

182 IISD, 'Summary of the Second Part of the 43rd Meeting of the Open-ended Working Group of the Parties to the Montreal Protocol: 14–17 July 2021' (2021) <https://enb.iisd.org/sites/default/files/2021-07/enb19156e.pdf> accessed 12 September 2022; Sovacool and others (n125); Pallav Purohit and others, 'Achieving Paris Climate Goals Calls for Increasing Ambition of the Kigali Amendment' (2022) 12 Nature Climate Change 339–342.

183 Montreal Protocol (n1) Preamble.

184 UNEP, 'Decision XIX/6: Adjustments to the Montreal Protocol with regard to Annex C, Group I, substances (hydrochlorofluorocarbons)' (UNEP/OzL.Pro.19/7) (21 2007) <https://ozone.unep.org/Meeting_Documents/mop/19mop/MOP-19-7E.pdf> accessed 5 May 2022, para. 11(b).

Further cooperation and the seeking of co-benefits to deal with some of the challenges identified above should be encouraged. For example, it has been proposed that a GWP-limit for substances used in, *inter alia*, air conditioning and refrigeration systems should be specified.[185] Under the climate regime, ensuring that HFCs are specifically included in country Parties' nationally determined contributions could strengthen HFC-related action.[186] This is also elaborated on in Chapter 3 of this book. In addition, further greenhouse gas emissions could be avoided by improving energy efficiency in refrigeration and air conditioning equipment and by improving insulation materials and building designs so that there is a reduced need for air conditioning.[187] Purohit et al project that '[w]hen fully implementing the technical potential for energy efficiency improvements, we estimate that compliance with the [Kigali Amendment] can bring electricity savings that correspond to more than 20% of the world's entire future electricity consumption'.[188] This would have further (co-)benefits in the form of reduced emissions of sulfur dioxide, nitrogen oxides and particulate matter with associated positive implications for human health and ecosystems.[189] Furthermore, since ODSs, including HFCs, are used in the production of plastics,[190] cooperation under the Montreal Protocol and a new globally binding treaty on plastics[191] should ideally be promoted.

6 Conclusion

Hailed as one of the most successful international environmental law agreements to date, the Montreal Protocol has thus far been successful in regard to protecting the ozone layer. Furthermore, even though HFCs do not deplete stratospheric ozone, they have been brought under the control of the Montreal

185 de Graaf (n158) 16.
186 Katherine Ross and others, 'Strengthening Nationally Determined Contributions to Catalyze Actions that Reduce Short-lived Climate Pollutants' (2018) <https://www.wri.org/research/strengthening-nationally-determined-contributions-catalyze-actions-reduce-short-lived> accessed 6 December 2021, 23–24.
187 see CCAC (n4).
188 Purohit and others (n26) 11321.
189 ibid, 11322.
190 Andersen and others (n112).
191 United Nations Environment Assembly of the United Nations Environment Programme (UNEA) *Draft Resolution: End Plastic Pollution: Towards an International Legally Binding Instrument* (UNEP/E.A.5/L.23/Rev.1) (2022) <https://wedocs.unep.org/bitstream/handle/20.500.11822/38525/k2200647_-_unep-ea-5-l-23-rev-1_-_advance.pdf?sequence=1&isAllowed=y> accessed 4 March 2022.

Protocol, with the result that the Montreal Protocol has also been beneficial for the climate. Despite these successes, several gaps have been identified under the Montreal Protocol. While some gapss could be addressed, for example, through the refinement of existing definitions and closing of loopholes, on a broader scale, it will also be important that further opportunities to coordinate efforts under different international law regimes are harnessed to ensure the continued effectiveness of the ozone regime and to guard against future problem shifting.

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