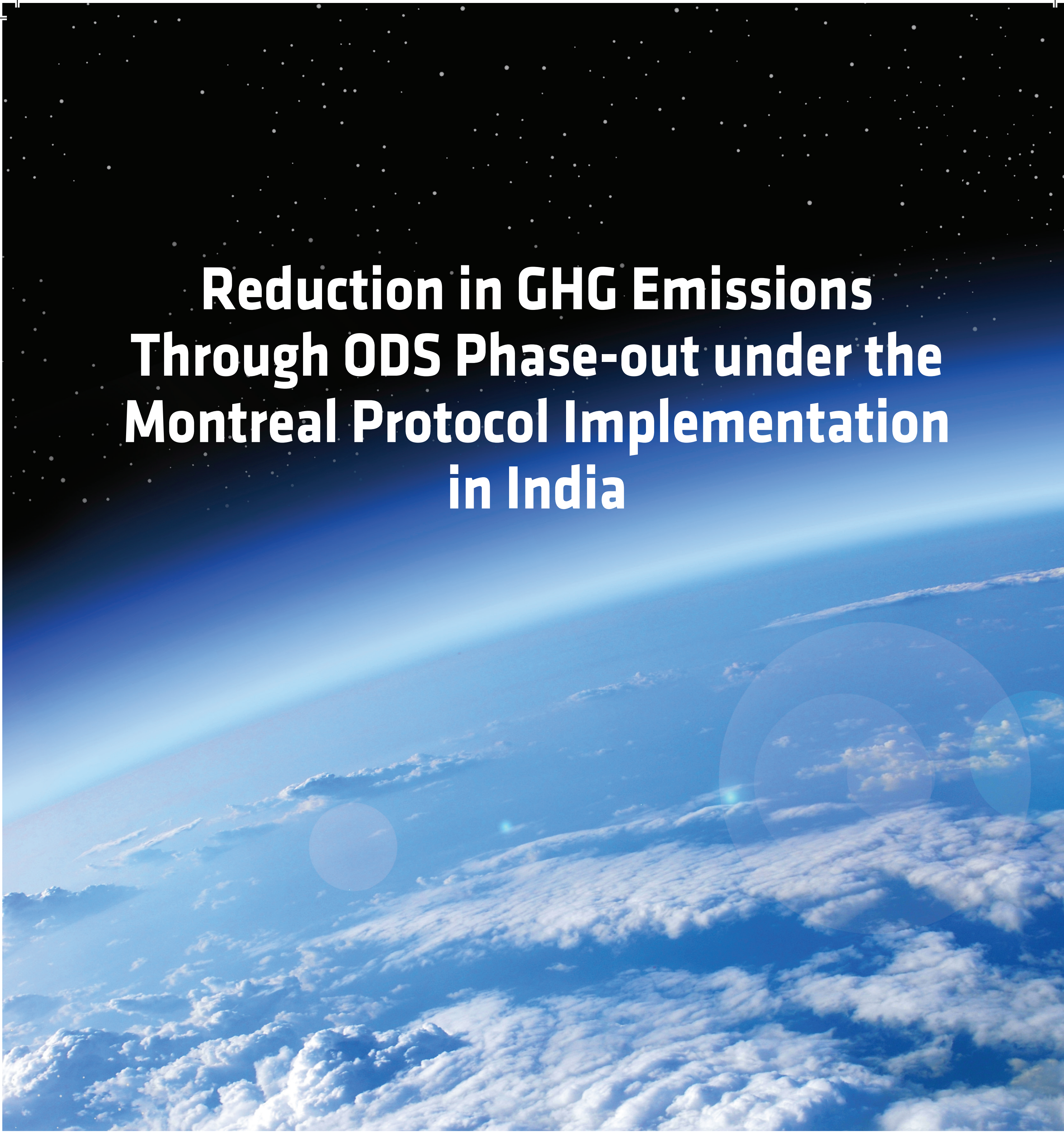
Reduction in GHG Emissions Through ODS Phase-out under the Montreal Protocol Implementation in India



OZONE CELL
MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

REDUCTION IN GHG EMISSIONS THROUGH ODS PHASE-OUT UNDER THE MONTREAL PROTOCOL IMPLEMENTATION IN INDIA

सत्यमेव जयते

OZONE CELL
MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA
NEW DELHI

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
और
श्रम एवं रोज़गार
भारत सरकार

सत्यमेव जयते

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR AND EMPLOYMENT
GOVERNMENT OF INDIA

भूपेन्द्र यादव
BHUPENDER YADAV

MESSAGE

The Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer were adopted in 1985 and 1987 respectively to protect the stratospheric ozone layer from the harmful ozone depleting substances (ODS).

The Montreal Protocol on Substances that Deplete the Ozone Layer having universal ratification, is recognized as a landmark international environmental treaty. It presents to the world the case study in international cooperation and concerted action to address global environment challenges. The extraordinary international cooperation of Parties to the Montreal Protocol has led not only the phase-out of production and consumption of several ODS but also a significant contribution to the protection of global climate. India, as a Party to the Montreal protocol has been successfully implementing phase-out of production and consumption of ODSs under the Montreal Protocol by accessing financial and technical assistance from Montreal Protocol's financial mechanism without undue economic burden to consumers, producers and equipment manufacturers.

India phased out the production and consumption of ozone depleting substances (ODS) such as Chlorofluorocarbons (CFCs), carbon tetrachloride (CTC), halons, for controlled uses and has met all the phase-out targets prescribed under the Montreal Protocol. Currently, Hydrochlorofluorocarbons (HCFCs), the last category of ODSs, are being phased out as per the accelerated phase-out schedule of the Montreal Protocol.

The phase-out of controlled uses of ODS has not only contributed towards protection of the stratospheric ozone but also resulted in reduction of greenhouse gas (GHG) emissions, which has also contributed significantly to global efforts to address climate change.

This study report on "Reduction in GHG emissions through ODS phase-out under the Montreal Protocol implementation in India" estimates the reduction of GHG emissions through the implementation of the Montreal Protocol in the country. I congratulate all team members for preparation of this Report.

With best wishes.

Date: 10 .09.2022

(Bhupender Yadav)

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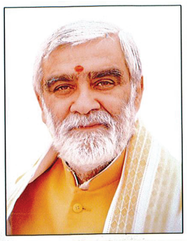

सत्यमेव जयते

आहारशुद्धौ सत्त्वशुद्धिः

स्वच्छ भारत
एक कदम स्वच्छता की ओर

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
भारत सरकार
MINISTER OF STATE
ENVIRONMENT, FOREST AND CLIMATE CHANGE
CONSUMER AFFAIRS, FOOD & PUBLIC DISTRIBUTION
GOVERNMENT OF INDIA

MESSAGE

The Montreal Protocol on Substances that Deplete the Ozone Layer is a global agreement to protect Stratospheric ozone layer by phasing out the production and consumption, including uses of chemicals that deplete it. The Agreement was signed on 16 September, 1987 and entered into force in 1989. The Montreal Protocol provides a set of practical, actionable tasks to phase out ozone-depleting substances.

The Montreal Protocol is one of the most successful and effective environmental treaties negotiated and implemented, due to the cooperation and commitment shown by the international community.

The implementation of Montreal Protocol has considerable co-benefits for addressing climate change because most of the ozone-depleting substances are also potent greenhouse gases that contribute to climate change. Montreal Protocol controls have led to a substantial reduction in the emissions of ozone-depleting substances. These reductions, while protecting the ozone layer, have the additional benefit of addressing climate change. It has been estimated that without Montreal Protocol controls, the climate forcing due to ozone-depleting substances could now be nearly two and a half times the present value.

India being a Party to the Montreal Protocol for 30 years, need to assess its contribution in the reduction of GHG emissions and protection of the climate system. The study report "Reduction in GHG emissions through ODS phase-out under the Montreal Protocol implementation in India" assesses the reductions of GHG emissions due to the Montreal Protocol implementation. I congratulate all those involved in the development of this Report.

(ASHWINI KUMAR CHOUBEY)

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The **Reduction in Greenhous Gas (GHG) Emissions Through ODS Phase-out under the Montreal Protocol Implementation in India** is the outcome of the collaborative efforts of the Ozone Cell, Ministry of Environment, Forest and Climate Change (MoEF&CC) and The Energy and Resources Institute (TERI).

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EXECUTIVE SUMMARY

The Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer came into existence in 1985 and 1987, respectively to protect the stratospheric ozone layer from the harmful ozone-depleting substances (ODS). India became the Party to the Vienna Convention on 18 March 1991 and the Montreal Protocol on 19 June 1992. The Government of India has entrusted the work relating to implementation of the Montreal Protocol to the Ministry of Environment, Forest and Climate Change (MoEF&CC). The MoEF&CC has set up the Ozone Cell as National Ozone Unit to render necessary services for effective and timely implementation of ODS phase-out projects, plans, and other related activities in India. India had prepared a detailed Country Program (CP) in 1993 to phase-out production and consumption of ODS in accordance with its National Industrial Development Strategy.

India being one of the Article 5 countries has been implementing the phase-out of production and consumption of ODS by accessing financial and technical assistance from the financial mechanism of the Montreal Protocol without undue economic burden to consumers, producers, and equipment manufacturers using ODS. The MoEF&CC while implementing phase-out of production and consumption of ODS has been making all efforts to minimize economic dislocation as a result of conversion to non-ODS technologies and maximize indigenous production.

ODS were used in the country in various sectors and subsectors. Chlorofluorocarbons (CFCs) were commonly used as aerosol propellants, refrigerants, solvents, process agents, and foam-blowing agents. Other chlorine and bromine-containing compounds include methyl chloroform, a solvent; carbon tetrachloride (CTC), a solvent as well as a widely used industrial chemical; halons, extremely effective fire-extinguishing agents; hydrochlorofluorocarbons (HCFCs), mainly used as a refrigerant and foam-blowing agent; and methyl bromide, an effective fumigant used in agriculture and grain storage.

India phased out the production and consumption of high ozone-depleting potential (ODP) chemicals, e.g., CFCs, CTC, halons, etc., as on January 1, 2010 and has met all the phase-out targets as per the Montreal Protocol phase-out schedule. The phase-out of production and consumption of HCFCs, which have lower ODP and are the last family of ODS, was scheduled after the phase-out of high-ODP ODSs. Phase-out of HCFCs is currently ongoing as per the accelerated phase-out schedule of HCFCs under the Montreal Protocol. The HCFC Phase-out Management Plan (HPMP) is being implemented in the country.

The phase-out of controlled uses of ODS and associated greenhouse gas (GHG) emissions has contributed to the protection of the stratospheric ozone and consequently helped global efforts to address climate change. In the process of phase-out of ODS, some HFCs have been accepted globally as alternatives to CFCs, HCFCs, etc. HFCs being potent GHGs, were introduced during phase-out of ODS. The Meeting of Parties to the Montreal Protocol at its 28th Meeting held in Kigali, Rwanda in October 2016 reached a historical agreement for phase-down of HFCs under the ambit of the Montreal Protocol.

India, since the inception of implementation of phase-out of production and consumption of ODS preferred to use low global warming potential (GWP) alternatives to ODS, wherever feasible, to minimize the use of high GWP HFCs and second/third conversions. Hydrocarbon aerosol propellants (HAPs) were adopted as substitutes to CFCs in the aerosol sector. Low-GWP foam blowing agents, e.g., hydrocarbon, methylformate (ECOMATE), CO_2, water and hydrofluoroolefins (HFOs), etc., are being used as substitutes to CFCs and HCFCs-based blowing agents. ABC powder, aqueous systems, CO_2-based extinguishing agents are used in place of ODS in the fire-extinguishing sector. Methyl bromide was used only for quarantine and pre-shipment applications.

The Report presents the study and assessment of the contributions made by India in the reduction of GHG emissions by phasing-out the production and consumption of ODS under the Montreal Protocol. To this end, a multiple activity approach has been adopted, the collation of data on ODS phase-out from secondary literature and alternative technology options by stakeholders consultations. It covers the estimation of GHG emission reductions from ODS consolidations by collection and collation of targeted chemicals data for the years 1992 to 2020, which includes the consumption, production, export and import (in ODP tonnes) across all major application sectors such as refrigeration and air-conditioning (RAC), foam-manufacturing, fire-extinguishing, aerosol and solvent cleaning, mobile air-conditioning (MAC), metered dose inhalers (MDIs) sector, etc.

The estimation of GHG emissions of ODS chemicals for the above mentioned sectors have been made for the following two scenarios:

(i) **Business-as-usual (BAU) scenario**: GHG emissions of ODS without the implementation of the Montreal Protocol. The estimation under BAU scenarios is analysed with two growth rates—the high growth rates and the low growth rates.

(ii) **The Montreal Protocol implementation scenario**: It considers the interventions leading to the phase-out of ODS-based chemicals in the country.

India's significant reduction in GHG emissions can be attributed to the successful implementation of the country's proactive policies towards the protection of the environment and regulatory framework and fiscal measures put in place in the country for phase-out of ODS. Comprehensive Ozone Depleting Substances (Regulation and Controls) Rules, 2000 were developed and amended several times in consultation with all the concerned stakeholders and put in place under the Environment (Protection) Act, 1986. Some of the proactive policies and approaches that resulted in early phase-out of high-ODP and high-GWP chemicals and adoption of low-GWP technical options are as follows:

(i) Banning the use of CFCs and halons in the manufacturing of new equipment from 1 January 2003.

(ii) Phase-out of production and consumption of virgin halons from 2002.

(iii) Accelerated phase-out of production and consumption of CFCs with effect from 1 August 2008, 17 months ahead of the Montreal Protocol phase-out schedule, except for use of pharmaceutical grade CFCs in manufacturing of Metered Dose Inhalers (MDIs) for Asthma, Chronic Obstructive Pulmonary Disease (COPD), and other respiratory ailments within the country and other Article 5 countries.

(iv) Adoption of low-GWP options, wherever feasible, since inception of the implementation of the phase-out of ODS.

(v) Conversion of entire foam manufacturing in the country from HCFCs to low-GWP foam-blowing agents.

(vi) Conversion of room air conditioner manufacturing lines from HCFC-22 to lower GWP refrigerant (HFC-32) during the implementation of HPMP Stage-II.

The study has estimated that the GHG emissions reduction due to implementation of the Montreal Protocol would be in the range of 778–1176 million tonnes CO_2e by 2030.

ABBREVIATIONS & ACRONYMS

CFCs	Chlorofluorocarbons
CTC	Carbon Tetrachloride
GHG	Greenhouse Gases
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HPMP	HCFC Phase-out Management Plan
MoEF&CC	Ministry of Environment, Forest and Climate Change
MOP	Meeting of the Parties to the Montreal Protocol
MT	Metric Tonne
ODP	Ozone-depleting Potential
ODS	Ozone-depleting Substances
RAC	Refrigeration and Air-conditioning
tCO_2e	Tonnes of Carbon Dioxide Equivalent
TCA	Methyl Chloroform
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
BAU	Business-as-usual

1
BACKGROUND

The Vienna Convention for the Protection of the Ozone Layer was agreed in 1985. Subsequently, the Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in 1987 to phase-out the production and consumption of the ozone-depleting substances (ODS) that are responsible for the depletion of the ozone layer. The Government of India has entrusted the works relating to the implementation of the Montreal Protocol to the Ministry of Environment, Forest and Climate Change (MoEF&CC) in the country. MoEF&CC has set up the Ozone Cell, invested with the responsibility for carrying out all tasks relating to the implementation of ODS phase-out.

ODS were used in various sectors and subsectors in India. Chlorofluorocarbons (CFCs) were commonly used as aerosol propellants, refrigerants, solvents, process agents, and foam-blowing agents. Other chlorine and bromine-containing compounds include methyl chloroform, a solvent; carbon tetrachloride (CTC), a solvent as well as a widely used industrial chemical; halons, extremely effective fire-extinguishing agents; hydrochlorofluorocarbons (HCFCs), mainly used as a refrigerant and foam-blowing agent; and methyl bromide, an effective fumigant were used in agriculture and grain storage.

The production and consumption of ODS like CFCs, CTC and halons have already been phased out globally, including in India. The HCFC Phase-out Management Plans (HPMPs) in India are currently being implemented for phase-out of production and consumption of HCFCs with an accelerated phase-out schedule of the Montreal Protocol.

India has been making all efforts since the inception of implementation of the conversion projects/plans from ODS to non-ODS technologies and low global warming potential (GWP) as alternatives to ODS, wherever feasible. Hydrocarbon aerosol propellants (HAPs) were adopted as substitutes for CFCs in the aerosol sector. Low GWP foam-blowing agents, e.g., hydrocarbon (cyclopentane), methylformate (ECOMATE), CO_2, water and hydrofluoroolephenes (HFOs), etc., are being used as substitutes to CFCs and HCFCs-based blowing agents. ABC powder, aqueous systems, CO_2-based extinguishing agents are used in place of ODS in the fire-extinguishing sector. Methyl bromide has been used only for quarantine and pre-shipment applications.

The phase-out of controlled uses of ODS and the related reductions have not only helped protect the ozone layer but have also contributed significantly to global efforts to address climate change. It has also protected human health and ecosystems by limiting harmful ultraviolet radiation from reaching the earth. India has played a proactive role in the implementation of phase-out activities related to ODS in the country, and has adhered to the phase-out schedule of the Montreal Protocol.

Some hydrofluorocarbons (HFCs) have also been introduced as alternatives to CFCs, HCFCs, etc. HFCs, being potent greenhouse gases (GHGs), were introduced in the implementation of phase-out of ODS. The Meeting of Parties to the Montreal Protocol at its 28th Meeting held in Kigali, Rwanda in October 2016 reached a historical agreement for the phase-down of HFCs under the ambit of the Montreal Protocol.

India harbours approximately one-sixth of global population and with its growing industrialization, economic activity and urbanization, the use of built environment and demand for facilities are projected to grow rapidly in the coming decades. With this, the penetration of air-conditioning and refrigeration systems in residential, commercial, industrial, agriculture, cold chain and transportation sectors are also projected to rise significantly.

This study has been focused on assessment of the contributions made by India in the reduction of GHG emissions by phasing-out the production and consumption of ODS under the Montreal Protocol. The study covers the estimation of GHG emission reductions from ODS consolidations by collection and collation of targeted chemicals data for the years 1992 to 2020, which includes the consumption, production, export and import (in ODP tonnes) across all major application sectors such as refrigeration and air conditioning (RAC) sector, foam sector, fire extinguishing sector, aerosol and solvent cleaning sector, mobile air-conditioning (MAC) sector, metered dose inhalers (MDIs) sector, etc.

2 OBJECTIVE

The study aims to assess the contributions made by India in the reduction of GHG emissions by phasing-out the production and consumption of ODS under the Montreal Protocol. A multiple-activity approach has been adopted, collation of data on phase-out of ODS from secondary literature and alternative technology options by stakeholders' consultation. The study covers the following for the estimation of GHG emission reductions from ODS consolidations:

- Data collation of targeted chemicals for the years 1992 to 2020, which includes the consumption, production, export and import (in ODP tonnes) across all major application sectors such as refrigeration and air-conditioning (RAC) sector, foam sector, fire-extinguishing sector, aerosol and solvent cleaning sector, mobile air-conditioning (MAC) sector, metered dose inhalers (MDIs) sector, etc.
- Estimation of GHG emissions of ODS chemicals (as shown in the graphic below) depicting above-mentioned sectors for two scenarios:
  - (i) Business-as-usual (BAU) scenario: GHG emissions of ODS without the implementation of the Montreal Protocol. The estimation under BAU scenarios is analysed with two growth rates: i.e., the high growth rates and the low growth rates.
  - (ii) Montreal Protocol implementation scenario: It considers the interventions leading to the phase-out of production and consumption of the following ozone-depleting chemicals in the country.

- Representation of the GHG emissions trends under the two intended scenarios from 1992 to 2020.
- Representation of the GHG emissions projections under the two intended scenarios till the year 2030.

3

BACKGROUND

3.1 The Vienna Convention and the Montreal Protocol

The first global agreement to protect the stratospheric ozone layer was reached in 1985, with the adoption of the Vienna Convention for the Protection of the Ozone Layer. This Convention became the foundation for the Montreal Protocol on Substances that Deplete the Ozone Layer to restore and protect the stratospheric ozone layer. The Montreal Protocol was adopted in 1987 to control the production and consumption of the chemicals that are harmful to the stratospheric ozone layer. The Vienna Convention and the Montreal Protocol are environmental treaties, which have been universally ratified, and all the 198 countries are Parties to the Vienna Convention and the Montreal Protocol. The Montreal Protocol has been regarded as the most successful environment protection agreement.

The Vienna Convention and its Montreal Protocol and all its amendments primarily are intended to reduce depletion of the stratospheric ozone and put the ozone layer on a path of recovery. However, the ambition to reduce and eventually eliminate the use of ODS has also produced co-benefits towards significant GHG emission reduction. ODS especially, the CFCs, halons, CTC and HCFCs and other chlorine and bromine-containing halogenated compounds typically have a high global warming potential (GWP) with a high capacity to trap heat in the Earth's atmosphere. With a GWP up to 10,000 times higher than carbon dioxide (CO_2), these gases can have a significant impact on total GHG emissions, even in very small concentrations.

The phase-out schedule of some of the commonly used ODS chemicals is provided in Table 1 (Ozone Secretariat, 2020). India falls under the Article 5 Party and has always followed the phase-out schedule of the Montreal Protocol.

Table 1: Phase-out schedule of ODS

Chlorofluorocarbons (applicable to production and consumption)			
Non-Article 5 parties		**Article 5 parties**	
Baseline	1986	Baseline	Average of 1995–1997
Freeze	July 1, 1989	Freeze	July 1, 1999
75 per cent reduction	January 1, 1994	50 per cent reduction	January 1, 2005
100 per cent reduction	January 1, 1996 (with possible essential use exemptions)	85 per cent reduction	January 1, 2007
		100 per cent reduction	January 1, 2010 (with possible essential use exemptions)
Halons (applicable to production and consumption)			
Non-Article 5 parties		**Article 5 parties**	
Baseline	1986	Baseline	Average of 1995–1997
Freeze	January 1, 1992	Freeze	January 1, 2002
100 per cent reduction	January 1, 1994 (with possible essential use exemptions)	50 per cent reduction	January 1, 2005
		100 per cent reduction	January 1, 2010 (with possible essential use exemptions)
Carbon tetrachloride (applicable to production and consumption)			
Non-Article 5 parties		**Article 5 parties**	
Baseline	1989	Baseline	Average of 1998–2000
85 per cent reduction	January 1, 1995	85 per cent reduction	January 1, 2005
100 per cent reduction	January 1, 1996 (with possible essential use exemptions)	100 per cent reduction	January 1, 2010 (with possible essential use exemptions)
Methyl chloroform (applicable to production and consumption)			
Non-Article 5 parties		**Article 5 parties**	
Baseline	1989	Baseline	Average of 1998–2000
Freeze	January 1, 1993	Freeze	January 1, 2003
85 per cent reduction	January 1, 1994	30 per cent reduction	January 1, 2005
100 per cent reduction	January 1, 1996 (with possible essential use exemptions)	70 per cent reduction	January 1, 2010
		100 per cent reduction	January 1, 2015 (with possible essential use exemptions)

HCFCs (Applicable to consumption)			
Non-Article 5 parties		**Article 5 parties**	
Baseline	1989 HCFC consumption + 2.8 per cent of 1989 CFC consumption	Baseline	Average of 2009–2010
Freeze	1996	Freeze	January 1, 2013
35 per cent reduction	January 1, 2004	10 per cent reduction	January 1, 2015
75 per cent reduction	January 1, 2010	35 per cent reduction	January 1, 2020
90 per cent reduction	January 1, 2015	67.5 per cent reduction	January 1, 2025
100 per cent reduction	January 1, 2020, and thereafter – allowance of 0.5 per cent of baseline consumption until January 1, 2030 for the uses defined in Article 2F paragraph 6(a) and – possible essential use exemptions	100 per cent reduction	January 1, 2030, and thereafter – allowance of 2.5 per cent of baseline consumption when averaged over ten years 2030–2040 until January 1, 2040 for the uses defined in Article 5 paragraph 8 ter (e) (i) and – possible essential use exemptions

3.2 Montreal Protocol in India

India is a Party to the Montreal Protocol since 19 June, 1992, and has been implementing phase-out of production and consumption of ODS. India has already phased out the production and consumption of high-ODP ozone-depleting substances, e.g., CFCs, CTC, Halons, etc., as on 1 January 2010, and has met all the phase-out targets as per the Montreal Protocol phase-out schedule. These chemicals were widely used as refrigerants, foam blowing agents, cleaning agents, aerosols, fire-extinguishing agents and industrial and medical aerosols in the country. The phase-out of HCFCs, which have lower ODP, and are the last family of ODS, the phase-out of production and consumption of these chemicals was scheduled after the phase-out of high-ODP ODS. Phase-out of HCFCs is currently ongoing as per the accelerated phase-out schedule of HCFCs under the Montreal Protocol. The HCFC Phase-out Management Plan (HPMP) is being implemented in the country.

India, accelerating its efforts toward more sustainable cooling, launched its strategic document 'India Cooling Action Plan' (ICAP) in March 2019. The ICAP vision document lays down India's 20-year (2017–18 to 2037–38) action plan with the following goals:

- Reduction of cooling demand across sectors by 20 to 25 per cent by the year 2037–38
- Reduction of refrigerant demand by 25 to 30 per cent by the year 2037–38
- Reduction of cooling energy requirements by 25 to 40 per cent by the year 2037–38

- Training and certification of 100,000 servicing sector technicians by the year 2022–23, synergizing with Skill India Mission

3.3 India's HCFC Phase-out Management Plans (HPMPs) as per the Montreal Protocol

With continued efforts from different stakeholders, industry and the domestic policies developed, India has successfully phased out the production and consumption of CFCs, CTC, halons and methyl chloroform as on 1 January 2010. As per the accelerated phase out of HCFCs under the Montreal Protocol, India initiated activities as early as 2009 by developing a roadmap for the phase-out of HCFCs.

3.3.1 HCFC Phase-out Management Plan (HPMP) Stage-I

The HPMP Stage-I (Ozone Cell MoEF&CC, 2013) was developed intending to implement the phase- out process for a period of four years from 2012 to 2016 to achieve the freeze target by 2013 and 10 per cent phase-out targets of HCFCs by 2015 as per the Montreal Protocol phase-out schedule. The plan prioritized the phase-out of HCFC-141b, used in foam manufacturing including conversion of 15 large enterprises in the foam manufacturing sector from HCFC-141b to non-ODS, low-GWP cyclopentane technology. The HPMP Stage–I also initiated activities in the refrigeration and air-conditioning (RAC) servicing sector to reduce the use of HCFCs. Enabling activities like awareness among the stakeholders, capacity building of enforcement officers, etc., have also been carried out to expedite the HCFC phase-out targets.

The HPMP Stage-I has successfully phased out a total of 341.77 ODP tonnes of HCFCs that includes 310.53 ODP tonnes of HCFC 141b, which has been phased out in the foam manufacturing sector and 31.24 ODP tonnes of HCFC-22 from the RAC servicing sector. With this, India successfully achieved its Montreal Protocol targets for HCFC freeze in 2013 and a 10 per cent reduction in 2015. The reductions have been more than the intended commitments and timelines and have also resulted in corresponding GHG emission reductions that will go a long way in the protection of both ozone layer and climate.

3.3.2 HCFC Phase-out Management Plan (HPMP) Stage-II

The HPMP Stage-II (Ozone Cell MoEF&CC) launched in February 2017 intended to completely phase-out HCFC-141b in the foam manufacturing sector by 2020. Further, the target aims to phase out HCFC-22 from six major room air-conditioner manufacturing enterprises in the country by 2022 and to train about 17,000 RAC service technicians on alternative technologies and good servicing practices. The HPMP Stage-II also aims to address the capacity building and awareness about the harmful effects of HCFCs with regards to ozone depletion and global warming both from emissions of HCFCs and energy consumption in the RAC Sector. The HPMP Stage-II also prioritizes the phase-out of HCFCs and increasing energy efficiency in the building sector. Under the HPMP Stage-II, more than 10,000 servicing technicians have already been trained, and more training programmes are being conducted across the country to achieve the target by the end of 2022. India has completely phased out HCFC-141b, used in foam manufacturing enterprises from 1 January 2020 (MoEF&CC, 2020).

3.4 Kigali Amendment and Phase-down of Hydrofluorocarbons

The introduction of HFCs as zero ODP alternatives to CFCs, HCFCs, etc., in several applications had mellowed down the impacts to the ozone layer. On the contrary, these HFCs are highly potent GHG emissions steering the persisting global warming effects. The increasing consumption of HFCs has alarmed the international community and countries, urging to look out for suitable alternative options. According to the UNEP report, *HFCs: A Critical Link in Protecting Climate and the Ozone Layer*, the HFC emissions are projected to rise to about 3.5 to 8.8 $GtCO_2$-eq (Giga tonnes of carbon dioxide equivalent) by 2050 under business-as-usual (BAU) scenario, which is comparable to the reduction of 11.6 $GtCO_2$-eq achieved due to phasing out of ODS between 1988 and 2010 (UNEP, 2011). This means that without intervention, HFC emissions are projected to offset the climate benefits achieved by the Montreal Protocol through phasing out ODS. Globally, there were several efforts and discussions held to address the continuing issues of HFC phase-down as part of the Montreal Protocol.

The 28th Meeting of Parties held in Kigali, Rwanda on 15 October 2016, agreed for an amendment to the Montreal Protocol for phase-down of HFCs. The 'Kigali Amendment' to the Montreal Protocol is unique, as the Parties decided for the first time to address the non-ODS as controlled substances under the Montreal Protocol on Substances that Deplete the Ozone Layer.

The phase-down schedule of HFCs under the Kigali Amendment to the Montreal Protocol for Article 5 countries is shown in Figure 1.

As per the Kigali Amendment, Article 5 Group 1 and Group 2 countries are expected to reduce the production and consumption of HFCs by 80–85 per cent from their respective baselines by 2047 through gradual phase-down steps.

It is estimated that the phase-down of HFCs is expected to avoid the global average temperature rise by about 0.3–0.5 0C by the year 2100 (Velders *et al.*, 2015). Many are potent greenhouse gases that contribute to climate change. Here, new global scenarios show that baseline emissions of HFCs could reach 4.0-5.3 $GtCO_2$-eq yr-1 in 2050.

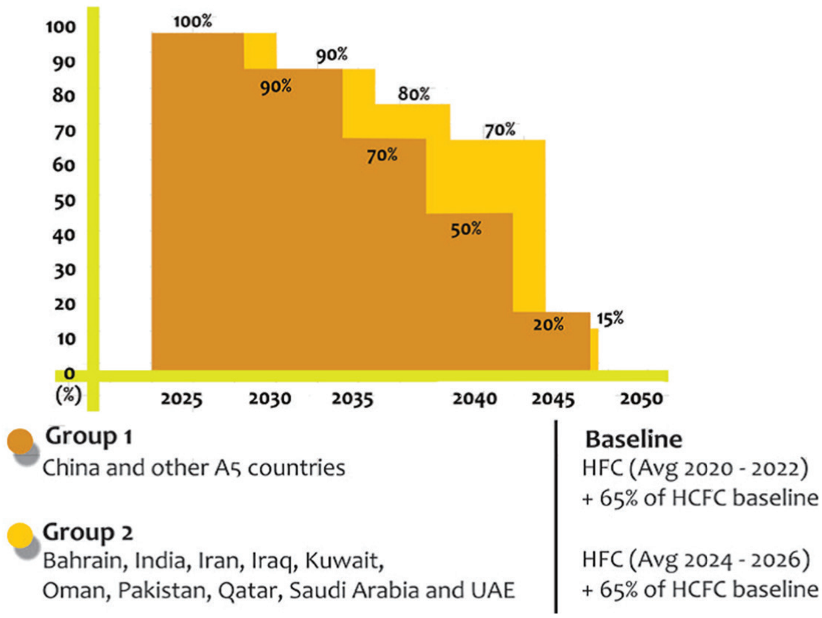


FIGURE 1
HFCs production/ consumption reduction schedule for Article 5 Parties

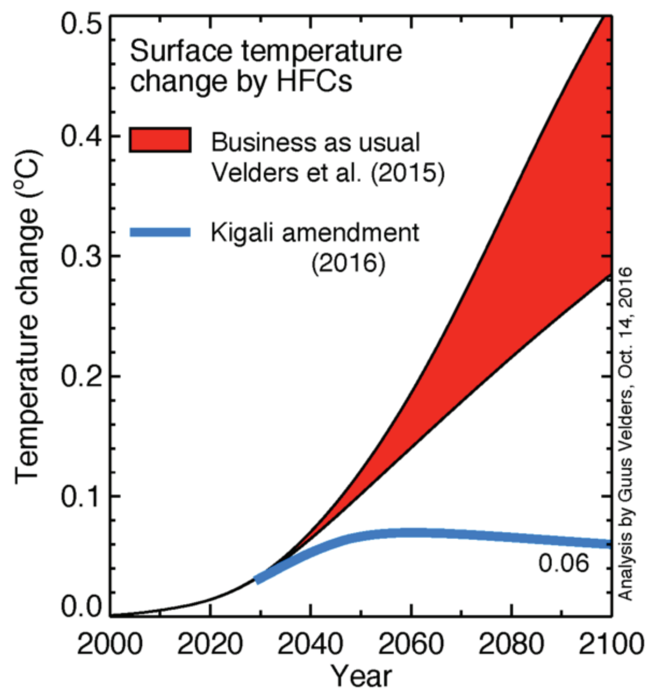


FIGURE 2
Avoidance of global surface temperature rise

For phase-down purposes, the countries have been divided into four groups with a specific schedule for HFC phase-down. India is part of Article 5 Group 2 countries and will start phasing down of production and consumption of HFCs with a freeze at the baseline level in 2028 and reduce to 15 per cent of the baseline by 2047.

The Kigali Amendment is unique, with respect to the control measures, calling for 'phase- down' instead of 'phase-out' since there are hardly any available alternative chemicals with zero GWP. In addition, the low-GWP alternatives to HFCs may not be available for all the applications. Earlier, the Protocol had no arrangement to incentivize improvement in energy efficiency and funding for R&D. On India's initiative, all these elements have been included in the Kigali Amendment. The Amendment will help the countries to leapfrog low-GWP technologies while implementing HPMPs and along with the multiple benefits in terms of improved energy efficiency, HFC phase-down would result in significant reduction in GHG emissions.

The Union Cabinet (GoI), in its meeting held on 18 August 2021, approved the ratification of the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer for phase- down of HFCs by India, adopted by the Parties to the Montreal protocol on October 2016 at the 28th Meeting of the Parties held at Kigali, Rwanda (Cabinet, 2021). Subsequently, India ratified the Kigali Amendment to the Montreal Protocol on 27 September 2021 and became the 126th country to ratify the Kigali Amendment (PIB, 2021). A licensing system for the import and export of HFCs has also been put in place in the country in March, 2022.

3.5 India's Institutional Framework for Implementation of the Montreal Protocol

The Government of India has entrusted the works relating to the ozone layer protection and implementation of the Montreal Protocol to the MoEF&CC. The Ministry has established an Empowered Steering Committee (ESC) Chaired by Secretary (EF&CC). The ESC is overall responsible for the implementation of the Montreal Protocol provisions, review of various policies including implementation options, project approvals and monitoring. The Ministry has set up the Ozone Cell (National Ozone Unit), which has been given the responsibility for carrying out all tasks relating to implementation of the Montreal Protocol. It governs day-to-day operations, promulgation of relevant policies and monitoring implementation of all phase-out projects, plans, and activities. Currently, the Ozone Cell is engaged in phase-out of production and consumption of HCFCs with an accelerated phase-out schedule as per the Montreal Protocol.

4

OZONE-DEPLETING SUBSTANCES (ODS)

Ozone-depleting substances include CFCs, HCFCs, halons, methyl bromide, carbon tetrachloride, and methyl chloroform. These ODS are generally very stable chlorinated and brominated compounds with a long atmospheric life. These degrade under intense ultraviolet radiations and specific low-temperature conditions, which are usually met in the stratosphere. When these chemicals break down, they release chlorine or bromine atoms, which then deplete stratospheric ozone.

RAC is one of the sectors using CFCs and HCFCs as refrigerants; the most commonly used ODS is a primary working fluid, which undergoes phase changes during heat absorption (evaporation) and heat-releasing (condensation) in a refrigeration system (Sameer Khandekar, 2020). Because of the ever-changing needs, constraints and regulations on refrigerants we are moving towards the fourth generation of refrigerants. In the first generation, we have used a variety of compounds like (ether, CO_2, NH_3, SO_2, H_2O, etc.) for almost a hundred years (1830–1930) and due to toxicity issues the world moved towards the next generation. In second generation (1931–1990) CFCs and HCFCs were invented and used. The impact of these refrigerants on the ozone layer led to the Montreal Protocol and phase-out of CFCs started. The third generation (1990–2010) of refrigerants includes chemical groups, such as HFCs that do not damage the ozone layer, however, they contribute to global warming and climate change. Fourth generation (2012 onwards) are like hydrofluoroolefins (HFOs), blends of HFCs/HFOs and natural refrigerants (Calm, 2008).

Aerosol sector continued to be one of the major sectors. Industrial aerosols and perfumes, shaving foams, pesticides, medications, paints, and inhalers are just a few of the applications where propellants are employed. In India, the Aerosol sector's manufacturing is significantly dominated by the small and medium enterprises. The aerosol sector has grown rapidly because of emerging customer base for personal care products, entry of multinational corporations in India leading to expansion of the manufacturing base in this sector, reduction in taxes on cosmetics, etc. CFC- based propellants were commonly used earlier in the 1990s but with CFC phase-out, most aerosol sub-sectors recognized hydrocarbon-based aerosol propellants as the ideal substitute technology such as butane, destenched liquefied petroleum gas (LPG), and so on.

Foam sector utilizes the blowing agents to stretch the plastic matrix before it solidifies, resulting in foam products. The final density of the foam formed is determined by the type and amount of blowing agent employed, as well as the processing parameters used. Initially prior to 2010, CFC-11 was widely used as foam-blowing agent. With the phase-out of CFCs, the HCFCs were commonly used as blowing agents in the sector but India has recently achieved the complete phase-out of HCFC-141b from the foam sector in 2020. Hydrocarbons (cyclopentane, n-pentane), modified water-blown formulations, supercritical carbon dioxide, methyl formate, HFOs, and high-GWP HFCs are all viable alternatives to HCFCs in the foam manufacturing sector. In some sectors, Indian foam-manufacturing industry has switchover to non-HFC low GWP alternatives while phasing out HCFC-141b.

ODS such as halons provide excellent fire-extinguishing characteristics and were used as firefighting agents in portable applications. After the phase-out of halons, HCFC-based alternatives have been employed in the sector and now with the ongoing HCFC phase-out, HFC-based alternatives are being deployed. For practically all new fire prevention applications that previously used halons, alternate extinguishing agents and technologies are now available, albeit for some applications, the only options are the original halon or a high-GWP HFC (HTOC, 2018).

Solvents sector consists of various sub-sectors including electronics and precision cleaning, metal cleaning, manufacture of pesticides and pharmaceuticals, chlorinated, and textile cleaning. CFCs, methyl bromide, and CTC are the primary solvents used in the sector and with their phase-out, intensive research and development efforts have been made to discover alternative solvents.

5

IMPLEMENTATION OF THE MONTREAL PROTOCOL IN INDIA

India had prepared a detailed Country Program (CP) in the year 1993 for the phase-out of ODS in accordance with its National Industrial Development Strategy by accessing funds from the Multilateral Fund for implementation of the Montreal Protocol, a financial mechanism of the Montreal Protocol. Since then, India had taken proactive measures such as phase-out project activities including technology transfer investments, technical assistance, training and capacity-building, information dissemination, and awareness-raising and regulations.

India has phased out the production and consumption of CFCs, CTC and halons as on 1 January 2010 [except use of pharmaceutical grade CFCs in the manufacturing of metered dose inhalers (MDIs) for asthma and chronic obstructive pulmonary disease (COPD) patients]. India has also phased-out production and consumption of methyl chloroform and methyl bromide except for controlled uses in quarantine and pre-shipment uses, which are still permitted to be used globally under the Montreal Protocol. The Government of India has entrusted the work relating to the ozone layer protection and implementation of the Montreal Protocol on Substances that deplete the Ozone Layer to the MoEF&CC. The Ministry has set up an Ozone Cell as a National Ozone Unit (NOU) to render necessary services for effective and timely implementation of the Montreal Protocol and its ODS phase-out programme. Currently, the Ozone Cell is engaged in phase-out of production and consumption of the next category of chemicals, HCFCs, with an accelerated phase-out schedule as per the Montreal Protocol. India successfully implemented the HPMP stage –I, and HPMP stage –II is ongoing (Ozone Cell MoEF&CC, 2021).

With the sustained growth in demand for refrigeration, air-conditioning and insulating foam products in developing countries the consumption and associated emissions of HFCs are projected to increase substantially in the coming decades in response to regulation of ozone depleting gases under the Montreal Protocol. New HFC scenarios are presented based on current HCFC consumption in leading applications, patterns of replacements of HCFCs by HFCs in developed countries, and gross domestic product (GDP) growth. Global HFC emissions in 2050 are equivalent to 9–19% (CO_2e basis) of projected global CO_2 emissions in BAU scenarios and contribute a radiative forcing equivalent to that from 6–13 years of CO_2 emissions near 2050 (Velders *et al.*, 2009).

To prepare a balanced scientific, technical and policy-relevant report regarding alternatives to ODS that affects the global climate system, the Intergovernmental Panel on Climate Change (IPCC) and Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol developed a report considering the effects of total emissions of ODS and their substitutes on the climate system and the ozone layer. The report presents the sector-wise options for reducing halocarbons (HFCs and PFCs) emissions and use of alternative substances and technology options for GHG emission reduction (IPCC/TEAP, 2005).

The 19th Meeting of the Parties in September 2007 decided to accelerate the phase-out of production and consumption of HCFCs for non-Article 5 (developed) and Article 5 (developing) countries for early recovery of the ozone layer. Based on the stakeholder consultation meetings including sectoral working group meeting for foam manufacturing, RAC manufacturing and servicing sectors a "Roadmap for phase-out of HCFCs in India" was developed and launched in 2009. This roadmap includes a long-term vision and action plan for phasing out of production and consumption of HCFCs in India. Under HPMP-Stage-I, India successfully met the 2013 target to freeze HCFC production and consumption and 10% phase-out target of HCFCs in 2015 for targeted sectors, as per the accelerated phase-out schedule of the Montreal Protocol (Ozone Cell MoEF&CC, 2013).

The HPMP stage–II was launched in March 2017, focusing on the MSME sector in foam manufacturing, and to reap the benefits of skilling and training, RAC servicing sector training programme with Skill India Mission of GoI as well as converting 10 manufacturing lines in six RAC manufacturing enterprises. The plan also integrated the promotion of energy efficiency, development of building codes for HCFC phase-out, cold chain development with non-HCFC alternatives, and development of standards for new non-ODS and low GWP alternatives, etc., under the enabling activities component (Ozone Cell MoEF&CC, 2017).

Table 2: Sector-wise projects and ODS phased out (in tonnes) as on 31-08-2021

Sector	No. of projects	Phase out of ODP (in tonne)
Aerosols Sector (CFC)	38	1702
Foams Sector (CFC)	163	5074
Firefighting Sector (Halons)	21	2719
Institutional Strengthening	12	-
Refrigeration & Air-conditioning Sector (CFC)	87	3983
Solvents Sector (including CTC production)	41	12,966
Production Sector (CFC and Halons)	15	20,107
HPMP Stage-I Preparation	1	-
HPMP Stage-I (HCFC-141b and HCFC-22)	1	342
HPMP Stage-II Preparation	1	-

Sector	No. of projects	Phase out of ODP (in tonne)
Demonstration Project in Foam Sector Preparation (HCFC-141b)	1	-
HPMP Stage-II (HCFC-141b and HCFC-22)	1	769
HPMP Stage-III Preparation	1	-
Total	383	47,662

5.1 India Cooling Action Plan

Cooling is an essential part of the economic growth and developmental need of a country. With rapid growth, the sector has become one of the largest consumer of electricity in the country. To provide socio-economic and environmental benefits related to reduced refrigerant use, climate change mitigation and Sustainable Development Goals (SDGs), the GOI developed India Cooling Action Plan (ICAP), which provides a long-term perspective and guidance with respect to cooling needs. It focuses on six thematic areas: (i) space cooling, (ii) cold chain, (iii) air conditioning and refrigeration technology, (iv) R&D and production sector - alternative refrigerants and technologies, (v) servicing sector, and (vi) transport air conditioning (car, bus, train and metro air conditioning). ICAP aims to provide a 20-year perspective plan (2018–2038) and policy recommendations, to address the cooling requirement across sectors (GoI, 2018). Rising per capita income, rapid urbanization and a largely tropical climate, would lead to rise in the demand for cooling. Addressing the rising cooling requirement provides a challenge as well as a unique opportunity, by allowing synergies in policies and actions to address the cooling requirement across sectors, while making it sustainable and accessible to all. Increasingly, cooling is recognized as a developmental need that is linked with achieving many Sustainable Development Goals. A large part of the cooling demand is catered through refrigerant-based cooling globally across sectors such as buildings, cold-chain, refrigeration and transport. Refrigerants used in cooling equipment are regulated under the Montreal Protocol regime. Another important aspect related to refrigerant-based cooling is energy use. The Kigali Amendment has recognized linkages between maintaining and improving the energy efficiency of the RAC equipment with refrigerant transition under the Montreal Protocol.

'The Montreal Protocol: India's Success Story', published annually by Ozone Cell, MoEF&CC presents India's status and progress on the implementation of the Montreal Protocol. Through structured implementation framework supported by a robust regulatory framework and fiscal measures along with active cooperation of industry have led to India successfully meeting all the ODS phase out targets of the Montreal Protocol including the phase out of production and consumption of CFC, CTC, halons, methyl chloroform as on 1 January 2010 except for controlled uses. Table 2 represents the consolidated status of sector-wise ODS phase-out projects and its corresponding ODP quantity of substances.

6

APPROACH AND METHODOLOGY

The intended study aims to estimate the reduction of GHG emissions as a result of the implementation of the Montreal Protocol in India through secondary desk research, stakeholder consultation, and field visits. An overview of the sequential steps carried out for the intended study is explicated in Figure 3.

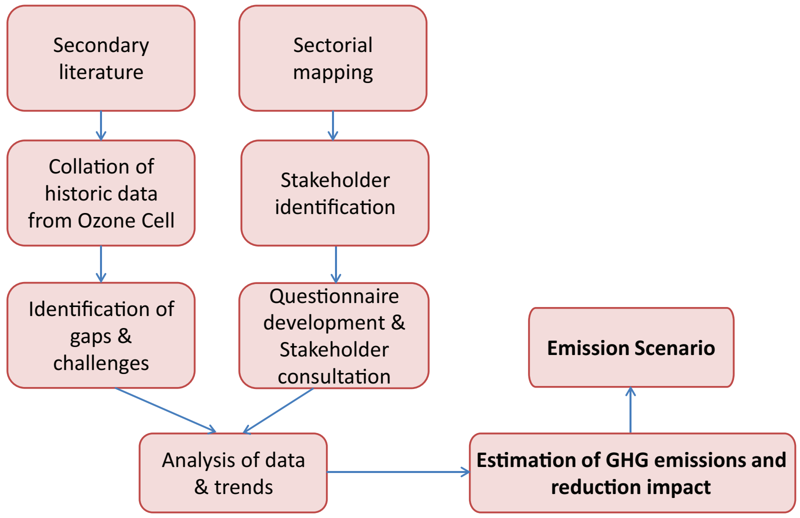


FIGURE 3 Approach

The study team instigated with a detailed review of various secondary literature resources primarily reports (ICAP, HPMP, etc.) and data centre resources of Ozone Cell website,[1] Ozone Secretariat – UNEP[2] and Country Programme for consolidation of the historic chemicals consumption across the various sectorial applications. The team involved multi-level stakeholder consultation with industry experts and academicians to perceive their expertise and technical inputs supporting the intended data collation. The team also conducted a follow-up consultation with the relevant experts to validate the consistency of the collated datasets.

[1] http://ozonecell.nic.in/home-page/resource-informations/data-centre/#article_7
[2] https://ozone.unep.org/countries/data-table

The three primary activities under the intended study are explained in Table 3.

Table 3: Proposed methodological steps

Steps	Description
I. Data collection and analysis	Collate the data pertaining to consumption, production, import and export of ODS across all suggested sectors, viz., (i) Refrigeration & air-conditioning sector (RAC); (ii) Foam sector; (iii) Fire extinguisher; (iv) Aerosol & solvent cleaning sector; (v) Mobile air-conditioning (MAC) sector; (vi) Metered dose inhalers (MDIs) sectors, etc.
II. GHG estimation of ODS used	Conduct required technical assessments using the collated information and standard guidelines to estimate the GHG emission for the (i) year 1992 and (ii) the timeline between 1992–2020.
III. Estimation of GHG projection	Conduct required technical assessments using the collated information and standard guidelines to estimate the GHG emission for the year 2030 considering the implementation of various interventions planned under the ICAP.

The estimation of GHG emissions for all scenarios is carried out using the standard practice provided with the following equation:

Annual GHG emissions (tCO_2/y) = Activity data × Emission factor

Where,

- Activity data = chemicals (ODS/ HFC) consumption (in tonnes)
- Emission factor = corresponding chemical GWP potential (tCO_2/t) [with respect to IPCC second assessment report provided in Annexure 1].

Assumptions for requisite data points were used in consultation with sectorial experts for the estimations of chemical consumptions (historical and projected) and GHG emissions. The study hasn't accounted the consumption of natural refrigerants and HFOs in the coming years due to its zero ODP and significantly low GWP, respectively.

The extrapolation of ODS chemical's consumption for both the intended scenarios are carried out using the compound annual growth rate (CAGR). CAGR is widely considered as one of the most accurate methods for representation of the data points over time. The historic data collated from secondary literature and stakeholders' consultations are used in the CAGR mathematical expression provided below for the estimation of consumption of chemicals for the intended timelines.

$$CAGR - \left[\left(\frac{EV}{BV} \right)^{\frac{1}{n}} - 1 \times 100 \right]$$

Where, EV = End value; BV = Beginning value; n = number of years

7

CONSUMPTION OF ODS AND ESTIMATED EMISSIONS AND PROJECTIONS

The intended exercise of estimation of chemicals (refrigerants) consumptions in ODP tonnes and its associated GHG emissions are primarily built for the following two scenarios:

i. **BAU scenario**: without the implementation of the Montreal Protocol; BAU scenarios are analysed with two growth rates:
   a. BAU scenarios – High Growth
   b. BAU scenarios – Low Growth

ii. **MP implementation scenario**: considers the interventions leading to the phase-out of ODS based chemicals.

7.1 Sectors and Sub-sectors Consuming Ozone-depleting Substances

The consumption of ODS and HFC chemicals in India spans wide range of applications and appliances/utilities that are primarily concentrated to the listed sectors and sub-sectors as explicated in Table 4.

Table 4: Overview of sectorial refrigerants distribution

No.	Sector	Chemicals
1	Refrigeration & air conditioning	CFC-11, CFC-12, HCFC-123, HCFC-22, HFC-134a, Blends (R-404A, R-407C, R-410A)
2	Mobile air conditioning (MAC)	HFC-134a
3	Solvent	CTC, CFC-113 , HCFC-141b, TCA
4	Fire extinguisher	Halon 1211, Halon 1301, HCFC-123
5	Aerosol	CFC-11, CFC-12, HFC-134a, TCA
6	Foam	CFC-11, HCFC-141b, HCFC-142b, HCFC-22

Around more than 15 ODS and HFCs are widely used in the country for the targeted study period (since 1992), which were majorly CFCs, CTC, halons, HCFCs, HFCs, HFC blends. The intended study instigated with the collation of historic chemicals consumption which were sourced primarily from the data centre of Ozone Secretariat—UNEP and Ozone Cell—MoEF&CC, GoI.

The following section presents detailed graphical illustrations of the intended analysis for both BAU scenario and the Montreal Protocol (MP) implementation scenario:

- Consumption of chemical groups (in ODP[1] tonnes)
- Consumption of individual chemicals (in ODP tonnes)
- Comparison of consumption of chemical groups (in ODP tonnes) for BAU scenarios and the MP implementation scenario
- Emissions of chemical groups (in million tCO_2e)
- Emissions of chemicals (in million tCO_2e)
- Comparison of emissions of chemical groups (in million tCO_2e) for BAU scenarios and the MP implementation scenario
- Sectorial consumption of chemical groups (in ODP tonnes) for series timelines (1995, 2000, 2005, 2010, 2015, and 2020) for MP implementation scenario
- Sectorial emissions of chemical groups (in million tCO_2e) for series timelines (1995, 2000, 2005, 2010, 2015, 2020, and 2030) for MP implementation scenario

[1] Annexure 1 provides the ODP values

8

SCENARIO 1 – BUSINESS-AS-USUAL (BAU)

Under the BAU scenario, the consumption of chemicals has been estimated and projected without the influence of the Montreal Protocol interventions. BAU scenarios have been developed and analysed with two growth rates, one BAU scenario with high growth and second scenario with low growth. The two growth rates are represented in Tables 6 and 7.

The consolidation of different chemicals consumption was estimated and projected using the CAGR mathematical model. The growth rates of all chemicals were extrapolated using staggered approach with incremental growth rates for the proposed time intervals. The incremental growth rates are presumed in consultation with the industry experts/stakeholders considering multiple variables, viz., historic data consumption, economic development, urbanization, population increase, etc. The consolidation of different chemicals consumption was estimated and projected using the CAGR mathematical model as presented below.

India started to report its production and consumption of ODS from 1992 under Article 7 of the Montreal Protocol. The CAGR has been computed for estimating and projecting the consumption of chemicals under the BAU scenarios using the consumption data of the year 1992 as the beginning value. The consumption data for the end of baseline year under the Montreal Protocol is used as the end value in the estimation of CAGR. These years have been used as there was unconstrained consumption of these chemicals without any phase-out controls of the Montreal Protocol.

As per the Montreal Protocol the phase-out schedule for different ODS chemicals has been followed as provided in Table 5.

Table 5: Phase-out schedules for India under Montreal Protocol

No.	Chemical	Baseline	Freeze	Complete Phase out
1	CFCs	Average of 1995–1997	July 1, 1999	January 1, 2010
2	Halons	Average of 1995–1997	January 1, 2002	January 1, 2010
3	CTC	Average of 1998–2000	-	January 1, 2010
4	TCA	Average of 1998–2000	January 1, 2003	January 1, 2010

8.1 Computation of CAGR of ODS Used in the Country

8.1.1 Chlorofluorocarbons

The CFCs were the widely used ODS in the country. The commonly used CFCs were CFC-11, CFC-12, and CFC-113. These were used in a variety of applications. CAGR was estimated to be 8.29 per cent between the years 1992 and 1997.

$$CAGR = \left[\left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1 \times 100\right] = \left[\left(\frac{6703.3}{4501}\right)^{\frac{1}{5}} - 1 \times 100\right] = 8.29\%$$

Where, EV (end value) for the year 1997 is 6703.3 ODP tonnes and BV (beginning value) for the year 1992 is 4501 ODP tonnes (Ozone Secretariat, 2022).

8.1.2 Halons

The halons, halon 1211 and halon 1301 were commonly used for fire-extinguishing in small as well as large firefighting equipment, although consumption of halons was limited, but was growing rapidly. The CAGR was estimated to be 14.46 per cent between the years 1993 and 2000, prior to the freeze year.

$$CAGR = \left[\left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1 \times 100\right] = \left[\left(\frac{556}{216}\right)^{\frac{1}{5}} - 1 \times 100\right] = 14.46\%$$

Where, EV (end value) for the year 2000 is 556 ODP[1] tonnes and BV (beginning value) for the year 1993 is 216 ODP tonnes (Ozone Secretariat, 2022).

8.1.3 Carbon tetrachloride

Carbon tetrachloride was used widely as solvent in various industrial processes in the country. The CAGR was estimated to be 11.47 per cent between the years 1992 and 2000.

$$CAGR = \left[\left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1 \times 100\right] = \left[\left(\frac{12147.3}{5097.4}\right)^{\frac{1}{8}} - 1 \times 100\right] = 11.47\%$$

Where, EV (end value) for the year 2000 is 12,147.3 ODP tonnes and BV (beginning value) for the year 1992 is 5097.4 ODP tonnes (Ozone Secretariat, 2022).

[1] The beginning value for halon CAGR estimation was taken from the year 1993 because the value for the year 1992 is too high and CAGR value would be negative with that.

8.1.4 TCA

The CAGR was estimated to be 12.89 per cent between the years 1992 and 2000.

$$CAGR = \left[\left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1 \times 100\right] = \left[\left(\frac{127.4}{48.3}\right)^{\frac{1}{8}} - 1 \times 100\right] = 12.89\%$$

Where, EV (end value) for the year 2000 is 127.4 ODP tonnes and BV (beginning value) for the year 1992 is 48.3 ODP tonnes (Ozone Secretariat, 2022).

8.1.5 Hydrochlorofluorocarbons

HCFC-22 was one of the HCFCs, which was used as refrigerant in the country since the beginning. Other HCFCs like HCFC-141b, HCFC-123, HCFC-142b, etc., were introduced as a result of the phase-out of CFCs. The CAGR has been estimated considering unconstrained growth of HCFC-22; the computed value of CAGR to be 7.91 per cent between the years 1992 and 2000.

$$CAGR = \left[\left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1 \times 100\right] = \left[\left(\frac{207}{141.5}\right)^{\frac{1}{5}} - 1 \times 100\right] = 7.91\%$$

Where, EV (end value) for the year 1997 is 207 ODP tonnes and BV (beginning value) for the year 1992 is 141.5 ODP tonnes (Ozone Secretariat, 2022).

The chemical consumptions over the timelines, has been estimated using two scenarios:

a) **High-growth scenarios**: Where growth rates are considered as constant for CFCs, halons, CTC and TCA as rates calculated above and listed in Table 6.
b) **Low-growth scenarios**: The staggered growth rate approach as tabulated in Table 7 where with the technology development, process optimizations, responsive use and market saturation the requirement of chemicals for various applications is anticipated to drive the growth on lower rates. Overall, a conservative approach has been adopted.

Table 6: Staggered growth rate for various chemical groups under BAU (high growth) scenario

Chemical group	CAGR growth rate (%)		
	1992 – 2010*	2011 – 2020*	2021 – 2030*
CFCs	8.29%	8.29%	8.29%
Halons	14.46%	14.46%	14.46%
CTC	11.47%	11.47%	11.47%
TCA	12.89%	12.89%	12.89%
HCFCs	7.91%		

* In case of high growth scenario the CAGR has been assumed the same from 1995–2030

Table 7: Staggered growth rate for various chemical groups under BAU (low growth) scenario

Chemical group	CAGR growth rate (%)		
	1992 – 2010	2011 – 2020	2021 – 2030
CFCs	8.29%	7.00%	6.00%
Halons	14.46%	12.00%	10.00%
CTC	11.47%	9.00%	8.00%
TCA	12.89%	11.00%	10.00%
HCFCs	7.91%		

Consumption and GHG Emissions of ODS under BAU

This section graphically presents the results of the study with respect to consumption of chemicals and their associated emissions for two BAU scenarios.

Chemical Consumption

The chemical consumption of various chemicals is shown individually in the figures to follow.

Figure 4 presents the trends for CFCs group catering multiple applications, viz., RAC, solvents, aerosols, and foam sectors. The CFC group witnessed an increase of consumption ~ 8.2 times and ~14.8 times in case of BAU low growth scenario and ~ 9.3 times and ~20.6 times in case of BAU high growth scenario, respectively in the 2020 and 2030 individually with respect to 1992 baseline consumption data.

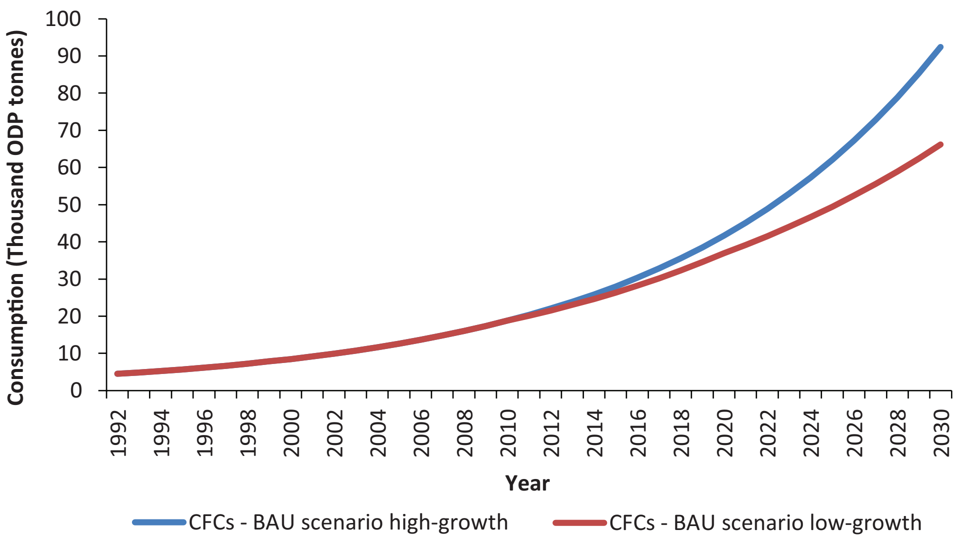


FIGURE 4
CFC consumption in thousand ODP tonnes under BAU scenario

Figure 5 presents the trends for consumption for halons groups catering to the fire extinguisher sector. The halons group witnessed an increase of consumption ~5.3 times and ~13.8 times in case of BAU low growth scenario and ~ 6.6 times and ~25.5 times in case of BAU high-growth scenario, respectively in 2020 and 2030 individually with respect to 1992 baseline consumption data.

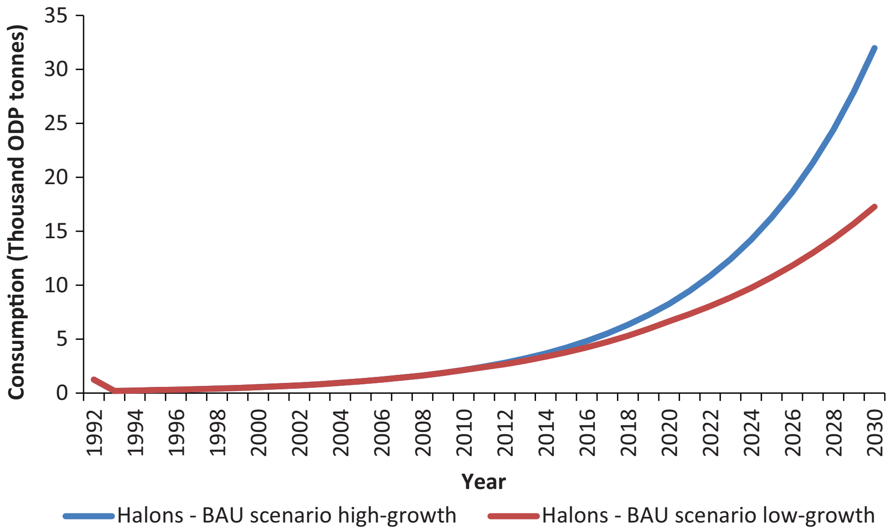


FIGURE 5
Halons consumption in thousand ODP tonnes under BAU scenario

Figure 6 presents the trends for consumption for CTCs groups catering the solvent sector. The CTC group witnessed an increase of consumption ~16.7 times and ~36 times in case of BAU low growth scenario and ~20.9 times and ~61.9 times in case of BAU high growth scenario, respectively in the 2020 and 2030 individually with respect to 1992 baseline consumption data.

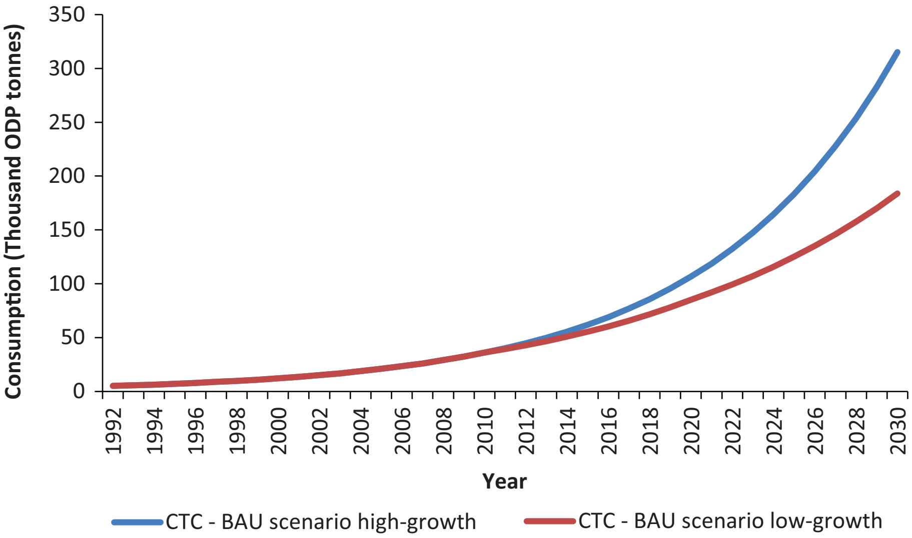


FIGURE 6
CTC consumption in thousand ODP tonnes under BAU scenario

Figure 7 presents the trends for consumption for TCA groups catering the solvent and aerosol sectors. The TCA group witnessed an increase of consumption ~25.2 times and ~65.3 times in case of BAU low growth scenario and ~ 29.8 times and ~100.2 times in case of BAU high growth scenario, respectively in 2020 and 2030 individually with respect to 1992 baseline consumption data.

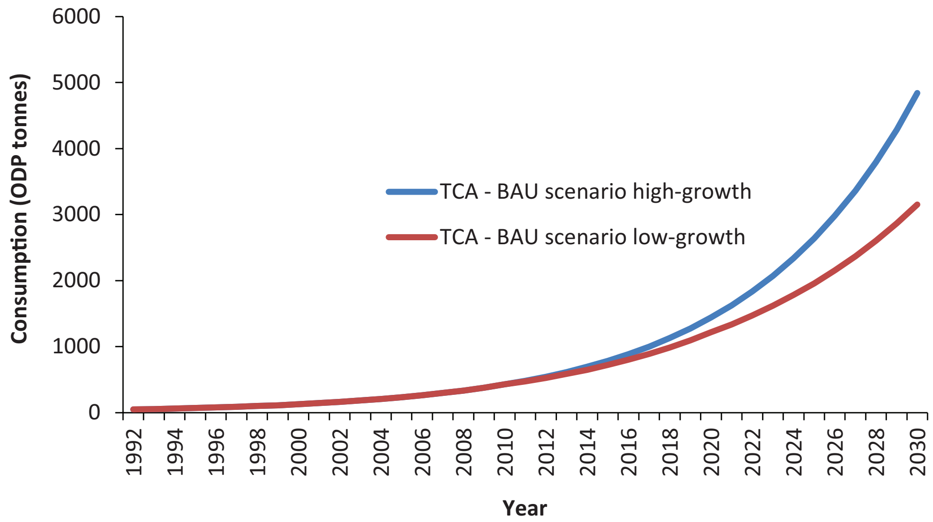


FIGURE 7
TCA consumption in ODP tonnes under BAU scenario

Figure 8 presents the trends for consumption for HCFCs groups catering to multiple applications, viz., RAC, solvents, aerosols, and foam sectors. The HCFCs group witnessed an increase of consumption ~8.4 times and ~18 times in 2020 and 2030 individually with respect to 1992 baseline consumption data.

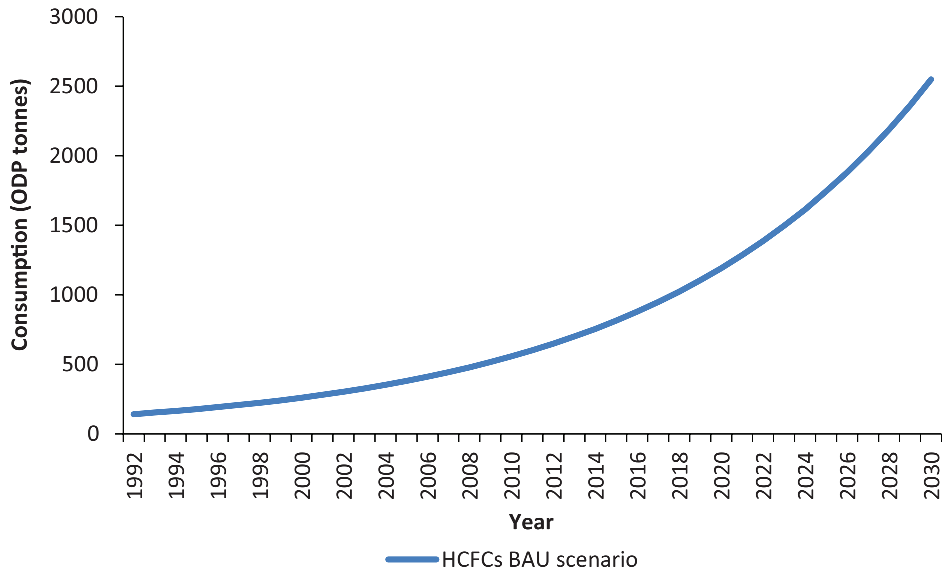


FIGURE 8
HCFCs consumption in ODP tonnes under BAU scenario

* For both the BAU scenarios of HCFCs, the growth rates are considered same

Figure 9 and Figure 10 present a set of graphical illustration of individual chemical group consumption. The increasing consumption is primarily due to its demand for multiple sectorial needs. It presents the consumption of chemical groups (in ODP thousand tonnes) from 1992 to 2030. The consolidated consumption of chemical groups is estimated using the baseline data for the year 1992 under the BAU scenario—high growth and low growth.

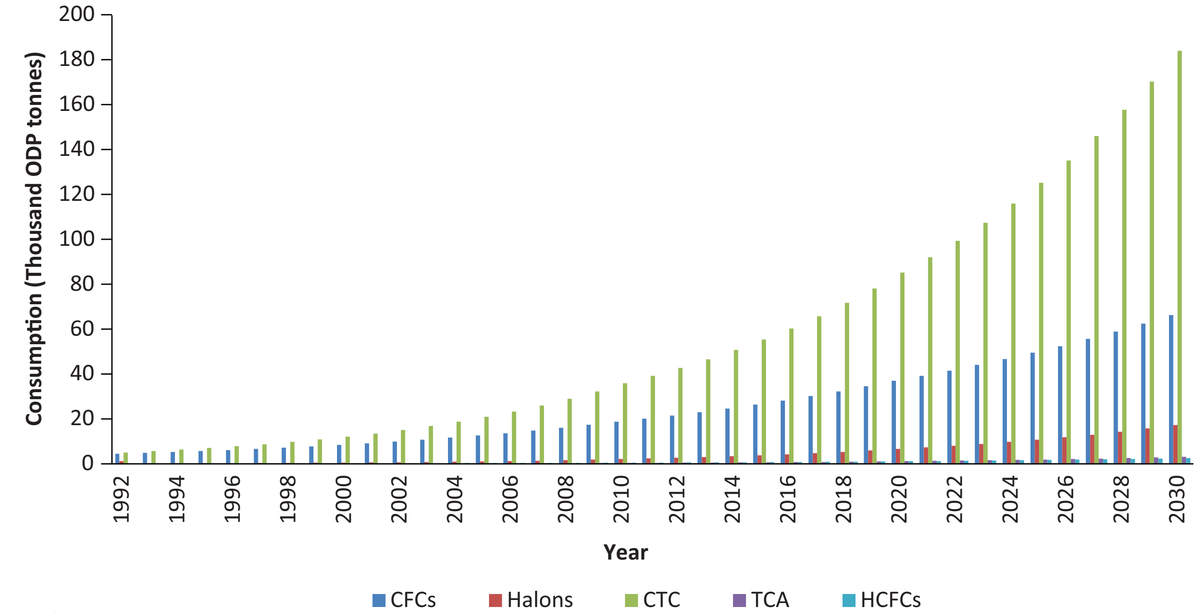


FIGURE 9

Consumption of chemical groups (in thousand ODP tonnes) under BAU scenario – low growth

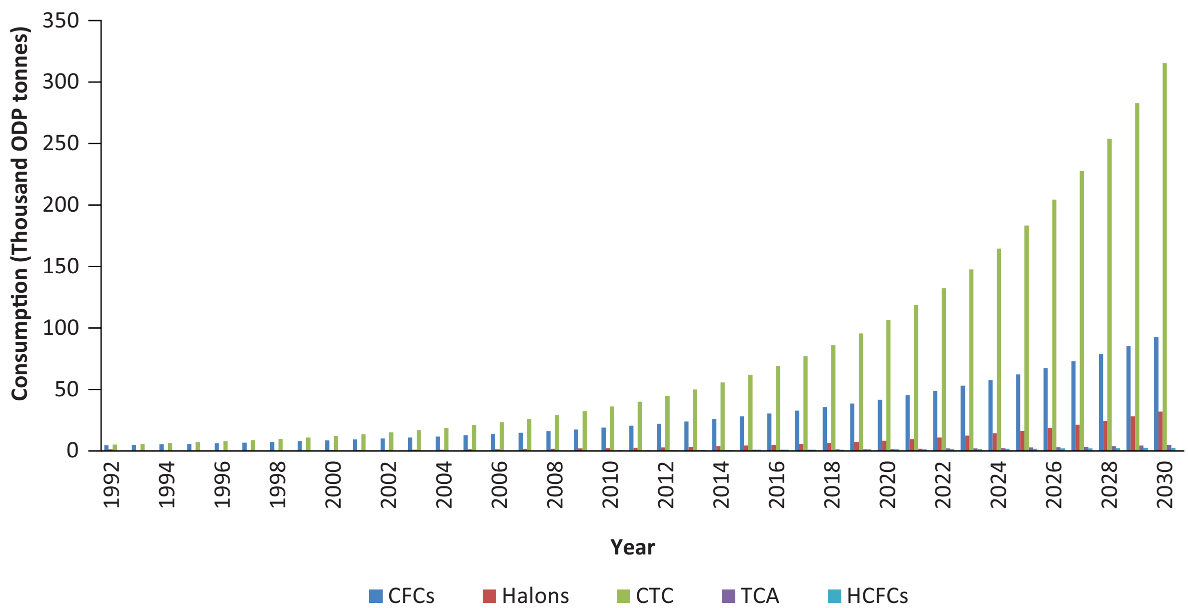


FIGURE 10

Consumption of chemical groups (in thousand ODP tonnes) under BAU scenario – high growth

Emissions

The emissions associated with the consumption of various chemicals are shown individually in the following figures.

Figure 11 presents the emission trends for CFCs group catering to multiple applications, viz., RAC, solvents, aerosols, and foam sectors. The GHG emissions for CFCs are coherent with their consumption as shown in Figure 4.

Figure 12 presents the trends for consumption for halons groups catering to the fire extinguisher sector. The GHG emissions for halons are coherent with their consumption as shown in Figure 5.

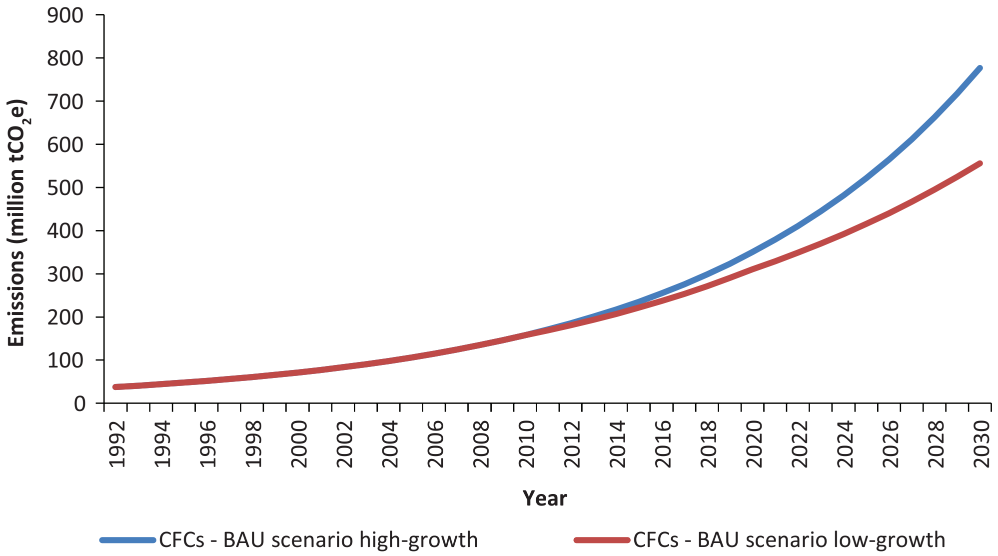


FIGURE 11
CFC emissions in million tCO_2e under BAU scenario

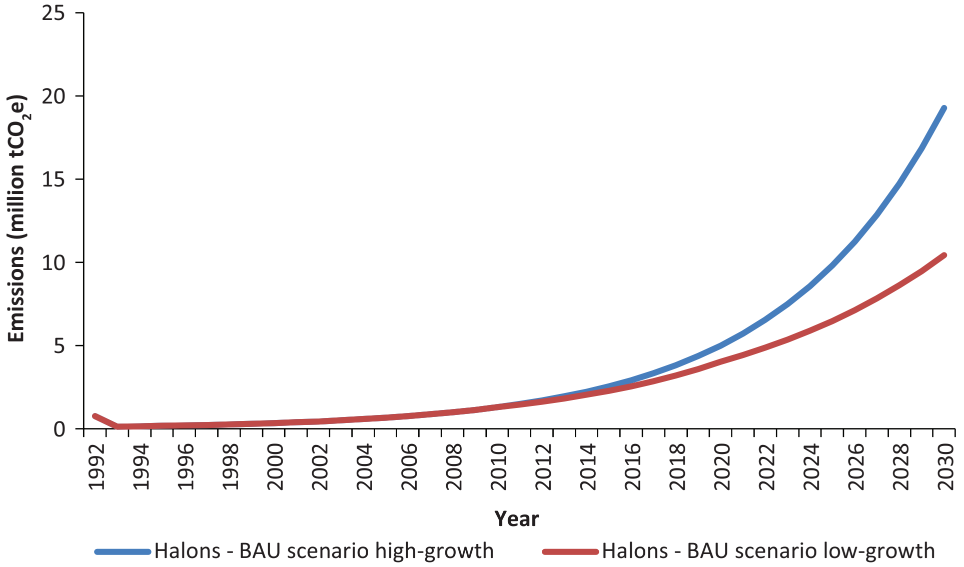


FIGURE 12
Halons emissions in million tCO_2e under BAU scenario

Figure 13 presents the trends for emission for CTC groups catering to the solvent sector. The GHG emissions for CTC are coherent with its consumption as shown in Figure 6.

Figure 14 presents the trends for consumption for TCA groups catering to the solvent and aerosol sectors. The GHG emissions for TCA are coherent with its consumption as shown in Figure 7.

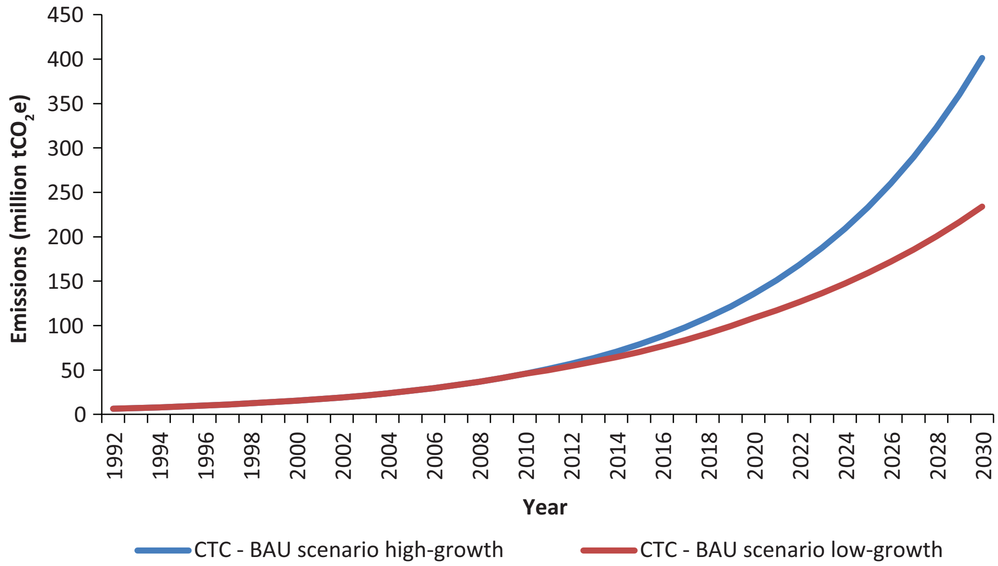


FIGURE 13
CTC emissions in million tCO_2e under BAU scenario

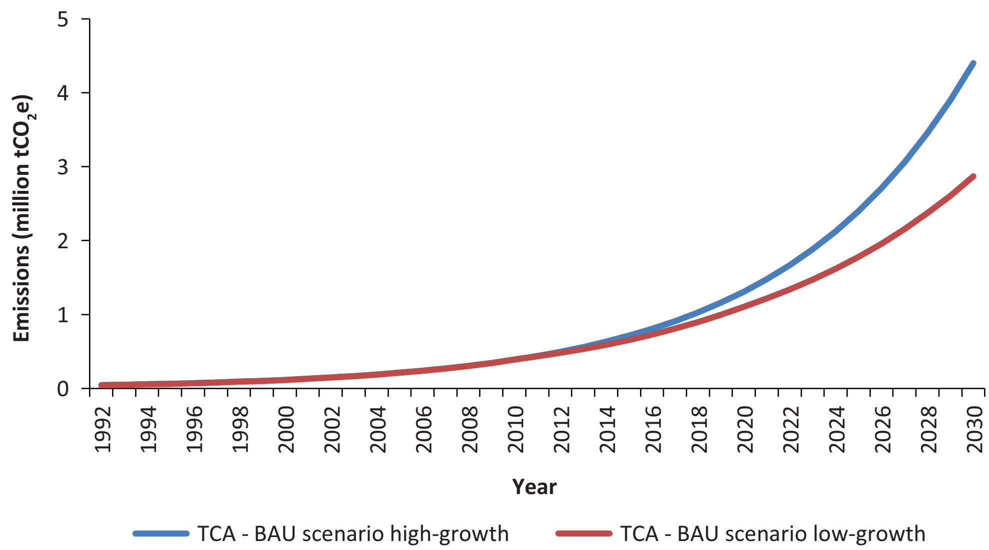


FIGURE 14
TCA emissions in million tCO_2e under BAU scenario

Figure 15 presents the trends for consumption for HCFCs groups catering to multiple applications, viz., RAC, solvents, aerosols, and foam sectors. The GHG emissions for HCFCs are coherent with their consumption as shown in Figure 8.

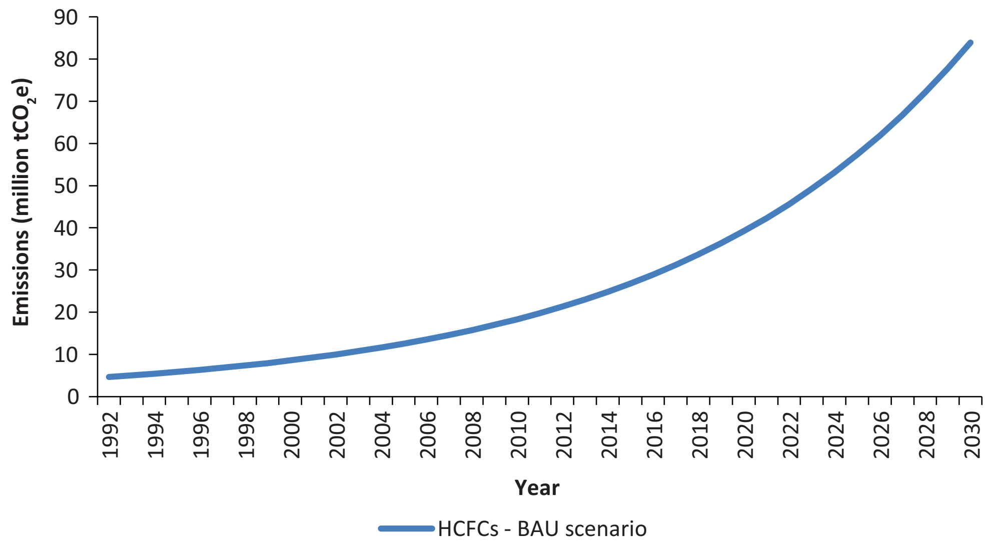


FIGURE 15
HCFCs emissions in million tCO_2e under BAU scenario

Figure 16 and Figure 17 present the GHG emissions for all chemical groups (in million tCO_2e) from 1992 to 2030 under the BAU scenario. The consolidated GHG emissions for chemical groups are estimated by multiplying the consumption activity data with its respective GWP values (provided in Annexure 1). The scenario doesn't account any implications of the Montreal

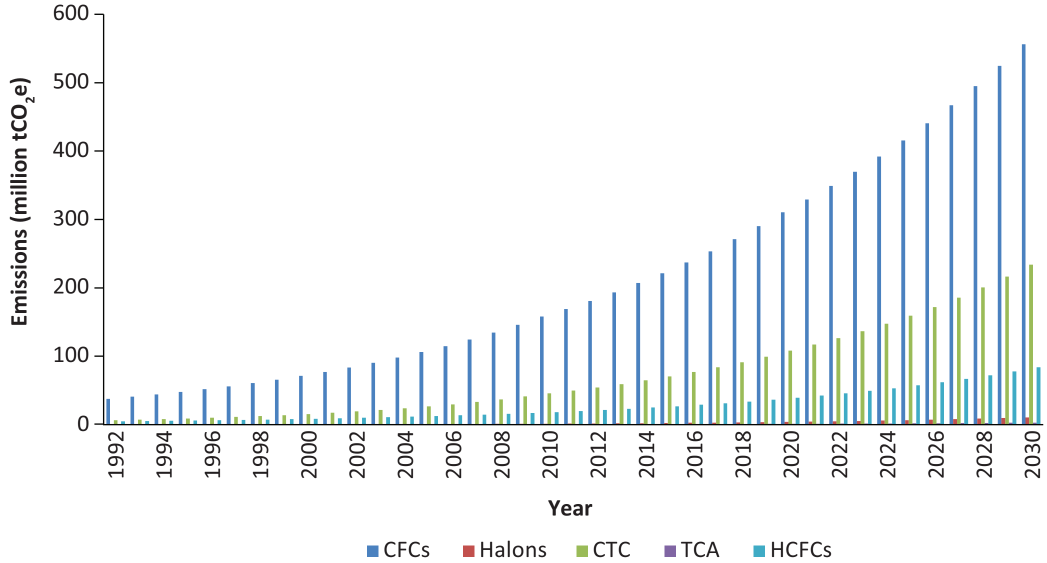


FIGURE 16
GHG emissions (in million tCO_2e) of various chemical groups under BAU scenario – low growth

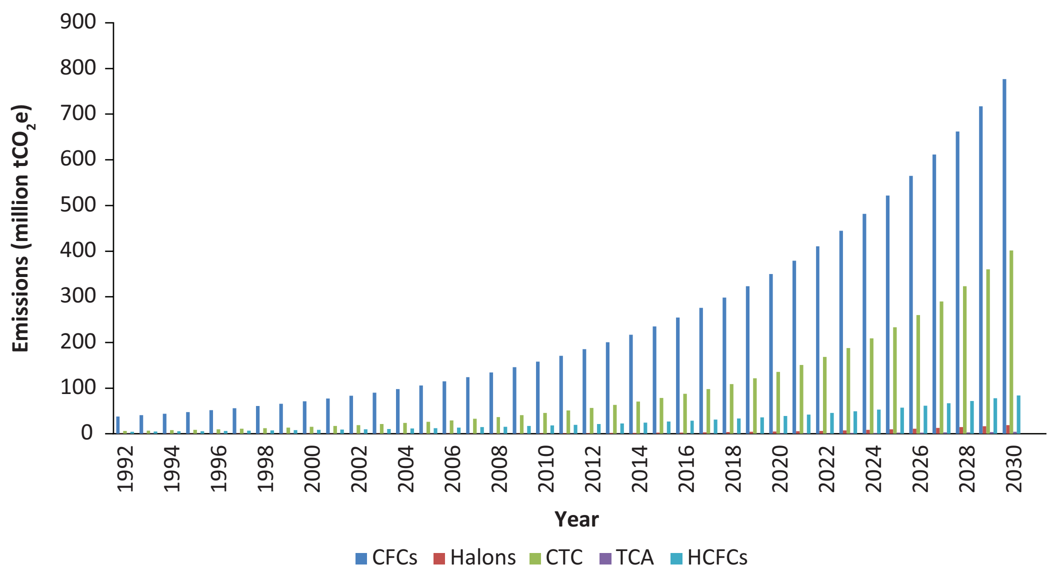


FIGURE 17
GHG emissions (in million tCO_2e) of various chemical groups under BAU scenario – high growth

Protocol interventions during the proposed timelines. It was observed that the total emissions for chemical groups (in million tCO_2e) increased by 9 times and 18 times approximately for 2020 and 2030, respectively with respect to the baseline emissions for the year 1992.

9

SCENARIO 2 – MONTREAL PROTOCOL (M P) IMPLEMENTATION SCENARIO

Under the Montreal Protocol implementation scenario, the consumption of chemicals are presented based on the actual phase-out of individual chemicals as per the reported data under Article 7 reporting requirement, except HCFCs, where phase-out will be completed by 2030. The Protocol promoted the adoption of non-ODS chemicals avoiding the release of ozone-depleting gases into the atmosphere. The consolidation of data for different chemicals consumption was sourced from the data centres of Ozone Secretariat-UNEP, Ozone Cell-MoEF&CC, Article 7 reporting.

- As per the reported data, the consumption of CFCs group chemicals (CFC-11, CFC-12, and CFC-113) and CTC were phased out completely for controlled applications in 2010
- The consumption of TCA and Halons (Halon-1211 and Halon -1301) were phased out for controlled applications in 2001 and 2003, respectively
- Under the M P implementation, the HFC group chemicals replaced the ODS-based chemicals. Due to its zero ODP values, the consumption of HFCs consumption (in ODP tonnes) is estimated to be zero
- Under the Montreal Protocol, India has committed to phase out the HCFC chemicals as presented in the schedule in Table 8.

Table 8: HCFC phase out schedule for India

Montreal Protocol maximum allowable consumption levels of Annex C Group 1 substances	Consumption limit (ODP tonnes)
Baseline (2009-2010 average)	1608.20
2013 – Freeze on baseline levels	1608.20
2015 – 90% of the baseline	1447.38
2020 – 65% of the baseline	1045.33
2025 – 32.5% of the baseline	522.67
2030 – 2.5% of the baseline	40.21
2040 – No consumption	0

- The HCFCs group includes HCFC-123, HCFC-124, HCFC-141b, HCFC-142b, HCFC-22, HCFC-133a, and HCFC-225. As per the reported data, the HCFCs excluding HCFC-123 and HCFC-22 were phased out at different time-period as illustrated here:

As per the Montreal Protocol, the consumption of HCFC-22 and HCFC-123 was extrapolated as shown in Table 9.

Table 9: HCFC-22 and HCFC-123 baseline consumption for India

No.	Chemical	Average of 2009 & 2010 - baseline data	2020 – 65 per cent of baseline data	2025 – 35 per cent of baseline data	2030 – 2.5 per cent of baseline data
1	HCFC-22	601.96	297.23	210.69	15.05
2	HCFC-123	10.59	0.78	3.71	0.26
All values are in OPD tonnes					
The sudden plunge in HCFC-123 consumption in the year 2020 is due to pandemic impacts.					

- **Consumption and GHG emissions under Montreal Protocol implementation scenario**

This section graphically presents the results of the study in form of consumption of chemicals and their associated emissions for the Montreal Protocol implementation scenario.

Chemical Consumption

The chemical consumption of various chemicals is shown individually in the figures below .

Figure 18 presents the trends for CFCs group catering multiple applications viz., RAC, solvents, aerosols, and foam sectors. The CFC group witnessed an accelerated phase out in 2009 and its consumption was replaced with HCFCs and HFCs.

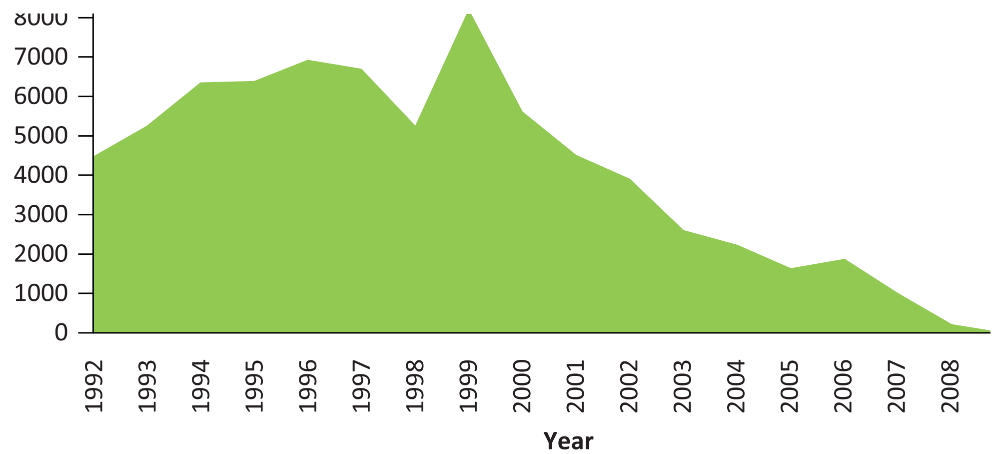


FIGURE 18
CFCs consumption in ODP tonnes under M P scenario

Figure 19 presents the trends for consumption for halons group catering to the fire extinguisher sector. The halons group witnessed an accelerated phase-out in 2003.

Figure 20 presents the trends for consumption for CTCs groups catering to the solvent sector. The CTC group witnessed an accelerated phase out in 2010.

Figure 21 presents the trends for consumption for TCA groups catering to the solvent and aerosol sectors. The TCA group witnessed an accelerated phase out in 2001.

Figure 22 presents the trends for consumption for HCFCs groups catering to multiple applications viz., RAC, solvents, aerosols, and foam sectors. The HCFCs group is currently under the phase-out process through HPMPs. Under the HPMPs, the HCFCs chemicals are anticipated to freeze consumption for equipment in 2025 and complete phase out in 2030. However, the servicing tail from 2030 to 2040 would support the existing utilities. The HCFCs consumption experience sudden plunge in 2020 due to the pandemic impacts.

FIGURE 19
Halons consumption in ODP tonnes under M P scenario

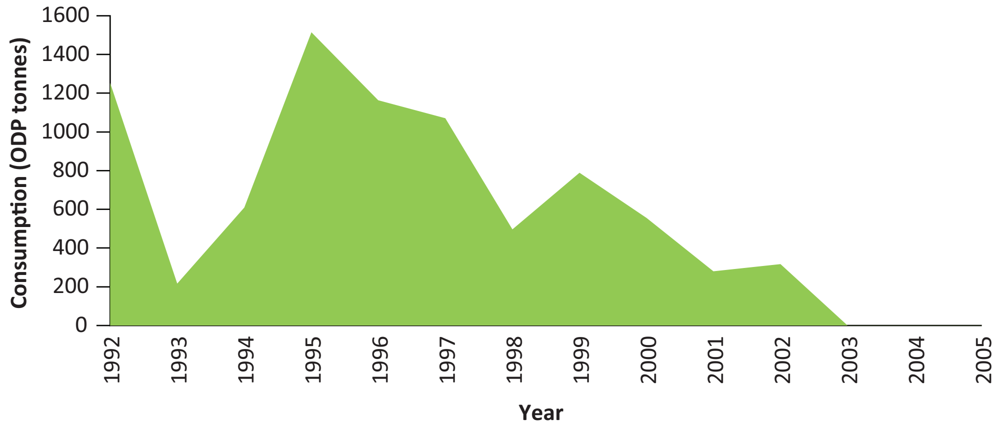


FIGURE 20
CTC consumption in ODP tonnes under M P scenario

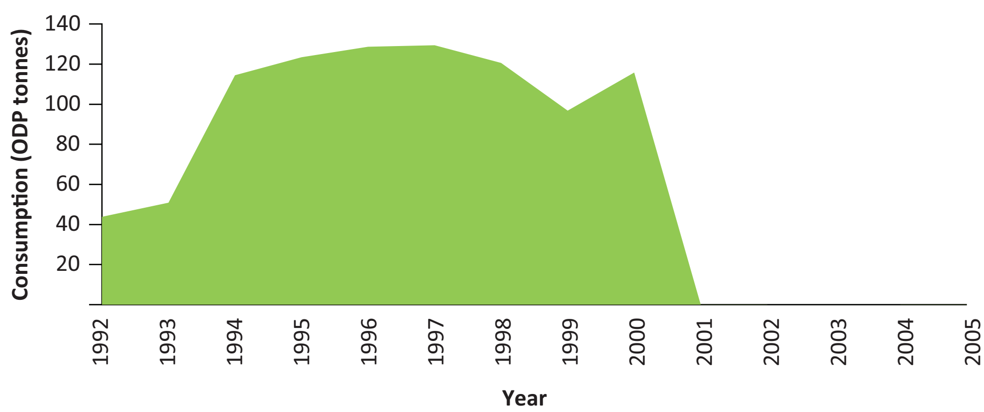
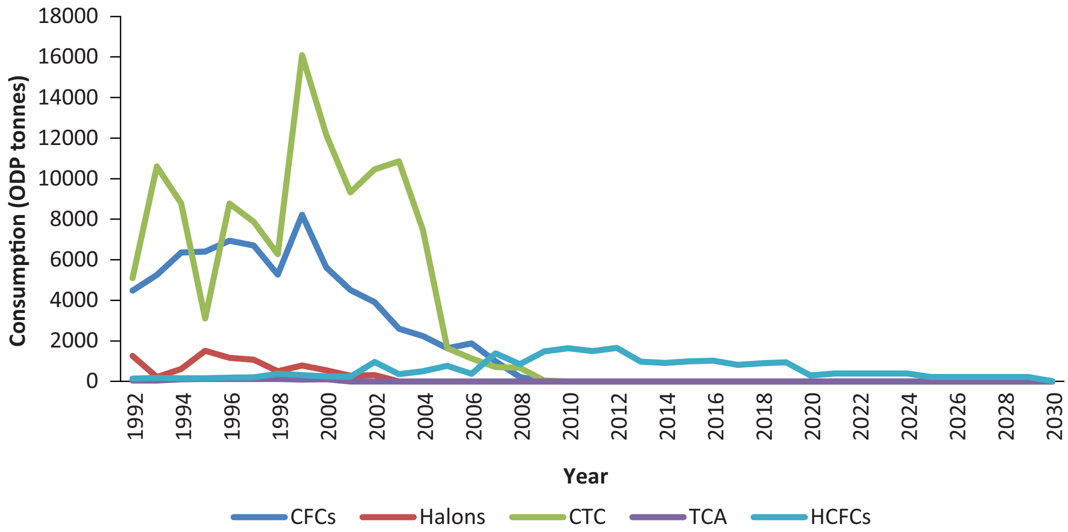


FIGURE 21
TCA consumption in ODP tonnes under M P scenario

FIGURE 22
HCFCs consumption in ODP tonnes under M P scenario

Figure 23 presents a set of graphical illustrations of individual chemical group consumption and its associated GHG emissions. The consumption and emissions trends are primarily influenced due to the introduction of non-ODS chemicals as a replacement. Figure 23 presents the consumption of chemical groups (in ODP thousand tonnes) from 1992 to 2030 under the implications of the Montreal Protocol interventions during the proposed timelines. It has been observed that the total consumption of chemical groups (in ODP tonnes) increased exponentially.

FIGURE 23
Consumption of chemicals group (in ODP tonnes) under Montreal Protocol implementation scenario



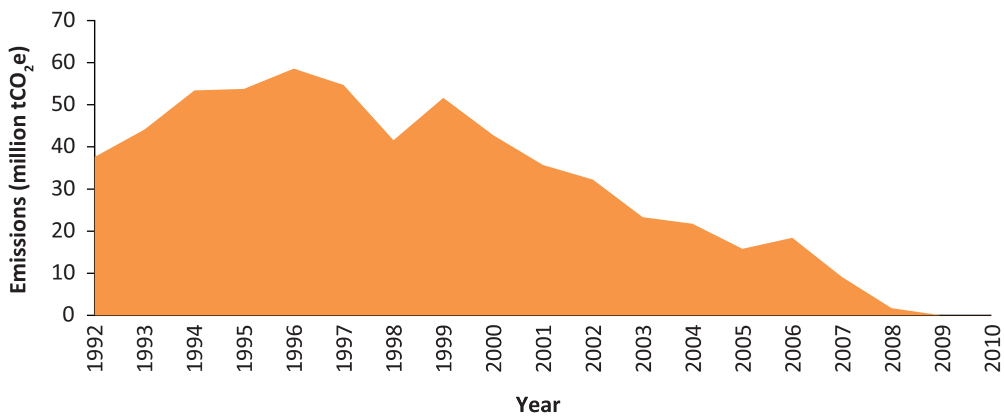
Emissions

The emissions associated with the consumption of various chemicals are shown individually in below figures.

Figure 24 presents the GHG emission trends for CFCs group catering to multiple applications viz., RAC, solvents, aerosols, and foam sectors. The CFC group witnessed an accelerated phase-out in 2009 and its consumption was replaced with low- GWP alternatives as well as by HCFCs and HFCs.

Figure 25 presents the GHG emission trends for Halons groups catering the fire extinguisher sector. The Halon group witnessed an accelerated phase-out in 2003.

FIGURE 24
CFCs GHG emissions (in million tCO_2e) under MP scenario



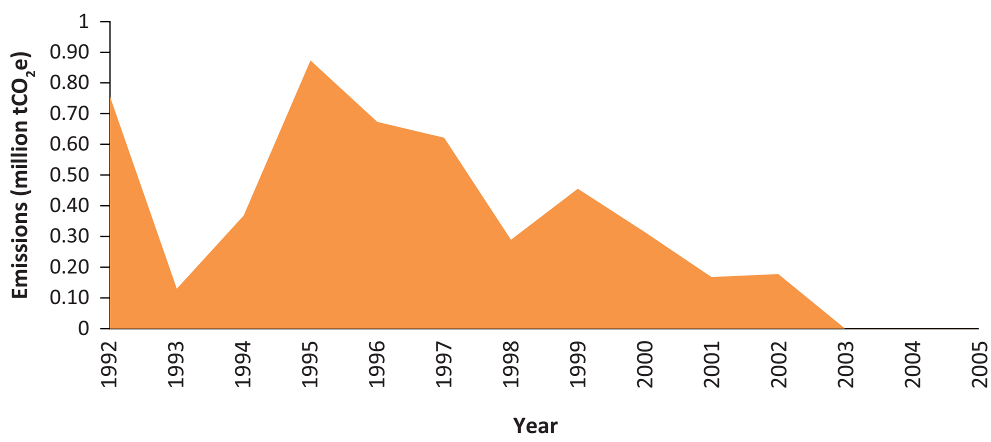


FIGURE 25
Halons GHG emissions (in million tCO_2e) under MP scenario

Figure 26 presents the GHG emission trends for CTCs groups catering the solvent sector. The CTC group witnessed an accelerated phase out in 2010.

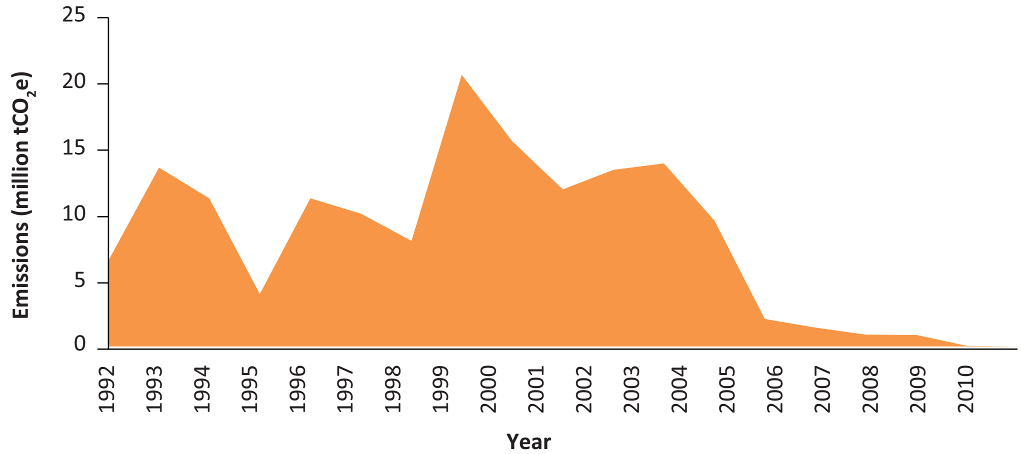


FIGURE 26
CTC GHG emissions (in million tCO_2e) under MP scenario

Figure 27 presents the GHG emission trends for consumption for TCA groups catering the solvent and aerosol sectors. The TCA group witnessed an accelerated phase out in 2001.

Figure 28 presents the GHG emission trends for HCFCs groups catering multiple applications viz., RAC, solvents, aerosols, and foam sectors. The HCFCs group is currently under the phase-out process through HPMPs.

Figure 29 presents the GHG emission trends for HFCs, and projected estimations based on the industry expert's consultations. The increasing trends of HFC GHG emissions are due to its uptake as a potential replacement of HCFCs under the HPMPs.

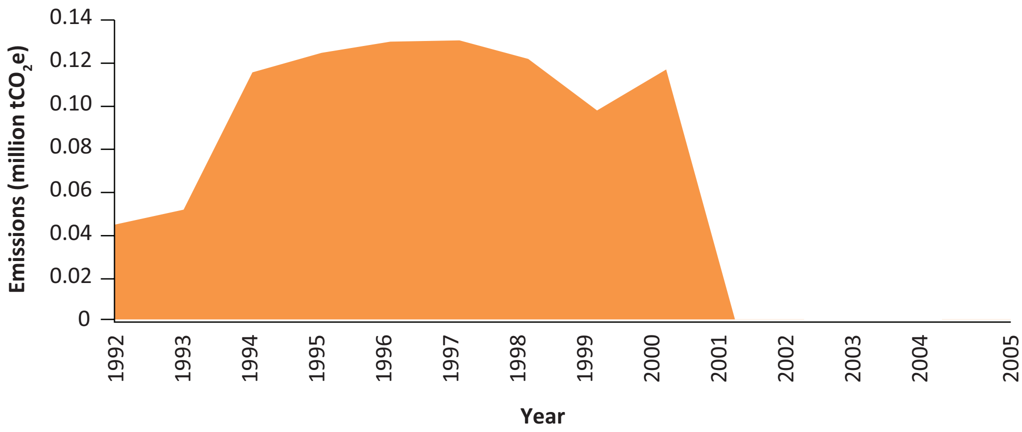


FIGURE 27 TCA GHG emissions (in million tCO_2e) under MP scenario

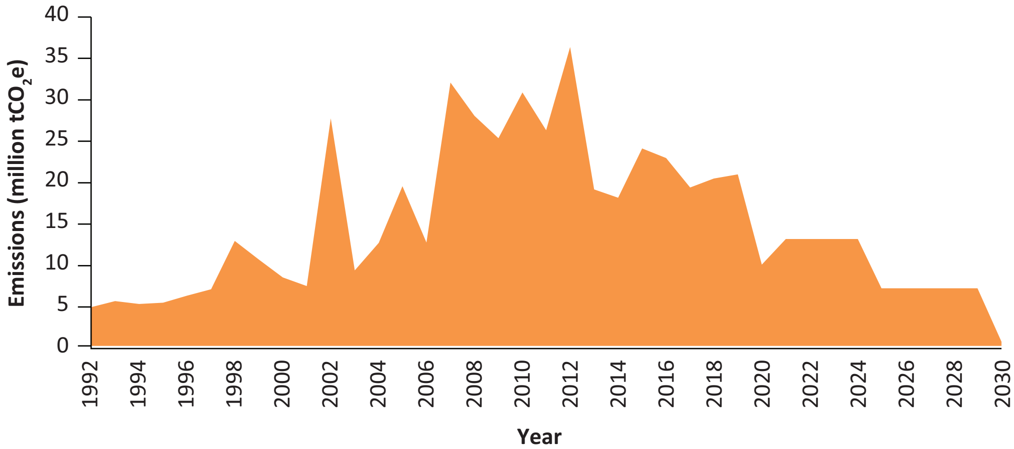


FIGURE 28 HCFCs GHG emissions (in million tCO_2e) under MP scenario

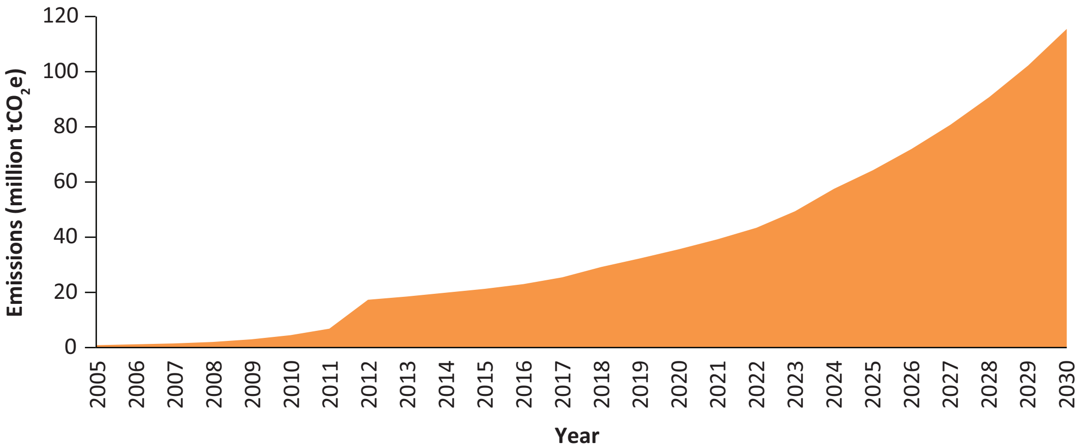


FIGURE 29 HFCs GHG emissions (in million tCO_2e) under MP scenario

Figure 30 presents the corresponding GHG emissions for all chemical groups (in million tCO_2e) from 1992 to 2030 under the Montreal Protocol implementation scenario. The consolidated GHG emissions for chemical groups are estimated by multiplying the consumption activity data with its respective GWP values (provided in Annexure 1). It was observed that the total emissions for chemical groups (in million tCO_2e) increased by 120 per cent approximately in 2030 with respect to the emissions for the year 1992.

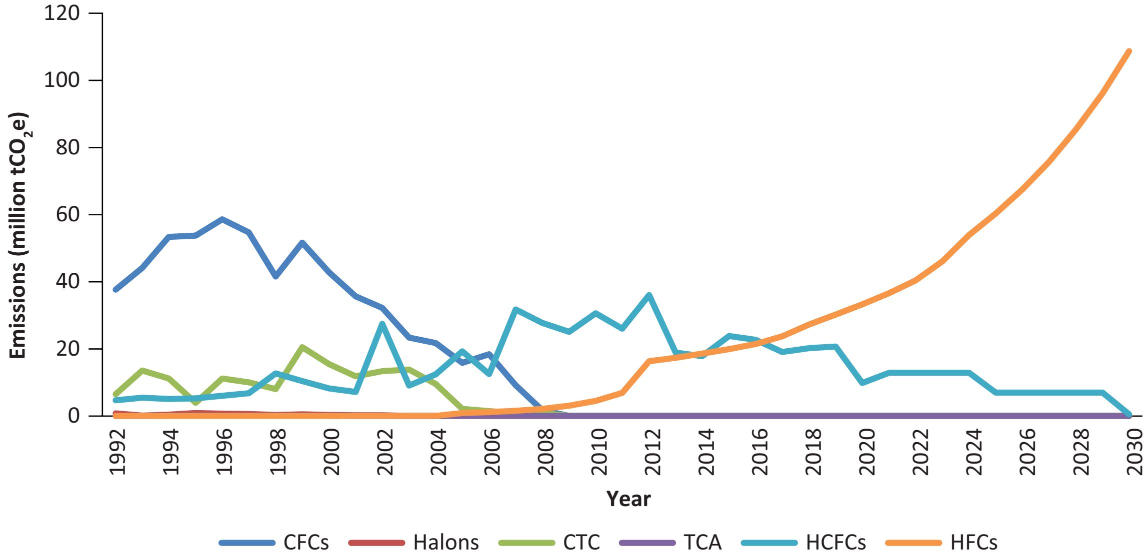


FIGURE 30

GHG emissions (in million tCO_2e) under Montreal Protocol implementation scenario

10 SECTORIAL DISTRIBUTION AND GROUP-WISE CONSUMPTION OF CHEMICALS AND ASSOCIATED EMISSIONS

Following sets of figures represent the chemical-wise and sectorial consumption along with its associated GHG emissions for the series of timelines. The graphical charts below in Figure 31 provide an overview of the transition of consumption of chemicals for various groups over the years.

Figure 32 represents the sectorial consumption of chemicals and their associated emissions over the years. It has highlighted the varying trends of sectorial usage across the shown timeline in ODP tonnes.

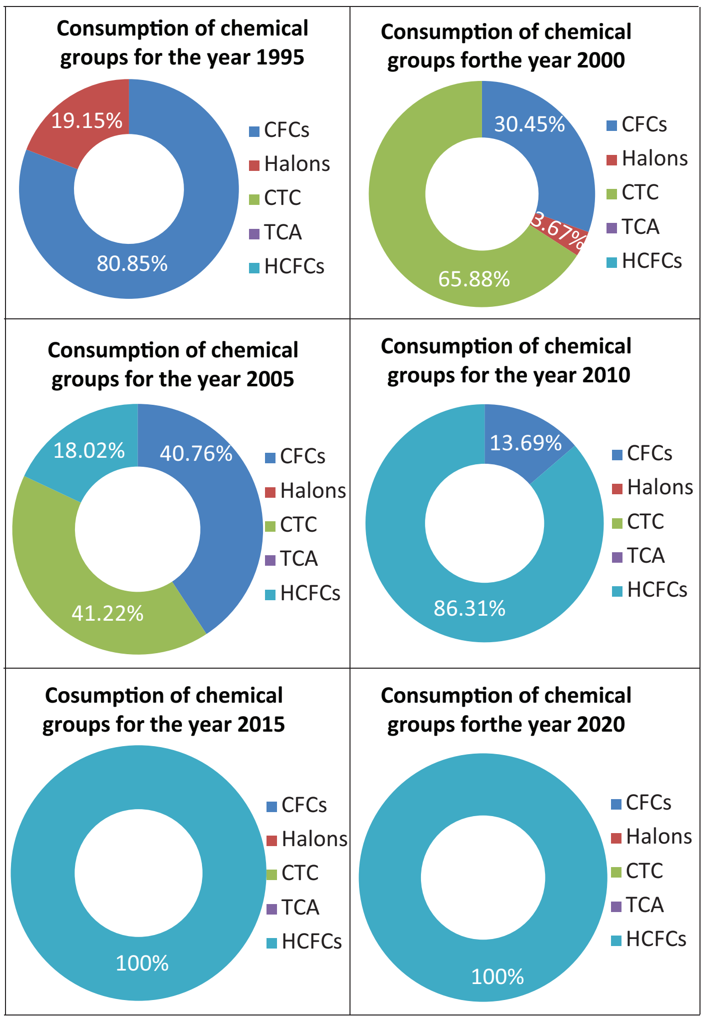
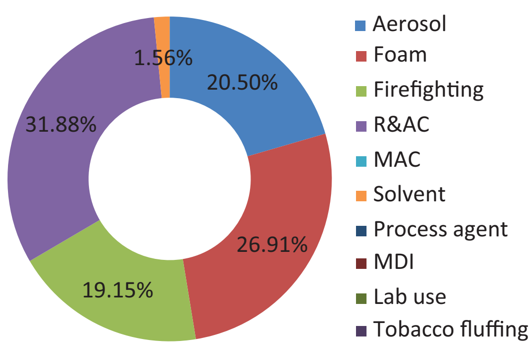


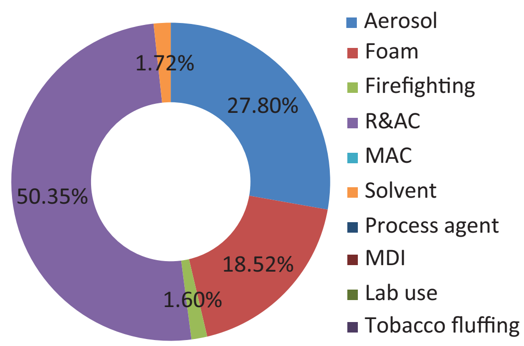
FIGURE 31
Chemical consumption of different groups over the years

* CFC consumption in 2010 in MDI under the essential use nomination provisions of the Montreal Protocol

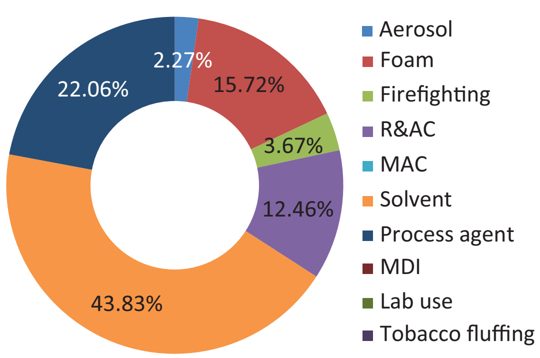
Sectorial consumption of chemicals for the year 1995



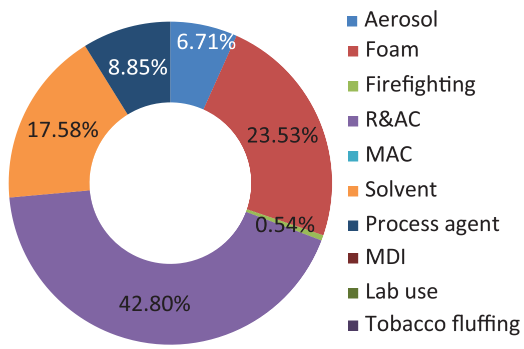
Sectorial emissions for the year 1995



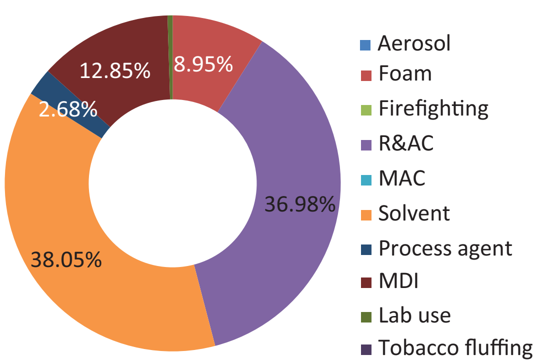
Sectorial consumption of chemicals for the year 2000



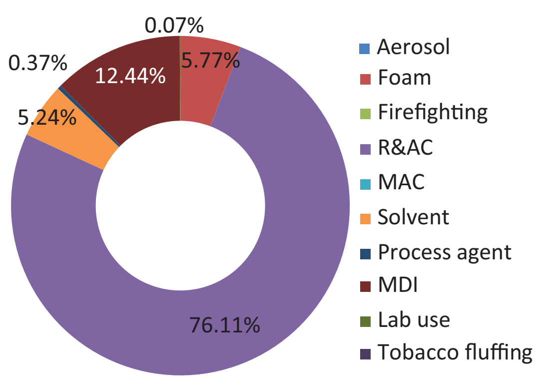
Sectorial emissions for the year 2000

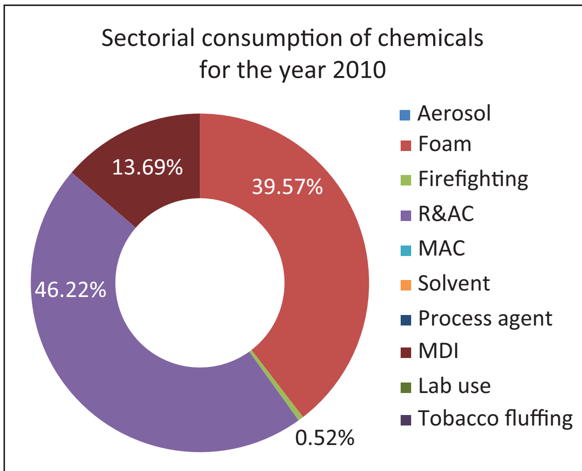


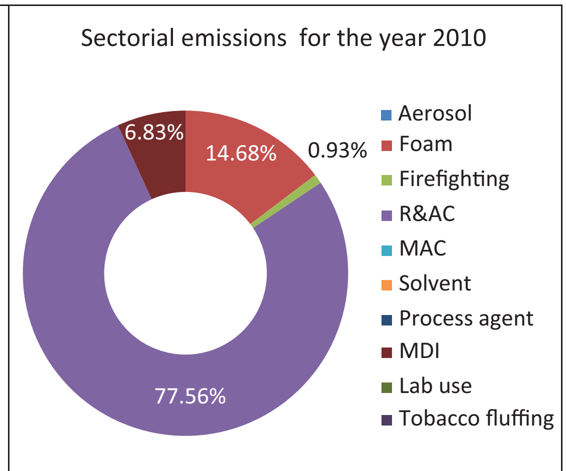
Sectorial consumption of chemicals for the year 2005

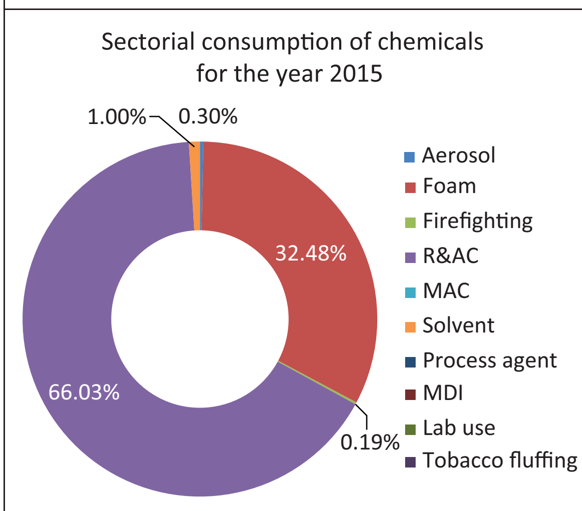


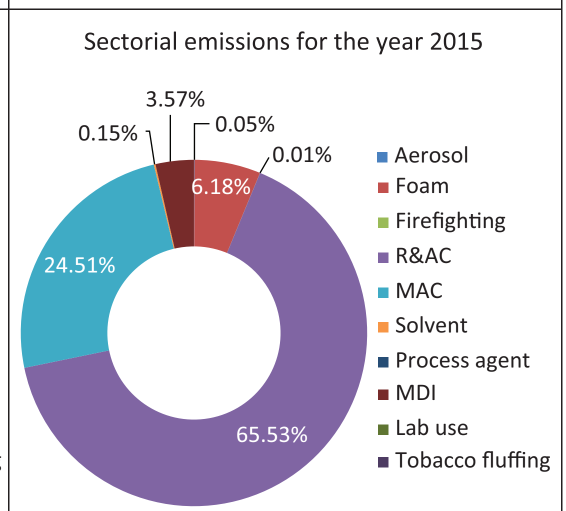
Sectorial emissions for the year 2005

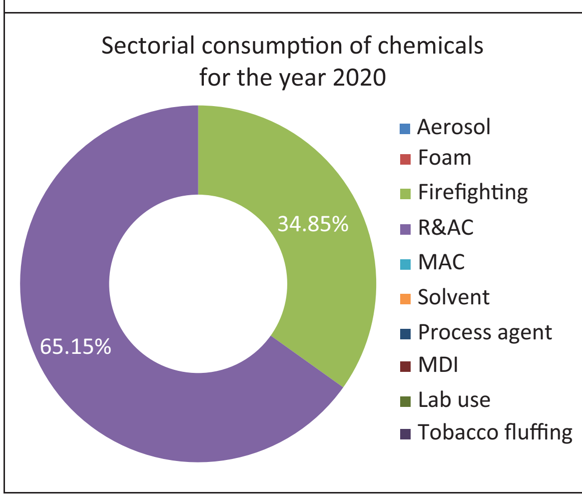



Sectorial consumption of chemicals
for the year 2010
13.69%
39.57%
46.22%
0.52%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing


Sectorial emissions for the year 2010
6.83%
14.68%
0.93%
77.56%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing


Sectorial consumption of chemicals
for the year 2015
1.00%
0.30%
32.48%
66.03%
0.19%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing


Sectorial emissions for the year 2015
3.57%
0.15%
0.05%
0.01%
6.18%
24.51%
65.53%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing


Sectorial consumption of chemicals
for the year 2020
34.85%
65.15%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing

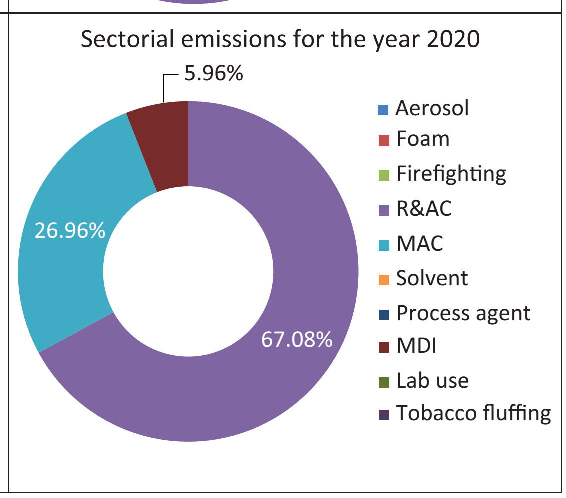
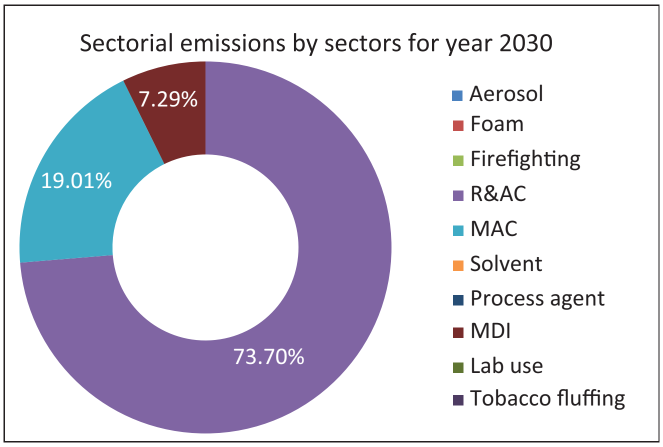

Sectorial emissions for the year 2020
5.96%
26.96%
67.08%
Aerosol
Foam
Firefighting
R&AC
MAC
Solvent
Process agent
MDI
Lab use
Tobacco fluffing

FIGURE 32

Sectoral consumption of chemicals and their associated emissions over the years

* CFC consumption in MDI under the essential use nomination provisions of the Montreal Protocol



11

GHG EMISSION REDUCTION THROUGH MONTREAL PROTOCOL IMPLEMENTATION

The ODSs are not only responsible for depletion of the stratospheric ozone but also contribute to global warming due to their high GWP. As a result of the implementation of the Montreal Protocol, India has not only contributed significantly toward protection of stratospheric ozone but also the climate system by reducing GHG emissions associated with the ODSs. The study has estimated that GHG emissions reduction would be in the range of 778 to 1176 million tonnes CO_2e by 2030.

The reduction in GHG emissions can be attributed to India's successful implementation of proactive policies towards protection of the environment, and regulatory framework and fiscal measures put in place in the country for phase-out of ODSs. Comprehensive Ozone Depleting Substances (Regulation and Controls) Rules, 2000 were developed in consultation with all concerned stakeholders and put in place under the Environment (Protection) Act 1986. Some of the proactive policy approaches adopted in consultation with stakeholders that resulted in early phase-out of high-ODP and high-GWP chemicals are as follows:

i. Banning the use of chlorofluorocarbons (CFCs) and halons in manufacturing of new equipment from as early as 1st January, 2003.
ii. Phase-out of production and consumption of virgin halons from 2002
iii. Accelerated phase-out of production and consumption of CFCs with effect from 1st August, 2008, nearly 17 months ahead of the Montreal Protocol schedule except for use of pharmaceutical grade CFCs in manufacturing of MDIs for Asthma, COPD, and other respiratory ailments within the country and other Article 5 countries.
iv. Adoption of low-GWP options wherever feasible since inception of the implementation of the phase-out of ODSs.
v. Conversion of entire foam manufacturing in the country from HCFCs to low-GWP foam-blowing agents.
vi. Adoption of lower GWP alternative refrigerant to HCFC-22 in room air conditioner (AC) manufacturing sector during implementation of HPMP Stage-II.

Tables 10 and 11 explain the consumption of chemicals under the two sets of intended scenarios. The persisting demand for these chemicals, catering to a wide range of applications, has immensely increased their consumption under both scenarios. However, the reduced estimation of consumption for M.P. implementation scenario arises due to increased adoption of non-ODS (with zero ODP) alternatives, which replaced the ODS chemicals under the Montreal Protocol.

Table 10: Comparison of consumption of ODS chemicals (in ODP tonnes) – BAU (high growth) vs M P implementation scenario

No.	Chemical groups	2000		2010		2020		2030	
		BAU	M P	BAU	M P	BAU	M P	BAU	M P
1	CFCs	8,472.09	5,618.33	18791.00	-	41678.21	-	92441.79	-
2	Halons	556.00	556.00	2146.23	-	8284.72	-	31980.06	-
3	CTC	12,147.30	12,147.30	35966.12	-	106489.64	-	315297.96	-
4	TCA	127.40	115.82	428.25	-	1439.54	-	4838.97	-
5	HCFCs	260.08	250.60	556.58	1,633.07	1,191.12	298.01	2,549.07	15.31
Total		21562.86	18,688.05	57888.17	1,633.07	159083.23	298.01	447107.86	15.31
(All values are in ODP tonnes)									

Table 11: Comparison of consumption of ODS chemicals (in ODP tonnes) - BAU (low growth) vs M P implementation scenario

No.	Chemical groups	2000		2010		2020		2030	
		BAU	M P	BAU	M P	BAU	M P	BAU	M P
1	CFCs	8,472.00	5,618.33	18,791.00	-	36,964.73	-	66,198.21	-
2	Halons	556.00	556.00	2,146.23	-	6,665.86	-	17,289.54	-
3	CTC	12,147.30	12,147.30	35,966.12	-	85,144.88	-	1,83,821.41	-
4	TCA	127.40	115.82	428.25	-	1215.98	-	3153.94	-
5	HCFCs	260.08	250.60	556.58	1,633.07	1,191.12	298.01	2,549.07	15.31
Total		21,562.86	18,688.05	57,888.17	1,633.07	1,31,182.58	298.01	2,73,012.17	15.31
(All values are in ODP tonnes)									

Similarly, the M P implementation has reduced the GHG emissions associated with these ODS chemicals for high growth and low growth scenarios, presented in Table 12 and 13, respectively.

Table 12: Comparison of GHG emissions for chemicals (in million tCO_2e) – BAU (high growth) scenario vs M P implementation scenario

No.	Chemical groups	2000		2010		2020		2030	
		BAU	M P	BAU	M P	BAU	M P	BAU	M P
1	CFCs	71.18	42.76	157.87	-	350.16	-	776.66	-
2	Halons	0.34	0.31	1.29	-	4.99	-	19.28	-
3	CTC	15.46	15.46	45.78	-	135.53	-	401.29	-
4	TCA	0.12	0.12	0.39	-	1.31	-	4.40	-
5	HCFCs	8.56	8.25	18.32	30.55	39.20	9.78	83.89	0.50
6	HFCs	-	-	-	4.49	-	33.22	-	108.72
Total		95.65	66.90	223.65	35.04	531.20	43.00	1285.51	109.22
(All values are in million tCO_2e)									

Table 13: Comparison of GHG emissions for chemicals (in million tCO_2e) – BAU (low growth) scenario vs M P implementation scenario

No.	Chemical groups	2000		2010		2020		2030	
		BAU	M P	BAU	M P	BAU	M P	BAU	M P
1	CFCs	71.18	42.76	157.87	-	310.56	-	556.17	-
2	Halons	0.34	0.31	1.29	-	4.02	-	10.42	-
3	CTC	15.46	15.46	45.78	-	108.37	-	233.95	-
4	TCA	0.12	0.12	0.39	-	1.11	-	2.87	-
5	HCFCs	8.56	8.25	18.32	30.55	39.20	9.78	83.89	0.50
6	HFCs	-	-	-	4.49	-	33.22	-	108.72
Total		95.65	66.90	223.65	35.04	463.25	43.00	887.3	109.22
(All values are in million tCO_2e)									

Figures 33 and 34 explicates the consumption of ODSs in ODP tonnes and the GHG emissions in millions tCO_2e associated with the ODSs, respectively under the BAU and the Montreal Protocol scenarios for the phase-out of production and consumption of ODSs period from 1992–2030.

The study clearly shows that implementation of the Montreal Protocol in India has contributed to significant reduction in GHG emissions through its environment-friendly policies and proactive actions. The estimated GHG emissions reduction would be in the range from 778 to 1176 million tonnes CO_2e by 2030.

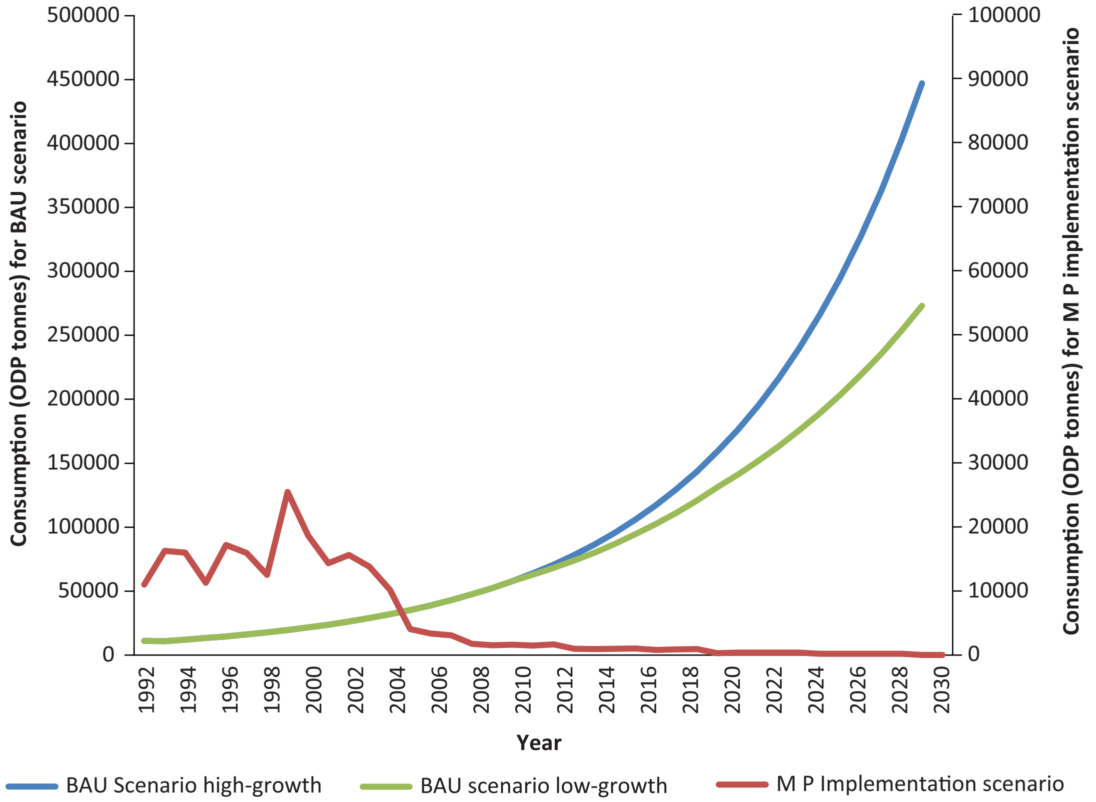


FIGURE 33

Comparison of total chemical group consumption (in ODP tonnes) - BAU scenario vs Montreal Protocol implementation scenario

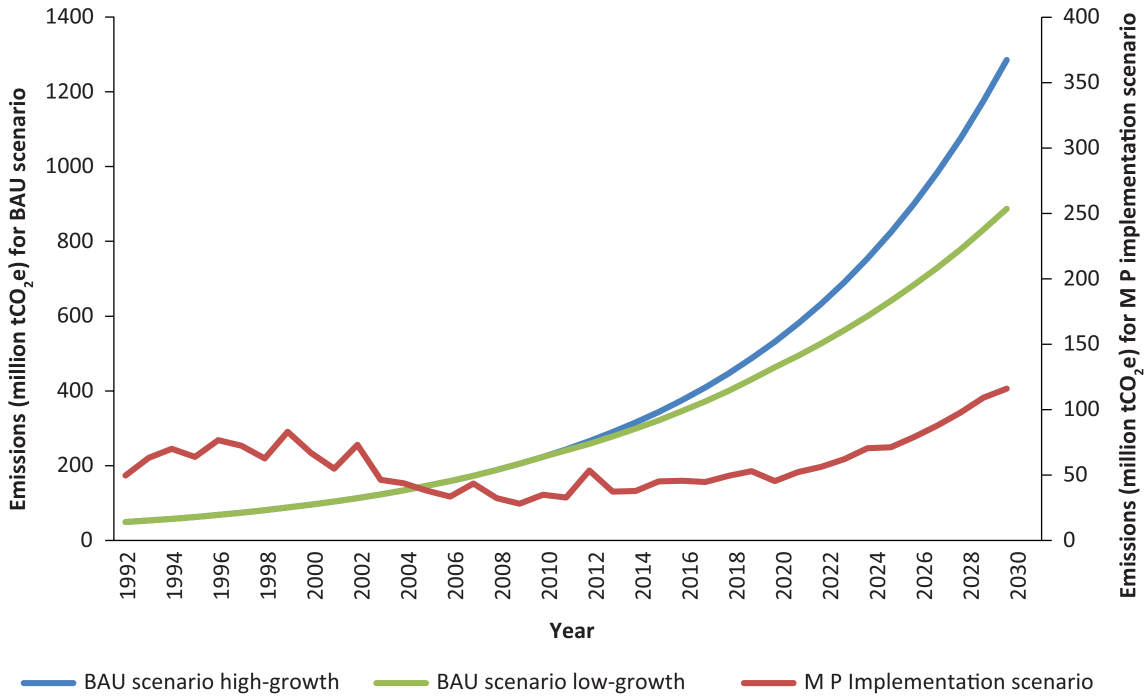


FIGURE 34

Comparison of total chemical group emissions (in million tCO_2e) - BAU scenario vs Montreal Protocol implementation scenario

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ANNEXURE 1: EMISSION FACTORS AND ODP OF CHEMICALS

Table 14: Emission factors and ODP of chemicals[1,2,3]

Refrigerant	GWP - for 100 year horizon	ODP values
CFC-11	4,750	1
CFC-113	6,130	0.8
CFC-12	10,900	1
CTC	1,400	1.1
Halon-1211	1,890	3
Halon-1301	5,400	10
TCA	100	0.1
HCFC-123	77	0.06
HCFC-124	609	0.04
HCFC-133a	380	0.06
HCFC-141b	725	0.11
HCFC-142b	2,310	0.065
HCFC-22	1,810	0.055
HCFC-225	122	0.07
HFC-134a	1,430	0
HFC-32	675	0
HFC-404A	3,922	0
HFC-407C	1,774	0
HFC-410A	2,088	0

1 https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials
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2 https://ozone.unep.org/treaties/montreal-protocol/articles/annex-controlled-substances

3 https://www.unep.org/ozonaction/gwp-odp-calculator

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