EXPLORING THE CURRENT STATUS OF OZONE DEPLETION SUBSTANCES' (ODS) PHASE-OUT AND STRATOSPHERIC TOTAL COLUMN OZONE OVER PAKISTAN

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2022

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A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Environmental Science

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Islamabad, Pakistan

2022

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"Exploring the Current Status of Ozone Depletion Substances' (ODS) phase-out and Stratospheric Total Column Ozone over Pakistan"

Submitted by

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Dedication

Dedicated to my exceptional parents and loving siblings whose tremendous support and cooperation led me to this wonderful accomplishment

Acknowledgements

All praise to ALLAH, The ALMIGHTY, the most BENEFICENT and The most MERCIFUL, on Whom ultimately we depend for sustenance and guidance. Who blessed me with wisdom and courage to accomplish this project, and Who fetch me to this stage and helped me to come up with this effort.

I would like to express special gratitude to my supervisor **Dr. Muhammad Fahim Khokhar**. His timely and efficient contribution helped me shape this into its final form and I express my sincerest appreciation for his assistance in any way that I may have asked.

I owe a debt of appreciation to my Guidance and Examination Committee comprising, **Dr. Muhammad Zeeshan Ali Khan** and **Dr. Sofia Baig** for their valuable advices required to complete this research project.

I would like to pay my regards to Sir Zia ul Islam (National Program Manager) from National Ozone Unit, Ministry of Climate Change for his generous support and cooperation provided to us for the completion of this project.

I would like to thank all the C-CARGO peers and seniors for their utmost help, support and cooperation who were always kind, amiable and helpful whenever I needed them.

Heartful gratitude to my **parents** and **siblings**, whose prayers surround me like a shield and have always been behind my success. Without their prayers, I am nothing.

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Abbreviations	Description
CFCs	Chlorofluorocarbons
CTC	Carbon Tetrachloride
DU	Dobson Unit
GWP	Global Warming Potential
HCFCs	Hydro Chlorofluorocarbons
HFCs	Hydrofluorocarbons
HPMP	HCFCs Phase-out Management Plan
KPIs	Key Performance Indicators
MT	Metric Tonnes
MMT	Million Metric Tonnes
MLF	Multilateral Fund
NOU	National Ozone Unit
ODP	Ozone Depleting Potential
ODS	Ozone Depletion Substances
PSCs	Polar Stratospheric Clouds
QBO	Quasi-biennial Oscillation

RAC	Refrigeration and Air Conditioning
SPSS	Statistical Package for Social Sciences
TCO	Total Column Ozone
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Program
VSLS	Very Short-Lived Substances
WOUDC	World Ozone and Ultraviolet Radiation Data Centre

ABSTRACT

Depletion of stratospheric ozone has become a serious environmental concern since the discovery of Southern Hemispheric Ozone Hole in 1985. The usage of synthetically produced ozone-depleting substances (ODSs) which contain stratospheric bromine and chlorine has accelerated ozone depletion which drastically. Ozone-depleting substances (ODSs) are utilized as refrigerants in air conditioning, foaming, solvents and fire-extinguishing agents. This particular study is aimed to analyze past and future consumption of ODSs and its alternatives including high, medium and low global warming potential (GWP) and their classification and distribution by various sectors of solvents, foam, fire suppression/protection, air conditioning and refrigeration in Pakistan. Another part of this study was the collection of data in the questionnaire form to find out the challenges faced by enterprises to phase-out ODSs in Pakistan. The SPSS analysis of the survey form responses indicated that ODSs' industry is aware of the utilization and phase out schedule of ODSs and had an understanding that all ODS consumption is being monitored through import quota allocated to the importers. In this research study, the evolution of stratospheric total column ozone (TCO) over Pakistan was also observed for a period of 2004-2020 using the OMI/AURA (OMDOAO3e) satellite data. The annual growth of 5.0% is projected in Pakistan during 2016-2030 in the domestic, commercial, industrial and transport refrigeration sector. 5.0% growth is estimated during 2016-2030 in air conditioning and foam sector of Pakistan and similarly, the projected equivalent CO_2 emissions for the years 2016-2030 in Pakistan will be 9.653 MMT during the year 2030. Stratospheric TCO was also studied over Pakistan. Minimum value of TCO was recorded to be 239.5 DU (2016). Maximum value of TCO was recorded as 305.9 DU (2018). Monthly average values for TCO were highest in spring and lowest in monsoon season. The yearly TCO mean in the Northern areas of the country vary from 260-305 DU, in the central areas from 260-280 DU and 246 -270 DU in the Southern areas of Pakistan for time period of 2004-2020. An absolute change of 5 DU is observed in TCO over Pakistan with a relative increase of 1.8% at the rate of 0.11% per year were observed during the time period of 2004-2020.

CHAPTER 1

INTRODUCTION

1.1 Background

Most of the harmful ultraviolet (UV) radiation are prevented from reaching the earth surface by stratospheric ozone layer. Ultraviolet (UV) radiation may cause cancer in humans and destruction in plants. The stratospheric and tropospheric infrared radiation are also absorbed by stratospheric ozone O_3. this infrared and UV radiation absorption by stratospheric O_3 plays a critical role in the formation of atmospheric temperature structure. Hence, surface climate is affected by changes in the stratospheric ozone layer (Bolaji and Huan, 2013).

Since the discovery of Antarctic ozone hole in 1985, the depletion of stratospheric ozone hole has become a serious environmental concern. For example, it has been found that there is maximum 4% depletion in the northern midlatitudes and 50% mean column ozone depletion per decade in austral spring (Jung and Park, 2020).

The usage of man-made ozone-depleting substances (ODSs) containing stratospheric chlorine and bromine has accelerated the ozone depletion in the stratosphere. Ozone-depleting substances (ODSs) are utilized as refrigerants, in air conditioning, solvents and fire-extinguishing agents (Ahmad et al., 2018).

The Montreal Protocol on substances that deplete the ozone layer was signed in 1987 and ratified two years later to control the damage caused by ODSs and to prevent further destruction of stratospheric ozone layer. The production and consumption of all of the primary long-lasting ODSs such as chlorofluorocarbons (CFCs) and bromine-containing halons has been curtailed by further amendments and changes in Montreal Protocol. The latest strict phase-out schedule stopped the consumption of chlorofluorocarbons (CFCs) in 2010 (Chipperfield et al., 2020).

The concentration of man-made bromine-containing compounds is decreasing. The stratospheric ozone layer is therefore expected to be recovered under the impact of Montreal Protocol, later this century. The scientists are not certain how the concentration of very short-lived substances VSLS bromocarbons will affect in coming years though man-made halogen loading to the stratosphere should decrease with the implementation of Montreal Protocol. Since bromocarbons are mainly formed by organic methods in the ocean, their emission concentrations might change with climate, affected by factors like ocean pH, sea surface temperature and surface wind stress (Yang et al., 2014).

Confident predictions about concentrations of VSLS could therefore not be made for stratosphere. Bromine containing halogens are hundred times more effective than chlorine containing halogens as ozone sink in the upper-latitude lower stratospheric area. Therefore, the rise in stratospheric bromine concentration, probably due to enhanced bromocarbon emissions or its diffusion into the stratosphere may lead to delay in stratospheric ozone layer recovery (Yang et al., 2014).

Ozone hole has been one of the major environmental concern for the past four decades. The ozone layer blocks biologically harmful solar ultraviolet (UV) radiation from reaching the earth surface and played a key role in making the conditions favorable for evolution of life on earth. The earth infra-red radiation are effectively absorbed by ozone, which is a “greenhouse gas” and which is produced in the atmosphere rather than being emitted directly at the earth surface. Recent studies have shown that there is a strong link between climate change and stratospheric ozone (Chipperfield et al., 2017; Jucks, 2018).

In the 1970s, it was discovered as a concern that the decomposition of chlorofluorocarbons CFCs in the stratosphere would produce chlorine atoms, which could destroy stratospheric ozone molecules. The Antarctic ozone hole discovery in 1985 of the Antarctic stratosphere in spring led to many other research activities. The Antarctic ozone hole was primarily formed because of rising levels of chlorine and bromine in the atmosphere. Secondly the stable chlorine reservoirs are converted into chemically active ozone-destroying species on the surface of polar stratospheric clouds (PSC) in winter and spring. Climate scientists were unable to detect the Antarctic ozone hole as they did not include such processes in their models which could help them in predicting the ozone hole in advance (Chipperfield et al., 2017).

After introducing official sanctions on the production, consumption, and transport of ozone depleting substances (ODS), official administrators had to fight against emerging threat of chlorofluorocarbons smuggling. Many industrial criminals exploited the gaps in national and international implementation mechanisms and helped buyers in importing chemicals in the US. Many developed countries including the United States could not provide adequate cooperation to developing nations to halt CFC production. The insufficient punishments from the international authorities caused a delay in earth's ozone hole recovery though the international community managed to fight the black market of CFC production (Welch, 2017; Godin-Beekmann, 2018).

The risk involved in considering a substitute for ODSs i.e., hydrofluorocarbons (HFCs) in the atmosphere is many-fold higher for disturbing the earth climate by worsening global warming and demands a strict response to avert this imminent danger. For this purpose, on October 15,2016, in Kigali, Rwanda an amendment to the agreement for the phase-out of HFCs by the name of 'Kigali Amendment' was signed. It is another progressive step towards decreasing greenhouse gas emissions. However, it also poses a threat for smuggling of these chemicals into the market. The international authorities need to check the lacunas in the past to control CFCs' production in order to achieve agendas of diminishing another harmful chemical called HFCs (Welch, 2017).

In this study, the consumption status of ODSs, by undertaking a nation-wide data collection for the alternatives to the Ozone Depleting Substance imported, exported and produced in the country was checked. This survey was aimed to better understand the historical and predicted consumption of ODS alternatives including medium, low and high-global warming potential (GWP) alternatives and their distribution by sector and subsector in refrigeration, air conditioning, foam, aerosol, solvent and fire protection/ suppression.

The study is also intended to provide a comprehensive overview of the national markets where ODS alternatives have been and will be phased in, while taking into consideration other existing technologies.

Another part of this study was the collection of data in the questionnaire form to find out the challenges faced by enterprises to phase-out ODS. For this purpose, a survey form was designed and circulated among importers, consultants and NGOs to inquire about the challenges involved in phase-out of ODS, the technological and financial assistance provided to the industries for cut down of ODS consumption. The alternate technologies that are being offered by implementing agencies to the industries rather than using conventional ODS were also inquired.

Some of the questions asked about the recommendations from the consultants to introduce policies which could streamline and expedite the process of ODS phase out. The awareness level of industries about the current and subsequent phase-out management plan and the safe disposal and recycling of refrigerants/ODS were also questioned in the survey form. A total of seventeen importers, consultant and NGOs responded to the questionnaire containing 23 questions. A spreadsheet was formed to record the responses. The frequencies of the responses were obtained by performing the SPSS analysis and presented in the form of tables in the result and discussion section.

In this research study, the evolution of stratospheric total column ozone (TCO) over Pakistan was also checked for a period of 2004-2020. The spatial and temporal distribution of TCO over Pakistan was explored and presented in the form of maps and time series. The satellite data for TCO was obtained from online website GIOVANNI and a combine product of OMI/AURA satellite observation was used for this purpose.

The ground-based data of TCO for Pakistan (Quetta) was obtained from world ozone and ultraviolet radiation data centre (WOUDC). The ground-based data and satellite data of Quetta for 2004-2018 for TCO were compared and findings are presented in the result and discussion section.

1.2. Justification For Selection of Research Study

The Antarctic ozone hole experiences a typical depletion in each spring that usually peaks in September and October. As mentioned above, in order to prevent further ozone depletion, the production and consumption of Chlorofluorocarbons (CFCs), the major cause of mad-made chlorine in the stratosphere were banned under Montreal Protocol. A few research studies suggest that the elimination of CFCs is helping the ozone layer to recover, especially in the month of September each year when the ozone hole becomes obvious. Ozone layer is depleted by gas-phase chemistry whereas polar stratospheric clouds (PSCs) are undergoing heterogeneous ozone depletion chemistry phase and cause severe ozone depletion in the Antarctic zone. Ivy et al., (2017) found out that natural phenomenon of volcanic eruptions increases the concentration of aerosols in the stratosphere. Consequently, the particle surface area is increased that causes ozone depletion. It was also confirmed in the study that the major eruption of Mount Pinatubo in the 1990s accelerated the Antarctic ozone depletion (Fountoulakis et al., 2018).

The ozone layer is getting damaged by human activities which are negatively impacting human and animal health and well-being. The stake for human health by ozone depletion is even more high. The growth of plants and phytoplankton is in peril which is a major source of food for humans and sea life. Photochemical smog is oxidized by ozone and the oxidation of molecules occur by ozone either by radical reactions or freely. Earth surface temperature is increasing and vice versa at higher surfaces due to abundance of CO_2 in stratosphere and trapping of heat. CO_2 and other chemical act as an insulating shield around the earth and do not allow the cold air above to mix with the warm air at earth surface. The man-made chemicals ODS release chlorine and bromine and are the real cause of major ozone depletion. (Murtaza, 2015).

Currently, the science behind the stratospheric ozone is based on good grounds based on the data available and its comparison with the climate models. Satellite and aerial data gathered on different chemical species indicate that there are no significant uncertainties in stratospheric chemistry that could potentially overrule the existing understanding. This was not the case in 1984 when little scientific knowledge was available about the photocatalytic reactions of chlorine and bromine (ClO + ClO & ClO +BrO) and the heterogeneous chemistry involved behind destruction of ozone layer, especially in the Antarctic zone. Moreover, the defining factors controlling ultraviolet and infrared radiations are also well understood (Newman, 2018; Staehelin et al., 2018).

The healing of Antarctic ozone layer is primarily connected to the future projections for ODSs. The primary ozone depletion substances that are responsible for equivalent effective stratospheric chlorine (EESC) include CFC-11, CFC-12, and CCl4 (carbon tetrachloride or CTC). Research findings indicate that in spite of CTC being in the controlled substances list under Montreal Protocol, its emission in the atmosphere is persistent. The emission of carbon tetrachloride CTC is likely due to the production plants utilizing chloromethane (CH_3Cl, CH_2Cl_2, $CHCl_3$ and CCl_4). The present ODS projections do not include such emissions of carbon tetrachloride (CTC) and if it is not the case, ODSs emissions have been reported to be much higher with consequent later recovery dates. Lately, a spike in CFC-11 emissions is found by scientists in earth surface measurements. However, zero production and consumption of CFC-11 has been reported to UNEP. Presently the reason of this spike in CFC-11 emissions is not understood. One of the aspects of compliance to Montreal Protocol includes tracking of ODS levels in the atmosphere. Atmospheric measurements that track ODS levels are part of a “compliance” aspect which ensures that parties show commitment to the Montreal Protocol in its true letter and spirit to achieve the goal of reduction in ozone depletion (Newman, 2018; Kurylo, 2018).

1.3. Relevance of Study for Pakistan

Atmospheric ozone columnar density is measured in Dobson unit (DU). 1 DU is defined as a layer of ozone which is 10 µm thick at standard temperature and pressure (STP). 1 DU contains 2.69×10^{16} molecules/cm^2. The reference value for ozone hole is chosen as 220 DU as total column ozone values less than 220 DU were not observed prior to 1979. A phenomenon known as Quasi-Biennial Oscillation (QBO) is responsible for transportation of stratospheric ozone from lower latitudes (tropics) to higher latitudes (polar regions). It is very obvious why polar areas have more total column ozone (TCO) than tropics (Wazir, 2011; Bencherif, 2020).

Stratospheric total column ozone (TCO) is widely studied since the discovery of ozone hole especially in the tropics. It is also well known that in between 25° S and 25 ° N, there is 38% of global total column ozone (TCO). Previous research studies indicated a decreasing trend of 3% in global total column ozone (TCO) for the period 1984-1993 (Wazir, 2011).

Similar other research studies on ozone were carried out which led to the conclusion that ozone levels were low in large ranges of latitudes in southern as well as in northern hemispheres. The largest dips in ozone concentrations were observed from 10 °N to 60 °N and 10 °S to 20 °S (Wazir 2011).

The scientific research is establishing the fact that there is a decreasing trend in global stratospheric ozone. Moreover, many scientific studies have been conducted regarding the trend of stratospheric ozone in South Asia region. One such study indicated a decreasing trend of TCO in northern parts of India. Another study conducted in Pakistan for the period 1987-2008 indicated a declining trend in stratospheric TCO with annual change of -5.67 DU and monthly decline of -4.2 DU for the above-mentioned period (Wazir, 2011).

The two major environmental agreements that are broadly considered successful global environmental agreement are Montreal Protocol and Vienna Convention. Both of these agreements helped in phase down of ozone depletion substances (ODS) by almost 97%. It was made possible because of useful and timely cooperation such as the trade facilities. Other provisions include strong institutions including implementing bodies, economic and research bodies, a unanimous resolve by all member parties and a full fledge financial support mechanism. According to a report published by UNEP in 2013, it was reported that ozone layer is moving towards recovery. In addition to that, 135 billion tons of CO_2e emissions have been avoided (Nair et al., 2013).

Montreal Protocol was ratified by all nations and Pakistan ratified it in 1992. The national ozone unit at the Ministry of Climate Change is primarily responsible for collaborating the dual benefits of this treaty for Pakistan i.e., reducing global warming potential GWP and consumption of ozone depletion substances. Pakistan has already achieved an obligation of phasing out chlorofluorocarbons (CFCs) by January 1st 2010. The next obligation was to phase out less harmful ODS i.e., HCFCs. The timeline set for that purpose was elimination of HCFCs to 10% of baseline levels by 2015. Consumption of HCFCs is to be reduced by 35% in 2020, 67.5% in 2025 with near complete phase-out by year 2030 (Polonara et al., 2017).

Pakistan has successfully completed its HCFCs phase out management plan stage one (HPMP I). the mission was to replace 71 ODP tons of HCFCs in the foam sector. It was finished in 2015. (HPMP II) 2016-2020 includes the rest of foam manufacturers and comprises a demonstration plan for an air conditioning assembler i.e., Dawlance (Karachi) to shift its refrigerant from HCFC-22 to propane (a hydrocarbon R-290) because of its low GWP 3. The proposal for HCFCs' phase out management plan stage two (HPMP II) was accepted in May 2016. The rest of the entities will convert HCFC-22 in the coming years. Multilateral Fund (MLF) under the MP will provide the cost of conversion, which is estimated at US $1.6 million. All of these efforts indicate seriousness of Pakistan towards reducing the consumption of ozone depletion substances ODS (Ul-Haq et al., 2016).

The scientists around the world are gauging the trend of ozone layer to keep a check on what happens next to the ozone layer. It is therefore pertinent here to check the impacts of phase down of ODS on the evolution of stratospheric ozone layer in Pakistan. The consumption status of different ODS in Pakistan needs to be checked to evaluate whether we are going in the right direction as stipulated in the Montreal Protocol.

The challenges faced by enterprises to phase down ODS is another gateway to understanding the status of Pakistan towards achieving its reduction targets. It could also provide help to our policy makers as to what needs to be done to facilitate the importers and manufacturers of ODS towards reducing the consumption of these harmful chemicals/refrigerants.

1.4. Significance of Study

It is important to study stratospheric total column ozone (TCO) over Pakistan and the consumption status of ozone depletion substances (ODS) in Pakistan. The greatest ambiguity in the recovery of stratospheric ozone is the changes brought by humans to climate that will lead to increased concentrations of methyl chlorine, methyl bromide and very short-lived substances (VSLS gases). If climate change triggers an increase in concentration of these gases in the atmosphere by 30%, which is expected to happen at the end of this century, the consequence on stratospheric TCO would be much significant than what may happens from man-made ODSs. Upgraded compliance and tracking of regulated ozone depletion substances ODSs and controlling climate change are critical to combat these consequences (Liang et al., 2017).

Scientists are using climate models to study the transport mechanism that connects the earth surface to the stratosphere. They discovered that less air originates in the lower stratosphere from Europe and North America as compared to Asian boundary layer where air portion in the tropical lower stratosphere is 20%. This finding infers those other populated regions are not efficient at transporting their emissions into the stratosphere than the Asian region (Orbe et al., 2015).

This finding is supporting other results which show that black carbon emissions are on the rise from Asian region for past few years. Generally, this study shows that Asian boundary layer to lower stratosphere circulation Overall, this study shows that transport from the Asian boundary layer to the lower stratosphere circulation are not only narratively important but also plays a vital role in deciding the long-term lower stratosphere climatic properties (Orbe et al., 2015).

After the signing of Montreal Protocol in the 1980s, scientists and politicians are trying to find the clues that legislative restrictions on the consumption and production of chlorine compounds are preventing the further depletion of ozone layer. For this purpose, they are monitoring the concentration of CFCs being used for industrial and commercial purposes and comparing it with atmospheric concentration by using airborne instruments near earth surface (Zahid and Rasul, 2010).

Researchers are using satellites, instrumental airplanes and airsondes to monitor stratospheric TCO around the world and over the south pole more particularly. They have deployed balloons, instrumented airplanes, and satellites to observe stratospheric ozone over the South Pole (in particular) and around the world (Vega et al., 2014).

The findings show that ozone recovery is under way. The amount of chlorinated compounds and other related chemicals is decreasing near earth surface. This is because of the substitute chemicals that the industry is using owing to being less harmful to the climate (Strahan and Douglass, 2018).

This research study is significant because it will provide

- A source of accurate data on the consumption of ODSs in Pakistan.
- The historical consumption data 2012-2015 on ODSs and the projected consumption data ODSs 2016-2030 will also be presented in this research study
- The challenges faced by enterprises to phase down consumption of ODSs will also be established under the scope of this study.
- The spatial and temporal evolution of stratospheric total column ozone (TCO) over Pakistan for 2004-2020 will also be carried out in this study
- The satellite and ground based data obtained from Quetta will be validated to check the coherence of stratospheric TCO data.

1.5. Objectives of Study

1. To check the status of ODSs consumption and phase-out in Pakistan.
2. To find out the challenges faced by enterprises to phase down consumption of ODSs.
3. To check the evolution of stratospheric TCO over Pakistan.

CHAPTER 2

LITERATURE REVIEW

2.1. Stratospheric Good Ozone

Two scientists named Molina and Rowland, in 1974 at the University of California, were the first ones to caution against the harmful impacts of chlorofluorocarbons which destroy the ozone layer in the earth's atmosphere. The mechanism involved in the destruction of ozone molecules was also revealed by them. They elaborated that chlorofluorocarbon molecules are chemically stable in the atmosphere but when they reach the mid stratosphere they are broken down into chlorine atoms with the help of UV rays. That's how they put forward this concept of destruction of large number of ozone molecules by CFCs in the stratosphere (Adeoye and Aina, 2019).

The sum of chlorine-containing species which are formed from photodecomposition of CFCs is named as Cly. These species have brief lifetimes but on the other hand their totality is saved as conserved entity and is considered as a trace amount gas. Cly circulation is defined by stratospheric transport and anomalies in the transport. Nitrous oxide has a lifetime of about one year beyond tropics at elevation below 30hPa and it is known as long-lived gas which is released at the surface of the earth. A research study employed the solid correlation between long lifetimes CFCs and nitrous oxide determined by calculating Cly dimensionless mixing ratios in the Northern and Southern hemisphere lower stratosphere during two airplanes operations. Further details elaborated that the obtained solid correlations were anticipated, counting the one obtained between nitrous oxide and Cly. The reason for this correlation was the shorter timescale for isentropic passage than the chemical substances local photodecomposition lifetime (Strahan et al., 2014).

Stratospheric ozone loss is being regulated by the universal treaty, the Montreal Protocol, which has banned the synthesis of long-lived CFCs in the atmosphere. HCl compound is ultimately formed by the breakdown of these halogenated gases in the upper stratosphere. Therefore, the measurement of HCl in the upper atmosphere is a way to check the efficacy of this Protocol. HCl volume mixing ratios altitude profiles are determined by measuring the earth's atmosphere infrared solar eclipse bands with the help of Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS). The prominence of this Protocol's success is obvious by the linear trend of time series of -4.8± 0.2% per decade (2004-2017) of HCl volume mixing ratio in the stratosphere (Bernath and Fernando, 2018).

Further cooling of stratosphere and a surge in water vapour content being convectively transported to the stratosphere is anticipated due to climate change scenario in which greenhouse gases' emission will increase. Research related to ozone loss procedure and the associated parameters such as increased water vapour content, impact of stratospheric cooling and higher concentration of sulfate particles is vital in understanding the influence of probable sulfate engineering and climate change impact on ozone at mid-latitude. By applying North American Monsoon tropopause conditions using a model named "box-model", it was found that the potential ozone loss for 20 parts per million by volume (ppmv) moisture mixing ratio was about 9%. Thorough examination of present and projected likelihoods is required to weigh if higher moisture content scenario in mid-latitude stratosphere in summer is linked with greater ozone deterioration or not. (Robrecht et al., 2019).

2.2. Dobson Unit for The Measurement of Ozone

To quantify total column ozone (TCO), BUISSON and FABRY spectrographs were economically less feasible than the spectrograph designed by **G. M. B. Dobson** in 1924, which was more favorable for daily use and economically viable as well. Therefore, nowadays, Dobson's name, the DU, is used as measurement unit for atmospheric TCO. 1 DU is described as a column containing $2.687\times10^{\mathbf{16}}$ O_3 molecules per cm^2. The DU defines the width of a pure ozone layer, provided the entire amount of ozone from surface of earth to stratosphere were subjected to standard temperature and pressure conditions: 1013 hPa pressure and 15 °C temperature. For instance, 300 Dobson Units of atmospheric TCO taken down to the earth surface would make a thick layer of 3 -millimeter pure O_3 molecules (Muller, 2009).

2.3. Universally Ratified Montreal Protocol

The signing of the global agreement, *Montreal Protocol* can be considered as an initial footstep in a sequence of progressively aspiring accords. The primary goals approved in the year 1987 obliged a fifty percent cut by year 1998. Furthermore, two other amendments namely Copenhagen and London amendments conveyed in the year 1992 and 1990 respectively imposed a comprehensive ban and included a wider array of molecules to the inventory of regulated ODSs. The goals approved in year 1987 can be construed as humble because these goals prearranged feasibility of ODSs' industries, spanning over a long time. It will be no exaggeration to assert that the industry at that time had minimum necessary technologies and information for the required change. However, what it meant was that the industry weighed that it will be able to achieve the goals with adequate funds in development and research sector (Dugoua, 2021).

To meet the international environmental needs, a fund called Interim Multilateral Fund was created and the purpose of this fund was to offer financial support to the developing states in dealing with environmental issues. This fund is managed by three main organizations, UN Environmental Program, United Nations Development Program and the World Bank. It is because of these contracts that by 1996, international usage of CFCs was reduced by more than 70 percent. In addition, ODSs Industry and other relevant entities have conformed to the ban of CFCs. This is another example of social awareness and a change in the social behavior (Ali et al., 2017).

2.4. Ozone Depletion

According to a research study, measurements obtained through satellite data have proved that since the beginning of 1980s, ozone has been greatly depleting in the South Pole region. As a result, the area is named as the "Ozone Hole" and lately it has come to 25 million sq. km, which is double the area of total Antarctic region. Although, at the moment the issue of ozone depletion is not being taken seriously but it has the propensity to become the main environmental concern of the world (Psomiadis et al., 2007).

One extensive study conducted from North Pole to South Pole (all of 36 zones with five degree accretion) for 1964-2009 was for annual zonal mean TCO. To evaluate trends in an active window with a time interval of 15 years, trend analysis practice was used. There was no ozone loss for time interval 1964-1979. After that, in the time interval ending in 1993, the evidence suggested that there was an increase of 0.93 DU/year. After time interval 1993, ozone loss rates were gradually declining in the next fifteen-year trend up until there was no depletion in the time interval ending up in 2003. After 2003, ozone accumulation was detected again after 2003 for the rest of the study time period and the time interval ended up in year 2009. During that last time interval, an accumulation rate of 0.23 DU/year was recorded. Absolute change in TCO indicated that ozone depletion for 46 years (1964-2009) was recorded as 5 DU, keeping in view that TCO varied from 295 DU in 1964 to about 290 DU in 2009 (Munshi, 2016).

In precedence of other global research studies, another study was made in which daily TCO data from ozone monitoring instrument and total ozone mapping spectrometer were processed to check hemispheric and worldwide TCO changeability. Two periods of TCO measurements were analyzed separately covering full years. The global decadal decrease rate of TCO was found out to be -4.3% (for period 1978 to 1994). In the Southern Hemisphere the decadal decrease rate was reported to be -4.5% whereas the decadal decrease in Northern Hemisphere was of -4.0%. (Pinedo-Vega et al., 2017).

The incremental four years of World Meteorological Organization (WMO) ozone assessment data from 2013 to 2016 indicated that since the chlorine species reached its maximum threshold in 1996, no significant trends have been observed so far. However for some latitudes of northern hemisphere and extratropics of Southern Hemisphere, there was a little positive trend of +1% per decade (Weber et al., 2018).

A steady ozone destruction process and increment in hypochlorite (ClO) were identified when the sunlight returned to austral spring. When the ClO observed peak time, a negative correlation relationship was recorded between $ClONO_2$ and ClO time series data at location of Syowa station. The negative relationship was linked between two factors i.e., inward edge of the polar vortex and the distance of Syowa station. At Syowa Station the time-based variabilities in species containing chlorine were influenced by formation of polar stratospheric clouds and reaction of NO_2 and hypochlorite which forms excessive $ClONO_2$. This phenomenon is caused by diffusion of NOx air from boundary region of polar vortex (Nakajima et al., 2018).

2.5. OMI/AURA Satellite Data

On board the Aura satellite project is the ozone monitoring instrument which is also defined as UV-VIS nadir view spectrometer. OMI possesses detectors which are two dimensional and their application offers daily global exposure for wavelengths of 308-500 nm with nadir viewing at high spatial resolution 13× 24 km. For wavelengths below 308 nm, the spatial resolution is 13 × 48 km. The atmospheric science data available through OMI ranges the time span of 2004-present. One of the unique key features of OMI that makes it ideal for ozone monitoring is its stability in terms of radiometry. That is why it undergoes only a minor fraction of decomposition only in the shorter ultraviolet bands. The ozone monitoring instrument is being followed by another instrument in line: “TROPOMI” instrument. This instrument was formally launched in 2015 and it was onboard the satellite “Sentinel-5 Precursor” (Hassler et al., 2014).

Through the past ten years, several studies have been performed where on the accurracy of satellite total column ozone TCO data were correlated either with data from different validation operations or ground based data. It not only assisted in identifying complications in the comparisons and classifying features but also facilitated to revise the satellite data and advance its algorithms. Other old research studies conducted by McPeters and Labow,1996 made a comparison of thirty (30) Northern pole Brewer and Dobson stations with Nimbus total ozone mapping spectrometer (TOMS) V7 TCO total ozone column data. It was discovered that satellite data of TOMS V7 correlated within ±1% for a time period of 14.5 years with ground-based station observations (Balis et al., 2007).

2.6. Ozone depletion substances and its impact on Ozone layer

It has been observed that the level of Stratospheric Chlorine is waning which will eventually improve the ozone level as it was in the early 1980s. However, according to a recent research study, the traces of dichloromethane-a gas that can deplete ozone, has also been found in the atmosphere and they are diffusing at higher rate. Through the use of model simulations, the observers have noticed that the effects of dichloromethane on ozone have escalated manifold and if the increase continues with the same speed, it would become difficult to bring ozone level to its pre-1980s level. The presence of CH_2Cl_2 would counterbalance the benefits gained by the Montreal Protocol and eventually slowing the recovery of ozone layer (Hossaini et al., 2017).

Solar proton flux can also change stratospheric chlorine interaction, but either solar particles efficiently stimulate or inactivate chlorine relies on radiance conditions. The residence time of CFCs has an effect on the readiness of ozone depletion substances (in the stratosphere) and is decided by the Brewer-Dobson Circulation which regulates the elevation and duration of exposure of an air parcel to photochemistry. Eventually, to contain the mean time or age of air for stratosphere and to detect the trends in BDC, gases containing chlorine can be used as tracers. Hypochlorite ion (ClO) is ideally quantified through its rotational vibrational frequency with remote sensing in the microwave and far-infrared radiation spectrum. For hypochlorous acid, (HOCl), the best measurement spectrum lies in the far infrared region, however some valuable measurement was also gathered through microwave and mid-infrared spectrum for HOCl.

Chlorine nitrate ($ClONO_{2)}$ is just quantified in the thermal infrared radiation (IR), whereas the quantifiable signal for HCl specie lies in the mid-infrared, far infrared and microwave spectrum (Von Clarmann, 2013).

In the stratosphere, the total reactive nitrogen known as “NOy” consists of the principal constituent HNO_3 or nitric acid. Total reactive nitrogen also comprises the sum of NO_2 and NO, which are the other oxides of nitrogen and are widely known as NOx. The foremost ozone loss phenomenon in the stratosphere is catalyzed by NOx whereas nitric acid is the secondary contributor in regulating stratospheric ozone. $HNO_{3,}$ also known as “nitric acid”, performs a very significant contribution in the creation of species i.e., polar stratospheric clouds in Arctic and Antarctic winters. Polar stratospheric clouds undergo various surface reactions which lead to the development of chlorine-containing species which are highly reactive in the colder months of Arctic and Antarctic stratospheric regions. This process contributes to ozone loss in the polar areas (Popp et al., 2009).

It is being estimated that the release of global hydrofluorocarbon will evidently surpass the preceding estimates after 2025 as the developing countries’ emission will be 800 percent greater than in industrialized states in 2050. International emission of Hydrofluorocarbon 2050 will be equal to 9 –19 percent of estimated global carbon dioxide releases in business as usual (BAU) circumstances and add a radiative forcing equal to that from 6 to 13 years of carbon dioxide emissions close to 2050 (Velders et al., 2009).

A sudden decrease in stratospheric ozone was detected with the max decrease happening 10 to 20 days right after solar proton incident. For more than one month the level of ozone remained very low and outside the polar vortex, no depletion was detected. Moreover, no thinning was witnessed with respect to 191 random timings at any of the location during the year. Findings hinted at the role of indirect ozone depletion and most probably through the speedy drop of old nitric oxide class in the circumpolar vortex throughout the tropical winter (Denton et al., 2018).

A research study was conducted by Ul Haq et al., 2014 in which the atmospheric data of total O_3 column retrieved from the Aura satellite employing ozone monitoring instrument (OMI) was used to analyze the temporal and spatial trend of stratospheric O_3 over Pakistan and contiguous areas of 3 states namely Iran, India and Afghanistan for time period October 2004 - March 2014. The study was unique in the context of this atmospheric data as this area was not previously explored in fine details. Over the entire region, the TCO annually averaged spatial value was observed to be 278 ±

2 DU. For the first time, per decade increase over the region was 1.3 percent in total column O_3 value. The study region was also identified as the area of greater temporal and spatial changeability of Total Ozone Column (Ul Haq et al., 2014).

In view of the significant role that is played by ozone in the atmosphere and the risk of its deterioration in Pakistan's scenario, total column ozone over entire Pakistan was checked through daily global data (Level 3) of AIRS onboard Aqua satellite. The spatial resolution of the data was 10 x 10 lat/long grid. For time period 2003 to 2011, year to year analysis of Total Column Ozone over Pakistan revealed that general trend of mean distribution of total column ozone variability were determined by latitude of country (location) and ranged from 297 DU-300 DU in KPK province and other northern parts and 275 DU - 278 DU in Baluchistan and Sindh regions. Cyclical seasonal changes indicated that for the region located at 23°-29°N, summer time (June, July, August) recorded highest value of ozone and it was recorded lowest in winter time (December, January, February). Spring season (March, April, May) and autumn season (September, October, November) observed varied trends. For the region located at 30°-37°N, the highest column ozone value was observed in spring (MAM) months and winter months (DJF) and lowest values of column ozone were recorded in summer months (JJA) and autumn (SON) months. A linear relationship was obtained among solar flares and year wise total column ozone after the statistical examination (Rafiq et al., 2017).

Considerable rise in the amount of well mixed greenhouse gases such as CO_2 in the atmosphere, for instance those events which are anticipated to ensue towards termination of 21st century by the influence of big radiative forcing setups, have previously been recognized in climate models as a reason for surge in Brewer-Dobson circulation. The findings of the study revealed through multi-model analysis show that more than half of the multi-modeled trend during 1980-2000 (two decades) in Brewer-Dobson circulation (BDC) is being caused by ODSs. It was also discovered in the study that reduction in production of ODSs in coming years will lead to slowing down of BDC till 2080. It will substantially decrease the age-of-air trends almost by half and it will prevent the equivalent CO_2 emissions. This is thus widely known that ODSs impart changes in Brewer-Dobson Circulation trends. In other words, ODSs bring hemispheric and seasonal anomalies through either recovery or depletion of South Pole stratospheric ozone. Therefore, it provides an opportunity for detection of ODSs in the stratosphere in coming years (Polvani et al., 2019)

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1. Consumption data of ODS and ODSA obtained from NOU

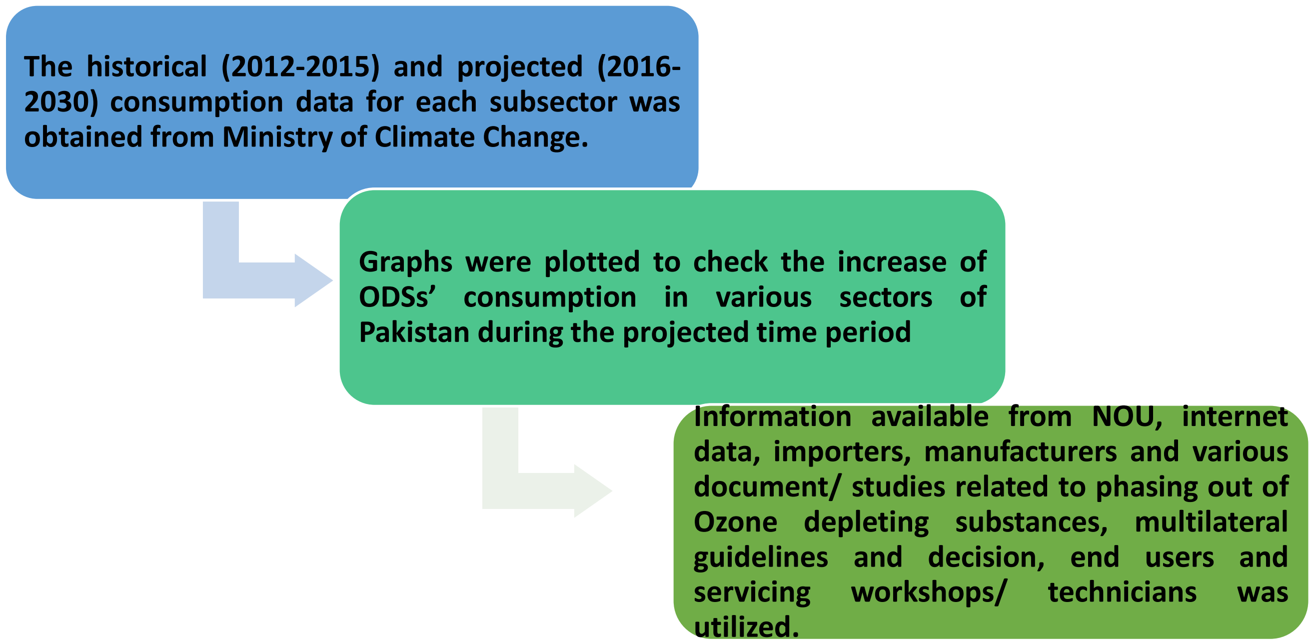


Figure 3.1 A Schematic Representation of Collection and Processing Of ODSs And ODSAs' Data From Relevant Sources

3.2. Survey Form Formation and Circulation Among Relevant Entities

A survey form was designed with the title below. The responses thus obtained were subjected to SPSS analysis and the key performance indicators were obtained on the basis of those responses given in the survey form by importers and companies using ODSs.

"Challenges faced by commercial enterprises to phase down the consumption of ozone depletion substances (ODS) in Pakistan: A questionnaire for the relevant entities/individuals"

Q. Name of respondent

Q. Gender

Q. Qualification

Q. Job/Employment/Institution

Q. Is vocational training available for technicians working in your company?

Q. What is the baseline year identified by government specifically for your entity for reduction in consumption of ozone depletion substances in the coming years?

Q. Was your company a part of HCFCs phase-out management plan stage 1 set out by government?

Q. What are your plans on cutting down HCFCs after 2020 under HPMP stage 2? Can you name those species?

Q. What are the target species of HCFCs which your company has already phased-out under HPMP stage 2?

Q. How many certified technicians are working in your enterprise currently and do they have enough knowledge and skills regarding each category of ozone depletion substances that they deal with?

Q. Training on flammable substances has been available in the last 5 years?

Q. What suggestions you have for the government to enhance the capacity of the companies to adopt alternative refrigerants (low global warming potential GWP)?

Q. What are some of the managerial constraints your company faces regarding the reduction of ODSs consumption?

Q. Which phase-out management plan you company is currently a part of and how successful you will be in achieving the targets set out in the current management plan?

Q. Are you aware of the government's incoming plan on cutting down HFCs? What do you think about this plan?

Q. Did the government provide enough financial support to your company for the implementation of ODSs phase-out plan?

Q. Do you want to convey your concerns in terms of policy constraints imposed by the government for compliance with the government's phase-out agenda for the upcoming years?

Q. What are the policy constraints by the government that hamper the phase down of ODS?

Q. What are the technology constraints in your sector to switch towards alternative refrigerants and ozone depletion substances alternatives (in terms of training technicians on good practices of maintenance and raise awareness to prevent leakages of refrigerants)?

Q. Are you satisfied regarding the measures taken by National Ozone Unit (NOU) in leading the companies towards technology shift?

Q. Could you mention some of the positive incentives provided to your company by NOU to achieve ODS reduction targets?

Q. How government may help you to overcome capacity related issues which is mostly a blend of high energy efficiency, minimum gas leakage, better energy efficiency and use of low GWP refrigerants for better performance of your enterprise?

Q. Does your company receive any subsidy or tax exemption to promote usage of environment friendly refrigerants/ODS with low GWP? Do you provide any consumer incentives to allow acceptability of alternate technology in the market?

Q. Do you think that some of the plausible solutions to overcome the challenges of phase down of ODSs include research and development, improvement in engineering design, training and education, increase in production capacity of ODSAs?

Q. Is there some authority/mechanism to check the safe disposal of existing refrigerants to curb the release of greenhouse gases into the atmosphere?

3.3. Data Analysis Flow Chart of Stratospheric TCO_3 Retrieval

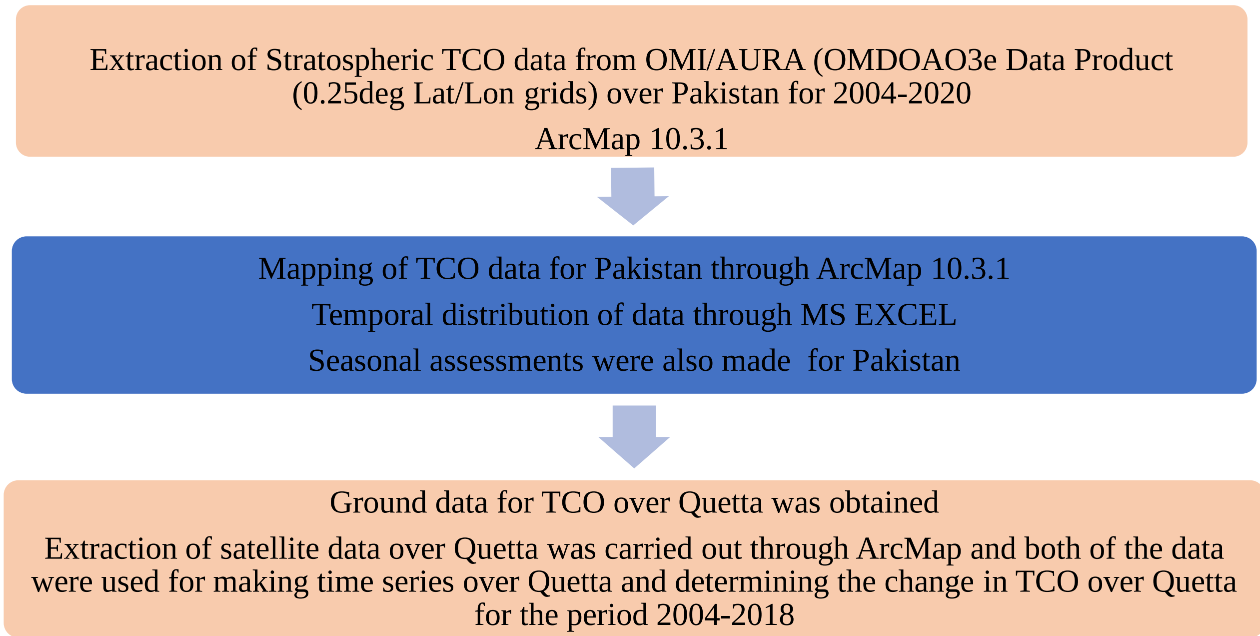


Figure 3.2 Flow Chart of Stratospheric Total Column Ozone Retrieval

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Exploring the current status of ozone depletion substances ODS' consumption and phase-out in Pakistan

Pakistan being in the article 5 (means those countries whose ODSs' consumption is below 300gm/capita) of Montreal Protocol has set out targets for phasing out HCFCs altogether by 2030 and replace them with ozone depletion substances alternatives (ODSAs)/natural refrigerants in the successive years. In Pakistan scenario, the country is neither producing nor exporting any ODSs and ODSAs. However, the consumption demand in manufacturing and servicing is being met through the import of these chemicals from different parts of the world.

Sectors identified consuming ODSs and ODSAs

1. Refrigeration manufacturing & servicing
2. Air Conditioning manufacturing & servicing
3. Foams manufacturing
4. Solvent manufacturing & servicing
5. Fire Protection servicing

Therefore, it is imperative to find the current consumption trend of ODS/ODSAs especially in context with global warming potential (GWP), replacement in terms of quantities, their commercial availability, challenges to the market entry etc. during 2016-2030.

For this purpose, historical consumption data (2012-2015) and future consumption data (2016-2030) for various chemicals, being used by above mentioned sectors, were obtained by National Ozone Unit (NOU). The graphs of the data obtained were plotted to check the growth in consumption of ODS/ODSAs for a span of nearly two decades.

4.2. Refrigeration Sector

There are 17 manufacturers in the country that are manufacturing domestic, commercial and large commercial sub-sectors. Whereas there are number of engineering companies that are fabricating industrial and transport units.

4.2.1. Domestic Refrigeration

There are 10 production companies that are producing domestic freezers/refrigerators. The names include Changhong Ruba, Singer Pakistan, Cool Industries, URIL, Haier, Electrolux, Orient, PEL, Icage and Dawlance. These companies are in the production of different capacities and designs of refrigerators. There are three ODSAs including HFC 134a, HC 600a, R-290 that are used in this subsector in manufacturing as well as in servicing. The historical consumption (2012-2015) and the projected consumption (2016-2030) for various chemicals being used in domestic refrigeration for manufacturing and servicing are presented in the graphs below

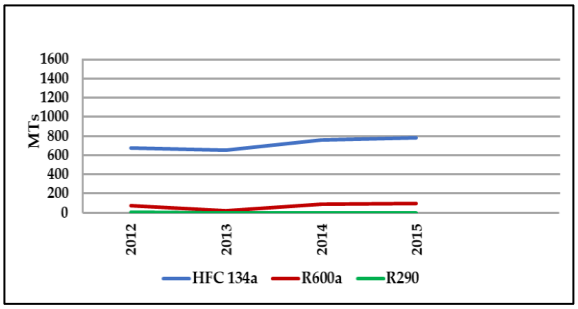


Figure 4.1 Historical Consumption for the Years 2012-2015 in Domestic Refrigeration

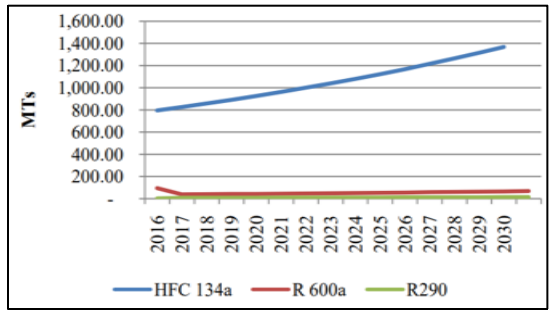


Figure 4.2 Projected Consumption for the Years 2016-2030 in Domestic Refrigeration

The average annual growth observed during 2012-2015 in domestic sector was 5.5%. The annual growth of 5.0% is estimated during 2016-2030 in domestic sub-sector. Expected annual high demand is either due to increase in the population, rapid urbanization, continuation of electrification of rural areas program and the replacement of existing retired population of refrigerators due to their aging/ replacement after their useful life. The discussion with the manufacturers/ trading association reveals that approximately 95% of the total demand is met by local production while 5% is through the import of equipments.

4.2.2. Commercial and Large Commercial Refrigeration

There are six manufacturers that are manufacturing commercial and large commercial refrigerator/ freezers including Mumtaz Engineers, Varioline, Shadman Electronics, Cool Point, SABRO and Patel Engineering. These manufacturing companies are in the production of various sizes and designs of refrigerators. Historical consumption (2012-2015) and projected consumption (2016-

2030) for various chemicals being used in this sector for manufacturing and servicing are presented in the figures below

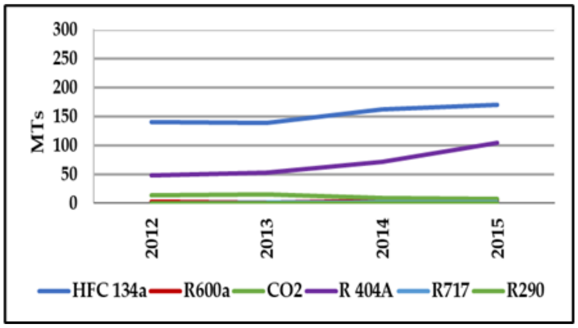


Figure 4.3 The historical Consumption (2012-2015) in Commercial Refrigeration

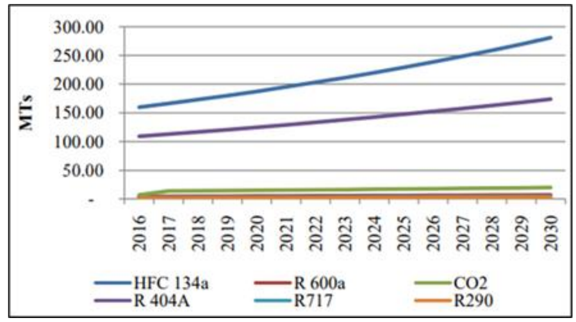
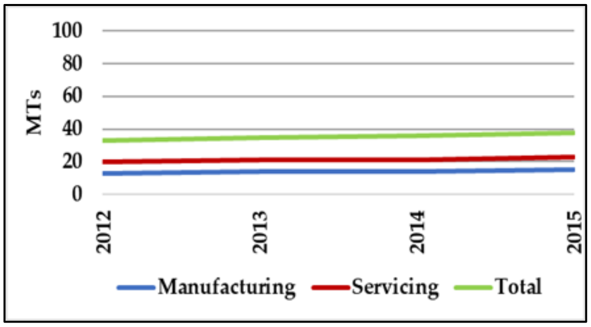


Figure 4.4 Projected Consumption (2016-2030) in Commercial Refrigeration

The average annual growth observed during 2012-2015 in commercial sector was 5.6%. The annual growth of 5.0% is estimated during 2016-2030 in commercial sub-sector. Whereas 4.0% growth has been estimated in large commercial sub-sector.

4.2.3. Industrial Refrigeration

There are number of engineering works that are manufacturing Industrial units in the major cities of Pakistan including Karachi and Lahore. These engineering works are involved in the production of various capacities and designs of cold storages. There is only one ODSA (R717) that is used in this sub-sector in manufacturing as well as in servicing. Average annual growth observed during 2012-2015 period in industrial sector was 5.0%. The annual growth of 5.0% is estimated during 2016-2030 in industrial sub sector. The historical consumption (2012-2015) and the projected consumption (2016-2030) in this sector for manufacturing and servicing are presented in the figures below



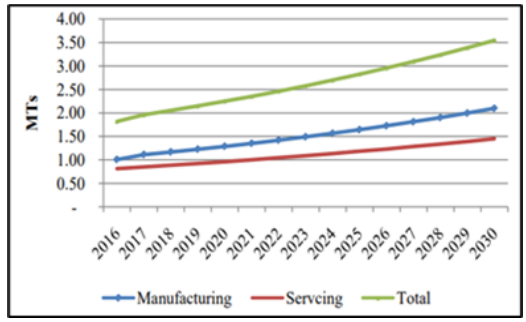
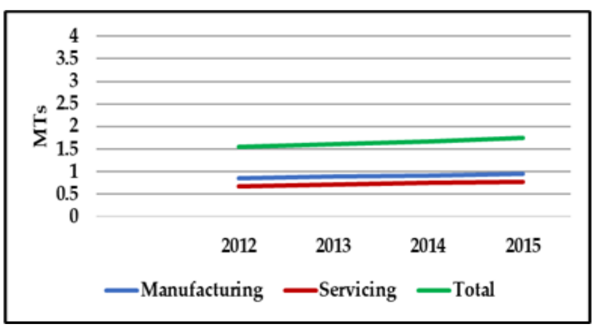


Figure 4.5 The Historical consumption (2012-2015) in Industrial Refrigeration

Figure 4.6 Projected Consumption (2016-2030) in Industrial Refrigeration

4.2.4. Transport Refrigeration

There are number of engineering works that are manufacturing transport units (Reefers) are mainly in Karachi. There is only one ODSA (R134a) that is used in this sub-sector in manufacturing as well as in servicing. In addition, R-22 is also used in this sub-sector. The average annual growth observed during 2012-2015 in transport sector was 3.8%. The annual growth of 5.0% is estimated during 2016-2030 in transport sub-sector. The historical consumption (2012-2015) and the projected consumption (2016-2030) in this sector for manufacturing and servicing are presented in the figures below



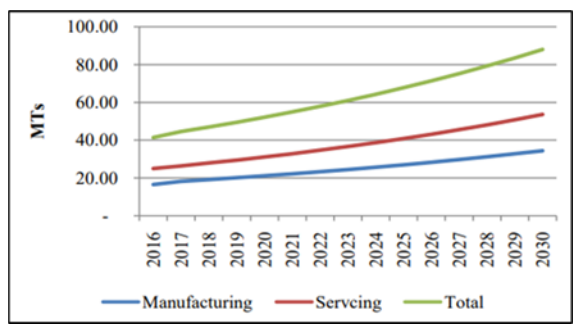


Figure 4.7 The Historical Consumption (2012-2015) in Transport Sector

Figure 4.8 Projected Consumption (2016-2030) in Transport Sector

4.3. Air Conditioning Sector

The Air Conditioning industry has also exhibited growth in Pakistan. The average annual growth observed during 2012-2015 in domestic, commercial and chiller sub-sector was around 2.0%. The annual growth of 5.0% is estimated during 2016-2030 in these sub-sectors. The expected annual high demand is either due to increase in the population, rapid urbanization continuation of electrification of rural areas program and the replacement of existing retired population of ACs due to their aging/ replacement after their useful life.

The discussion with the manufacturers and NOU reveals that approximately 70% of the total demand is met by local production while 30% is through the import of equipments. There are 9 manufacturers in the country that are manufacturing domestic, commercial and chillers whereas 8 manufacturers are in the automobiles manufacturing requiring mobile ACs.

4.3.1. Stationary (residential, commercial and chillers)

There are nine manufacturers that are manufacturing domestic & commercial ACs and Chillers including Dawlance, Haier, Orient, PEL, Digital World, R&I Electrical, SABRO, Petal Engineering and Cool Point. These productions are in the production of ACs ranging between 1 ton to 4 tons in the domestic ACs. There are five ODSAs including HFC 134a, R 410A, R 290, R407C and R32 are used in this sub-sector in manufacturing as well as in servicing. Currently, R-22 is also used in this sub-sector. The historical consumption (2012-2015) and the projected consumption (2016-2030) data in this sub-sector of ACs are presented in the figures below

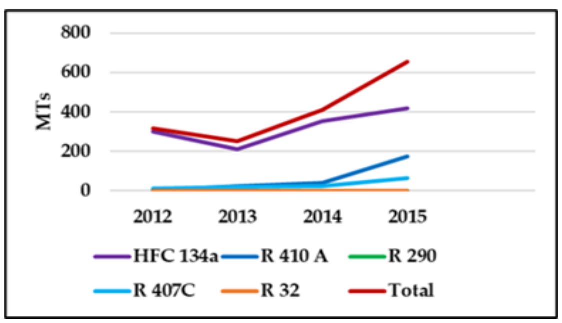


Figure 4.9 Historical Consumption (2012-2015) in Stationary ACs

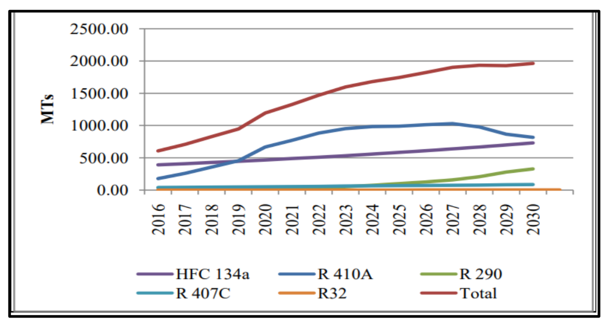


Figure 5.0 Projected Consumption (2016-2030) in Stationary ACs

4.3.2. Mobile Air Conditioning

There are eight manufacturers that are manufacturing vehicles requiring mobile ACs including Indus Motor, Honda Atlas Cars Ltd., Dewan Faroouqe, Pak Suzuki Motor, Hinopak Motors and Master Motor Corporation**.** There is only one ODSA (HFC 134a) that is used in this sub-sector in manufacturing as well as in servicing.

The historical consumption of this chemical in this sub-sector (2012-2015) and the projected consumption in manufacturing as well as in servicing in this sub-sector during 2016-2030 is presented in the graphs below:

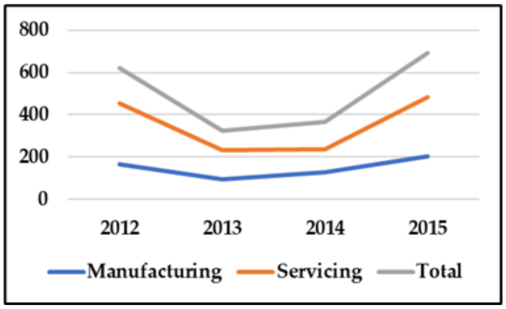


Figure 5.1 Historical Consumption (2012-2015) in Mobile ACs

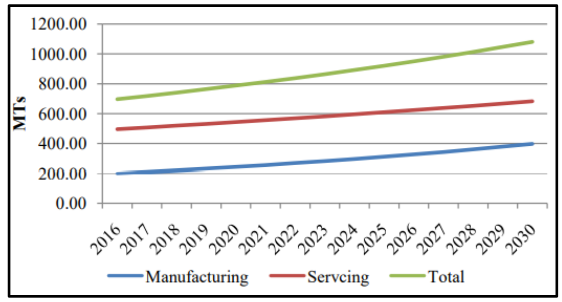


Figure 5.2 Projected Consumption (2016-2030) in Mobile ACs

4.4. Foam Sector

In the foam sector there are number of sub-sectors that are operating in Pakistan including PU insulation in domestic & commercial refrigeration, Sandwich panel discontinuous, flexible foam, thermoware PU foam, pipe insulation, spray foam and XPS board. These industries are exhibiting reasonable growth in Pakistan. The annual growth of 5.0% is estimated during 2016-2030 in these sub-sectors. The expected annual high demand is either due to increase in population and replacement of existing retired articles due to their aging/ replacement after their useful life. The discussion with the manufacturers/ trading association reveals that almost 100% of the total demand is met by local production.

The projected consumption in foam sector (2016-2030) is presented in graph below

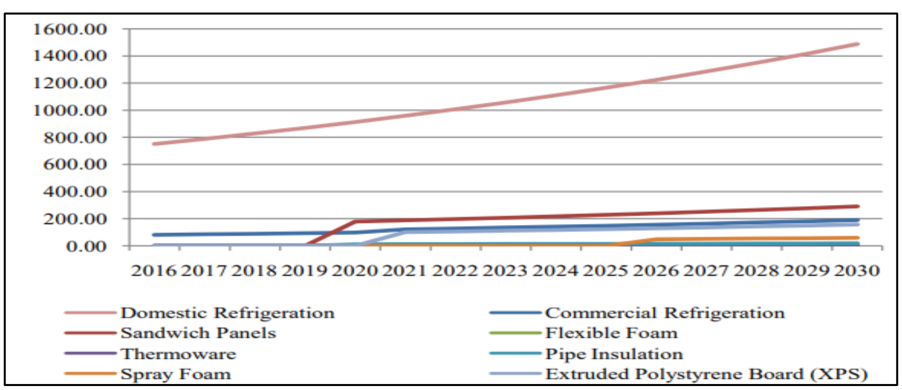


Figure 5.3 Projected Consumption (2016-2030) in Foam Sector

4.5. Solvents

A number of projects have been implemented in Pakistan for the phasing out of solvents including CTCs and CFC-113 through the funding of MLF during 1999 to 2009. Currently, these industries are consuming three ODSAs including dichloro ethane, tetrachloro ethylene and perchloro ethylene. The historical consumption of ODSAs in this subsector in MT and projected consumption in this subsector are presented in the graphs

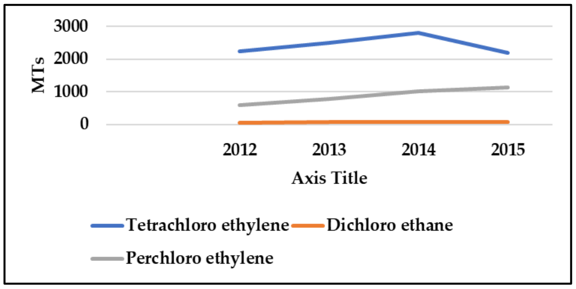


Figure 5.4 Historical Consumption (2012-2015) in Solvent Sector

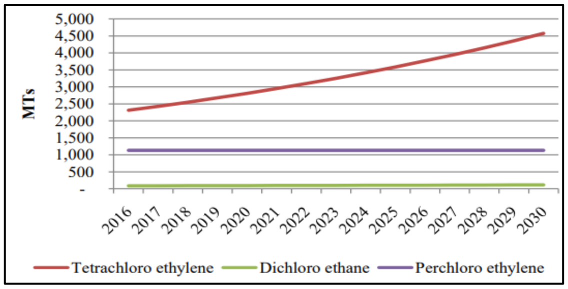


Figure 5.5 Projected Consumption (2016-2030)

4.6. Fire Protection & Suppression system

There are few engineering works in Karachi and Lahore that are currently working to develop fire protection and fire suppression system. Beside local development, a number of systems are being imported from different parts of the world. The chemicals covered under Halon group have already been phased out to a number of ODSAs including HFC227ea, HFC23, HFC236fa and HFC125. The historical consumption of ODSAs in this subsector in MT and the projected consumption are presented in the graphs below

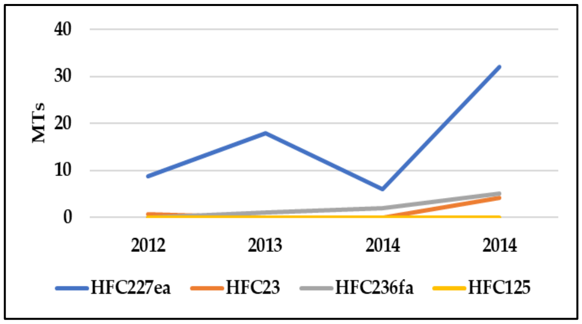


Figure 5.6 Historical Consumption (2012-2015) in Fire Protection and Suppression System

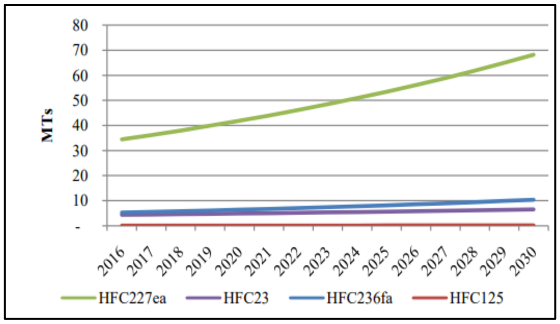


Figure 5.7 Projected consumption (2016-2030) in Fire Protection and Suppression System

4.7. Sector wise projected consumption of ODSs and ODSAs for 2016-2030

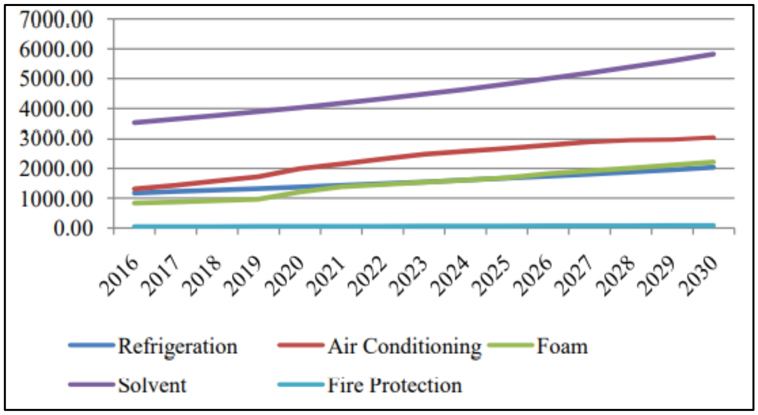


Figure 5.8 Projected Consumption 2016-2030 of ODS and ODSAs in all Sectors

It is evident from the graph that the consumption of ODSs and ODSAs will be highest in solvent sector and lowest in fire protection and suppression system.

4.8. Impact of ODSAs on the Environment

ODSs and ODS alternatives impact on the environment has been examined very critically. The annual historical emission during 2012-2015 and projected emissions for the years 2016-2030 were estimated based on the expected consumption and presented in the graphs below

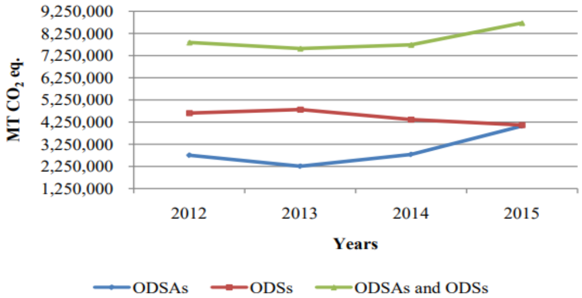


Figure 5.9 Historical Emissions during 2012-2015 of ODS and ODSAs

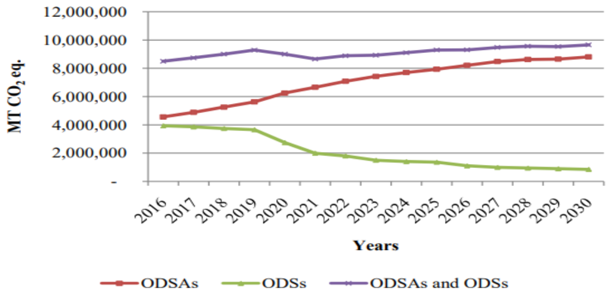


Figure 6.0 Projected Emissions for the Years 2016-2030 of ODS and ODSAs

4.9. Phase-out Schedule for ozone depletion substances (ODSs) in Pakistan

4.9. (a) CFCs' phase-out in Pakistan

Pakistan met a critical Montreal Protocol obligation to phase out chlorofluorocarbons (CFCs) by 1st January 2010.

4.9. (b) HCFCs's Phase Out Schedule

Table 4.1: HCFCs's Phase Out Schedule

Base level:	Average 2009-10.
Freeze:	Ist January, 2013.
10 %: reduction	Ist January, 2015.
35 %: reduction	Ist January, 2020.
67.5 % reduction	Ist January, 2025.
100 %: reduction	Ist January, 2030.

4.9. (c) HCFCs' Phase out Project Implemented by UNIDO

Table 4.2 HCFCs' Phase out Projects

Name of Project	Sector	Location	Status
Dawlance Pvt Ltd	Foam	Karachi	Implemented
United Refrigeration	Foam	Karachi	Implemented
HNR Pvt Ltd	Foam	Lahore	Implemented
Varioline Intercool	Foam	Lahore	Implemented
Shadman Electronics	Foam	Karachi	Implemented

4.9. (d) HFCs Phase Out Schedule

Table 4.3 HFCs Phase Out Schedule

Base level:	Average 2024-2026
Freeze:	2028
15 per cent: reduction	2047 thereafter

4.10. Finding out major obstacles to reduce consumption of ODSs by small to medium enterprises (SMEs) through survey

- A questionnaire was designed with the title "Challenges faced by commercial enterprises to phase down the consumption of ozone depletion substances (ODS) in Pakistan: A questionnaire for the relevant entities/individuals" and circulated among ODS consuming sectors of Pakistan.
- It contained 23 questions related to six key performance indicators KPIs namely 1. Companies' awareness about ODS usage and phase-out, 2. Industries' efficiency and performance in terms of compliance with the Montreal Protocol, 3. Preparedness for future phase-out projects, 4. Financial support, policy support and related constraints. 5. Technological support and constraints faced, 6. Optimum resource utilization and capacity building of the relevant industries.
- The SPSS analysis of the responses obtained in the form of questionnaires from various small and medium enterprises (SMEs) and Government organizations, was carried out and the results obtained are as follows:

Gender					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Male	14	82.4	82.4	82.4
	Female	3	17.6	17.6	100.0
	Total	17	100.0	100.0	-

Job/Employment/Institution					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Consultant	1	5.9	5.9	5.9
	Crescent Corporation	1	5.9	5.9	11.8
	Luck Corporation	1	5.9	5.9	17.6
	Kaghan Chemicals Company	1	5.9	5.9	23.5
	Varioline Intercool Pvt. Ltd	1	5.9	5.9	29.4
	Digital World Pakistan (Pvt.) Ltd (GREE/EcoStar)	1	5.9	5.9	35.3
	World Wide Fund for Nature	1	5.9	5.9	41.2
	Haier Pakistan	1	5.9	5.9	47.1
	Dawlance	1	5.9	5.9	52.9
	Razi Sons	1	5.9	5.9	58.8
	Nasir Corporation	1	5.9	5.9	64.7
	Jillani Trading Company	1	5.9	5.9	70.6
	Salman Traders	1	5.9	5.9	76.5
	Pakistan Oxygen Limited/Linde Pakistan	1	5.9	5.9	82.4
	S.T Brothers	1	5.9	5.9	88.2
	Shadman	1	5.9	5.9	94.1
	United Refrigerators	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

Vocational Training Available for Technicians					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	6	35.3	35.3	35.3
	No	11	64.7	64.7	100.0
	Total	17	100.0	100.0	-

Qualification					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bachelors/Masters	10	58.8	58.8	58.8
	MS/M-Phil	7	41.2	41.2	100.0
	Total	17	100.0	100.0	-

What Are the Target Species of HCFCs Which Your Company Has Already Phased-Out Under HPMP Stage 2					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HCFC-141b, HCFC-22 and HCFC-142b	6	35.3	37.5	37.5
	HCFC-141b and HCFC-142b	10	58.8	62.5	100.0
	Total	16	94.1	100.0	-
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

How Many Certified Technicians Are Working in Your Enterprise Currently and Do They Have Enough Awareness					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	7	41.2	43.8	43.8
	Irrelevant	9	52.9	56.3	100.0
	Total	16	94.1	100.0	-
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

Baseline Year for Reduction in ODS					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2009-2010	10	58.8	71.4	71.4
	2010	4	23.5	28.6	100.0
	Total	14	82.4	100.0	-
Missing	System	3	17.6	-	-
Total		17	100.0	-	-

Was Your Company a Part of HCFCs Phase-Out Management Plan (HPMP) Stage 1 Set Out by Government					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	8	47.1	50.0	50.0
	No	5	29.4	31.3	81.3
	Irrelevant	3	17.6	18.8	100.0
	Total	16	94.1	100.0	-
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

Are You Familiar with The HCFCs Phase-Out Management Plan (HPMP) Stage 2 Set Out by Government					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Irrelevant	1	5.9	6.7	6.7
	No	1	5.9	6.7	13.3
	They achieved the target in stage 1	13	76.5	86.7	100.0
	Total	15	88.2	100.0	-
Missing	System	2	11.8	-	-
Total		17	100.0	-	-

Training on Flammable Substances Has Been Available in The Last 5 Years					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	16	94.1	100.0	100.0
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

What Suggestions You Have for The Government to Enhance the Capacity of The Companies To Adopt Alternative Refrigerants					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Awareness programs	1	5.9	6.3	6.3
	Ozone friendly refrigerants should have low duty structure	5	29.4	31.3	37.5
	No taxes at import stage	6	35.3	37.5	75.0
	To ensure adoption of the low GWP refrigerants	1	5.9	6.3	81.3

	To launch more vocational trainings and awareness programs	1	5.9	6.3	87.5
	By running an online digital campaign through live sessions on radio, static posts	1	5.9	6.3	93.8
	Irrelevant	1	5.9	6.3	100.0
	Total	16	94.1	100.0	-
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

What Are Some of The Managerial Constraints Your Company Faces Regarding the Reduction of ODSs Consumption					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Flammability of refrigerants	7	41.2	41.2	41.2
	We do not have contacts of end-users	1	5.9	5.9	47.1
	Adoption of market and to educate customer for a new refrigerant	6	35.3	35.3	82.4
	We are not facing any such constraints	3	17.6	17.6	100.0
	Total	17	100.0	100.0	-

Which Phase-Out Management Plan You Company Is Currently A Part Of					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Our imports are in line with phase-out management plan	10	58.8	58.8	58.8
	HCFC has been phased out totally	6	35.3	35.3	94.1
	Irrelevant	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

Are You Aware of The Government's Incoming Plan on Phase Down of HFCs					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Phase down will be implemented from 2026	6	35.3	35.3	35.3
	Trying to switch on Alternatives	10	58.8	58.8	94.1
	Irrelevant	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

Have Agencies Provided Enough Financial Support for The Implementation of ODSs Phase-Out Plan					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	When projects are approved, funds are available	12	70.6	70.6	70.6
	No support	4	23.5	23.5	94.1
	Irrelevant	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

Have Agencies Provided Enough Financial Support for The Implementation of ODSs Phase-Out Plan					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	When projects are approved, funds are available	12	70.6	70.6	70.6
	No support	4	23.5	23.5	94.1
	Irrelevant	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

The Policy Constraints by the Government that Hamper the Phase Down of ODS					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Incentives needed either downstream or upstream	7	41.2	41.2	41.2
	Revision of the import policies to prohibit entrance of refrigerants/technologies with high GWP	9	52.9	52.9	94.1

	No specific constraints faced	1	5.9	5.9	100.0
	Total	17	100.0	100.0	-

Your Concerns in Terms of Policy Constraints Imposed by the Government for Future					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Develop policy & solutions to research for the less GWP and ODS materials	7	41.2	41.2	41.2
	No concerns	1	5.9	5.9	47.1
	Discourage illegal trade	9	52.9	52.9	100.0
	Total	17	100.0	100.0	-

Satisfaction Regarding the Measures Taken by Implementing Agencies in Leading the Companies Towards Technology Shift					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Satisfied	16	94.1	100.0	100.0
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

The Technology Constraints in Your Sector to Switch Towards Alternative Refrigerants and Ozone Depletion Substances Alternatives					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Safety, in other words flammability of refrigerants	5	29.4	29.4	29.4
	Our technicians will face problems due to lack of training institutes	5	29.4	29.4	58.8
	No constraints	1	5.9	5.9	64.7
	A lack of technical capacity of the RAC/MAC dealers	1	5.9	5.9	70.6
	Training and learning on new refrigerants for	5	29.4	29.4	100.0

	customer as well as for technician.				
	Total	17	100.0	100.0	-

Can You Mention Some of The Positive Incentives Provided to Your Company by NOU to Achieve ODS Reduction Targets					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Continuous support & technical assistance	6	35.3	35.3	35.3
	Human resources assistance regarding visits and trainings	7	41.2	41.2	76.5
	Funding by MLF	4	23.5	23.5	100.0
	Total	17	100.0	100.0	-

Does Your Company Receive Any Subsidy or Tax Exemption to Promote Usage of Environment Friendly Refrigerants					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	16	94.1	100.0	100.0
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

Is There Some Authority/Mechanism to Check the Safe Disposal of Existing Refrigerants to Curb the Release of Greenhouse Gases into the Air					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Through recovery machines	7	41.2	43.8	43.8
	No mechanism in place	9	52.9	56.3	100.0
	Total	16	94.1	100.0	-
Missing	System	1	5.9	-	-
Total		17	100.0	-	-

4.11. Findings on the Basis of KPIs:

a. Companies' awareness about ODS usage and phase-out

Refrigeration and air conditioning industry is passing through an important phase where the refrigerants in both domestic and commercial air conditioning are now being shifted to new refrigerants. In Refrigerator production the industry is heading towards HC-600a refrigerant from HFC-134a while in domestic air conditioning the manufacturers/assemblers have shifted their production to HFC-410A which is ozone friendly but has high GWP. Actually, this conversion did not take place due to phasing out of ODS. Instead, the conversion was due to the kits available from China which was designed on HFC-410A and Pakistani Industry, merely assemblers, did not have any choice.

While the air-conditioners as mentioned above had a bad conversion i.e., with high GWP refrigerant instead of conversion to low GWP refrigerant, the situation is very critical now as the transformation from HFC-410A to other alternative such as HC or HFC with low GWP will take place in the next six to eight years. The servicing sector will face major pressure to service four kind of refrigerants in air-conditioning instead of one refrigerant which was previously HCFC-22.

To prevent any untoward incident, it is imperative that the technicians are provided with training on safe handling and storage of such highly flammable refrigerants. After this bad conversion to HFC-410A, the industry may switch over to HC-290 or HFC-32 depending on the decision of the management. However, with R-290 safety issues exist at present and it is most likely that some of the manufacturers may opt for HFC-32 which has GWP of 675. It also seems that the industry will be influenced with the technology adopted by China – as at present they have both options – to switch over to hydrocarbons HC or to go for low GWP refrigerant R-32.

Because Pakistan falls under HAT (high ambient temperature) countries group so there are chances that Pakistan may still have time for the conversion to low GWP refrigerants or HC refrigerant.

During discussion with the industry, it was found that relevant industry is aware of the utilization and phase out schedule of ODS and understands that all ODS consumption is being monitored through import quota allocated to the importers. Main consumption of ODSs is in air conditioning and refrigeration sector. However, there is nominal consumption of ODSs in foam sector as well that is remaining and will be converted to ozone friendly technology soon. The industry using ODSs have been surveyed and are included in the phase out schedule of ODSs which is being controlled and monitored by NOU. Selection of technology is done in consultation with the industry.

b. Industries' efficiency and performance in terms of compliance with the Montreal Protocol

There are two types of industries - one is Foam and the other one is Refrigeration & Air Conditioning. At present there is no use of ODS in domestic refrigerators. All the refrigerator manufacturing units have converted their production from ODS (CFC-12) to non-ODS (HFC-134a) in the first phase (2006) of phasing out of CFCs. In domestic air conditioning as the ODP value was less (HCFC-22 with 0.055) it was not considered in the first phase. However, accelerated HCFC phase out plan was later considered and the countries were asked to prepare HCFC Phase-out Management Plant (HPMP). HPMP a strategic document for Pakistan was prepared to completely phase out ODS by 2030.

NOU Pakistan is now working with two implementing agencies – UNIDO and UNEP and HCFCs are being phase-out through investment and non-investment projects respectively. In air conditioning and refrigeration sector, technicians are vital for servicing and maintenance of the equipment. There is link between industry and technical institutes, who device training courses for Vocational Training and Diploma in a RAC technology. If this link is strengthened, it is most likely that the industries can perform much better than the status quo. There is an emergent need to build the capacity of service sector across the country and make them aware of the use of ODSs and consequent impacts on human health and ecosystem. It is also required that the technicians should be aware of the new refrigerants that are coming in the market.

c. Preparedness for future projects

If the industry is part of conversion (in any stage) then the implementing agency is responsible for their conversion as they provide both financial and technical assistance to the implementing partner. The funds are provided for the conversion but it is not necessary that the funds available may be sufficient for conversion. The funds for conversion are available based on the usage of ODS. The goal is to phase-out ODS and the technology selected, is approved by the Ex.com for conversion to new alternatives. After receiving funds, the industry is responsible for shifting on new alternate technologies within stipulated time frame.

In short, the industries are well on the track of handling future projects with the cooperation of implementing agencies and guidance from regulatory authorities. However, there are market forces that play an important role in conversion to alternative technologies. It is also possible that the enterprises decide by themselves for conversion if they feel this will help them in preventing negative cash flow. The conversion at any stage, whether it is through MLF funding or the industry decides by itself, is very critical and comes through the technologies that are being adopted by our neighboring countries like China. Policies and penalties should also be implemented to discourage illegal trade of ODS.

d. Financial support and policy support and related constraints

The multilateral fund (MLF) provided financial support to the industries for the phase-out of ODS. Before implementing any project, discussions are held with the beneficiaries for the conversion. Once the project is approved funds are available, though more incentives are needed - downstream or upstream. However, policy & solutions should be developed to research for the alternate materials with less GWP and ozone depletion potential (ODP).

e. Technological support and constraints faced

It is the industry which decides technology shift from ODS to non-ODS. Most of the industries are satisfied with the technology support provided to them. Safety, in other words flammability of refrigerants, is a major challenge. The technicians may face problems due to lack of training. A lack of technical capacity of the RAC/MAC dealers is another challenge for the industries. Training and learning on new refrigerants for customers as well as for technicians is crucial.

f. Optimum resource utilization and capacity building of the relevant industries

Standards are needed to be adopted and implemented by the government for the safe use of refrigerants having low GWP - Standards are adopted by the government but becomes a challenge when it comes to implementation at micro-scale levels. By addressing the problems of manufacturers timely, the industries' phase-out capacity may be enhanced. Reduction on the custom duty on the ozone and climate friendly alternatives to ODS is another option for yielding benefits of optimum resource utilization by the industries.

4.12. Evolution of stratospheric total column ozone (TCO) over Pakistan from 2004-2020

4.12.1. Spatial distribution of TCO over Pakistan from 2004-2020

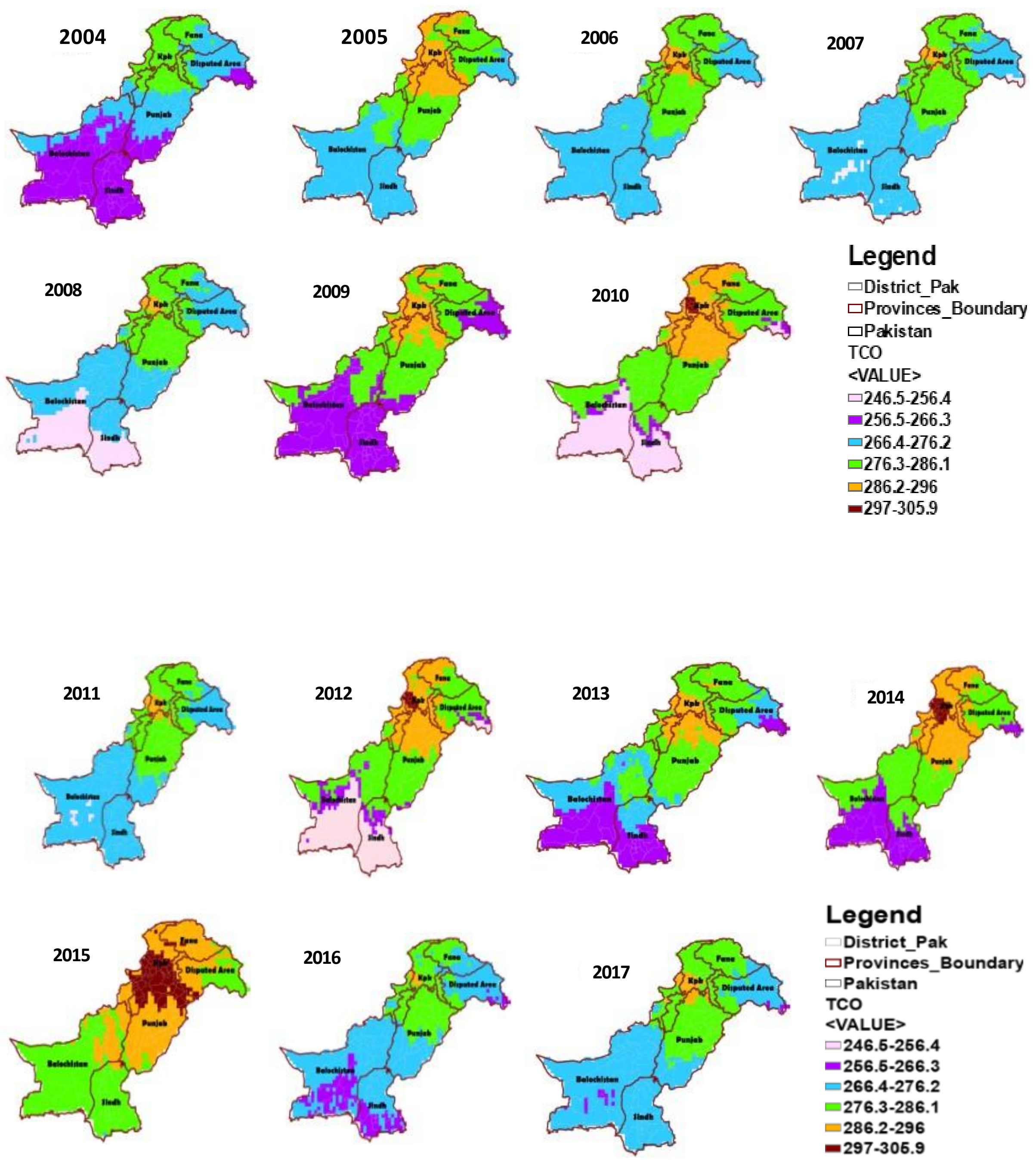


Figure 6.1 Yearly Average Maps of Stratospheric TCO over Pakistan from 2004-2017

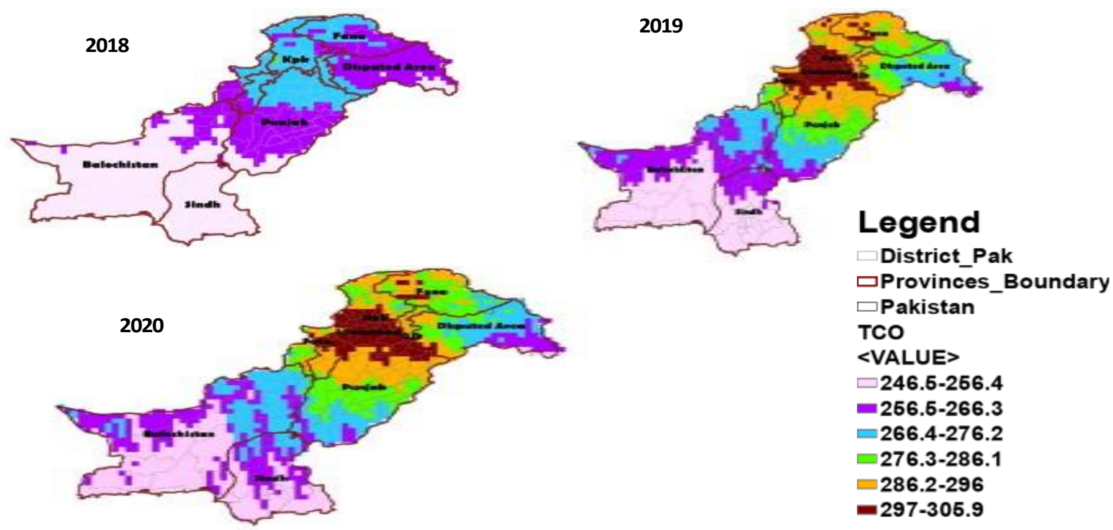


Figure 2.2 Yearly Average Maps of Stratospheric TCO over Pakistan from 2018-2020

Stratospheric TCO was also studied over Pakistan to check its trend in the stratosphere due to the prevention strategies employed by Montreal Protocol. TCO value below 220 DU is considered for ozone hole formation. Pakistan's TCO value was well above this threshold value. Averaged yearly maps of TCO from 2004-2020 were made to show spatial distribution of TCO over Pakistan. Pakistan is at 30.3753° N latitude, which signifies that Pakistan is located in the Northern Hemisphere. Minimum monthly value of TCO was recorded to be 239.5 DU in 2016. Maximum monthly value of TCO was recorded as 305.9 DU in 2018. Monthly average values for TCO were highest in spring and lowest in monsoon season.

The annual ozone averages in the upper parts of the country vary from 260 DU to 305 DU, in the central parts from 260 DU to 280 DU and 246 DU to 270 DU in the lower parts of Pakistan for the period 2004-2020.

Mean zonal TCO values for time period 2004-2020 vary from 266-293 DU over Pakistan. The northern part of Pakistan shows higher TCO value as compared to the southern part. Khyber Pakhtunkhwa (KPK), FATA and Azad Jammu and Kashmir (AJK) are the regions with higher concentration of stratospheric TCO than southern regions i.e., Baluchistan and Sindh regions.

4.12.2. Spatial distribution Averaged Map of Stratospheric TCO over Pakistan during 2004-2020

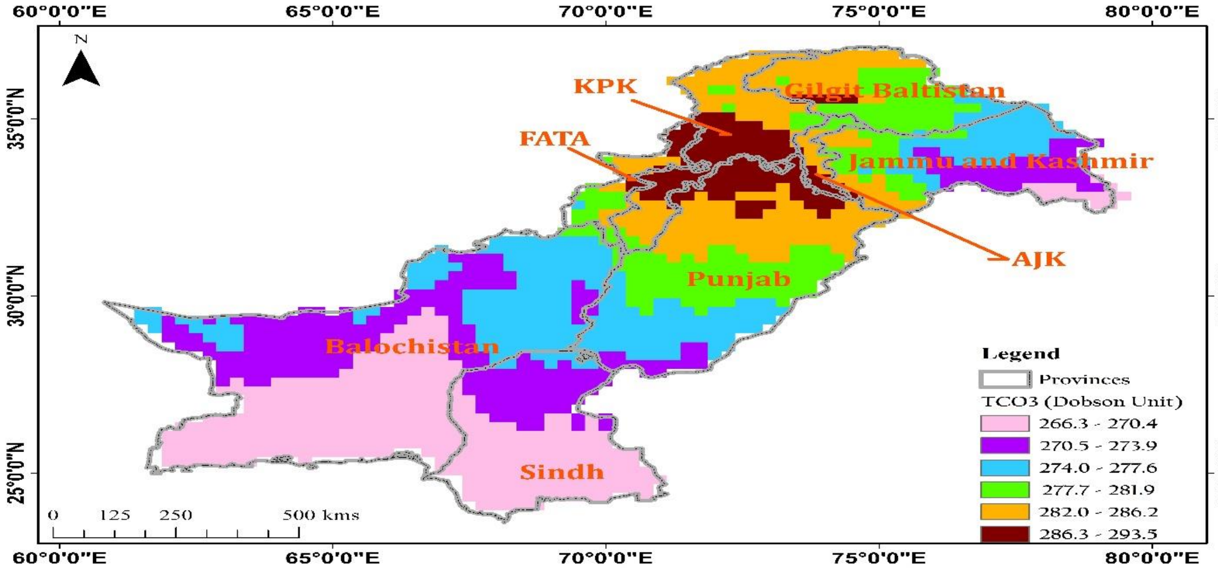


Figure 6.3 Average Spatial Distribution of Stratospheric TCO Over Pakistan from 2004-2020

The minimum average zonal TCO value from 2004-2020 over Pakistan is found out to be 266 DU and the maximum average zonal TCO value for 2004-2020 is 293 DU in Pakistan. The results of zonal statistics showed mean TCO value in Azad Jammu & Kashmir to be 284 DU. Mean value in Balochistan was observed to be 271 DU. In Gilgit Baltistan the mean TCO value was 281 DU. In Khyber Pakhtunkhwa the mean value was observed to be 285 DU. In Punjab the mean TCO value was 280 DU. In Sindh mean TCO value was found to be 270 DU.

4.12.3. Temporal evolution of stratospheric TCO over Pakistan derived from OMI/AURA satellite data for 2004-2020

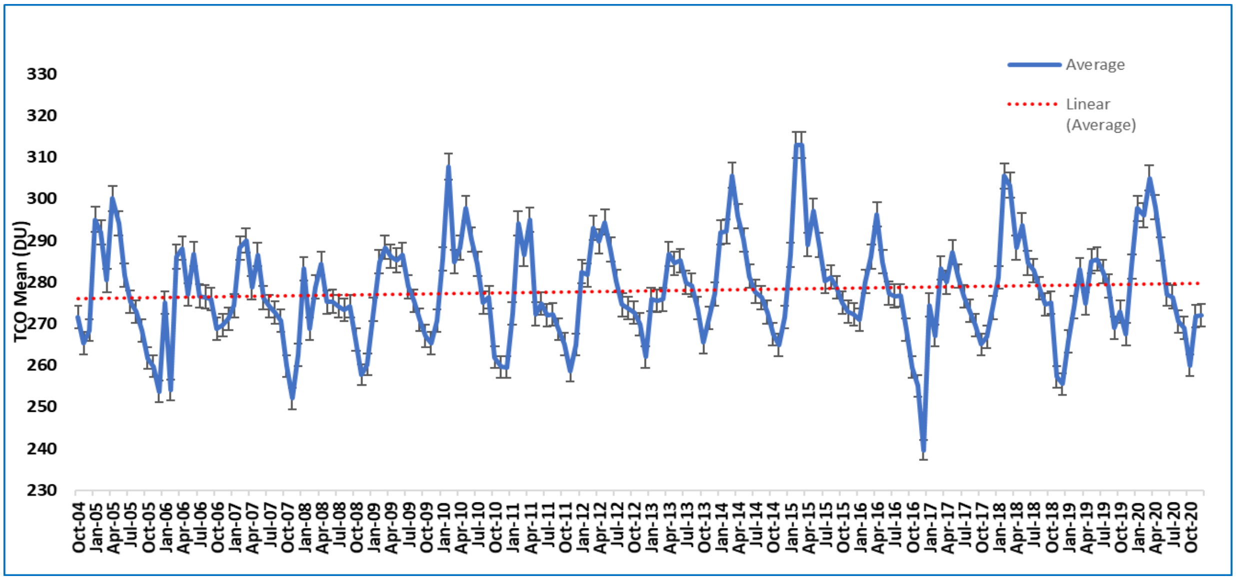


Figure 6.4 Temporal Distribution of Stratospheric TCO Over Pakistan (Satellite Data) for 2004-2020

The temporal evolution of stratospheric TCO derived from OMI/AURA satellite over Pakistan is presented in the time series. TCO showed a marked seasonal variation exhibiting peaks in spring season and dips in monsoon season. Error bar indicates the standard deviation of TCO values for respective months. Absolute temporal change in stratospheric TCO over Pakistan was observed to be 5 DU with a relative increase of 1.8% at the rate of 0.11% per year were observed during the time period of October 2004- October 2020.

4.12.4. Temporal distribution of Satellite and Ground data of Quetta from 2004-2018

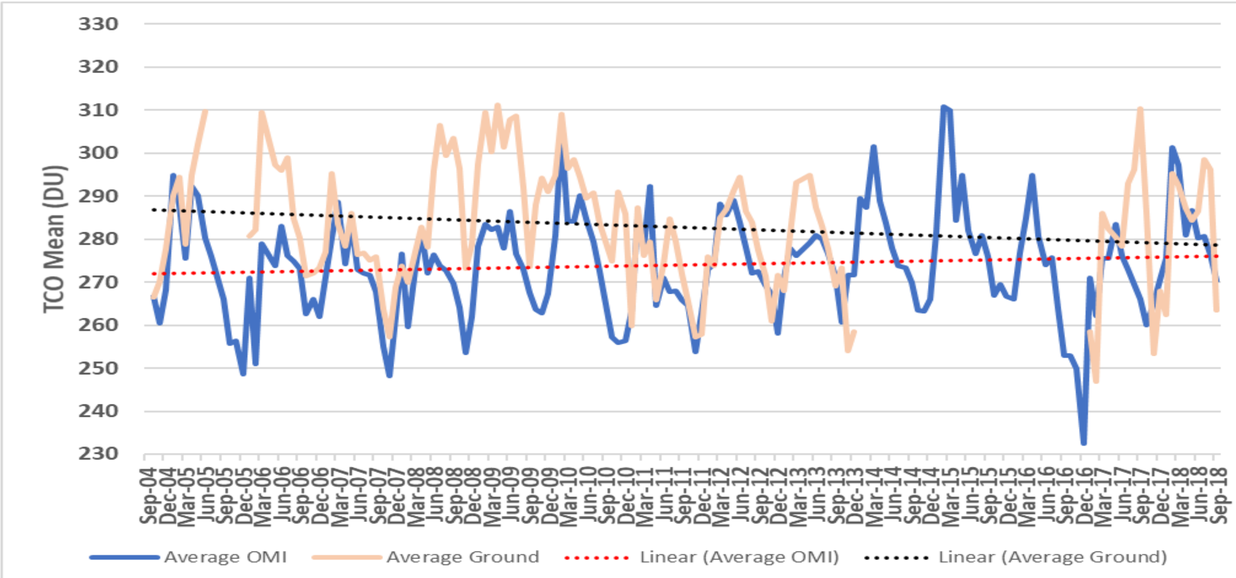


Figure 6.5 Monthly Average Stratospheric TCO Over Quetta (Satellite and Ground Data) for 2004-2018

The temporal evolution of stratospheric TCO derived from OMI/AURA satellite and Brewer Dobson spectrometer ground data over Quetta is presented in the form of time series above. TCO shows no particular seasonal variations as it was in case of Pakistan i.e., peaks in spring season and dips in monsoon season. Absolute temporal change in stratospheric TCO over Quetta for ground station was observed to be -9 DU with a relative decrease of 3.14% at the rate of 0.21% per year during the time period of September 2004- September 2018.

Absolute temporal change in stratospheric TCO over Quetta for satellite data was observed to be +4 DU with a relative increase of 1.47% at the rate of 0.1% per year during the time period of September 2004- September 2018.

4.12.5. Satellite versus ground stratospheric total column ozone measurements for Quetta

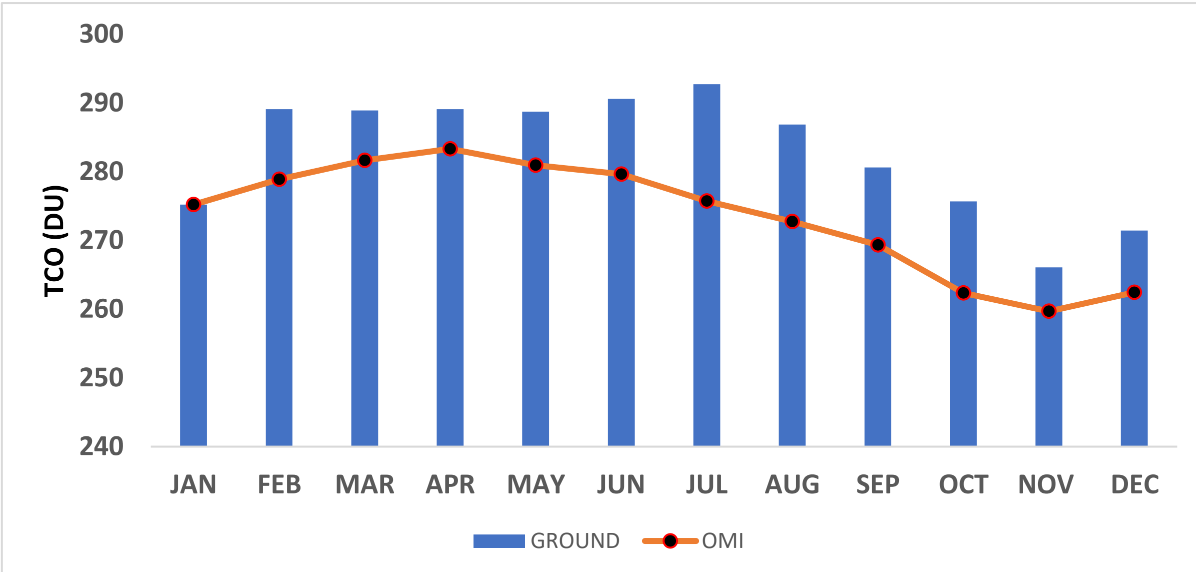


Figure 6.6 A Comparison of Seasonal variation of TCO over Quetta (Satellite versus Ground Data 2004-2018)

It can be observed that ground-based Dobson Spectrometer does not follow the general trend maintained by the OMI/AURA satellite measurements. Significant underestimation by OMI/AURA satellite is observed during many months when ground measurements of ozone are the highest. This may be due to several defining factors such as moisture content, aerosols and cloud cover in the atmosphere which significantly obscure the ground.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Pakistan has undertaken development works related to legislation for the phasing down of HFCs upon signing a formal agreement. This would include import quota system for HFCs, training of technicians for the alternate technologies, adoption of policy measures relating to handling transportation and storage of hydrocarbons, emission monitoring & reporting and awareness rising with private sector.

The period for the ODSs and ODSAs' historical consumption data collection was done for 2012-2015. The projection of consumption of ODSs and ODSAs in manufacturing as well as servicing sector was up to a horizon of 2030. Desk studies using information available from NOU, data on the import, economic survey of Pakistan report, net data, importers, manufacturers and various document/ studies related to phasing out of Ozone depleting substances, multilateral guidelines and decision, end users and servicing workshops/ technicians were used for achieving research objectives related to ODSs.

The summary of ODSAs & ODSs imported under various alternatives during 2012-2015 in MT is provided in the table below

Table 5.1: ODSAs & ODSs imported under various alternatives during 2012-2015 in MT

Alternatives	2012	2013	2014	2015
HFCs and Blends	1,818.57	1,453.00	1,816.24	2,530.51
HFOs	0.00	0.00	0.00	0.00
Natural Refrigerant	344.89	313.07	629.99	938.30
Synthetic Alternatives	2911.82	3364.24	3897.40	3414.20
Total annual import ODSAs	**5,075.27**	**5,130.31**	**6,343.63**	**6,883.01**
Total annual import ODSs	**3,483.26**	**3,606.08**	**3,151.69**	**2,779.84**
Total annual import	**8,558.53**	**8,736.39**	**9,495.32**	**9,662.85**

It is evident from the above table that the maximum import in Pakistan during this period with reference to alternative categories was for synthetic alternatives. However, with reference to chemicals, the HFC 134a was imported in the maximum quantity. There was no import of HFOs during this period.

Projected future consumption for the year 2016-2030 about each ODSs and ODSAs (keeping in view the reduction targets, available alternate solutions and historical growth observed during 2012-2015) were also presented. The growth in industrial consumption is assumed 8% whereas growth in servicing sector in various sub-sectors ranges between 2.5%-4.0%. The specific growth assumed in each applicable sub-sector is provided in the result and discussion section.

There are 17 manufacturers in Pakistan that are manufacturing domestic, commercial and large commercial refrigeration equipments. Whereas there are number of engineering companies that are fabricating industrial and transport refrigeration units. In the Country, 9 manufacturers are manufacturing domestic & commercial ACs and chillers whereas 8 manufacturers are in the automobiles manufacturing requiring mobile ACs.

In the foam sector, there are number of sub-sectors that are operating in Pakistan including PU insulation in domestic & commercial refrigeration, Sandwich panel discontinuous, flexible foam, thermoware PU foam, pipe insulation, spray foam and XPS board. These industries are exhibiting reasonable growth in Pakistan. In the solvent sector, a number of projects have been implemented in Pakistan for the phasing out of solvents including CTCs and CFC-113 through the funding of MLF during 1999 to 2009. There are also few engineering works in Karachi and Lahore that are currently working to develop fire protection and fire suppression system.

The annual historical emission during 2012-2015 was calculated and it was found that emission eq. to CO_2 in metric ton was 8.713 MMT during the year 2015. Similarly, the projected emissions for the years 2016-2030 was also estimated based on the excepted consumption during the same period. The calculation indicates that the emission will be almost 9.653 MMT during the year 2030.

To find out major obstacles to reduce consumption of ODS by small to medium enterprises (SMEs) through survey a questionnaire was designed with the title “Challenges faced by commercial enterprises to phase down the consumption of ozone depletion substances (ODS) in Pakistan: A questionnaire for the relevant entities/individuals” and circulated among ODS consuming sectors of Pakistan. It contained 23 questions related to six key performance indicators KPIs namely

- Companies’ awareness about ODS usage and phase-out
- Industries’ efficiency and performance in terms of compliance with the Montreal Protocol
- Preparedness for future phase-out projects
- Financial support, policy support and related constraints
- Technological support and constraints faced
- Optimum resource utilization and capacity building of the relevant industries

During discussion with the industry, it was found that relevant industry was aware of the utilization and phase out schedule of ODS and had an understanding that all ODS consumption is being monitored through import quota allocated to the importers. There is an emergent need to build the capacity of service sector across the country and make them aware of the use of ODS and consequent impacts on human health and atmosphere.

It is also essential that the technicians should be aware of the new refrigerants that are coming in the market. The industries are well on the track of handling future projects with the cooperation of implementing agencies and guidance from regulatory authorities. However, there are market forces that play an important role in conversion to alternative technologies.

The multilateral fund (MLF) provided financial support to the industries for the phase-out of ODS. The technicians may face problems due to lack of training. A lack of technical capacity of the RAC/MAC dealers is another challenge for the industries. Reduction on the custom duty on the ozone and climate friendly alternatives to ODS is another option for yielding benefits of optimum resource utilization by the industries.

Stratospheric TCO was also studied over Pakistan to check its trend in the stratosphere due to the prevention strategies employed by Montreal Protocol. TCO value below 220 DU is considered for ozone hole formation. Pakistan’s TCO value was well above this threshold value. Averaged yearly maps of TCO from 2004-2020 were made to show spatial distribution of TCO over Pakistan. Minimum monthly averaged value for TCO was recorded to be 239.5 DU (2016). Maximum monthly averaged value of TCO was recorded as 305.9 DU (2018). Monthly averaged values for TCO were highest in spring and lowest in monsoon season.

The annual ozone averages in the Northern parts of the country vary from 260-305 DU, in the central regions from 260-280 DU and in the Southern parts from 246-270 DU for the time period 2004-2020.

The mean zonal TCO values for time period 2004-2020 vary from 266 DU to 293 DU over Pakistan. The northern part of Pakistan shows higher TCO value as compared to the southern part. Khyber Pakhtunkhwa (KPK), FATA and Azad Jammu and Kashmir (AJK) are the regions with higher concentration of stratospheric TCO than southern regions i.e., Baluchistan and Sindh regions.

The minimum average zonal TCO value from 2004-2020 over Pakistan is found out to be 266 DU and the maximum average zonal TCO value for 2004-2020 is 293 DU in Pakistan.

5.2. Recommendations

- The findings of this research study may be used to evaluate the consumption status of ODSs in Pakistan and the challenges faced by enterprises to curb the consumption of ODSs in Pakistan
- For effective implementation of Montreal Protocol, ban on import of products and equipment using or containing HCFC and HCFC blends is important.
- Duty relaxation on non-HCFC based products and higher duties on HCFC based products and raw material is recommended.
- Ban should be placed on new enterprises producing refrigerators, air conditioning equipment and foam manufacturing material using HCFC and/ or HCFC blends
- Ban on investment in building new plants using HCFC and/or HCFC blends should be placed
- There should be ban on uncontrolled release of HCFC and HCFC blends during servicing
- Strict control of investment in new, enlarged or technically reformed enterprises consuming HCFC and HCFC blends should be ensured by legislative bodies.
- This study also finds the ongoing trend of stratospheric TCO over Pakistan by using satellite data (OMI/AURA) which may help in bridging the gap of atmospheric data available in South Asian countries.
- The ground-based data of ozone in Pakistan is only available for Quetta and should be continued for the comparison of satellite observation.

- The trend of stratospheric TCO should be monitored for successive years so that the causes for any potential decline or anomaly in stratospheric ozone could be checked on time.

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